The Effect of Economic Factors on Carbon Emissions in the USA

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Abstract

This study investigates how key economic factors such as gross domestic product (GDP), industrial production, inflation, and the federal funds effective rate affect carbon dioxide (CO_2) emissions across nine major sectors in the United States. While previous research has primarily concentrated on aggregate national emissions, this analysis takes a sectoral approach by using linear regression to quantify how each economic variable impacts specific categories of CO_2 emissions. The findings indicate that economic growth and industrial activity are significant contributors to emissions, although their effects differ from one sector to another. In sectors like electric power and total emissions from all fuels, the models account for over 60% of the variation in emissions, emphasizing the strength of these relationships. In contrast, inflation and monetary policy appear to have the weakest and most inconsistent influence across sectors, showing limited statistical significance in most of the models. These results highlight the complexity of the relationship between the economy and emissions, underscoring the need for sector specific policies and technological innovation to help achieve the U.S. goal of net-zero emissions by 2050. This research provides evidence-based insights for policymakers who aim to balance economic development with environmental sustainability.

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Finally, I dedicate this work to my father, Bekele Sime, with love and gratitude for all that you have given me

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1.Introduction

The relationship between economic factors and carbon emissions in the United States has become a key area of academic research, particularly as the country faces the critical challenges of climate change and seeks sustainable development pathways (Stern, 2004; Holtz-Eakin & Selden, 1995; Shahbaz et al., 2016). As one of the largest economies and a significant emitter of carbon dioxide (CO_2), it is essential to understand how various economic indicators such as gross domestic product (GDP), industrial output, inflation, and monetary policy affect carbon emissions. This understanding is crucial for developing effective environmental policies that foster sustainable economic growth. Research indicates that these economic variables can significantly influence CO_2 emissions, and theoretical frameworks like the Environmental Kuznets Curve (EKC) provide valuable insights into these dynamics (Dinda, 2004; Grossman & Krueger, 1995).

Economically driven carbon emissions are closely tied to industrial activity, energy consumption, and urbanization, all of which are correlated with economic growth. The EKC hypothesis suggests an inverted U-shaped relationship between income levels and environmental degradation: while initial economic growth may worsen environmental issues, it can eventually lead to improvements through innovations and regulatory reforms (Stern, 2004). Scholars have also examined how financial development and technological innovation impact environmental quality, further broadening the EKC discourse and highlighting the importance of analyzing these interconnected dynamics (Shahbaz et al., 2013). Additionally, as nations achieve higher income levels, shifts in industrial composition and increased environmental awareness may contribute to reductions in CO_2 emissions, indicating a complex relationship in this context (Grossman & Krueger, 1995).

Empirical studies show that factors such as institutional stability, strong environmental regulations, and the adoption of cleaner energy technologies play crucial roles in mitigating emissions (Böhringer et al., 2012; Aldy, 2006). This complex interplay emphasizes the need to understand how structural economic conditions, policy frameworks, and energy market dynamics influence emission trajectories (Aldy, 2006). Urbanization and trade openness are critical components of this emissions narrative; while urbanization initially increases emissions due to higher energy demand, it can also enhance energy efficiency and infrastructure over time (Shahbaz et al., 2016). Conversely, while trade can promote the distribution of environmentally friendly technologies, it may also contribute to environmental degradation through the relocation of polluting industries (Antweiler et al., 2001).

Despite these insights, a significant gap remains in understanding the intricate dynamics between economic factors and sectoral CO_2 emissions in the U.S., particularly through recent empirical lenses. Much of the existing literature aggregates emissions and economic indicators without thoroughly examining specific sectoral impacts or utilizing advanced analytical methods (Stern, 2004). This lack of detail obscures important interactions among various economic dimensions and emission pathways. A comprehensive analysis focusing on the relationships between specific economic indicators and distinct categories of CO_2 emissions can address this knowledge gap and help inform more effective policy frameworks aimed at achieving the U.S. goal of net-zero emissions by 2050 (Rogelj et al., 2015).

Consequently, this study aims to quantify the marginal effects of key economic variables namely GDP, industrial production, inflation, and the effective federal funds rate on multiple categories of CO_2 emissions in the U.S. using a linear regression approach. By clarifying these relationships, this research contributes valuable insights to the academic discourse and provides actionable information for policymakers working to balance economic progress with environmental responsibility.

The relationship between economic factors and carbon emissions in the United States is a complex issue that the existing literature inadequately addresses. While substantial research has been conducted on economic growth and its environmental impacts, significant gaps remain, particularly concerning the interactions between different sectors and emission types. Many past studies have taken an aggregate approach, overlooking the need to dissect emissions into sector-specific categories, which is essential for understanding how particular economic indicators influence carbon outputs in a diverse economic landscape (Mahmood & Houaneb, 2023; Fang et al., 2018).

Moreover, the varied definitions, methodologies, and time frames used in existing studies have led to inconsistent findings regarding the effectiveness of economic policies aimed at reducing emissions (Mahmood & Houaneb, 2023). The validity of the Environmental Kuznets Curve (EKC) has been debated, with critics arguing that it oversimplifies complex environmental realities by failing to account for institutional, technological, and sectoral diversity (Mahmood & Houaneb, 2023). These conflicting conclusions contribute to uncertainty about the extent to which economic growth can lead to meaningful environmental improvements.

Additionally, much of the existing research does not adequately consider contemporary economic dynamics or the latest policy frameworks emerging in response to climate change, especially given the push for net-zero emissions by 2050 (Mahmood & Houaneb, 2023). This failure to incorporate recent data and analytical approaches results in a knowledge gap regarding the current economic-emission nexus in the U.S., particularly in light of technological advancements and evolving regulations.

Recent studies indicate that sectoral EKC patterns can differ, suggesting that some U.S. sectors may not conform to the typical inverted-U shape associated with the EKC. For example, recent research highlights the effects of ecological innovation and green policies across various sectors, demonstrating discrepancies in how economic activities influence carbon emissions (Chien et al., 2021). Even within the renewable energy context, the differential impacts on economic growth in certain sectors emphasize the complexity of the emissions relationship (Mahmood & Houaneb, 2023).

While specific factors such as inflation, industrial production, and monetary policy have been examined individually, comprehensive studies analyzing these economic variables in relation to various categories of CO_2 emissions remain scarce. This presents an opportunity to bridge the gap by employing a robust linear regression framework that captures the marginal influences of different economic indicators on diverse dimensions of carbon emissions.

This study aims to examine how key macroeconomic variables namely gross domestic product (GDP), industrial production, inflation, and the federal funds effective rate affect sector-specific carbon dioxide (CO_2) emissions in the United States. By utilizing a linear regression framework, the research seeks to identify the marginal impact of each economic factor across nine emission categories. The objective is to provide a detailed understanding of how economic dynamics shape environmental outcomes in different sectors, ultimately offering evidence-based insights that support policy decisions balancing economic growth with sustainability goals.

2.Literature Review

The relationship between economic growth and carbon emissions has been extensively studied in the field of environmental economics. A significant amount of research has focused on how the expansion of national economies affects environmental outcomes (Jaunky, 2011; Stern, 2004; Dinda, 2004; Holtz-Eakin & Selden, 1995; Liddle & Sadorsky, 2014; Wang et al., 2016). A central concept in this discussion is the Environmental Kuznets Curve (EKC) hypothesis. This hypothesis suggests that as economies develop, carbon emissions initially increase due to heightened industrial activity and energy consumption. However, emissions are expected to decline eventually as higher income levels facilitate the adoption of cleaner technologies and stricter environmental regulations (Grossman & Krueger, 1995; Dinda, 2004; Stern, 2004; Galeotti et al., 2006).

While foundational studies by Grossman and Krueger (1995) established the theoretical basis for the EKC, empirical results within the United States have been mixed. For example, Liddle & Sadorsky (2014) argue that ongoing economic growth, especially in sectors like transportation and manufacturing, continues to drive emissions upward because of a persistent reliance on energy-intensive processes. Additionally, Wang et al. (2016) utilized advanced econometric models to identify a strong positive relationship between GDP growth and carbon emissions, highlighting significant contributions from sectors such as transportation and industrial manufacturing. In contrast, Galeotti et al. (2006) present evidence that higher income levels can ultimately lead to improved environmental performance, supporting the EKC hypothesis. More recent research by Aldy (2006) indicates that strategic policy interventions and a shift toward clean energy could help decouple economic growth from carbon emissions in the long run. This suggests a potential transition towards a more sustainable growth model within the U.S. context. However, further empirical evidence is needed to determine whether this decoupling has been firmly established nationwide.

Energy consumption is a significant driver of carbon emissions, with the United States being one of the world's largest energy consumers. The nation's energy supply primarily relies on fossil fuels, which greatly contribute to overall emissions (Jaunky, 2011; U.S. Energy Information Administration, 2022). Pao and Tsai (2011) highlight that increased energy consumption, often driven by strong economic growth, is a major factor behind rising emission levels. However, studies by Sadorsky (2009) indicate that improvements in energy efficiency and the integration of renewable energy sources can help mitigate these emissions. Despite the growing adoption of renewable energy, Gillingham and Huang (2021) observe that fossil fuels remain dominant in the U.S. energy landscape, resulting in persistently high overall emissions. Additionally, Apergis and Payne (2010) emphasize the moderating role of renewable energy use and financial development, suggesting similar strategies could be employed in the U.S. to transition toward a cleaner energy mix.

Industrial activity is another major contributor to carbon emissions, though its impact varies significantly across different sectors. Manufacturing and heavy industries rely heavily on coal, natural gas, and petroleum, making them substantial sources of emissions (Payne, 2010). Sorrell (2010) points out that energy-intensive industrial processes continue to challenge emission reduction efforts, even with technological advancements. Johnstone et al. (2010) argue that shifts toward automation and cleaner production methods have the potential to lower emissions, although sector-specific constraints may limit these improvements.

The transportation sector is also a primary source of emissions in the U.S., largely due to its reliance on gasoline and diesel. Research by Davis and Boundy (2020) and Popp et al. (2021) finds that while the adoption of electric vehicles and enhancements in fuel efficiency show promise, their overall impact is hindered by infrastructural challenges and slow market penetration. In the commercial and residential sectors, activities such as heating, cooling, and electricity use in buildings contribute significantly to carbon emissions. Research by Ürge-Vorsatz et al. (2020) underscores the importance of implementing stricter energy efficiency standards, providing incentives for energy-efficient systems, and developing smart grid technologies to achieve meaningful reductions in emissions.

The impact of trade openness on carbon emissions has garnered significant attention, particularly in the context of globalization's effects on production and transportation. Antweiler et al. (2001) and Copeland & Taylor (2004) argue that trade liberalization can lead to increased industrial output and, consequently, higher carbon emissions, especially when production is energy intensive. Conversely, Cole and Elliott (2003) and Kalaycı & Hayaloğlu (2019) suggest that globalization may also facilitate the diffusion of cleaner technologies and promote greater environmental awareness. In the U.S., Shahbaz et al. (2017) find that while trade openness drives economic growth, it is also associated with increased emissions due to heightened domestic production and logistics. Liddle & Sadorsky (2014) further observe that trade flows can have opposing effects; for instance, exports may lower consumption-based emissions, while higher imports can increase them. Although these trends are observed globally, the specific dynamics within the U.S. require further empirical validation. Aldy (2006) proposes that policy measures, such as carbon border adjustments, could help mitigate the negative environmental impacts of trade by discouraging the relocation of high-emission industries to countries with less stringent regulations.

Economic policy instruments and regulatory interventions are crucial in shaping the trajectory of carbon emissions. Market-based tools, such as carbon taxes, cap-and-trade systems, and renewable energy subsidies, have been extensively studied for their effectiveness in reducing emissions without hindering economic growth (Böhringer et al., 2012). Stavins (1998) provides a comprehensive analysis of how these instruments, when effectively implemented, can internalize the environmental costs of emissions. For example, the Regional Greenhouse Gas Initiative (RGGI) and California's cap-and-trade program have successfully lowered emissions while supporting continued economic expansion (Burtraw et al., 2018). Schmalensee and Stavins (2017) note that policies like the Clean Air Act have significantly contributed to emission reductions in the U.S., although Metcalf (2019) cautions that political resistance and economic costs remain substantial barriers to further progress.

Technological progress is widely recognized as a key factor in mitigating the environmental impact of economic activities. Jaffe, Newell, and Stavins (2005) document that advancements in energy efficiency, carbon capture, and clean energy technologies have contributed to declines in emissions intensity in developed economies, including the United States. Nevertheless, the slow diffusion of green technologies remains a challenge, as highlighted by Popp et al. (2021) and Johnstone, Haščič, and Popp (2010). Aghion et al. (2016) emphasize that sustained investment in research and development is essential for achieving long-term reductions in emissions, especially in sectors like transportation and power generation. Recent research by Zhou et al. (2022) provides evidence from both the U.S. and China, demonstrating a significant inverse relationship between renewable energy consumption and carbon emissions. This suggests that regions with more advanced renewable energy transitions tend to have lower emissions. Furthermore, Rehman et al. (2014) employ a multicriteria decisionmaking approach to show that increased wind and solar energy generation can substantially reduce carbon emissions, reinforcing the critical role of technological innovation in addressing environmental challenges.

In summary, the existing literature underscores the complexity of the relationship between economic development and carbon emissions, highlighting the importance of sectoral analysis, the evolving role of energy sources, and the influence of trade, policy, and technological innovation. These insights provide a foundation for further empirical investigation into the detailed dynamics of economic factors and carbon emissions in the United States. A detailed summary of the reviewed literature is provided in Table 1.

Table 1: Summary of Main Findings from the Literature Review

Study	**Data/Market**	**Main Findings**
Jaunky (2011)	Global	Economic growth can lead to increased carbon emissions; however, the relationship requires nuanced examination across different contexts.
Stern (2004)	Global	Emphasized the significance of policy frameworks in shaping the relationship between economic growth and carbon emissions.
Dinda (2004)	Global	Proposed the EKC hypothesis, suggesting that economic growth initially increases emissions, followed by a decrease as income rises.
Holtz-Eakin & Selden (1995)	U.S.	Confirmed that economic activity significantly impacts air quality, highlighting the need for specific regulations and strategies.
Liddle & Sadorsky (2014)	U.S.	Asserted that economic expansion, particularly in energy-intensive sectors, continues to drive emissions upward despite cleaner technologies.
Wang et al. (2016)	U.S.	Identified a strong relationship between GDP growth and carbon emissions, with particular emphasis on the transportation and manufacturing sectors.
Galeotti et al. (2006)	Global	Found that higher incomes correlate with improved environmental performance, supporting the EKC hypothesis.
Aldy (2006)	U.S.	Suggested that strategic policy interventions can decouple economic growth from carbon emissions, indicating a pathway to sustainable growth.
Pao & Tsai (2011)	U.S.	Highlighted that rising energy consumption associated with economic growth is a primary driver of increased carbon emissions.
Sadorsky (2009)	U.S.	Discussed how enhancements in energy efficiency and the integration of renewable energy can mitigate rising emissions.
Gillingham & Huang (2021)	U.S.	Noted that fossil fuels continue to dominate the U.S. energy landscape, leading to substantial emissions despite a growing renewable sector.
Apergis & Payne (2010)	U.S.	Demonstrated the moderating role of renewable energy use in reducing emissions, emphasizing the need for cleaner energy transitions.
Payne (2010)	Global	Examined industrial activities as significant sources of emissions, stressing the necessity for sectoral improvements.
Sorrell (2010)	Global	Identified energy-intensive industrial processes as ongoing challenges despite advancements in technology for emissions reduction.

Johnstone et al. (2010)	Global	Highlighted potential emissions reductions through advancements in automation and cleaner production methods, though sector-specific constraints persist.
Davis & Boundy (2020)	U.S.	Reported that while electric vehicles and fuel efficiency improvements hold promise, slow market penetration and infrastructural issues limit their impact.
Popp et al. (2021)	U.S.	Discussed infrastructural challenges hindering significant emission reductions from the adoption of electric vehicles.
Ürge-Vorsatz et al. (2020)	Global	Stressed the importance of stricter energy efficiency standards and incentives for clean energy systems to achieve substantial emissions reductions.
Antweiler et al. (2001)	Global	Suggested that trade liberalization could heighten emissions through increased industrial output especially in energy-intensive production sectors.
Copeland & Taylor (2004)	Global	Indicated that globalization may foster the diffusion of cleaner technologies along with greater environmental awareness.
Cole & Elliott (2003)	Global	Found mixed impacts of trade on emissions, noting that while exports may reduce emissions, higher imports can increase them significantly.
Kalaycı & Hayaloğlu (2019)	Global	Advocated for further empirical validation of the dynamics between trade patterns and emissions, especially in the U.S. context.
Shahbaz et al. (2017)	U.S.	Identified trade openness as a driver of economic growth but also linked it to higher emissions through increased production demands.
Böhringer et al. (2012)	Various countries	Analyzed market-based tools such as carbon taxes and cap-and-trade systems for their effectiveness in reducing emissions while supporting economic growth.
Stavins (1998)	U.S.	Provided insights on how effective regulatory instruments can internalize environmental costs associated with emissions.
Burtraw et al. (2018)	U.S.	Discussed successful emission reduction through programs like the RGGI and California's cap-and-trade system while maintaining economic growth.
Schmalensee & Stavins (2017)	U.S.	Noted significant contributions from policies like the Clean Air Act in achieving emission reductions, despite facing political resistance.
Metcalf (2019)	U.S.	Warned about substantial barriers to progress, including political opposition and economic costs associated with further emission reductions.
Jaffe, Newell, & Stavins (2005)	Developed countries	Documented how technological advancements in energy efficiency and carbon capture have contributed to reduced emissions intensity.
Popp et al. (2021)	Global	Highlighted challenges due to the slow diffusion of green technologies, which hampers emission reduction efforts.
Aghion et al. (2016)	Various sectors	Stressed the importance of ongoing investment in R&D to achieve long-term emissions reductions across key sectors.
Zhou et al. (2022)	U.S. & China	Found an inverse relationship between renewable energy consumption and carbon emissions, indicating that those regions with advanced renewable transitions experience lower emissions.
Rehman et al. (2014)	Various regions	Illustrated that increasing wind and solar energy generation can notably mitigate carbon emissions, emphasizing the role of innovation.

2.1. Limits of the Literature

Despite a significant body of research examining the relationship between economic growth and carbon emissions, there are several critical limitations that remain. Many studies adopt an aggregate approach to emissions analysis, which obscures important differences among sectors. Foundational work based on the Environmental Kuznets Curve (EKC) hypothesis often treats the economy as uniform and fails to disaggregate emissions by sectors such as transportation, electric power, manufacturing, and residential activities. For instance, Mazzanti et al. (2007) demonstrate that national-level analyses tend to mask sectoral differences, and that using disaggregated data can reveal multiple EKC dynamics that vary by period, country, and industry. Similarly, research focused on developing accurate carbon intensity metrics at the product level indicates that aggregation obscures the complexities inherent in sector-specific emissions data (Wiedmann et al., 2007). Additional evidence from the analysis of climate-related financial policies by Campiglio et al. (2018) further highlights that a broadly aggregated approach fails to capture the subtle and complex impacts of economic activities on emissions, particularly when such analyses overlook the spatial and sectoral diversity in energy use and environmental performance.

Furthermore, there is a notable underrepresentation of monetary and financial variables in the existing literature. While GDP and energy consumption have been extensively analyzed, key financial indicators such as inflation and the Federal Funds Effective Rate remain relatively underexamined. This gap is significant because monetary conditions and financial market dynamics can indirectly influence industrial production and consumer demand, thereby affecting carbon emissions. Recent research emphasizes the importance of including such variables to provide a more comprehensive understanding of the economic-emission nexus (Thorbecke, 2023; Chen et al., 2021).

Although technological progress, often measured through proxies like R&D intensity or technology subsidy programs, may mitigate the emissions impact of economic growth, this aspect is frequently treated in isolation or merely mentioned as background rather than being systematically integrated into empirical models (Stern, 2017).

Therefore, the literature underscores the urgent need for more detailed empirical analyses that disaggregate emissions data by sector and incorporate a broader set of economic variables.

2.2. Research Objectives

The primary objective of this study is to examine how current and past key economic factors specifically inflation, GDP, industrial production, and the effective federal funds rate affect different types of carbon dioxide (CO_2) emissions across various sectors in the United States. By employing multiple linear regression analysis, the research will investigate nine categories of CO_2 emissions, including those from commercial, electric power, industrial, residential, transportation, and fuel-specific sources.

The study aims to compare the influence of these economic indicators on each sector to identify which factors have the most significant impact on carbon emissions. The findings are intended to provide practical insights for policymakers and researchers looking to understand the connections between economic conditions and environmental outcomes. Ultimately, the goal is to support efforts in developing targeted strategies for reducing emissions while fostering economic growth.

2.3. Contributions

This study makes several important contributions to the literature and policy discourse on the relationship between current and past economic factors and carbon emissions in the United States. By disaggregating carbon emissions into nine distinct categories, it provides nuanced insights into how economic variables such as GDP, industrial production, inflation, and the federal funds effective rate differentially influence emissions across sectors, addressing limitations of previous studies that relied on aggregated data. The incorporation of underexplored monetary indicators alongside traditional economic measures broadens understanding of the macroeconomic and financial determinants of emission patterns. Using a rigorous multiple linear regression framework with recent data, the study ensures empirical validity and relevance to current economic and regulatory contexts, including efforts toward net-zero emissions by 2050. The findings offer policymakers actionable evidence to prioritize emission reduction strategies in sectors most sensitive to economic dynamics, supporting targeted and efficient policy design that balances sustainable growth with environmental protection. Additionally, by exploring the Environmental Kuznets Curve hypothesis across multiple sectors with updated empirical evidence, the study contributes to theoretical understanding of the relationship between economic growth and environmental outcomes. Overall, this research contributes to ongoing scholarship by linking sector-specific economic activities to carbon emissions, providing a useful foundation for both academic inquiry and practical policymaking.

3.Methodology

This research adopts a quantitative approach to investigate the relationship between economic variables and carbon dioxide (CO_2) emissions in the United States from 1974 to 2021. The analysis is based on annual time series data spanning 48 years. All data were obtained from the Federal Reserve Economic Data (FRED) database, maintained by the Federal Reserve Bank of St. Louis, which provides reliable, consistent, and publicly available macroeconomic and environmental indicators over time.

The study focuses on sector specific CO_2 emissions as dependent variables, capturing emissions from distinct economic activities and fuel types. Specifically, nine categories of carbon emissions are modeled as dependent variables: commercial sector emissions, electric power generation emissions, coal industrial sector emissions, residential sector emissions, transportation sector emissions, total emissions from all sectors (coal only and all fuels), aviation gasoline transportation emissions, and jet fuel transportation emissions. This disaggregated approach allows for a more precise assessment of how different sectors respond to economic conditions.

The independent variables selected for this analysis are four key macroeconomic indicators: inflation, real gross domestic product (GDP), the industrial production index, and the federal funds effective rate. These variables were chosen based on their theoretical relevance and support from existing literature. Inflation reflects the general price level and may influence production costs and consumption behavior. Real GDP serves as a measure of overall economic activity, which is often associated with higher energy use and emissions. The industrial production index provides an indication of the output of the industrial sector, which tends to be energy intensive. The federal funds rate represents the stance of monetary policy and can affect both investment and household consumption, thereby indirectly influencing emissions.

The general form of the regression equation is:

$$Yi = \beta_0 + \beta_1X_1 + \beta_2X_2 + \beta_3X_3 + \beta_4X_4 + \varepsilon. \quad (1)$$

In this equation, Yi represents the CO_2 emissions for a particular sector, X_1 through X_4 denote the independent variables (X1inflation, X2real GDP, X3industrial production index, and X4federal funds rate, respectively), β_0 is the intercept, β_1 to β_4 are the estimated coefficients, and ε is the error term capturing the variation not explained by the model.

Python is used for data analysis and modeling, leveraging libraries such as pandas for data manipulation, stats models for statistical modeling, and matplotlib for visualizations. Key regression diagnostics were reported for each model, including the coefficients and their associated p-values, R-squared and adjusted R-squared values, the F-statistic and its significance level, and both the Akaike Information Criterion (AIC) and the Schwarz Bayesian Criterion (BIC). These diagnostics enable the evaluation of model robustness, explanatory power, and the statistical significance of each predictor in explaining variations in CO_2 emissions.

This study investigates how four key macroeconomic indicators real GDP, Industrial Production (IP), Inflation, and the Federal Funds Effective Rate (FER) are expected to influence sectoral CO_2 emissions in the United States. Economic theory and prior empirical evidence (Grossman & Krueger, 1995; Stern, 2004; Ang, 2007) suggest that higher levels of economic activity tend to increase energy consumption and, consequently, emissions. Accordingly, real GDP and industrial production are expected to exhibit positive relationships with CO_2 emissions, particularly in energy-intensive sectors such as electric power, coal, and transportation, where increases in output typically require greater use of fossil fuels.

The expected effects of inflation are less clear. On the one hand, higher inflation may reduce real incomes and dampen consumption and investment, potentially lowering energy demand and emissions. On the other hand, inflation can also coincide with periods of strong demand and overheating, which may raise production and energy use. Given this ambiguity, no strong prior hypothesis is formulated regarding the sign or magnitude of the inflation–emissions relationship.

The Federal Funds Effective Rate (FER), a key instrument of monetary policy, can influence emissions indirectly by affecting borrowing costs, investment, and overall economic activity. Tighter monetary policy (higher interest rates) is generally associated with slower growth and lower investment, which may reduce emissions, especially in sectors that depend heavily on credit-financed capital and durable goods, such as industry and transportation. Therefore, FER is expected to have a non-positive (zero or negative) effect on emissions in most sectors.

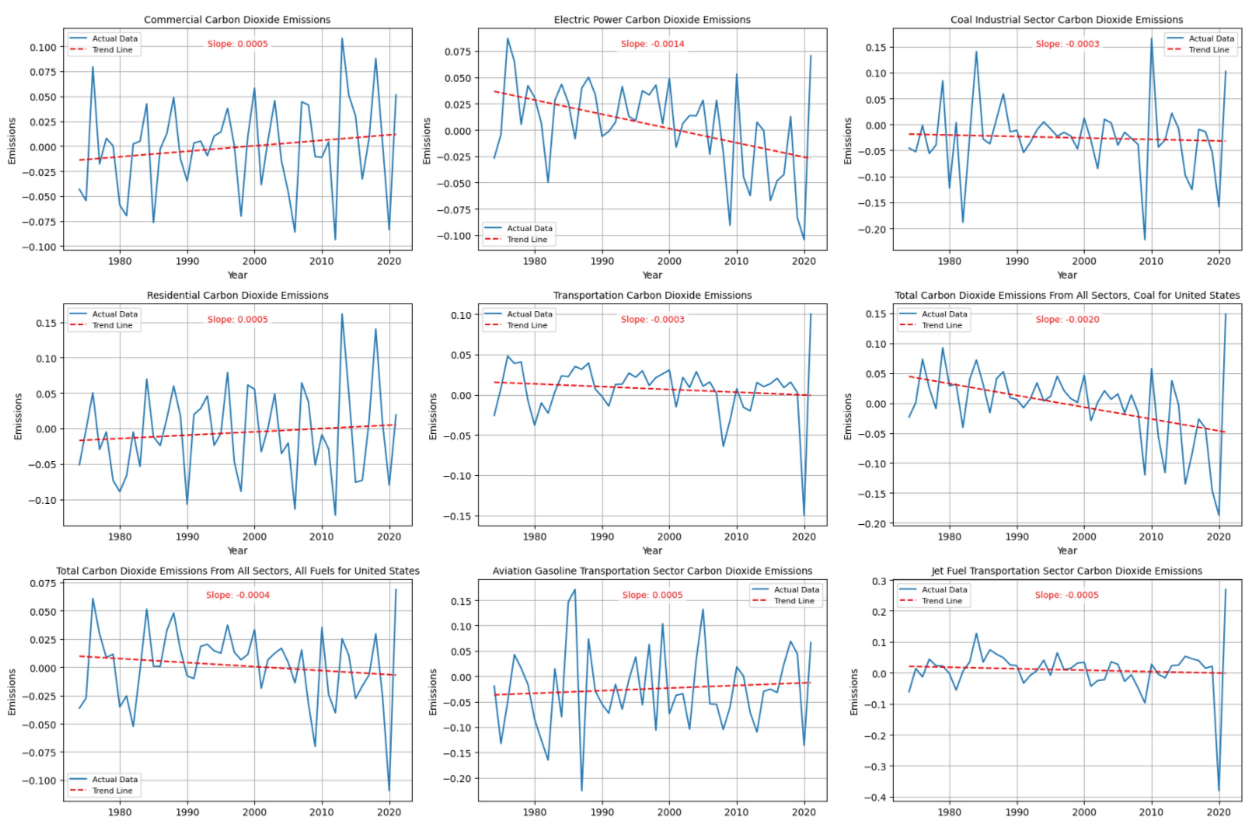
These expected signs provide an economic rationale for including the four macroeconomic variables in the regression models and offer a benchmark against which the empirical findings in Section 4 are interpreted. It is anticipated that real GDP and IP will show strong positive effects in electric power, coal, and total emissions sectors, while inflation and FER may exhibit weaker, less consistent effects across sectors.

4.Empirical Results and Explanatory data analyses

Figure 1 offers an overview of the time series and linear trends in sectoral carbon dioxide emissions in the United States from 1974 to 2021. Each subplot displays both the actual annual emissions and a linear trend line, with the slope of the trend line annotated for clarity. The results reveal a varied pattern across different sectors.

Notably, emissions from the electric power sector, the coal industrial sector, transportation, and total coal emissions across all sectors show negative slopes, indicating a gradual decline over time. For example, electric power and total coal emissions have slopes of –0.0244 and –0.0209, respectively, reflecting the nation's shift away from coal and improvements in electricity generation efficiency. Additionally, transportation emissions demonstrate a modest downward trend (slope: –0.0103), likely due to advances in vehicle efficiency and the use of alternative fuels.

Figure1: Timeseries of Emission of CO2 from various sectors



In contrast, commercial and residential carbon dioxide emissions exhibit slight positive slopes (0.0035 and 0.0015, respectively), suggesting that emissions in these sectors have remained relatively stable or have experienced a marginal increase. Aviation gasoline emissions also show a small positive trend (slope: 0.0065), while jet fuel emissions display a slight decrease (slope: –0.0065). Overall, total carbon dioxide emissions from all fuels across all sectors present a small negative slope (–0.0084), indicating a slow overall reduction in emissions, despite the mixed trends at the sectoral level.

A particularly striking feature across all sectors is the sharp drop in CO_2 emissions in 2020, which marked the lowest point in the time series for most sectors. This significant decline can be directly attributed to the widespread economic disruptions caused by the COVID-19 pandemic. The pandemic led to substantial reductions in industrial activity, transportation, air travel, and energy demand due to lockdowns, travel restrictions, and changes in consumer behavior. Consequently, CO_2 emissions in 2020 fell to levels not seen in decades, highlighting the sensitivity of emissions to large-scale societal and economic changes.

Overall, these trends indicate that while significant progress has been made in reducing emissions from coal and electric power, sectors such as commercial, residential, and aviation gasoline have not experienced notable declines. The year-to-year variability in emissions across all sectors suggests that they are influenced by a combination of economic, technological, and policy factors. These findings emphasize the need for targeted policy interventions, particularly in sectors where emissions remain stable or are increasing, to achieve broader climate goals.

Figure 2: cross correlation between dependent and independent variables.

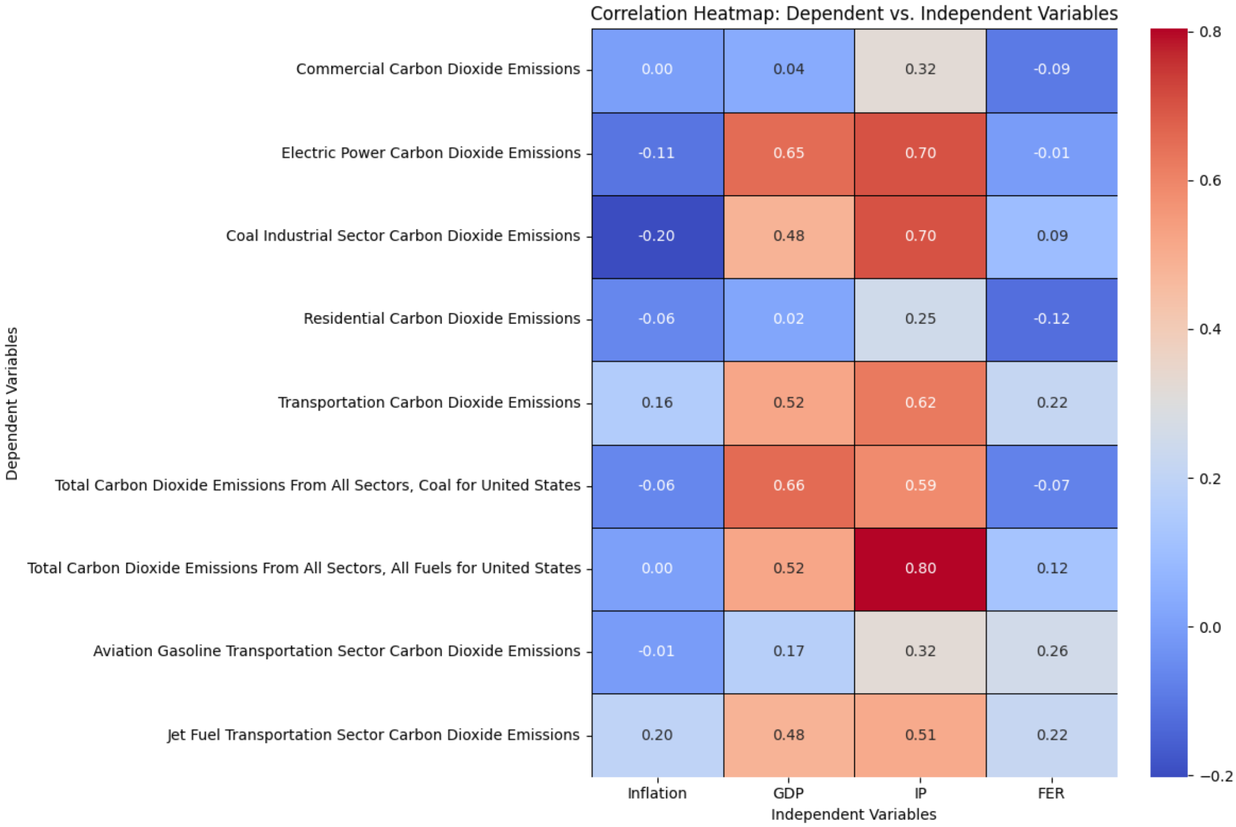


Figure 2 displays a heatmap that shows the Pearson correlation coefficients between sectoral carbon dioxide emissions (the dependent variables) and key economic indicators (the independent variables: Inflation, GDP, Industrial Production (IP), and the Federal Funds Effective Rate (FER)). The color gradient ranges from blue, indicating a negative correlation, to red, indicating a positive correlation, with specific correlation values annotated in each cell.

A closer look at the heatmap reveals several important patterns. Industrial Production is the economic variable most strongly and consistently correlated with emissions across multiple sectors. For example, it shows a very strong positive correlation with total CO_2 emissions from all fuels (0.80), electric power emissions (0.70), and coal sector emissions (0.70). This suggests that increases in industrial activity are closely linked to higher emissions, particularly in energy-intensive industries.

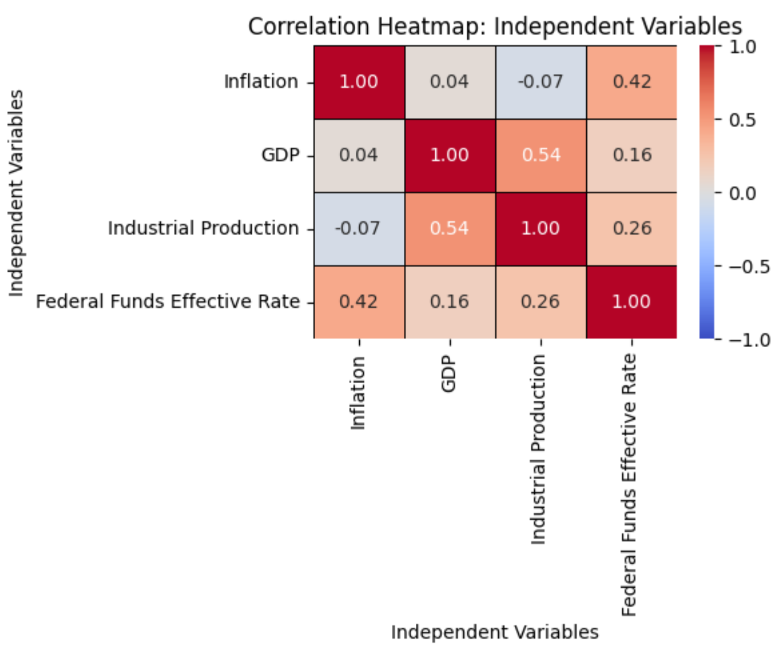
GDP also exhibits moderate to strong positive correlations with several emissions categories, especially with total coal sector emissions (0.66), electric power emissions (0.65), and transportation emissions (0.52). This relationship reflects the general trend that economic growth leads to increased energy use, although the correlation is weaker in the residential and aviation gasoline sectors.

Inflation generally shows weak correlations with emissions, with most values close to zero or slightly negative. The exceptions are transportation (0.16) and jet fuel emissions (0.20), where the correlations are positive but still modest. This indicates that changes in price levels have a limited direct impact on sectoral emissions.

The Federal Funds Effective Rate (a proxy for monetary policy) displays mostly weak correlations, with the highest positive values found in aviation gasoline (0.26), transportation (0.22), and jet fuel emissions (0.22). This suggests that changes in interest rates may influence emissions in transportation-related sectors, possibly by affecting investment and consumption patterns, although the overall effect is not strong.

In conclusion, the heatmap illustrates that industrial production and GDP are the primary economic drivers of carbon emissions in the U.S., particularly in the electric power, coal, and transportation sectors. In contrast, inflation and monetary policy appear to have a much smaller direct impact. These insights can assist policymakers in prioritizing interventions in the sectors most sensitive to emissions and enhance their understanding of the macroeconomic factors most closely linked to environmental outcomes.

Figure3: cross-correlation between independent variables.



The correlation heatmap presented above in Figure 3 illustrates the linear relationships among the four independent variables analyzed in this study: Inflation, GDP, Industrial Production, and the Federal Funds Effective Rate. Each cell in the heatmap displays the Pearson correlation coefficient between pairs of variables, with values ranging from –1 (indicating a perfect negative correlation) to +1 (indicating a perfect positive correlation). The color gradient visually emphasizes the strength and direction of these relationships, with deeper red shades representing stronger positive correlations and blue shades indicating negative correlations.

According to the heatmap, the independent variables in this dataset show only weak to moderate correlations with one another. The strongest relationship observed is between GDP and Industrial Production, with a correlation coefficient of 0.54, indicating a moderate positive association expected due to the close link between overall economic output and industrial activity. The Federal Funds Effective Rate also has a moderate positive correlation with Inflation (0.42), suggesting that higher interest rates are typically associated with higher inflation during the analyzed period. However, its correlations with GDP (0.16) and Industrial Production (0.26) are relatively weak. Inflation itself is nearly uncorrelated with GDP (0.04) and has a slight negative correlation with Industrial Production (–0.07), suggesting that changes in price levels are largely independent of output growth and industrial activity in this sample.

Overall, the absence of high correlations generally considered to be above 0.8 among these independent variables indicates that multicollinearity is not a significant concern for the regression models used in this study. This finding supports the validity of including all four variables as separate predictors in the analysis, as their effects on the dependent variables can be estimated without substantial risk of redundancy or distortion.

Table 2: Summary of the regressions result Dependent Variables Regressed on Current Macroeconomic Indicators

	Dependent variables								
	Y1	**Y2**	**Y3**	**Y4**	**Y5**	**Y6**	**Y7**	**Y8**	**Y9**
Estimated coefficients									
Intercept (p-value)	0.01 (0.06)	-0.04 **(0.00)**	-0.06 **(0.00)**	0.00 (0.84)	-0.02 (0.07)	-0.07 **(0.00)**	-0.02 **(0.02)**	-0.04 (0.19)	-0.05 **(0.04)**
Inflation (p-value)	0.00 (0.35)	0.00 (0.98)	-0.01 (0.18)	0.00 (0.70)	0.00 (0.12)	0.00 (0.57)	0.00 (0.26)	0.00 (0.58)	0.01 (0.13)
VIF Inflation	1.27	1.27	1.27	1.27	1.27	1.27	1.27	1.27	1.27
GDP (p-value)	-0.29 (0.24)	0.54 **(0.00)**	0.38 (0.17)	-0.32 (0.35)	0.26 (0.08)	0.96 **(0.00)**	0.12 (0.27)	0.01 (0.98)	0.70 (0.06)
VIF GDP	1.44	1.44	1.44	1.44	1.44	1.44	1.44	1.44	1.44
IP (p-value)	0.56 **(0.01)**	0.56 **(0.00)**	1.01 **(0.00)**	0.60 **(0.03)**	0.43 **(0.00)**	0.60 **(0.00)**	0.63 **(0.00)**	0.49 (0.15)	0.70 **(0.02)**
VIF IP	1.57	1.57	1.57	1.57	1.57	1.57	1.57	1.57	1.57
FER (p-value)	-0.02 (0.13)	-0.02 (0.05)	0.00 **(0.00)**	-0.02 **(0.03)**	0.00 **(0.00)**	-0.03 **(0.02)**	-0.01 (0.16)	0.03 (0.17)	0.00 (0.96)
VIF FER	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35
Regression statistics									
R-Squared	0.18	0.64	0.54	0.12	0.47	0.57	0.67	0.14	0.36
Adjusted R-Squared	0.10	0.61	0.49	0.04	0.42	0.53	0.64	0.06	0.30
F-Statistic	2.30	19.22	12.49	1.47	9.56	14.33	22.24	1.77	6.13
Prob (F-Statistic)	0.07	0.00	0.00	0.23	0.00	0.00	0.00	0.15	0.00
Akaike Criterion	-294.99	-342.77	-283.96	-263.68	-343.91	-298.34	-371.02	-239.32	-256.73
Schwartz Criterion	-285.64	-333.42	-274.60	-254.33	-334.56	-288.98	-361.66	-229.96	-247.38
Durbin-Watson	2.06	2.11	2.14	2.15	2.24	1.79	1.85	2.45	2.48
White Test Statistic (p-value)	12.01 (0.61)	16.37 (0.29)	34.37 **(0.00)**	12.33 (0.58)	27.88 **(0.01)**	20.77 (0.11)	21.50 (0.09)	11.86 (0.62)	23.40 (0.05)

Y1: Commercial Carbon Dioxide Emissions, Y2: Electric Power Carbon Dioxide Emissions, Y3: Coal Industrial Sector Carbon Dioxide Emissions, Y4: Residential Carbon Dioxide Emissions, Y5: Transportation Carbon Dioxide Emissions, Y6: Total Carbon Dioxide Emissions from All Sectors, Coal for United States, Y7: Total Carbon Dioxide Emissions from All Sectors, All Fuels for United States, Y8: Aviation Gasoline Transportation Sector Carbon Dioxide Emissions, Y9: Jet Fuel Transportation Sector Carbon Dioxide Emissions

As table 2 shows the regression analysis examined the contemporaneous effects of inflation, industrial production, GDP, and the federal funds effective rate on nine categories of CO_2 emissions (Y_1–Y_9) across U.S. economic sectors. The models revealed considerable variation in explanatory power, with adjusted R-squared values reaching as high as 0.64 for total CO_2 emissions from all fuels (Y_7). The electric power sector (Y_2) and total CO_2 from coal (Y_6) also exhibited strong model fits, with adjusted R-squared values of 0.61 and 0.53, respectively. In contrast, the residential (Y_4) and aviation gasoline (Y_8) models demonstrated very low explanatory power, suggesting that the selected economic variables explain only a small portion of emissions variability in these sectors.

Among the independent variables, industrial production consistently emerged as the most influential and statistically significant predictor of CO_2 emissions across nearly all models. Its regression coefficients were positive and substantial, ranging from 0.38 in the residential sector (Y_4) to 1.01 in the industrial sector (Y_3), with similarly high values in total CO_2 emissions (Y_7, 0.63) and jet fuel (Y_9, 0.70). These results indicate that increases in industrial activity are closely linked to higher emissions, reinforcing its role as a key economic driver of environmental impact.

GDP also exhibited significant effects in several sectors. It was particularly influential in the electric power (Y_2, coefficient = 0.54) and coal-based (Y_6, 0.96) sectors, and showed moderate effects in transportation (Y_5, 0.26) and jet fuel (Y_9, 0.70). However, its influence was less consistent across other categories, where coefficients were smaller and statistically insignificant.

In contrast, inflation had negligible impact across all models, as reflected in coefficients near zero (ranging from −0.01 to 0.01) and consistently high p-values. The federal funds effective rate similarly showed limited effects, with the exception of coal-based emissions (Y_6, coefficient = −0.03), where its influence was modest but statistically significant. In most other sectors, the coefficients for the federal funds rate remained small and statistically insignificant.

The overall fit and significance of the models were assessed using F-statistics. Strong model significance was observed in total CO_2 emissions (Y_7), electric power (Y_2), coal (Y_6), industrial (Y_3), and transportation (Y_5) sectors, all of which had p-values below 0.01. Models for jet fuel (Y_9) were also statistically significant, while those for residential (Y_4) and aviation gasoline (Y_8) were not, indicating that factors beyond macroeconomic indicators may be more relevant for explaining emissions in those categories.

In summary, the empirical results highlight industrial production as the primary economic driver of CO_2 emissions across most U.S. sectors. GDP also plays an important, though more sector-specific, role. In contrast, inflation and the federal funds effective rate show minimal influence. The explanatory power of the models varies considerably by sector, being strongest in electric power, coal, and total emissions, and weakest in residential and aviation gasoline.

Table 3 Dependent Variables Regressed on Lagged Macroeconomic Indicators

	Dependent variables								
	Y1	**Y2**	**Y3**	**Y4**	**Y5**	**Y6**	**Y7**	**Y8**	**Y9**
Estimated coefficients									
Intercept (p-value)	0.02 (0.22)	-0.02 (0.24)	-0.01 (0.82)	0.02 (0.37)	0.01 (0.41)	-0.03 (0.12)	0.01 (0.63)	0.00 (0.92)	0.02 (0.56)
Lagged Inflation (p-value)	0.00 (0.74)	0.00 (0.63)	0.00 (0.64)	0.00 (0.96)	0.00 (0.39)	0.00 (0.51)	0.00 (0.61)	0.01 (0.54)	0.01 (0.42)
VIF lagged Inflation	1.44	1.44	1.44	1.44	1.44	1.44	1.44	1.44	1.44
Lagged GDP (p-value)	-0.33 (0.23)	0.43 (0.08)	-0.30 (0.46)	-0.46 (0.21)	-0.04 (0.84)	0.64 (0.07)	-0.05 (0.79)	-0.51 (0.28)	-0.12 (0.80)
VIF lagged GDP	1.40	1.40	1.40	1.40	1.40	1.40	1.40	1.40	1.40
Lagged IP (p-value)	-0.04 (0.85)	-0.07 (0.69)	0.02 (0.96)	0.13 (0.64)	0.08 (0.60)	-0.25 (0.35)	0.05 (0.76)	0.51 (0.17)	0.21 (0.55)
VIF lagged IP	1.54	1.54	1.54	1.54	1.54	1.54	1.54	1.54	1.54
Lagged FER (p-value)	0.00 (0.87)	-0.03 (0.05)	-0.02 (0.40)	0.01 (0.67)	-0.02 (0.21)	-0.04 (0.09)	-0.01 (0.23)	0.00 (0.86)	-0.03 (0.27)
VIF lagged FER	1.57	1.57	1.57	1.57	1.57	1.57	1.57	1.57	1.57
Regression statistics									
R-Squared	0.06	0.15	0.04	0.04	0.04	0.14	0.04	0.06	0.03
Adjusted R-Squared	-0.03	0.07	-0.05	-0.05	-0.05	0.05	-0.05	-0.03	-0.06
F-Statistic	0.62	1.81	0.49	0.44	0.44	1.66	0.44	0.62	0.35
Prob (F-Statistic)	0.65	0.15	0.75	0.78	0.78	0.18	0.78	0.65	0.84
Akaike Criterion	-148.68	-160.89	-109.44	-120.06	-175.14	-124.74	-179.25	-95.26	-97.98
Schwartz Criterion	-139.43	-151.64	-100.19	-110.81	-165.89	-115.49	-170.00	-86.01	-88.72
Durbin-Watson	2.23	1.96	2.43	2.18	2.05	1.98	1.97	2.34	2.38
White Test Statistic (p-value)	20.45 (0.12)	21.95 (0.08)	20.35 (0.12)	21.30 (0.09)	7.50 (0.91)	21.58 (0.09)	14.13 (0.44)	5.02 (0.99)	9.42 (0.80)
Y1: Commercial Carbon Dioxide Emissions, Y2: Electric Power Carbon Dioxide Emissions, Y3: Coal Industrial Sector Carbon Dioxide Emissions, Y4: Residential Carbon Dioxide Emissions, Y5: Transportation Carbon Dioxide Emissions, Y6: Total Carbon Dioxide Emissions from All Sectors, Coal for United States, Y7: Total Carbon Dioxide Emissions from All Sectors, All Fuels for United States, Y8: Aviation Gasoline Transportation Sector Carbon Dioxide Emissions, Y9: Jet Fuel Transportation Sector Carbon Dioxide Emissions									

As Table 3 presents, the regression analysis explored the lagged effects of inflation, industrial production, GDP, and the federal funds effective rate on nine categories of carbon dioxide emissions (Y_1–Y_9) across major U.S. economic sectors. The overall explanatory power of the models remained relatively weak, with adjusted R-squared values mostly negative or near zero, indicating that the selected macroeconomic indicators explain only a small fraction of the observed variations in CO_2 emissions. The electric power sector (Y_2) displayed the highest explanatory strength (Adj. $R^2 = 0.07$), while residential (Y_4) and jet fuel transportation (Y_9) emissions recorded the lowest (Adj. $R^2 = -0.05$ and -0.06, respectively). The F-statistics across all models were statistically insignificant ($p > 0.05$), confirming that the relationships between the dependent and independent variables lack overall significance.

Among the explanatory variables, GDP lagged by one period showed the most notable yet inconsistent effects. Positive coefficients appeared in the electric power (Y_2, 0.43, $p = 0.08$) and total coal-based (Y_6, 0.64, $p = 0.07$) sectors, suggesting that increases in economic activity may modestly raise emissions in these areas. However, the influence was not statistically robust across the remaining categories. Inflation ($Inflation_{t-1}$) and industrial production (IP_{t-1}) demonstrated negligible effects, with coefficients near zero and high p-values, underscoring their minimal role in explaining emissions variability. The federal funds effective rate (FER_{t-1}) similarly lacked significance, except for a weak negative association in the electric power sector (Y_2, $p = 0.05$).

Diagnostic indicators support the validity of the regression estimates. Durbin–Watson statistics ranged between 1.96 and 2.43, suggesting no autocorrelation in the residuals, while White test results ($p > 0.05$) indicate homoskedasticity across all models. Variance inflation factors (VIFs) were consistently low (≈1.4–1.6), confirming the absence of multicollinearity among regressors.

Overall, the results reveal that lagged traditional macroeconomic indicators exert limited influence on CO_2 emissions at the sectoral level in the United States. Lagged GDP shows the most notable but inconsistent association, while inflation, industrial production, and the federal funds rate appear largely irrelevant within this framework.

A comparison between the two regression specifications where the dependent variables were regressed first on current and then on lagged independent variables reveals only limited dynamic effects in the relationship between macroeconomic indicators and sectoral CO_2 emissions. In the current-variable model, the explanatory power was relatively higher, with several sectors such as electric power, total emissions, and industrial sectors showing moderate adjusted R-squared values and statistically significant coefficients for GDP and industrial production. This suggested that contemporaneous changes in economic activity were more immediately associated with variations in emissions levels.

By contrast, in the lagged-variable model, the overall explanatory strength declined notably across all sectors, with adjusted R-squared values turning negative in most cases and F-statistics losing significance. This indicates that past values of the economic indicators explain little of the current emissions behavior. While GDP lagged by one period remained weakly positive for the electric power and coal-based sectors, these effects were small and statistically insignificant, implying that the influence of macroeconomic activity on emissions tends to be contemporaneous rather than delayed. Inflation, industrial production, and the federal funds effective rate also showed no improvement in predictive capacity when lagged values were introduced.

Taken together, these findings suggest that the relationship between macroeconomic conditions and carbon emissions in the U.S. is largely contemporaneous, with minimal lagged effects. In other words, changes in GDP or industrial output tend to impact emissions within the same period rather than carrying over to future periods. The weak dynamic component highlights the need for models that incorporate structural or sector-specific variables such as energy consumption patterns, fuel substitution, or policy interventions to better capture the temporal behavior of emissions across industries.

5.Discussion

5.1 Main findings

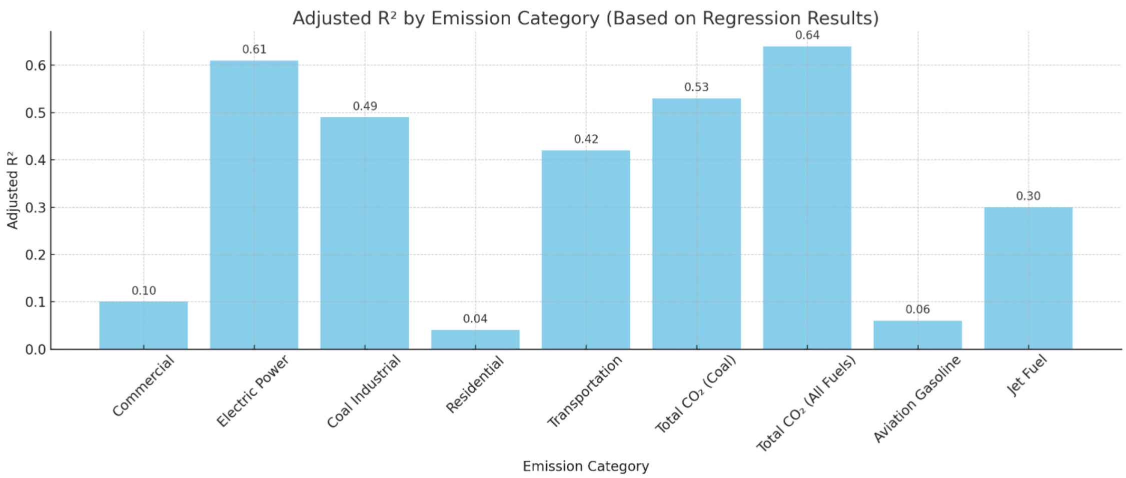
The primary goal of this study was to evaluate how key macroeconomic indicators specifically inflation, GDP, industrial production, and the federal funds effective rate affect carbon dioxide (CO_2) emissions across nine major sectors in the United States. By employing multiple linear regression analysis, two models were estimated: one based on current independent variables and another incorporating lagged (past) values. This dual approach allowed for examining both immediate and delayed effects of economic activity on emissions. The sectoral focus provides a more granular understanding of how economic dynamics shape environmental outcomes, which is critical for designing targeted policy responses.

The empirical results from the current-variable model indicate that industrial production is the most consistent and significant driver of CO_2 emissions across nearly all sectors. Its positive and statistically significant coefficients underscore the environmental cost of industrial growth, especially in energy-intensive sectors such as manufacturing, electric power, and fuel-based categories. GDP also exerts a positive influence, particularly in the electric power and coal-based sectors, confirming that higher economic output generally corresponds with higher emissions. In contrast, inflation and the federal funds effective rate show weak and inconsistent effects, suggesting that short-term monetary or price-level changes do not directly influence emission levels.

When considering the lagged-variable model, the results reveal that the influence of past economic conditions on current emissions is relatively limited. The explanatory power of the lagged model declines, and most lagged coefficients lose statistical significance. Only lagged GDP retains a weak positive association in a few sectors, particularly in electric power and coal, implying that the impact of economic activity on emissions occurs primarily within the same period rather than carrying over to subsequent periods.

Overall, the comparison between the two models suggests that the relationship between macroeconomic indicators and emissions is largely contemporaneous, with industrial activity exerting an immediate and dominant effect. This finding underscores the short-term responsiveness of emissions to economic fluctuations and highlights the challenge of decoupling industrial growth from environmental degradation in the near term.

Figure 4: Adjusted R ^2 obtained from the nine regression models.



The bar chart in Figure 4 provides a visual summary of the explanatory power of the regression models across different emission sectors. It is immediately apparent that the models for Total CO_2 (All Fuels) and Electric Power have the highest adjusted R^2 values (0.64 and 0.61, respectively), indicating that the selected economic variables explain a substantial proportion of the variance in emissions within these sectors. Similarly, the Total CO_2 (Coal) and Coal Industrial categories also show relatively strong model fits, with adjusted R^2 values of 0.53 and 0.49.

In contrast, the models for Residential and Aviation Gasoline emissions exhibit very low adjusted R^2 values (0.04 and 0.06), suggesting that macroeconomic variables play a much smaller role in explaining emissions in these sectors. The Commercial and Jet Fuel categories also display modest explanatory power, with adjusted R^2 values of 0.10 and 0.30, respectively.

This visualization reinforces the study's main finding that the relationship between economic activity and emissions is highly sector dependent. In sectors such as electric power and industrial coal, economic fluctuations are closely linked to changes in emissions, making them suitable targets for economic or regulatory interventions. Conversely, in sectors with low adjusted R^2 values, emissions are likely driven by other factors such as technology adoption, consumer behavior, or sector-specific regulations, highlighting the need for alternative policy approaches.

5.2. Managerial implications

From a policy and managerial perspective, these results suggest that efforts to reduce emissions should prioritize industrial decarbonization and cleaner production technologies.

The strong influence of industrial production implies that emission-reduction strategies should target structural changes in how goods are manufactured, and energy is consumed. For instance, promoting energy efficiency, carbon capture technologies, and renewable energy use within the industrial sector could significantly curb emissions without compromising output. Furthermore, the sector-specific role of GDP points to the need for differentiated policies that recognize the varying sensitivity of emission categories to economic expansion. Sectors where GDP has a strong impact such as electric power and transportation may benefit from growth-oriented green investment, while those with weaker links may require regulatory or behavioral interventions.

5.3 Limitations of the Study

Despite its contributions, this study has several limitations. The analysis is based solely on macroeconomic indicators and does not account for the full range of factors that influence emissions, such as technological innovation, regulatory changes, energy prices, or behavioral shifts. The sectoral models, while robust for energy-intensive industries, have limited explanatory power for sectors like residential and aviation gasoline, indicating the need for a broader set of explanatory variables. Additionally, the study relies on annual data and a limited set of macroeconomic variables and does not account for all possible determinants of emissions. Future research should consider longer records, incorporating additional factors, higher-frequency data, and alternative/non-linear modeling approaches to further enhance our understanding of the complex dynamics driving sectoral emissions.

5.4 Future research directions

This study provides valuable insights but also underscores several potential avenues for future research.

First, expanding the analytical framework to include policy variables such as environmental regulations and carbon pricing along with factors related to technological innovation, like renewable energy adoption and improvements in industrial efficiency, as well as behavioral aspects, such as shifts in consumer preferences, could enhance the explanatory power of emissions models. This is particularly important for sectors where macroeconomic variables alone are insufficient.

Second, future studies could utilize nonlinear or dynamic modeling approaches to better capture the evolving relationship between economic activity and emissions, especially in contexts marked by rapid technological change or external shocks.

Third, incorporating higher-frequency or more granular data such as emissions data at the regional or firm level could expose additional sources of variability and facilitate more targeted policy interventions.

Finally, conducting comparative studies across different countries or regions could help identify best practices and assess the applicability of findings in various economic and regulatory contexts.

By broadening the scope of analysis and integrating a wider range of variables, future research can provide a more comprehensive and accurate understanding of the drivers of carbon emissions. This, in turn, will support the development of more effective climate and economic policies aimed at achieving net-zero goals.

6.Conclusion

This thesis set out to quantitatively investigate the relationship between key macroeconomic indicators and carbon dioxide (CO_2) emissions across major U.S. economic sectors from 1974 to 2021. Using sector-specific multiple regression models based on long-term data from the Federal Reserve Economic Data (FRED) database, the study explored both contemporaneous (current) and dynamic (lagged) relationships between inflation, real GDP, industrial production, and the federal funds effective rate and their influence on CO_2 emissions. This dual-model approach provided a more comprehensive understanding of how economic conditions shape environmental outcomes over time.

The results indicate that the effects of macroeconomic variables on CO_2 emissions are largely sector-dependent and predominantly contemporaneous. Industrial production consistently emerged as the strongest and most statistically significant determinant of emissions across nearly all sectors, particularly in the industrial, electric power, and total emissions categories. GDP also played a notable role, especially in the electric power and coal-based sectors, although its influence varied across categories. In contrast, inflation and the federal funds effective rate showed weak or statistically insignificant effects in most cases, suggesting that short-term monetary conditions have minimal direct impact on emissions.

When lagged variables were used, the explanatory power of the models generally declined, and most coefficients lost statistical significance. This finding suggests limited dynamic persistence in the relationship between economic activity and emissions implying that changes in production or output influence emissions primarily within the same period rather than across time. The variation in adjusted R^2 values across sectors further highlights that past economic activity alone cannot fully explain emissions trends; other factors such as current economic factor, technological innovation, environmental regulations, and behavioral changes likely play an important complementary role.

From a policy and managerial perspective, these findings underscore the need for targeted, sector-specific strategies to reduce emissions effectively. Sectors with strong economic-emission linkages, such as industry and electric power, may benefit most from production-side interventions including carbon pricing, cleaner technologies, and efficiency incentives. Conversely, sectors where economic variables have limited explanatory power, such as residential or aviation gasoline, may require behavioral or technological approaches, such as consumer incentives for green choices or stricter efficiency standards.

In summary, this thesis contributes to the growing body of evidence highlighting the heterogeneous and short-term nature of the economic determinants of CO_2 emissions. It emphasizes that sustainable emission reductions require a combination of economic, technological, and policy-driven measures that reflect the distinct characteristics of each sector.

Future research should expand the analysis by incorporating policy, technological, and behavioral factors, employ advanced modeling techniques, utilize more granular data, and conduct comparative studies across regions to deepen understanding of the complex drivers of carbon emissions and inform effective climate policies.

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