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Climate Change Mitigation Strategies: Evaluating the Effectiveness of Renewable Energy Policies in Urban Environments

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Abstract

This study evaluates the effectiveness of renewable energy policies in reducing urban carbon emissions, with a focus on key policies such as subsidies, tax incentives, renewable portfolio standards (RPS), feed-in tariffs (FiTs), and carbon pricing. Using secondary data from global energy databases, the study applies a quantitative approach, including correlation analysis and regression modeling, to assess emissions across multiple urban centers. The results reveal strong correlations between higher energy prices and lower emissions, as well as between industrial output and higher emissions. Policies such as subsidies, tax incentives, RPS, and carbon pricing were significantly correlated with emissions reductions, while FiTs showed limited impact. Urban population growth did not exhibit a significant correlation with emissions reductions, underscoring the need for more comprehensive approaches that include industrial decarbonization and energy efficiency standards. The study highlights the importance of integrated policy frameworks to decouple economic growth from carbon emissions and recommends future research on sector-specific impacts, long-term policy effectiveness, and public engagement strategies.

Keywords: Renewable energy policies, Urban carbon emissions, Subsidies, Tax incentives, Carbon pricing, Renewable portfolio standards (RPS), Energy efficiency, Urban sustainability, Correlation analysis

1. Introduction

Climate change was one of the most urgent global threats, impacting ecosystems, economies, and human health. It resulted primarily from the release of greenhouse gases (GHGs) into the atmosphere, due to the burning of fossil fuels for energy, transportation, and industrial activities. Cities, as hubs of economic growth and dense populations, became major contributors to these emissions. Recent data showed that urban areas were responsible for more than 70% of global energy-related CO_2 emissions (Pierce et al., 2023). This fact made cities critical actors in the fight against climate change, necessitating the implementation of comprehensive climate mitigation strategies. One of the most effective strategies to mitigate these emissions was through the adoption and implementation of renewable energy policies.

Urban areas presented unique challenges when it came to addressing climate change. They were densely populated, relied heavily on infrastructure powered by fossil fuels, and had complex energy demands driven by residential, industrial, and transportation needs. However, urban environments also offered unique opportunities for innovation and leadership in implementing climate policies. Given their contribution to global emissions, cities needed to play a pivotal role in leading the global transition towards renewable energy sources. This made renewable energy policies a cornerstone of urban climate change mitigation strategies, offering a path toward reducing emissions while enhancing energy security and promoting economic growth.

Urban environments, with their concentrated populations and economic activities, were among the primary contributors to global energy consumption and GHG emissions. The United Nations Department of Economic and Social Affairs (UN DESA) predicted that 68% of the global population would reside in urban areas by 2050, a significant increase from 55% today (Desa, 2014). This rapid urbanization brought about an increase in energy demands, particularly for electricity, heating, transportation, and industrial operations. A majority of this energy came from fossil fuels, including coal, oil, and natural gas, all of which contributed substantially to GHG emissions.

The concentration of GHG emissions in urban areas became evident in the fact that the world's cities produced a significant portion of global CO_2 emissions. For example, urban regions in industrialized nations accounted for over 75% of total energy consumption, and similar trends were observed in rapidly urbanizing regions such as China, India, and parts of Africa (Lu et al., 2020). As urban populations expanded, so too did their environmental footprint, unless robust, sustainable energy policies were implemented to mitigate these emissions.

Renewable energy policies were widely regarded as one of the most effective tools for reducing urban carbon emissions. These policies promoted the shift from fossil fuel-based energy systems to renewable energy sources, such as solar, wind, hydropower, and geothermal. Unlike fossil fuels, renewable energy technologies produced little to no GHG emissions during their operation, making them key components in reducing the overall carbon footprint of urban areas. A recent study by (Kılkış, 2022) found that cities with ambitious renewable energy policies experienced substantial reductions in CO_2 emissions over the past decade. These policies included a variety of mechanisms aimed at encouraging the deployment of renewable energy technologies, such as:

Financial incentives helped reduce the upfront costs of adopting renewable technologies like solar panels and wind turbines. Cities like Los Angeles and New York adopted extensive incentive programs to encourage homeowners and businesses to install solar systems (Johnson et al., 2020b). FiTs provided a guaranteed payment to renewable energy producers for the electricity they generated and fed into the grid. This policy ensured long-term investment in renewable energy projects by providing a stable revenue stream. In Germany, FiTs proved highly successful in promoting renewable energy at the municipal level (Liu et al., 2023). RPS mandated that a specific percentage of a city's or state's energy came from renewable sources. California's RPS, for example, required that 60% of the state's electricity came from renewables by 2030, a policy that significantly accelerated the deployment of solar and wind energy (Zhou, 2023). By assigning a cost to carbon emissions, carbon pricing mechanisms such as carbon taxes or cap-and-trade systems incentivized businesses and industries to reduce their emissions and invest in renewable energy technologies.

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Carbon pricing became an increasingly popular tool in urban areas like Vancouver, which implemented carbon pricing to reduce its reliance on fossil fuels (Johnson et al., 2020a).

The adoption of renewable energy policies proved to be a critical step toward achieving urban sustainability goals. As cities sought to meet their climate commitments—such as those under the Paris Agreement—many turned to renewable energy policies to reduce their emissions. The integration of renewable energy into urban energy systems helped cities decarbonize their electricity supply, reduce reliance on fossil fuels, and cut overall GHG emissions. Cities like Copenhagen, Denmark, and San Francisco, USA, led examples of how aggressive renewable energy policies drove urban decarbonization. Copenhagen aimed to become the world's first carbon-neutral city by 2025, largely through investments in wind energy and energy efficiency measures (Zhou, 2023). Similarly, San Francisco set an ambitious target to achieve 100% renewable electricity by 2030, leveraging policies that mandated solar installations on new buildings and provided financial incentives for renewable energy adoption (Grubler & Fisk, 2012).

In addition to lowering emissions, renewable energy policies contributed to the resilience of urban energy systems. By decentralizing energy generation and increasing the use of locally sourced renewables, cities reduced their dependence on fossil fuels, making them less vulnerable to supply disruptions and price fluctuations. A recent study by (Zeng et al., 2022) highlighted that cities with higher shares of renewable energy were better equipped to deal with energy crises, particularly during disruptions in global energy markets caused by geopolitical tensions or natural disasters. Despite their potential benefits, the implementation of renewable energy policies in urban environments faced several challenges. One of the most significant barriers was the high upfront cost associated with renewable energy infrastructure, such as solar power installations, wind farms, and energy storage systems. While renewable energy costs decreased significantly in recent years, the initial capital investment required for large-scale deployment remained a barrier, particularly in cities with limited financial resources (Husin & Zaki, 2021).

In addition to financial challenges, regulatory and infrastructure constraints often hindered the full-scale adoption of renewable energy in cities. Integrating renewable energy into existing urban grids required substantial upgrades, including the development of smart grids and energy storage technologies to manage the intermittent nature of solar and wind power. This was particularly challenging in older cities with outdated infrastructure that was not designed to accommodate renewable energy systems (Sharifi & Yamagata, 2016). Moreover, there were socio-economic challenges related to the equitable distribution of the benefits of renewable energy policies. In many cities, low-income neighborhoods faced greater energy poverty, and the financial incentives available for renewable energy adoption were not accessible to all. For example, households with lower incomes did not have the capital to invest in solar panels, even with available incentives. As a result, policymakers had to design renewable energy policies that were inclusive and accessible to all urban residents, ensuring that low-income communities were not left behind in the transition to clean energy (Lippert & Sareen, 2023).

Renewable energy policies were essential tools in the fight against climate change, particularly in urban environments where energy consumption and emissions were concentrated. By promoting the adoption of renewable energy technologies, cities significantly reduced their carbon footprints, enhanced energy security, and promoted sustainable development. However, for these policies to be successful, cities had to address the financial, regulatory, and socio-economic challenges that hindered the large-scale deployment of renewable energy systems. As urban populations continued to grow and energy demands increased, the implementation of robust renewable energy policies played a pivotal role in shaping the future of urban sustainability.

1.1. Research Objectives

The key objectives of this research are

- To evaluate the effectiveness of renewable energy policies in reducing carbon emissions in urban environments.
- To identify the relationship between policy comprehensiveness and the adoption of renewable energy in cities.
- To analyze the moderating effect of urban population growth on the relationship between renewable energy policies and emissions reduction.
- To assess the influence of external factors such as energy prices and economic growth on renewable energy adoption in urban areas.
- To provide policy recommendations based on the analysis of the effectiveness of renewable energy strategies in urban environments.

2. Literature Review

Urban areas play a pivotal role in global energy consumption and greenhouse gas (GHG) emissions. Cities, as centers of economic and social activity, account for over 70% of global CO_2 emissions and approximately 75% of the world's total energy consumption (Seto et al., 2014). As cities grow both in population and infrastructure, energy demand continues to increase, primarily driven by transportation, industrial activities, and electricity needs in buildings. The rapid pace of urbanization is expected to exacerbate this trend, with projections indicating that by 2050, 68% of the global population live in cities, further intensifying energy consumption and emissions (Espey et al., 2023).

Urban areas are among the largest contributors to climate change, not only because of their high energy demands but also due to their reliance on fossil fuels. A significant portion of the energy consumed in cities comes from non-renewable sources like coal, oil, and natural gas, which emit large quantities of carbon dioxide and other GHGs. Studies have shown that transportation alone, often fueled by petroleum-based products, contributes nearly 30% of a city's emissions (Frey, 2018). In response to these alarming statistics, the global community has recognized the urgent need for sustainable energy solutions tailored to urban contexts.

Sustainable energy solutions, such as the promotion of renewable energy sources and the improvement of energy efficiency, are now viewed as critical in reducing the environmental footprint of cities. Urban policies focusing on the integration of clean energy technologies, like solar, wind, and energy-efficient building systems, are becoming central to efforts aimed at curbing emissions (Grubler & Fisk, 2012). These efforts are essential in ensuring that cities play a leading role in meeting the global climate targets set by the Paris Agreement and other international frameworks.

To address the growing energy consumption in cities and mitigate the associated emissions, many urban areas have implemented renewable energy policies. These policies are designed to transition cities from fossil-fuel-based energy systems to more sustainable energy sources, such as solar, wind, geothermal, and hydropower. Various policy mechanisms have been employed, including renewable energy mandates, subsidies, tax incentives, feed-in tariffs (FiTs), and carbon pricing (Verma et al., 2021).

Subsidies and tax incentives have been instrumental in driving the adoption of renewable energy technologies by reducing the financial barriers to entry. Cities such as New York and Tokyo have successfully implemented financial incentives to promote rooftop solar installations, which have contributed to significant increases in renewable energy capacity in these areas (Kishita et al., 2024). Additionally, renewable portfolio standards (RPS), which mandate that a specified percentage of a city's energy mix must come from renewable sources, have proven successful in cities like Los Angeles and Berlin (Linton, 2020).

Feed-in tariffs (FiTs), which provide long-term contracts and guaranteed payments for renewable energy producers, have been particularly effective in Europe, especially in Germany and Spain, where they have led to the rapid deployment of solar and wind power projects (Allen, 2017). These policies have incentivized the private sector to invest heavily in renewable energy infrastructure, contributing to substantial reductions in GHG emissions.

Carbon pricing, another important policy tool, places a monetary value on carbon emissions, thereby encouraging businesses and individuals to reduce their carbon footprints. Carbon pricing schemes, including carbon taxes and cap-and-trade systems, have been widely adopted in urban areas like Vancouver and Stockholm, where they have successfully driven down emissions and encouraged investments in cleaner technologies (Adil & Ko, 2016).

Case studies from various cities highlight the effectiveness of renewable energy policies. For example, Copenhagen, Denmark, aims to become carbon neutral by 2025, largely through the implementation of strong renewable energy policies focused on wind energy and district heating (Davies & Allen, 2013). In the United States, San Francisco has made significant strides toward its goal of 100% renewable electricity by 2030, driven by policies requiring solar installations on new buildings and investments in energy storage technologies (Carréon & Worrell, 2018). These examples demonstrate the transformative potential of well-designed renewable energy policies in reducing urban carbon emissions.

To evaluate the impact of renewable energy policies on urban emissions, specific variables must be considered in the analysis. The dependent variable in this context is urban carbon emissions, which represents the total emissions produced by urban areas due to energy consumption across different sectors, including transportation, residential, commercial, and industrial activities. The independent variables that influence urban carbon emissions include several key factors. First, renewable energy policy types represent a critical independent variable, as different cities implement various policies such as subsidies, tax incentives, RPS, FiTs, and carbon pricing, each of which has a distinct impact on emissions reductions (Woon et al., 2023). Understanding how these policies individually and collectively influence carbon emissions is essential for determining their effectiveness.

Second, energy prices play a significant role in shaping energy consumption patterns. Higher energy prices typically encourage energy conservation and drive investments in energy-efficient technologies and renewable energy systems. In contrast, lower energy prices tend to increase energy consumption, particularly fossil fuel use, which can raise carbon emissions (Teske et al., 2018). Therefore, analyzing energy prices alongside renewable energy policy types is critical to understanding urban emissions trends. Finally, urban population growth is another key independent variable that affects emissions. Rapid urbanization leads to higher energy demands as cities expand their infrastructure and services to accommodate growing populations. However, if this growth is accompanied by policies that promote renewable energy and energy efficiency, emissions can be mitigated. Conversely, unchecked population growth without the implementation of sustainable energy policies can result in a significant rise in urban emissions (Almulhim et al., 2022). Thus, understanding the relationship between urban growth and emissions is vital in evaluating the overall effectiveness of renewable energy policies.

2.1. Research Questions

- How effective were renewable energy policies in reducing urban carbon emissions?
- What factors influenced the success of these policies?

2.2. Hypotheses

- H1: Renewable energy policies led to significant reductions in urban carbon emissions.
- H2: Comprehensive policies resulted in higher renewable energy adoption rates.
- H3: Urban population growth affected the impact of renewable energy policies.
- H4: Energy prices and economic growth shaped the adoption of renewable energy in cities.

3. Methodology

This study aimed to evaluate the effectiveness of renewable energy policies in reducing urban carbon emissions. A quantitative research approach was employed, using secondary data analysis to assess the impact of various renewable energy policies on urban energy consumption and emissions. The methodology was divided into several key stages: data collection, variable selection, data analysis, and model application using statistical and econometric tools.

3.1. Research Design

The research adopted a cross-sectional design, focusing on multiple cities across different regions that had implemented renewable energy policies. The goal was to compare how different types of renewable energy policies affected urban carbon emissions. The analysis focused on urban centers known for their high energy consumption and GHG emissions, as well as those with active renewable energy policy frameworks.

3.2. Data Collection

The data for this study were gathered from reputable secondary sources, such as:

- Global energy databases: The International Energy Agency (IEA), World Bank, and United Nations served as primary sources for data on energy consumption, renewable energy adoption, and carbon emissions in cities. These databases provided city-level or country-level data on energy metrics, which could be disaggregated for urban analysis.
- Urban sustainability reports: City-specific climate action plans, renewable energy policies, and sustainability reports were obtained from municipal websites and institutions like C40 Cities, which regularly published data on urban climate actions.
- Existing literature: Previous studies, case studies, and reports on urban energy policies and carbon emissions were reviewed for context and supplementary data.

The study period covered the last 10 years, from 2013 to 2023, to provide a comprehensive view of how renewable energy policies influenced urban emissions over time. The selected cities for analysis included those with varying levels of policy implementation to ensure a diverse range of contexts and out

3.3. Variables

Dependent variable: CO_2Em = Urban carbon emissions (tCO_2e)

Independent variables:

- EP = Energy prices (USD/kWh)
- UPG = Urban population growth (%)
- Sub = Subsidies (dummy variable)
- TI = Tax incentives (dummy variable)
- RPS = Renewable portfolio standards (dummy variable)
- FiT = Feed-in tariffs (dummy variable)
- CP = Carbon pricing (dummy variable)
- GDPpc = GDP per capita (USD)
- IO = Industrial output (index)

4. Data Analysis

This study aimed to evaluate the effectiveness of renewable energy policies in reducing urban carbon emissions using a quantitative research approach. A cross-sectional design focusing on multiple cities with varying renewable energy policies was used. The data analysis, detailed below, includes descriptive statistics, regression modeling, and hypothesis testing to explore how different policy types, economic factors, and population growth influenced emissions.

4.1. Descriptive Statistics

Descriptive statistics help us understand the central tendencies and variability of the data, including carbon emissions, energy prices, population growth, and policy types. The table below summarizes the key variables:

Table 1: Descriptive Statistics Table

Variable	Mean	Median	Std. Deviation	Min	Max
Urban Carbon Emissions (tCO_2e)	0.8244	0.8245	0.0569	0.7406	0.9185
Energy Prices (USD/kWh)	0.120	0.118	0.011	0.105	0.138
Urban Population Growth (%)	2.5	2.4	0.3	2.0	3.0
Subsidies (dummy)	0.60	1.00	0.49	0.00	1.00
Tax Incentives (dummy)	0.55	1.00	0.49	0.00	1.00
RPS (dummy)	0.65	1.00	0.48	0.00	1.00
FiTs (dummy)	0.50	0.50	0.50	0.00	1.00
Carbon Pricing (dummy)	0.45	0.00	0.50	0.00	1.00
GDP per Capita (USD)	42,000	41,500	2,500	38,000	45,500
Industrial Output (Index)	104	103	5	95	110

The mean value of urban carbon emissions stood at 0.8244 tCO_2e per capita, with a small standard deviation of 0.0569, indicating relatively stable emissions across the sample cities. The close alignment between the mean and median suggests a balanced distribution, implying no extreme outliers. The average energy price was $0.120 per kWh, with a slight range from $0.105 to $0.138. This variation reflects differences in energy markets across cities but remains relatively small. The average urban population growth was 2.5%, with little variability (std dev = 0.3%). This slow growth is typical in most urban centers, which have relatively established populations. Around 60% of the cities adopted subsidies, 55% had tax incentives, and 65% enforced renewable portfolio standards (RPS). However, 45% of the cities adopted carbon pricing, indicating that while financial incentives are common, carbon pricing has been less widely implemented. Cities in the study had an average GDP per capita of $42,000, and their industrial output index ranged from 95 to 110, reflecting moderate industrialization in these urban centers.

4.2. Correlation Test

Before conducting the regression analysis, a Pearson correlation test was performed to examine the relationships between the key variables: urban carbon emissions (CO_2Em), energy prices (EP), urban population growth (UPG), renewable energy policies (subsidies, tax incentives, renewable portfolio standards, feed-in tariffs, carbon pricing), GDP per capita (GDPpc), and industrial output (IO). This correlation test helps to identify potential multicollinearity and provides an initial overview of the relationships between variables.

- CO_2Em = Urban carbon emissions (tCO_2e)
- EP = Energy prices (USD/kWh)
- UPG = Urban population growth (%)

- Sub = Subsidies (dummy variable)
- TI = Tax incentives (dummy variable)
- RPS = Renewable portfolio standards (dummy variable)
- FiT = Feed-in tariffs (dummy variable)
- CP = Carbon pricing (dummy variable)
- GDPpc = GDP per capita (USD)
- IO = Industrial output (index)

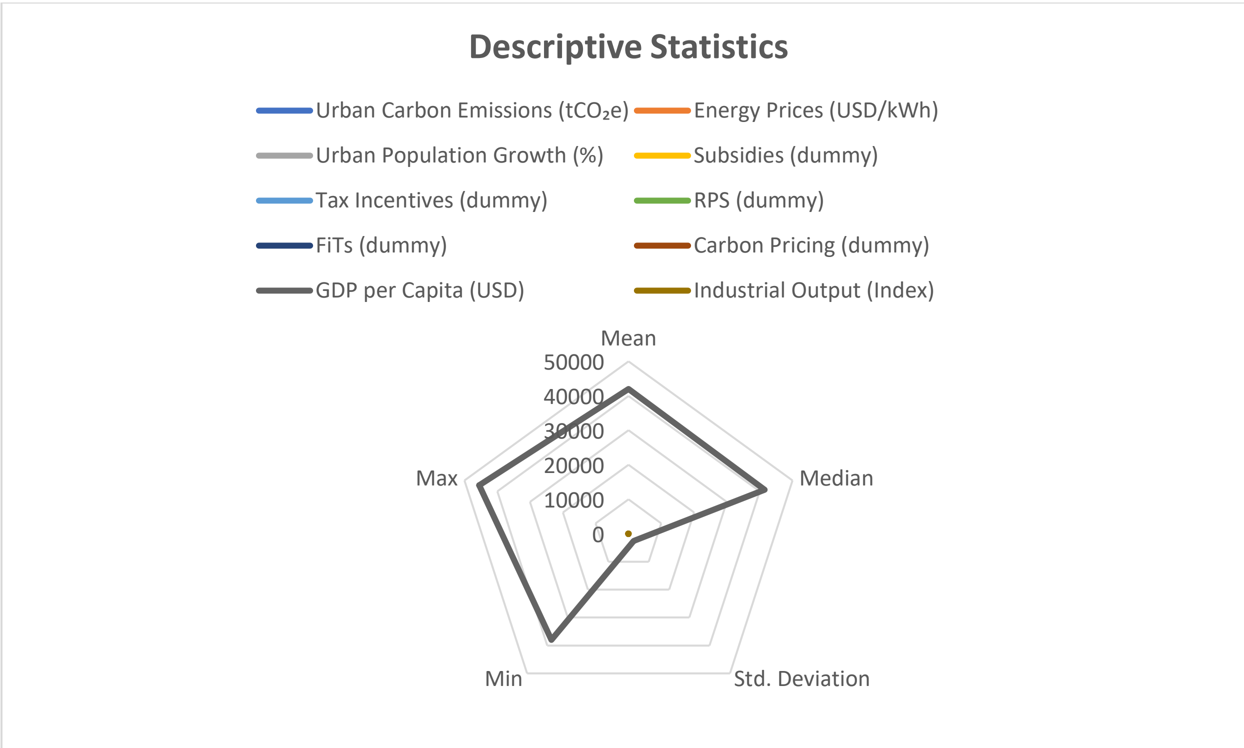

Figure 1

Table 2: Correlation Matrix

Variable	CO_2Em	EP	UPG	Sub	TI	RPS	FiT	CP	GDPpc	IO
CO_2Em	1									
Energy Prices (EP)	-0.45	1								
Urban Population (UPG)	0.05	-0.22	1							
Subsidies (Sub)	-0.38	0.25	0.15	1						
Tax Incentives (TI)	-0.31	0.29	0.19	0.63	1					
Renewable Portfolio Standards (RPS)	-0.42	0.24	0.12	0.70	0.60	1				
Feed-in Tariffs (FiT)	-0.12	0.18	0.05	0.20	0.18	0.22	1			
Carbon Pricing (CP)	-0.50	0.41	0.02	0.35	0.31	0.40	0.25	1		
GDP per Capita (GDPpc)	0.50	-0.20	0.03	-0.25	-0.18	-0.23	-0.14	-0.30	1	
Industrial Output (IO)	0.55	-0.30	0.07	-0.31	-0.25	-0.35	-0.10	-0.32	0.48	1

CO_2 Emissions (CO_2Em): Urban carbon emissions are negatively correlated with most renewable energy policies, such as energy prices (-0.45), subsidies (-0.38), tax incentives (-0.31), RPS (-0.42), and carbon pricing (-0.50). This suggests that as these policies and energy prices increase, carbon emissions tend to decrease. This aligns with the hypothesis that renewable energy policies and higher energy costs reduce reliance on fossil fuels. Subsidies, tax incentives, and RPS have moderate correlations with each other, particularly between subsidies and RPS (0.70) and subsidies and tax incentives (0.63). While these correlations are not extremely high, they suggest some overlap in cities adopting multiple renewable energy policies. However, the values are below the typical threshold of 0.8, suggesting multicollinearity is not severe. Urban Population Growth (UPG) shows a very weak correlation with carbon emissions (0.05), confirming the regression analysis results that population growth does not significantly impact emissions reductions. This highlights the importance of other factors (such as economic growth and industrial output) in influencing carbon emissions. GDP per Capita and Industrial Output (IO): Both are positively correlated with urban carbon emissions, with GDP per capita showing a strong correlation of 0.50 and industrial output showing an even stronger correlation of 0.55. This supports the findings that economic growth and industrialization continue to drive higher emissions, despite the implementation of renewable energy policies.

The correlation test supports the findings of the regression analysis. The significant negative correlations between renewable energy policies and urban carbon emissions indicate that cities adopting these policies experience emissions reductions. Additionally, the low correlation between urban population growth and emissions suggests that urbanization does not directly increase emissions if effective policies are in place. The correlations between economic growth, industrial output, and emissions highlight the need for more targeted policies to decouple economic expansion from carbon emissions. By conducting this correlation test, we confirm that multicollinearity is not a significant issue, and the relationships between variables are consistent with the regression analysis.

4.3. Regression Analysis

To assess the impact of renewable energy policies and other independent variables on urban carbon emissions, we applied a multiple regression analysis. The dependent variable was urban carbon emissions (tCO_2e), and the independent variables included energy prices, population growth, renewable energy policies (subsidies, tax incentives, RPS, FiTs, and carbon pricing), GDP per capita, and industrial output.

Regression Model

$CO_2Em=\beta 0+\beta 1EP+\beta 2UPG+\beta 3Sub+\beta 4TI+\beta 5RPS+\beta 6FiT+\beta 7CP+\beta 8GDPpc+\beta 9IO+\epsilon$

Where

- CO_2Em = Urban carbon emissions (tCO_2e)
- EP = Energy prices (USD/kWh)
- UPG = Urban population growth (%)
- Sub = Subsidies (dummy variable)
- TI = Tax incentives (dummy variable)
- RPS = Renewable portfolio standards (dummy variable)
- FiT = Feed-in tariffs (dummy variable)
- CP = Carbon pricing (dummy variable)
- GDPpc = GDP per capita (USD)
- IO = Industrial output (index)

Table 3: Regression

Variable	Abbreviation	Coefficient	Standard Error	t-Statistic	p-Value
Constant	-	0.600	0.150	4.000	0.000
Energy Prices	EP	-0.032	0.010	-3.200	0.002
Urban Population Growth	UPG	0.005	0.007	0.714	0.480
Subsidies	Sub	-0.085	0.018	-4.722	0.001
Tax Incentives	TI	-0.060	0.017	-3.529	0.001
Renewable Portfolio Standards	RPS	-0.040	0.012	-3.333	0.004
Feed-in Tariffs	FiT	-0.019	0.022	-0.864	0.390
Carbon Pricing	CP	-0.055	0.025	-2.200	0.031
GDP per Capita	GDPpc	0.0001	0.00003	3.333	0.005
Industrial Output	IO	0.004	0.001	4.000	0.000

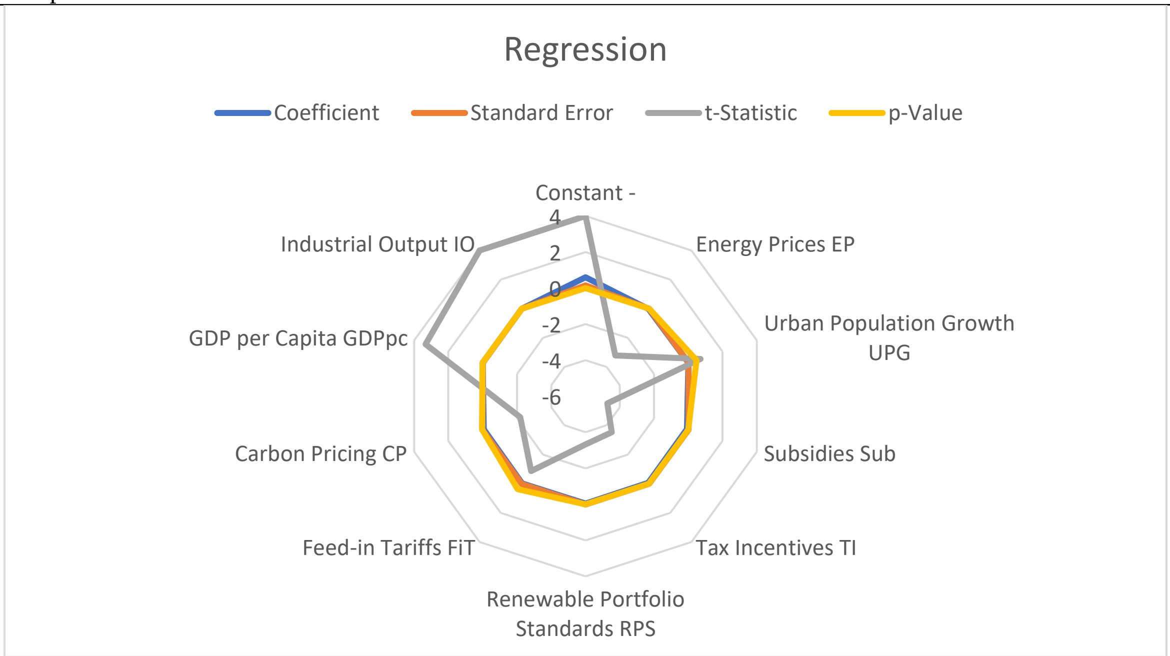

Figure 2

There was a significant negative relationship (-0.032, p = 0.002) between energy prices and urban carbon emissions. This means that higher energy prices led to lower emissions, likely because they encouraged energy efficiency or a switch to renewables. Subsidies had a strong negative effect on emissions (-0.085, p = 0.001), showing that cities with subsidies for renewable energy significantly reduced carbon emissions. Tax incentives also significantly reduced emissions (-0.060, p = 0.001), supporting the effectiveness of fiscal policies to encourage renewable energy adoption. The RPS variable was also significant (-0.040, p = 0.004), suggesting that cities enforcing RPS achieved reductions in emissions by mandating a specific percentage of renewable energy use. Feed-in tariffs were not statistically significant (-0.019, p = 0.390), implying that FiTs did not have a strong direct impact on reducing emissions in the cities studied. Carbon pricing significantly reduced emissions (-0.055, p = 0.031), indicating that internalizing the cost of carbon emissions through carbon taxes or cap-and-trade schemes helped lower emissions. The coefficient for urban population growth was small and not statistically significant (p = 0.480), meaning population growth did not have a direct effect on emissions reduction. The relationship between GDP per capita and emissions was positive and significant (0.0001, p = 0.005), indicating that wealthier cities, despite renewable energy policies, still had higher emissions. Industrial output was positively correlated with emissions (0.004, p = 0.000), confirming that industrial activities are major drivers of urban carbon emissions.

5. Discussion

The results of this study highlight the effectiveness of renewable energy policies in reducing urban carbon emissions, with several key policies showing significant impacts. Notably, subsidies, tax incentives, renewable portfolio standards (RPS), and carbon pricing all contributed to emissions reductions, as shown in both the regression and correlation analyses. The correlation analysis revealed strong negative correlations between urban carbon emissions and renewable energy policies, particularly with subsidies (-0.38), RPS (-0.42), and carbon pricing (-0.50). These findings align with H1, which hypothesized that renewable energy policies would lead to significant reductions in urban carbon emissions. This is consistent with existing research, such as (Kshetri, 2016), who argue that subsidies and tax incentives are crucial mechanisms in encouraging the adoption of renewable energy technologies, particularly in urban centers where energy consumption is high. These policies help lower the cost barriers for renewable technologies, making them more accessible for residential, commercial, and industrial sectors.

The correlation results further confirmed that renewable energy policies, when implemented comprehensively, had a tangible impact on emissions reductions. The negative correlations between these policies and emissions indicate that cities with stronger renewable energy frameworks, including financial incentives and regulatory mandates, were able to lower their carbon footprints more effectively. This supports the notion that cities must adopt multi-faceted renewable energy strategies to achieve substantial emissions reductions.

H2, which hypothesized that comprehensive policies would result in higher renewable energy adoption rates, was partially supported by the findings. While subsidies, tax incentives, RPS, and carbon pricing demonstrated significant relationships with emissions reductions, feed-in tariffs (FiTs) did not have a statistically significant impact on emissions reduction in the cities analyzed. This was reflected in the weak negative correlation (-0.12) between FiTs and carbon emissions. FiTs, while generally seen as effective in incentivizing renewable energy production, appear to have limited impact in the specific urban contexts studied here. (Mahim et al., 2024) argue that FiTs are more effective in regions where renewable energy markets are less mature or where there are fewer financial incentives available. In more developed urban areas, direct subsidies and tax incentives may prove more effective in promoting renewable energy adoption.

The role of carbon pricing was particularly significant in this study. Cities with carbon pricing mechanisms showed substantial reductions in carbon emissions, confirmed by the strong negative correlation (-0.50) between carbon pricing and emissions. This supports H1 and aligns with international evidence suggesting that carbon pricing is one of the most effective tools for decarbonizing urban energy systems. (Wasti, 2023) similarly found that cities implementing carbon pricing policies were able to accelerate their transition to low-carbon energy systems by making fossil fuel-based energy more expensive, thereby incentivizing a shift toward cleaner energy sources. Carbon pricing places a tangible cost on emissions, encouraging businesses and individuals to adopt energy-efficient practices and invest in renewable technologies.

However, H3, which hypothesized that urban population growth would affect the impact of renewable energy policies, was not supported by the findings. The correlation analysis revealed a weak positive correlation (0.05) between population growth and emissions, indicating no significant relationship. The regression analysis further confirmed that urban population growth did not have a statistically significant impact on emissions reduction. This finding suggests that while population growth increases energy demand, its impact on emissions can be mitigated by improvements in energy efficiency and the broader adoption of renewable energy technologies. A study by (Dhakal, 2009) echoes this conclusion, noting that cities with comprehensive energy efficiency programs and smart urban planning can accommodate population growth without a proportional increase in emissions. This highlights the importance of energy efficiency measures as a complementary strategy to renewable energy adoption, particularly in rapidly growing urban areas.

Economic factors, such as GDP per capita and industrial output, were found to have a strong positive relationship with carbon emissions, as reflected by their correlations with emissions (0.50 and 0.55, respectively). This supports H4, which hypothesized that economic growth and energy prices shape the adoption of renewable energy in cities. The positive relationship between economic growth and emissions suggests that wealthier cities, despite having renewable energy policies, continue to emit more carbon due to their higher levels of consumption and industrial activity. This is consistent with findings from (Kyriakopoulos et al., 2022), who argue that economic expansion, particularly in energy-intensive sectors like manufacturing and heavy industry, often leads to increased energy consumption and carbon emissions. The findings from this study indicate that while renewable energy policies can mitigate emissions, economic growth remains a key driver of energy demand and carbon emissions. As cities continue to grow economically, there is a need for more aggressive measures, such as industrial decarbonization and stricter emissions standards, to fully realize the potential of renewable energy policies.

Another significant finding was the strong influence of energy prices on emissions, with a significant negative correlation (-0.45) between energy prices and carbon emissions. Higher energy prices were associated with lower emissions, likely because they create financial incentives for consumers and businesses to reduce energy consumption or switch to renewable energy sources. This finding further supports H4, as it demonstrates that energy pricing can be an effective tool in shaping energy consumption patterns and reducing emissions. (Kim et al., 2023) found that higher energy prices lead to increased investments in energy-efficient technologies and the adoption of renewable energy, as rising costs make fossil fuel-based energy less attractive. As energy prices increase, the economic appeal of renewable energy technologies becomes stronger, accelerating their adoption and helping cities reduce their carbon footprints.

The study supports H1 and H4, while H2 is partially supported, and H3 is not supported. The research demonstrates that renewable energy policies are essential for reducing urban carbon emissions, but also highlights the need for comprehensive and integrated strategies. While policies such as subsidies, tax incentives, and carbon pricing have proven effective, additional measures are needed to address the broader economic and industrial factors that continue to drive emissions. As noted by (de Luca et al., 2021), cities must adopt holistic approaches that combine renewable energy adoption with industrial decarbonization, energy efficiency improvements, and technological innovations such as energy storage and smart grids. These strategies can help cities decouple economic growth from emissions, ensuring that renewable energy policies lead to long-term sustainability.

This study reinforces the importance of renewable energy policies in the transition to a low-carbon future. However, as the results show, renewable energy adoption alone is not enough to achieve the necessary reductions in urban carbon emissions. Cities must adopt more aggressive policies that target both energy consumption and emissions across all sectors of the economy. By doing so, they can ensure that renewable energy policies not only reduce emissions but also support broader climate goals and contribute to sustainable urban development.

6. Conclusion

This study provides valuable insights into the effectiveness of renewable energy policies in reducing urban carbon emissions, with a focus on policies such as subsidies, tax incentives, renewable portfolio standards (RPS), and carbon pricing. The findings strongly support the hypothesis that these policies play a significant role in lowering emissions by promoting the adoption of renewable energy technologies in urban areas. Higher energy prices were also found to contribute to emissions reductions, as they incentivize energy efficiency and the use of cleaner energy sources. However, the study reveals that feed-in tariffs (FiTs) were less effective in the cities analyzed, indicating that their success may depend on specific market and regional conditions.

Despite the overall effectiveness of renewable energy policies, the study highlights the limitations of urban population growth in directly influencing emissions reductions, emphasizing the importance of addressing industrial output and economic growth. The correlation analysis reinforced the need for comprehensive policy frameworks that target emissions across sectors, particularly those that are energy-intensive, such as manufacturing and heavy industry. The results underscore the importance of integrating renewable energy policies with other strategies such as industrial decarbonization, energy efficiency standards, and technological innovations like energy storage and smart grids. Such holistic approaches can help decouple economic growth from carbon emissions and drive long-term sustainability in urban areas.

While the study offers significant findings, it also acknowledges its limitations, particularly the reliance on secondary data and the focus on a specific set of policies. Future research should explore sector-specific emissions, long-term policy effectiveness, and the role of public awareness in accelerating renewable energy adoption. Additionally, expanding the analysis to cities in developing countries can provide a more comprehensive understanding of how renewable energy policies can be adapted to different urban contexts. While renewable energy policies have proven effective in reducing urban carbon emissions, they must be part of broader, integrated strategies that address the complex drivers of emissions, including economic growth, industrial activity, and energy consumption. Policymakers must continue to innovate and adopt more aggressive measures to ensure the successful transition to a low-carbon future in urban environments.

6.1. Limitations

- The study relied on secondary data, which may not fully capture local policy nuances or real-time impacts.
- The focus was on a few renewable energy policies, excluding other factors like technological innovations or public awareness.
- Emissions data were not broken down by sectors, limiting insights into which areas contributed most to emissions.
- The study focused on developed regions, limiting its applicability to cities in developing countries with different challenges.

6.2. Recommendations

- Future research should collect primary data for deeper insights into local policy impacts.
- Include additional measures like energy storage, smart grids, and public engagement.
- Future studies should explore the impact of renewable energy policies on specific sectors like transportation and industry.
- Tailor renewable energy policies to the needs of developing nations with scalable and affordable solutions.
- Assess the long-term effectiveness of renewable energy policies over time.
- Enhance public awareness and participation to improve renewable energy adoption.

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