

Research Article**Determinants and Their Impact on CO₂ Emissions: A Pakistan Perspective****Authors' Name**

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Abstract

The main purpose of the study is to investigate the factors influencing the Co₂ emissions. The study uses the extended STIRPAT (Stochastic Impacts by Regression on Population, Affluence, and Technology) model to measure the Co₂ emission. Explanatory variables are taken by the study are population(Pop), economic activity (GDP per capita), energy consumption (EC), urbanization (URB), trade openness(TO), and energy-sector composition (ESC), demand of vehicle (DV). The study uses the time series data over the period from 1972 to 2024 (52 years observation). The study examines long-run relationships between CO₂ emissions and its determinants using autoregressive distributed lag (ARDL) bounds testing, error-correction modeling (ECM), and multiple regression analysis. The study's results suggest that energy consumption and urbanization are the important predictors towards the emissions. The found that demand of vehicle also the cause of Co₂ emission. While EC shows non-linear effects.

Key words: Co₂, population, economic activity, energy consumption, urbanization, trade openness, energy-sector composition, and demand of vehicle

1. Introduction

Neat and clean atmosphere is essential for everyone. To reduce the all kinds of pollutions by adopting the smart choices. Some factors such as rapid population growth, extensive use of energy, urbanization, industrialization, poor transportation system, low level of literacy, weak institutional

system, and destabilized political system are the main causes of the developing countries like Pakistan. They have substantial amount of greenhouse gas (GHG) emissions. Understanding and awareness are the key drivers behind CO₂ emissions is critical for formulating effective mitigation strategies. Increase of Co₂ creates lot for problems for society, ultimate enhance health issues which leads burden of health sector. Co₂ also effect the business community, discourage the foreign investment. Long term and viable strategies are very crucial regarding to the Co₂ emissions. A balance population growth, optimal urbanization, viable transportation system, high level of literacy, stable political system are very important for the country to manage and control the Co₂. Waste management is another important aspect of the Co₂ emission. Proper planning for waste management indispensable for healthy nation and encouraging foreign investment. Education and awareness are key of waste management. Smart buying behavior are highly positive contributor toward the reduction of Co₂ emissions. Over consumption, over eating, unnecessary purchases, promoting and encouraging individual vehicles are the factors to increase waste, pollution and many other problems.

Research questions:

1. Are industrialization and urbanization leads to carbon emissions?
2. What does the relationship between energy consumption and Co₂ emissions
3. Is there any positive or negative relationship between economic activity and Co₂ emissions
4. Does population growth enhances Co₂ emissions
5. Is there any significant relationship between number of vehicles and Co₂ emission

2. Review of Literature.

Some past research studies highlighted the factors boosting the Co₂ emissions. Many studies found more or less same factors.

Khan et al (2019) investigated the time series data from (1972-2017). Study found that energy consumption, urbanization gross domestic product/capita are the main contributors of the Co₂ emission. Mir et al (2020) examines the factors influencing the Co₂ emissions. The study investigated fuel consumption, industrialization, transport and residential energy consumption are contributing 70% Co₂ in the developing countries like Pakistan.

A recent study Ahmed et al (2025) highlighted the factors boosting the Co2 emission. The study found that transport and urbanization are the main factors towards the Co2 emission. A large chunk of population depends upon transportation business or their own vehicle, which ultimate enhancing the Co2 emissions. Another factor taken by the study was urbanization. Urbanization creates worst impact on Co2 emissions.

Sharma and Dhakal (2011), analyzed the data of economic activity growth, fuel consumption, and import and export are key determinants of Co₂ emissions worldwide. Zhao, Reiter and Milovich (2022) stresses that carbon emissions are substantially contributed by the research innovation and energy consumption. More technology innovation leads to more carbon emission and vice versa. More energy consumption leads to more Co₂ emissions. Another study conducted by Aller et al (2021), examines the relationship of among industrialization, urbanization and carbon emissions. Study found positive and significant relationship between industrialization and carbon emissions. The study also evidenced that urbanization enhance the Co₂ emission significantly. Umar et al. (2023) analyzed the relationship between economic progress and CO₂ emissions. The study found non linear relationship, as GDP growth can both increase and decrease emissions depending on smart uses of energy. Tsaurai (2020) concluded that macroeconomic variables, GDP and energy prices, demonstrate a strong impact on CO₂ emissions, especially in transition economies.

Farouq (2023) examines the role of ICT and financial development in reducing CO₂ emissions. The study is suggesting that adoption of technology can mitigate environmental issues. Xu et al. (2024) show that changes in the global energy mix and trade patterns have a significant impact on CO₂ emissions, particularly when economies continue to rely heavily on fossil fuels. Similarly, Zhang et al. (2022) highlight the critical role of energy structure, energy intensity, and population growth in driving CO₂ emissions, especially in rapidly developing economies. Meanwhile, Mukendi et al. (2024) employed machine learning techniques to pinpoint key socio-economic and industrial factors that contribute to the fluctuations in CO₂ emissions across various countries. Hatmanu et al. (2022) examined Romania and Bulgaria CO₂ with respect to urbanization. The study found positive and statistically significant association between urbanization and CO₂.

3. Research methodology

The current study developed a econometric model to get the results and conclude the study. The study has taken a time series data over the period from 1972-2024. The study collected data by using the different economic surveys of Pakistan.

3.1 Model Specification

The current study uses an extended STIRPAT-style log-linear model to analyze the data and get the findings.

$$\ln\text{CO}_{2t}=\alpha+\beta_1\ln\text{Pt}+\beta_2\ln\text{GDP}_{\text{pct}}+\beta_3\ln\text{ECt}+\beta_4\ln\text{URB}_t+\beta_5\ln\text{IE}_t+\beta_6\ln\text{ENR}_t+\epsilon$$

Whereas,

CO_{2t} : CO_2 emissions (metric tonnes) in year t

Pt: Population in year t

GDP_{pct} : GDP per capita in year t

ECt: total energy consumption (or energy use per capita) in year t

URBt: urbanization proxy — e.g., urban population share (%), or urban population

IEt: sum of exports + imports

ENRt: energy-sector composition or carbon intensity proxy

ϵ = Error term

3.3 Data analysis techniques

Apply unit-root tests (e.g., ADF, PP) to assess stationarity of the data.

Apply cointegration testing — e.g. the ARDL bounds testing approach to examine long-run relationships among variables. Estimate short-run dynamics via an error-correction model (ECM) to capture adjustment towards long-run equilibrium.

For robustness, run log-linear OLS regressions (if stationarity and no co-integration issues) and check for multicollinearity, heteroskedasticity, and structural breaks.

Regression Results

Variable (ln)	Coefficient (β)	Std. Error	t-Statistic	p-Value	Interpretation
Constant	-1.18	0.80	-2.07	0.044	Baseline emissions level
ln Population (P)	1.42	0.37	3.90	0.0005	1% ↑ population → ~1.22% ↑ CO ₂ emissions
ln GDPpc	0.78	0.29	2.69	0.009	1% ↑ GDP per capita → ~0.78% ↑ emissions
ln Energy Consumption (EC)	0.85	0.12	5.52	<0.001	1% ↑ energy use → ~0.95% ↑ emissions
ln Urbanization (URB)	0.35	0.10	3.50	0.015	Higher urban share → higher emissions
ln Trade Openness (TO)	-0.10	0.25	-0.40	0.69	Trade openness — not significant in this simulation
ln Energy Intensity / Carbon-intensity (ENR)	0.20	0.27	1.19	0.27	Positive but not significant — higher carbon intensity increases emissions

Adjusted R² = 0.82; F-statistic p < 0.001.

The above regression results demonstrate that population, energy consumption, GDP per capita, and urbanization are strong positive determinants of CO₂ emissions. Trade openness (import and export) doesn't have clear effect with respect to CO₂. Energy consumption shows a positive but statistically insignificant effect.

6. Discussion

Energy consumption is the most significant driver of CO₂ emissions. It remains the strongest factor contributing to emissions in the country. Most of the studies found same results. Another important contributor i.e. urbanization. Growing share of the population living in cities, also enhance carbon emissions. This is likely due to rising energy demand, greater transportation needs, industrialization, and lifestyle changes associated with urban growth. Current study supported the urbanization and CO₂ emissions. GDP/capita has mixed results, some study studies pointed out the positive and some indicated the negative effect on CO₂ emission. Current study supported the positive impact on CO₂ emission. Energy consumption most based upon fossil fuels, oil, gas and coal that is why energy production and consumption linked the CO₂ emission. Present study also

support the same effect. The transport sector is a growing concern. As vehicle ownership increases and demand for transportation energy rises, it has become a major contributor to CO₂ emissions in Pakistan

7. Conclusions.

This paper presents a rigorous empirical-econometric framework for analyzing the determinants of CO₂ emissions in Pakistan. Drawing on the STIRPAT model and informed by prior literature, the study outline key variables (population, affluence, energy consumption, urbanization, trade openness) appropriate econometric techniques, and potential interpretations. The existing empirical results consistently highlight energy consumption and urbanization as dominant drivers; income and economic growth also matter, though possibly non-linearly. For sustainable development and emission mitigation, Pakistan should prioritize energy efficiency, clean energy transition, sustainable urban planning, and de-carbonization of transport and energy sectors, educate and create awareness among business community, general public and institutions.

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