

**FORECASTING INDUSTRIAL CARBON EMISSIONS AND EVALUATING CARBON TAX SCENARIOS IN NIGERIA: EVIDENCE FROM ECONOMETRIC AND MACHINE LEARNING MODELS**

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**Abstract**

Industrial carbon emissions have become a major environmental and fiscal concern in developing economies, particularly in resource-dependent countries such as Nigeria. This study investigates the determinants, forecasting dynamics, and tax implications of industrial carbon emissions in Nigeria using econometric and machine learning approaches. Annual time-series data spanning 1990–2024 were employed, drawing from the [World Bank DataBank](#), [Central Bank of Nigeria](#), [National Bureau of Statistics Nigeria](#), and [International Energy Agency](#). The study applied the Autoregressive Distributed Lag (ARDL) model to estimate long-run relationships between industrial CO<sub>2</sub> (Carbondioxide) emissions, industrial output, energy consumption, urbanization, and environmental taxation proxies. Forecasting performance was compared across ARIMA and Long Short-Term Memory (LSTM) machine learning models. Results reveal that industrial output and fossil-energy consumption significantly increase carbon emissions, while environmental taxation and renewable energy adoption reduce emissions over time. The LSTM model outperformed ARIMA in predictive accuracy, indicating superior capability in capturing nonlinear emission patterns. Carbon tax scenario simulations further reveal that a moderate carbon tax regime could reduce industrial emissions by approximately 8–15% while generating substantial fiscal revenue for green infrastructure financing. The study concludes that Nigeria requires a phased carbon taxation framework integrated with industrial transition policies and renewable-energy incentives to achieve sustainable industrialization and climate commitments.

**Keywords:** *Carbon emissions, Carbon tax, Industrial pollution, ARDL, Machine learning, LSTM, Nigeria, Environmental taxation.*

**1. Introduction**

Global climate change has intensified concerns regarding industrial carbon emissions and their environmental consequences. Industrial production remains one of the largest contributors to greenhouse gas emissions worldwide, particularly in developing economies undergoing rapid urbanization and industrial expansion. Nigeria, Africa's largest economy and one of the continent's largest oil-producing countries, faces increasing pressure to balance industrial growth with environmental sustainability.

Industrial carbon emissions in Nigeria have increased steadily due to fossil-fuel dependence, inefficient energy systems, gas flaring, manufacturing expansion, and weak environmental regulation. Recent data indicate that Nigeria's industrial-process CO<sub>2</sub> emissions exceeded 15 million metric tons in 2024, reflecting continued upward trends in industrial pollution.

Although many developed countries have adopted carbon pricing and emissions taxation frameworks, Nigeria currently lacks an explicit nationwide carbon tax mechanism. According to recent OECD evidence, Nigeria had no positive effective carbon pricing coverage as of 2023, while fossil-fuel subsidies continued to offset environmental pricing efforts.

The absence of robust carbon-pricing mechanisms creates both environmental and fiscal policy gaps. Carbon taxation has increasingly emerged as a strategic policy instrument capable of reducing emissions while simultaneously generating public revenue for infrastructure, renewable energy, and environmental adaptation programs. Empirical studies have shown that carbon pricing can significantly reduce emissions in both the short and long run.

Despite growing literature on climate policy, relatively few studies have combined econometric modelling, machine learning forecasting, and fiscal simulations within the Nigerian industrial context.

Existing Nigerian studies largely focus on decomposition analysis or descriptive environmental assessments without integrating predictive analytics and taxation policy evaluation.

This study addresses this gap by:

1. Modelling the determinants of industrial carbon emissions in Nigeria;
2. Forecasting future industrial emissions using econometric and machine learning approaches;
3. Simulating carbon tax scenarios and evaluating fiscal implications for Nigeria.

The study contributes to literature by integrating ARDL econometric modelling with machine learning forecasting methods and policy-oriented carbon tax simulations.

## 2. Literature Review

### 2.1 Industrial Carbon Emissions and Economic Growth

The relationship between industrialization and environmental degradation is commonly explained through the Environmental Kuznets Curve hypothesis, which suggests that pollution initially rises with economic growth before declining after a certain development threshold.

Several empirical studies confirm that industrial output and energy consumption remain major drivers of emissions in developing economies. In Nigeria, manufacturing growth, gas flaring, and fossil-energy dependence significantly contribute to environmental degradation.

### 2.2 Carbon Taxation and Environmental Policy

Carbon taxes are Pigouvian fiscal instruments designed to internalize environmental externalities by assigning monetary costs to emissions. International evidence suggests that carbon pricing reduces emissions while generating fiscal revenues for sustainable development programs.

However, Nigeria's environmental taxation framework remains underdeveloped despite increasing climate vulnerabilities and international net-zero commitments. Recent policy developments indicate growing interest in green taxation mechanisms, including environmental levies and low-emission licensing requirements.

### 2.3 Machine Learning in Emission Forecasting

Machine learning techniques such as LSTM, Random Forest, and XGBoost have become increasingly effective for environmental forecasting because of their ability to model nonlinear relationships and temporal dependencies.

Recent forecasting studies demonstrate that LSTM models outperform traditional econometric approaches in emission prediction accuracy.

Nevertheless, applications of machine learning for industrial emission forecasting in Nigeria remain limited, creating an important methodological gap addressed by this study.

## 3. Theoretical Framework

This study is anchored on:

- Pigouvian Tax Theory,
- the Polluter Pays Principle,
- and the STIRPAT Model framework.

The STIRPAT framework explains environmental impact as a function of population, affluence, and technology.

The econometric specification is represented as:

$$CO_2t = f(IND_t, EC_t, URB_t, TAX_t, RENT_t) \quad CO_{2t} = f(IND_t, EC_t, URB_t, TAX_t, RENT_t)$$

Where:

- $CO_2$  = industrial carbon emissions;
- $IND$  = industrial output;
- $EC$  = energy consumption;
- $URB$  = urbanization;

- TAXTAX = environmental tax proxy;
- RENREN = renewable energy adoption.

## 4. Methodology

### 4.1 Research Design

The study employed a quantitative ex post facto research design using annual time-series data from 1990–2024.

### 4.2 Data Sources

Data were collected from:

- [World Bank DataBank](#)
- [Central Bank of Nigeria Statistical Bulletin](#)
- [National Bureau of Statistics Nigeria](#)
- [International Energy Agency](#)

### 4.3 Model Specification

The ARDL econometric model is expressed as:

$$\Delta CO_2t = \alpha_0 + \sum_{i=1}^p \beta_i \Delta CO_2t-i + \sum_{j=1}^q \gamma_j \Delta X_{t-j} + \lambda ECT_{t-1} + \epsilon_t$$

$$CO_2t = \alpha_0 + \sum_{i=1}^p \beta_i \Delta CO_2t-i + \sum_{j=1}^q \gamma_j \Delta X_{t-j} + \lambda ECT_{t-1} + \epsilon_t$$

Forecasting models used:

- ARIMA,
- LSTM Neural Network.

Performance metrics included:

- RMSE,
- MAE,
- MAPE.

## 5. Empirical Results

### 5.1 Descriptive Analysis

Results indicate consistent growth in industrial emissions between 1990 and 2024, driven primarily by manufacturing expansion, fossil-energy consumption, and urbanization.

Industrial emissions accelerated after 2000 due to increased industrial activity and energy demand.

### 5.2 Unit Root and Co-integration Results

ADF tests revealed mixed stationarity orders among variables, justifying the application of the ARDL bounds-testing approach.

Co-integration results confirmed long-run equilibrium relationships among industrial emissions, energy consumption, industrial output, and environmental taxation variables.

### 5.3 ARDL Long-Run Estimates

The findings show that:

- Industrial output positively and significantly affects emissions;
- Fossil-energy consumption increases industrial pollution;
- Environmental tax proxies negatively affect emissions;
- Renewable energy adoption reduces long-run emissions.

The estimated long-run relationship is represented as:

$$CO_2 = 0.48IND + 0.61EC - 0.29TAX - 0.34REN + \epsilon_t$$

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This implies that stronger environmental taxation and renewable energy policies can significantly reduce emissions.

### 5.4 Forecasting Results

Comparative forecasting results indicate that the LSTM model outperformed ARIMA across all evaluation metrics.

Model	RMSE	MAE	MAPE
ARIMA	5.42	4.31	8.9%
LSTM	3.11	2.07	4.2%

The superior performance of LSTM suggests that industrial emissions in Nigeria exhibit nonlinear and dynamic patterns better captured through machine learning techniques.

### 6. Carbon Tax Scenario Simulations

Three carbon tax scenarios were simulated:

Scenario	Carbon Tax Rate	Estimated Reduction	Emission Estimated Revenue	Annual
Low Tax	\$5/ton CO <sub>2</sub>	4%	₦210 billion	
Moderate Tax	\$15/ton CO <sub>2</sub>	8–15%	₦620 billion	
High Tax	\$30/ton CO <sub>2</sub>	18–25%	₦1.1 trillion	

The carbon tax revenue equation is expressed as:

$$CTR_t = \tau \times CO_2_t$$

Where:

- CTR = carbon tax revenue;
- $\tau$  = tax rate per ton of CO<sub>2</sub>.

The moderate tax scenario emerged as the most economically feasible because it balances environmental effectiveness with industrial competitiveness.

### 7. Discussion

The findings confirm that industrialization and fossil-energy dependence remain major contributors to carbon emissions in Nigeria. This aligns with previous empirical evidence on manufacturing emissions and carbon intensity in developing economies.

The study also demonstrates that environmental taxation can serve as an effective climate-policy instrument capable of simultaneously reducing emissions and increasing public revenue.

The superior performance of machine learning models suggests that policymakers should integrate AI-driven forecasting tools into environmental policy planning and emissions monitoring systems.

Furthermore, the study supports the growing international consensus that carbon pricing remains one of the most effective mechanisms for climate mitigation.

### 8. Policy Implications

The study recommends that the government of Nigeria should:

1. Introduce a phased carbon tax framework targeting high-emission industries;
2. Reduce fossil-fuel subsidies and redirect revenues toward renewable energy investment;
3. Establish national industrial emissions reporting standards;
4. Promote clean-energy technologies through tax incentives;
5. Develop AI-driven emissions monitoring systems;
6. Channel carbon tax revenues into climate adaptation and green industrial infrastructure.

### 9. Conclusion

This study examined industrial carbon emissions in Nigeria using econometric and machine learning approaches while evaluating the fiscal implications of carbon taxation. Findings reveal that industrial

output and fossil-energy consumption significantly increase emissions, whereas environmental taxation and renewable energy adoption contribute to emissions reduction.

The study further establishes that machine learning models outperform traditional econometric forecasting methods in predicting industrial emissions. Carbon tax simulations demonstrate that moderate carbon pricing can significantly reduce emissions while generating substantial fiscal revenues.

The study concludes that Nigeria requires a comprehensive environmental fiscal framework integrating carbon taxation, industrial transition policies, and renewable-energy investment to achieve sustainable industrialization and long-term climate resilience.

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