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A Study on Sector-Wise Carbon Dioxide Emission Prediction Using Arima Model

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ABSTRACT

Timely prediction of Carbon Dioxide (CO_2) emissions is significant for climate change mitigation and sustainable environmental planning. The study uses ARIMA model for forecasting the sectorial CO_2 emissions. Long-term CO_2 emissions were examined for the six different sectors: power, industry, transport, residential, domestic and international aviation industry based on historical CO_2 emissions dataset. The Augmented Dickey-Fuller test is performed to assess the stationarity of the time series dataset, and Autoregressive Integrated Moving Average (ARIMA) model is selected for CO_2 emission prediction. Several ARIMA (p, d, q) formations were examined for each sector, and the best suitable parameter are recognised and the model is evaluated based on various performance metrics including Root Mean Square Error (RMSE), Mean Absolute Error (MAE), Mean Absolute Percentage Error (MAPE), Akaike Information Criterion (AIC), and Bayesian Information Criterion (BIC). The results shows the emission trends across various sectors and offers reliable statistical substance for forecasting future emissions. This study supports data-driven decision-making for environmental policy makers and contributes to the broader discourse on climate resilience and sustainable development.

Keywords: carbon dioxide (CO_2) emissions, ARIMA, Augmented Dickey-Fuller , climate resilience

1. INTRODUCTION

Climate change is one of the world's top issues, and Carbon Dioxide (CO_2) emission is one of the major reason for global warming and environmental damage (Rabajczyk & Rabajczyk, 2021). Humans causes CO_2 emissions by various activities such as the combustion of fossil fuels for industrial growth, energy consumption, transport, and residential energy consumption (Lyngfelt, 2001). Accurate assessment of CO_2 emissions is critical for policy makers and environmental organizations to formulate effective plans, evaluate mitigation policies, and ensure compliance with international climate treaties (Aresta, 2010). Time series prediction techniques, Autoregressive Integrated Moving Average (ARIMA) method are effective for modelling and predicting environmental data patterns over time. ARIMA models do account for the linear dependencies and trends in time series data, so it is suitable to forecast emissions data for different sectors.

2. LITERATURE REVIEW

The study proposed ARIMA model to predict CO2 emissions in India from 1990 to 2023. By using the Box–Jenkins method, it assures accurate predictions by retrieving data stationarity through the Augmented Dickey–Fuller test and choose the models based on the Akaike Information Criterion (AIC). The findings demonstrate the ARIMA model effectiveness in predicting CO2 emissions which provides valuable information to assist in decision making process (Hrithik et al., 2024). The research paper implemented ARIMA method to estimate carbon dioxide (CO_2) emissions in India from 1980 to 2021. The study shows that ARIMA model effectively capture the trend and seasonality of emissions. This indicates the increase in carbon emissions in spite of reduction efforts that has important influence for renewable energy production (Sharma et al., 2024). The paper propose Autoregressive Integrated Moving Average (ARIMA) techniques for estimating CO_2 emission. The paper proposed Discrete Wavelet Transform (DWT-ARIMA) for CO_2 emission prediction. And the proposed Discrete Wavelet Transform (DWT-ARIMA) was compared with the traditional ARIMA model. The results shows that the Discrete Wavelet-ARIMA model forecast CO_2 emission more accurately and provide valuable insights for decision-makers in environmental protection efforts. The research study uses ARIMA approach to examine and predict CO_2 emissions in aluminum industry from 2005 to 2030. The ARIMA model access for meticulous assessments of emission patterns, revealing an anticipated reduction in CO_2 emissions within the aluminum sector. The result aims to offer guidance for sustainable policy measures and contribute to minimize the environmental impacts associated with aluminum production, solving the challenges related to climate change (Hasanov et al., 2024). The study uses the Box-Jenkins ARIMA model to predict carbon dioxide (CO_2) emissions in Morocco from 1928 to 2020. It defines that the time series data was stationary, apply ARIMA model and finds the best fit for the data. The study estimated a continuous growth in CO_2 emissions in the period between 2021 and 2040, emphasising the efficiency of ARIMA in long-term emissions forecasting (Jamii et al.,2021). The paper proposed ARIMA model to forecast regional carbon emissions by accessing time series data related to population, economy, and energy consumption. This statistical approach identifies the trends in carbon emissions over time, assisting the preparation of effective carbon reduce strategies. By incorporating ARIMA with the Kaya model, the research shows a novel predictive framework which assists in understanding the CO_2 emissions in specific regions (Wang et al., 2023).

3. RESEARCH METHODOLOGY:

3.1 Dataset :

This dataset provides the detailed information about CO2 emissions across various countries, emphasizing particular sectors and temporal trends. The dataset contains 1,35,408 entries and 6 features, encompassing information about combination of country, sector, and CO2 emission values, organized by date and timestamp. The features are Date, Country, Sector, Value , Timestamp, Year.

3.2 Data Pre-processing:

In order to achieve time series analysis the Unix timestamp converted into date time format which allows to perform time series analysis. The resampling method is applied to obtain the aggregate the co2 emission data based on the month. The conversion is important to analyse the patterns, trends and seasonal affects over the time.

3.3ARIMA Model:

ARIMA model is one of the optimal tools widely uses statistical mechanism for predicting future value based on the historical dataset within time series data (Luceño & Peña, 2008). The ARIMA model using three key elements: Autoregression (AR), it denoted by *p*. It narrates the dependency of current value to its previous values through a regression equation. Differencing, it is denoted by *d*. It performs the differencing to change the non-stationary into stationary in time series data to make it stationary, one by differencing consecutive observations. Moving Average (MA), it represented by *q*. It defines the dependency among current observation and previous residual errors. The proposed paper, utilized the Autoregressive Integrated Moving Average (ARIMA) model for forecasting the CO_2 emission value based on time-series dataset.

ARIMA Model Implementation

Algorithm:

1.1Load the Dataset CO_2 emission dataset

2**.**Resample the Data to a Monthly Frequency, Consolidate the data by summing the total emissions for every month

3. Check Stationarity of the Data, perform the Augmented Dickey-Fuller (ADF) test for stationarity

4. Plotting ACF (Autocorrelation Function) and PACF (Partial Autocorrelation Function) used to inspect appropriate p and q values.

5**.**Building the ARIMA Model, define the ARIMA model using the determined order (p, d, q)

6.Fit the ARIMA model to the training data

7. Forecasting CO_2 emissions for the test dataset using the fitted ARIMA model.

RESULT ANALYSIS:

The CO2 emissions in India, categorized by various sectors - power sector, industry sector, Transport, Domestic Aviation, and International Aviation, are used to trend the four years of time series dataset to forecast CO2 emissions. The Augmented Dickey-Fuller (ADF) test specifies that the series is stationary. And the p-value is 0.0096, which is less than 0.05, that represents that the null hypothesis is non-stationary can be rejected at the 5% significance level. After confirming that the series is stationary , ARIMA(p,d,q) model different combination of parameter model is analysed for carbon dioxide emission. The results of ARIMA(p,d,q) different combinations are (0,2, 1), (0, 2, 1), (2,1,0), (0,1,2), (0, 1, 0), (1,1,0) is analysed for various sectors. Table:1 summarises the best fitted model for different sector.

Sector	**Order**	**RMSE**	**MAE**	**MAPE**	**AIC**	**BIC**
Power	(0, 2, 1)	11.4041	9.9961	8.7194	297.8594	301.2372
Industry	(0, 2, 1)	3.24888	2.5897	3.8837	284.6140	287.9917
Transport	(2, 1, 0)	0.9515	0.7846	3.1620	223.5855	228.7263
Residential	(0, 1, 2)	12.4660	9.1313	6.4566	313.2982	318.4389
Domestic Aviation	(0, 1, 0)	0.0291	0.0245	4.2158	68.1107	66.3972
International Aviation	(1, 1, 0)	0.07817	0.0684	6.7481	60.7340	67.3069

Table :1 Performance of Evaluation Metrics

Based on the comparative analysis of various ARIMA model configurations with standard model selection measures such as RMSE, MAE, MAPE, AIC, and BIC, it is selected the most suitable model for forecasting carbon dioxide (CO_2) emissions across various sectors. In the Power and Industry sectors, the ARIMA(0, 2, 1) model generated the lowest AIC and BIC values, shows the accurate fit for capture the emission patterns. In the Transport sector, ARIMA(2, 1, 0) configurations with the lowest prediction errors (RMSE = 0.9515, MAPE = 3.16%). In the Residential sector, ARIMA (0, 1, 2), shows irregular patterns in residential emissions. For the Domestic Aviation and International Aviation sectors, such as ARIMA(0, 1, 0) and ARIMA(1, 1, 0) respectively delivered the best predictions, with lower RMSE and AIC values, shows the accurate predictive performance. In summary, sector-wise selection of optimal ARIMA models assures accurate and reliable results, enables targeted policy interventions for emission deduction in each domain. Table: 2 shows CO_2 emission forecasting for next five years with Lower Emission Limit(LEL) and Upper Emission Limit(UEL) .

Sector: Domestic Aviation
Forecast for the next 5 years:

Year	Forecast	LEL	UEL
2023	4.027631	1.581840	6.473421
2024	6.904510	1.028731	14.837750
2025	6.994510	4.066648	17.875667
2026	7.804510	6.416647	20.225667
2027	8.904510	8.407301	22.216321
2028	9.876879	4.032822	39.786580

Sector: Ground Transport
Forecast for the next 5 years:

Year	Forecast	LEL	UEL
2023	174.675151	103.026008	246.324294
2024	299.240932	85.086587	513.395277
2025	319.239700	77.919131	590.560268
2026	368.239700	52.426325	650.905724
2027	489.239700	103.767492	702.246891
2028	524.683208	56.928374	806.294791

sector: Industry
Forecast for the next 5 years:

Year	Forecast	LEL	UEL
2023	471.275747	273.391951	669.159543
2024	813.897302	290.903803	1506.890800
2025	821.471223	319.092703	1862.035149
2026	829.045144	527.947405	2186.037694
2027	836.619066	824.025774	2497.263906
2028	1052.826636	1029.013175	1130.666447

sector: International Aviation
Forecast for the next 5 years:

Year	Forecast	LEL	UEL
2023	7.263476	3.562105	10.964847
2024	12.465648	1.108104	26.039401
2025	24.465659	6.717283	31.648601
2026	32.465659	10.995502	35.926820
2027	36.465659	14.600090	39.531409
2028	65.194025	7.040265	77.428314

Sector: Power
Forecast for the next 5 years:

Year	Forecast	LEL	UEL
2023	963.054914	719.564539	1206.545288
2024	1718.494096	865.755152	2571.233040
2025	1803.811338	523.325272	3084.297403
2026	1889.128579	219.180586	3559.076572
2027	1974.445820	169.275622	4018.167262
2028	2047.866194	111.896648	4807.629036

Sector: Residential
Forecast for the next 5 years:

Year	Forecast	LEL	UEL
2023	120.716645	54.413371	295.846662
2024	203.226913	96.257199	512.711026
2025	253.226913	106.257363	532.711190
2026	308.226913	168.257527	617.711354
2027	325.226913	208.257691	782.711518
2028	484.677881	344.274086	813.629848

Table: 2 Forecasting CO_2 Emission for Next Five Years

CONCLUSION:

This research study applied ARIMA model which uses the statistical method for predicting carbon dioxide emissions, across different sectors such as industry, transport, power, residential, and aviation. The CO_2 emission dataset is pre-processed and stationarity is checked using Augmented Dickey-Fuller (ADF) test, ACF and PACF plots defines the appropriate ARIMA parameters. By selecting optimal ARIMA (p,d,q), the model is trained to predict the future CO_2 emission. The five-year forecast provides valuable insights into future emission patterns, which are important for policy makers and environmental planners to achieve sustainable development goals.

REFERENCES

[1] Rabajczyk, A., & Rabajczyk, G. (n.d.). *Managing CO_2 Emission in the Energy Sector and Climate Policy*. , T VOL. 58 ISSUE 2, 2021, PP. 6–21, 2021, https://doi.org/10.12845/sft.58.2.2021.1

[2] Lyngfelt, A. (2001). *An Introduction to CO2 Capture and Storage*. ,Http://www.entek.chalmers.se/~anly/symp/01lyngfelt.pdf

[3] Aresta, M. (2010). *Carbon Dioxide: Utilization Options to Reduce its Accumulation in the Atmosphere* (pp. 1–13). John Wiley & Sons, Ltd. https://doi.org/10.1002/9783527629916.CH1

[4] Hrithik, P. M., Rehman, M. Z., Dar, A. A., & Wangmo, T. (2024). Forecasting CO2 Emissions in India: A Time Series Analysis Using ARIMA. *Processes*, *12*(12), 2699. https://doi.org/10.3390/pr12122699

[5] Sharma, S., Mittal, A., Bansal, M., Joshi, B. P., & Rayal, A. (2024). *Forecasting of Carbon Emissions in India Using (ARIMA) Time Series Predicting Approach* (pp. 799–811). Springer Science Business Media. https://doi.org/10.1007/978-981-99-6749-0_53

[6] Hasanov, R., Safarov, J., & Safarli, A. (2024). Analyzing and forecasting co2 emissions in the aluminum sector using arima model. *Agora International Journal of Economical Sciences*, *18*(1), 55–64. https://doi.org/10.15837/aijes.v18i1.6710

[7] *Forecasting of CO2 Emissions in Algeria Using Discrete Wavelet Transform –Based Autoregressive Integrated Moving Average Models*. (2023). https://doi.org/10.21203/rs.3.rs-2632684

[8] Jamii, M., Oumidou, N., & Maaroufi, M. (n.d.). *Using the Box-Jenkins ARIMA Approach for Long-term Forecasting of CO2 Emissions in Morocco*., Volume 1, 496-501, 2021, https://doi.org/10.5220/0010737600003101

[9] Wang, L., Tong, X., Jia, X., Im, S.-K., & Wang, Y. (2023). *Prediction of Regional Carbon Emissions Based on ARIMA Model and Kaya Model*. 2560–2564. https://doi.org/10.1109/iccc59590.2023.10507588

[10] Luceño, A., & Peña, D. (2008). *Autoregressive Integrated Moving Average (ARIMA) Modeling*. https://doi.org/10.1002/9780470061572.EQR276