2024 SICASH
SLIIT INTERNATIONAL CONFERENCE ON ADVANCEMENTS IN SCIENCES & HUMANITIES

# Unveiling Climate Change in North Africa Through Carbon Dioxide Emissions and Surface Temperature Dynamics: A Panel Regression and Kaya Identity Analysis

C. R. Punchihewa[1], Thanula Gunaratne[2], Shamah Badurdeen[3], Sajani Liyanage[4], Ruwan Jayathilaka*[5]

[1,2,3,4,5] *Sri Lanka Institute of Information Technology*

Email address of the corresponding author - *ruwan.j@sliit.lk

**Abstract**

The North African (NA) region has recorded the highest average Carbon Dioxide ($CO_2$) emissions in Africa and endures a growing rate in Mean Surface Temperature (MST) levels. Focusing on six NA countries: Algeria, Egypt, Libya, Morocco, Sudan, and Tunisia, this study examines the period from 1990 to 2020. A mathematical identity for anthropogenic $CO_2$ emissions was derived using the Kaya identity, expressing individual countries through four drivers: population, GDP per capita, energy intensity, and carbon intensity. Panel Regression and Simple Linear Regression (SLR) analysis were further conducted to determine the regional and country-specific impact of $CO_2$ emissions on MST. The key findings indicate a notable elevation in the four drivers among countries, resulting in over a 50% increase in $CO_2$ emissions by 2020 compared to 1990. Regression results suggest that regional and local $CO_2$ emissions significantly positively impact MST variations in the NA region. The study proposes customised local policies to address the drivers of $CO_2$ emissions to mitigate the negative climatic consequences of rising $CO_2$ levels.

***Keywords:*** Carbon dioxide emissions; Mean surface temperature; Kaya identity framework; Panel regression

## Introduction

Climate change is a growing concern in Africa, resulting in diminished agricultural yields, unpredictable weather patterns, and the spread of diseases (Bedair et al., 2023). Carbon Dioxide ($CO_2$) has been identified as the most important contributor to climate change. Africa currently contributes around 4% of global $CO_2$ emissions (Roser, 2020). However, over the last twenty years, Africa has experienced an average annual $CO_2$ emission growth rate of 2.64%, surpassing the declining global growth rates of 1.3% and 1.9%. Moreover, the region's contribution to global $CO_2$ emissions has steadily increased over the past five decades (Espoir et al., 2021). Studies have highlighted that the forces behind the increase in $CO_2$ emissions in Africa were mainly led by economic development, energy production, and industrial activity (Gershon et al., 2024).

The anthropogenic emissions of $CO_2$ influence the long-term global warming trend. Hence, the future increase in the Mean Surface Temperature (MST) depends on how much $CO_2$ emissions occur in the coming decade. All countries in NA face significant current temperature variations and frequent droughts (Schilling et al., 2020). Hence, understanding the drivers of $CO_2$ emissions in NA and determining how $CO_2$ emissions impact the regional and local MST

https://doi.org/10.54389/DHIJ9533

levels is crucial for the countries in the NA region to understand the implications of growing emissions. Further, determining the trends of the drivers of $CO_2$ emissions would assist in policy implications to achieve regional climate stability and future climate targets.

The study's primary objective is to investigate the drivers of $CO_2$ emissions and the impact of $CO_2$ emissions on MST in the NA region. Accordingly, this study contributes to the existing literature in two ways. Firstly, it evaluates the shifts in the driving forces of $CO_2$ emissions over an extended temporal span for the NA region and individual countries. While global warming and the impact of anthropogenic emissions are well-researched, there is a gap in understanding how regional emissions affect regional climate dynamics. Hence, econometric techniques were incorporated to shed light on the regional and local impact of $CO_2$ emissions on MST change.

**Materials and Methods**

The study employs a quantitative research design and incorporates the countries of Algeria, Egypt, Libya, Morocco, Sudan, and Tunisia from 1990 to 2020. The strongly balanced panel dataset thus reveals dynamic relationships and facilitates the computation of statistical inferences. Table 1 presents the variables considered in the study and the respective data sources.

**Table 1:** Data Sources and Variables

| Variable | Measurement | Sources |
|---|---|---|
| Population | Total | World Bank Indicators |
| GDP | US Dollars | World Bank Indicators |
| Energy use | Kilowatt-hours per person | Our World in Data |
| $CO_2$ Emission | Kilotons | World Bank Indicators |
| MST | Degree Celsius | IMF Dashboard |

To capture the broader regional interactions across the NA region, Panel regression analysis was employed to account for both cross-sectional and time-series variations (Jayathilaka, Athukorala, et al., 2022). Subsequently, Simple Linear Regressions (SLR) were conducted on individual countries to isolate and illuminate the country-specific dynamics. This was accompanied by linear regression graphs for individual countries in the region visualizing the impact of $CO_2$ emissions on MST change. Supporting the analysis of the regional impact of $CO_2$ emissions on MST, Eq 1 was developed while Eq 2 was derived to analyse how $CO_2$ emissions impact MST across different countries in the NA region.

$$MST_{it} = \beta_0 + \beta_1 logCO2_{it} + \varepsilon_{it} \quad (1)$$

$$MST_t = \beta_0 + \beta_1 logCO2_t + \varepsilon_t \quad (2)$$

The logarithmic value of $CO_2$ emissions ($logCO2_{it}$) is employed to encapsulate the diminishing marginal and non-linear relationship that exists between $CO_2$ emissions and MST change. Accordingly, $MST_{it}$ denotes the MST value, the country is represented by $i$, with the time period as $t$ and $\varepsilon_{it}$ denotes the error term.

The study further computes three specification tests to evaluate the model's characteristics (Jayathilaka, Jayawardhana, et al., 2022). Thus, the F Test, Hausman test, and Breusch-Pagan Lagrange Multiplier test were conducted to determine the most appropriate model of estimation among Random Effect (RE), Fixed Effect (FE), and Pooled Ordinary Least Squares (POLS) models.

While panel regressions and SLR quantify the impact of $CO_2$ emissions on MST, this study integrates the Kaya identity which explicitly decomposes $CO_2$ emissions into its key contributing factors supporting the identification of policy interventions (Nwani et al., 2024). Eq 3 presents the Kaya identity applied to analyse the drivers of the NA's anthropogenic $CO_2$ emissions over the period from 1990 to 2020.

$$CO_2 = P\left(\frac{G}{P}\right)\left(\frac{E}{G}\right)\left(\frac{CO_2}{E}\right) \quad (3)$$

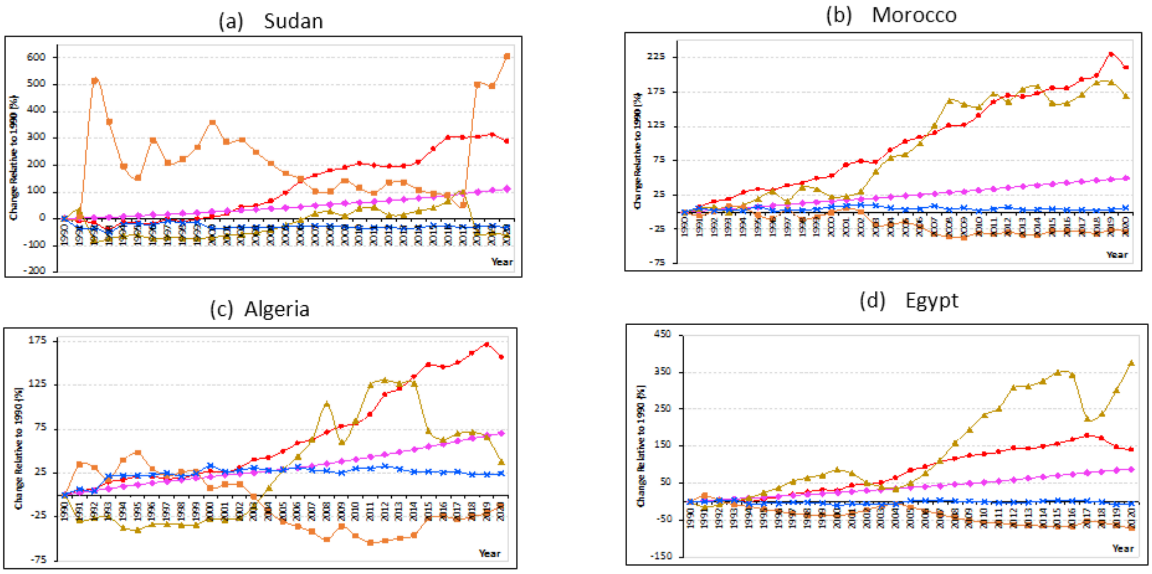
In this equation, $CO_2$ represents the $CO_2$ emissions, whereas $P$ indicates Population, $G$ indicates Aggregate GDP, and $E$ denotes Energy Consumption. $\frac{G}{P}$ represents GDP per capita, $\frac{E}{G}$ denotes energy intensity (energy consumed per unit of GDP) and $\frac{CO_2}{E}$ represents carbon intensity ($CO_2$ emissions per unit of energy consumed) (Kaya, 1989).

## Results and Discussions

The results of this study show that energy intensity in NA has reduced by 39% between 1990 and 2020. During the same period, population, carbon intensity, and GDP per capita have increased by 78%, 8%, and 105%, respectively, resulting in a 142% increase in $CO_2$ emissions. Along with fluctuations in the factors across individual nations in the region, $CO_2$ emissions show an upsurge by 2020, as visualized in Figure 1.

The trends in Kaya factors of the top three countries with the highest rate of emission growth from 1990 to 2020 are shown in Figure 1 (a) - (c). Compared to 1990, Sudan shows the most rise in $CO_2$ emissions of 287.6% in 2020. This is not surprising, as Sudan shows an increase in population and energy intensity by 111% and 606%, respectively. Being the third largest producer of oil in Africa, the country serves a significant proportion of its total energy demand with oil. Notwithstanding the initiation of renewable energy technologies in Morocco, the country's $CO_2$ emissions have increased by 210%, along with a 169% rise in per capita GDP in 2020 compared to 1990. Moreover, during this period, carbon intensity has risen by 7%. As reported by the IEA, oil accounted for 57% of the total $CO_2$ emissions from fuel combustion in 2021, while the sectors of electricity production and transportation accounted for over 73% of total energy-based $CO_2$ emissions by 2022.

The countries of Algeria and Egypt further indicate a surge in $CO_2$ emissions of 157% and 140% by 2020, compared to 1990. These developing nations place greater importance on acquiring rapid economic growth. According to the IEA, in Algeria and Egypt, 66% and 55% of the total energy supply is sourced from natural gas (IEA, 2021). Tunisia, with an average $CO_2$ emission of 23,689.50kt over 31 years, shows an increase in per capita GDP by 140% in 2020 compared to 1990. Accordingly, the country has experienced a decrease in energy intensity by 44% due to the orientation towards the tertiary sector. Nevertheless, the country continues to have increased energy dependency due to insufficient fossil fuel production (Saadaoui et al., 2024). Consequently, over the period from 1990 to 2020, $CO_2$ emissions increased by 100%. Similarly, $CO_2$ emissions in Libya rose by 55% in 2020 compared to 1990, with a 24% increase in carbon intensity. The IEA reports, that over 60% of the total energy supply in Libya comes from oil (IEA, 2020). Thus, the energy sector in Libya contributes significantly to the country's emissions.



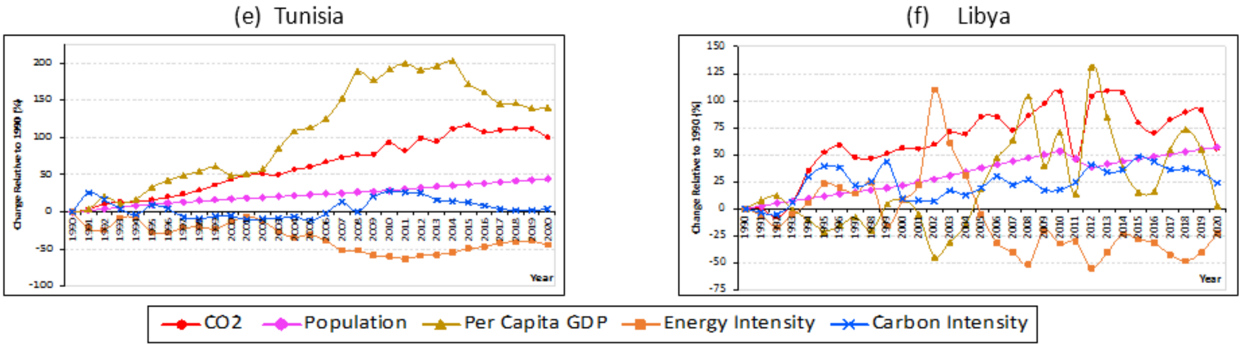



**Figure 1.** Trends in Kaya Factors in North Africa. All the trends are derived as percentage changes relative to 1990

The conducted correlation analysis between MST and log($CO_2$) for NA is presented in Appendix 1. The analysis reveals significant positive relationships for NA and all countries in the region at a 1% level of significance. Notably, Sudan exhibits the strongest correlation, suggesting a stronger relationship between rising temperatures and $CO_2$ emissions in this country. Upon conducting the Levin Lin and Chu test, the panels used in the study indicated stationarity. Further, the Panel Vector Autoregression test indicated the stability of the model as shown in Appendix 2. As presented in Appendix 3, the conducted specification tests determined FE estimation as the most suitable model for the analysis. The FE estimation assumes that the unobserved country-specific effects are correlated with log ($CO_2$), and controls for the time-invariant factors. Moreover, the heteroskedasticity of the model was tested using the Modified Wald test for groupwise heteroskedasticity. With the existence of heteroskedasticity, the robust standard error was employed accordingly. Panel Regression results disclose that a 1% increase in $CO_2$ emissions causes a 0.8170C increase in MST in the NA region (Table 3). The results suggest that regional anthropogenic $CO_2$ emissions have a significant positive impact on regional MST variations.

***Table 3.*** North Africa Panel Regression Results

| Variable | *MST* |
|---|---|
| *LogCO$_2$* | 0.817*** |
| | (0.146) |
| Constant | -7.725*** |
| | (1.559) |
| F-value | 31.30*** |

Note: *** represents 1% significance level and the parenthesis stands for robust standard error.

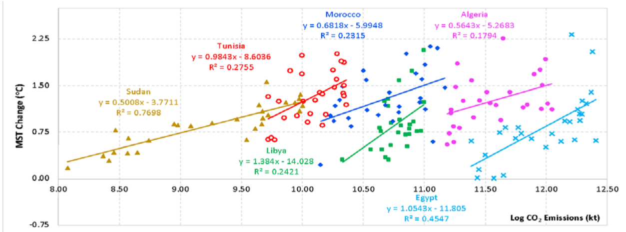



**Figure 2.** Regression Lines on MST Change vs. $CO_2$ Emissions for Individual Countries in North Africa

$CO_2$ emissions in all countries in the NA region showed a positive significant impact on local MST at the 1% level of significance as depicted in Figure 2. R2 values for all countries in the region are greater than 0.25, with Sudan exhibiting the highest value, indicating that a substantial amount of MST variations in Sudan can be explained by changes in Log ($CO_2$). Given the complexity of climate processes other variables may influence the local climate. However, the R2 values signify that curbing local emissions would alleviate local warming.

## Policy Implications

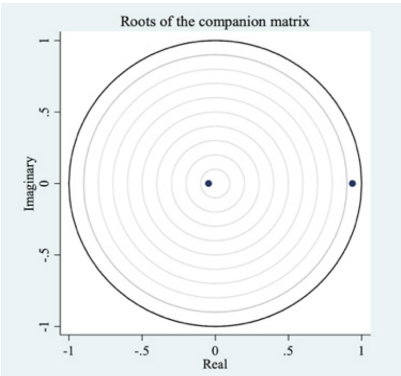
Given the study's results, effective policy implications would contribute to regional climate stability. Sudan should reduce energy intensity by updating outdated machinery, investing in energy-efficient technologies like preheaters, and optimising processes through waste heat recovery and improved insulation. Resource distribution among industries and implementing energy management systems are also recommended.

On the contrary, Morocco, Libya, Algeria, and Tunisia should focus on cutting emission intensity and diversifying energy sources. Morocco should continue investing in solar energy, Libya should shift from oil to natural gas and develop wind power, Algeria should expand solar farms, and Tunisia should promote energy-efficient appliances. Additionally, these countries should improve oil and gas infrastructure, enhance public transport, promote electric vehicles, and collaborate on acquiring advanced technologies from developed countries.

## Conclusion

In conclusion, as a resource-limited continent, Africa's contribution to global $CO_2$ emissions is minimal compared to other continents. However, this study's findings indicate over a 100% surge in $CO_2$ emissions in some NA countries. Also, $CO_2$ emissions play a critical role in MST variations within the region. According to the study results, countries in the NA

Appendix 2: VAR Stability Test Used in EgenValues




have shown a sharp increase in temperature over the past 20 years. Accordingly, the region experienced a significant growth of $CO_2$ emissions driven by a population rise of 78% and an increase of 108% per capita GDP. Sudan is the only country in the region that has experienced an increase in energy intensity, while the emission intensity in other countries has risen throughout the study period. The panel regression analysis reveals that a 1% increase in $CO_2$ emissions leads to a 0.8170C rise in MST, indicating that $CO_2$ emissions have a substantial impact on local climate dynamics. Furthermore, the study shows countries in the region have varying sensitivity to regional emissions, with Libya being the most sensitive. The study revealed an increase in $CO_2$ drivers and resulting increment of $CO_2$ emissions in the region. This is mainly attributable to economic and population growth; the study also recognises the impact of energy intensity and carbon efficiency on future emission levels. Consequently, this study calls for urgent policy measures to mitigate $CO_2$ emissions by reducing energy intensity, increasing carbon efficiency, and stabilising population growth to enhance climate resilience and sustainable economic development in NA.

Appendices

Appendix 1: Correlation Coefficient Results.

| | | MST | Log(CO2) |
|---|---|---|---|
| North Africa | MST | 1 | |
| | Log(CO2) | 0.199 | 1 |
| Algeria | MST | 1 | |
| | Log(CO2) | 0.508 | 1 |
| Egypt | MST | 1 | |
| | Log(CO2) | 0.729 | 1 |
| Libya | MST | 1 | |
| | Log(CO2) | 0.645 | 1 |
| Morocco | MST | 1 | |
| | Log(CO2) | 0.547 | 1 |
| Sudan | MST | 1 | |
| | Log(CO2) | 0.868 | 1 |
| Tunisia | MST | 1 | |
| | Log(CO2) | 0.591 | 1 |

Note: Correlation for all entities was significant at the 0.01 level.

Appendix 3: North Africa Specification Tests.

| | | |
|---|---|---|
| **F Test** | $H_0$: POLS / $H_1$: FEM | 29.91*** |
| **Hausman Test** | $H_0$: REM / $H_1$: FEM | 55.65*** |
| **Breusch Pagan LM Test** | $H_0$: POLS / $H_1$: REM | 94.01*** |

Note: *** represents a 1% significance level.

## References


Bedair, H., Alghariani, M. S., Omar, E., Anibaba, Q. A., Remon, M., Bornman, C., Kiboi, S. K., et al. (2023). Global Warming Status in the African Continent: Sources, Challenges, Policies, and Future Direction. International Journal of Environmental Research, 17(3), 45. doi:https://doi.org/10.1007/s41742-023-00534-w

Espoir, D. K., & Sunge, R. (2021). $CO_2$ Emissions and Economic Development in Africa: Evidence from A Dynamic Spatial Panel Model. ZBW - Leibniz Information Centre for Economics. Kiel, Hamburg. Retrieved from https://hdl.handle.net/10419/234131

Gershon, O., Asafo, J. K., Nyarko-Asomani, A., & Koranteng, E. F. (2024). Investigating the nexus of energy consumption, economic growth and carbon emissions in selected african countries. Energy Strategy Reviews, 51, 101269. doi:https://doi.org/10.1016/j.esr.2023.101269

IEA. (2020). $CO_2$ Emissions from fuel combustion. Retrieved from https://iea.blob.core.windows.net/assets/474cf91a-636b-4fde-b416-56064e0c7042/WorldCO$_2$_Documentation.pdf

IEA. (2021). Africa. Retrieved from https://www.iea.org/regions/africa

IPCC. (2014). Climate change 2014–Impacts, adaptation and vulnerability. Part B: Regional aspects. Contribution of Working Group II to the Fifth Assesment Report of the Intergovernmental Panel of Climate Change. (D. J. D. C.B.Field, M.D. Mastrandrea, K.J. Mach, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White Ed.) Cambridge University Press. Cambridge, United Kingdom and New York, NY, USA. pp. 668. Retrieved from https://books.google.lk/books?hl=en&lr=&id=aJ-TBQAAQBAJ&oi=fnd&pg=PA1142&ots=v3NvIJ79JE&sig=t7bGHLei0PuZ3rv140cXXygpQ_s&redir_esc=y#v=onepage&q&f=false

Jayathilaka, R., Athukorala, O., Ishara, S., Silva, D., & Pathirage, T. (2022). Alcohol brings burdens: A global and continent wise study on alcohol consumption and global burden of diseases. PLOS ONE, 17(7), e0270998. doi:https://doi.org/10.1371/journal.pone.0270998

Jayathilaka, R., Jayawardhana, C., Embogama, N., Jayasooriya, S., Karunarathna, N., Gamage, T., & Kuruppu, N. (2022). Gross domestic product and logistics performance index drive the world trade: A study based on all continents. PLOS ONE, 17(3), e0264474. doi:https://doi.org/10.1371/journal.pone.0264474

Kaya, Y. (1989). Impact of carbon dioxide emission control on GNP growth: interpretation of proposed scenarios. Intergovernmental panel on climate change. Retrieved from https://cir.nii.ac.jp/crid/1570291225678384256

Nwani, C., Effiong, E. L., Ikechukwu Okere, K., & Terhemba Iorember, P. (2024). Beyond the barrels: The impact of resource wealth on the energy-economy-climate targets in oil-rich economies. Heliyon, 10(3), e25666. doi:https://doi.org/10.1016/j.heliyon.2024.e25666

Roser, H. R. a. M. (2020). $CO_2$ emissions. OurWorldInData.org. Retrieved from https://ourworldindata.org/CO$_2$-emissions

Saadaoui, H., Omri, E., & Chtourou, N. (2024). The transition to renewable energies in Tunisia: The asymmetric impacts of technological innovation, government stability, and democracy. Energy, 293, 130686. doi:https://doi.org/10.1016/j.energy.2024.130686

Schilling, J., Freier, K. P., Hertig, E., & Scheffran, J. (2012). Climate change, vulnerability and adaptation in North Africa with focus on Morocco. Agriculture, Ecosystems & Environment, 156, 12-26. doi:https://doi.org/10.1016/j.agee.2012.04.021

Schilling, J., Hertig, E., Tramblay, Y., & Scheffran, J. (2020). Climate change vulnerability, water resources and social implications in North Africa. Regional Environmental Change, 20(1), 15. doi:https://doi.org/10.1007/s10113-020-01597-7

Tanarhte, M., De Vries, A. J., Zittis, G., & Chfadi, T. (2024). Severe droughts in North Africa: A review of drivers, impacts and management. Earth-Science Reviews, 250, 104701. doi:https://doi.org/10.1016/j.earscirev.2024.104701