Outcomes of Modelling Carbon (IV) Oxide Concentrations in Nairobi Metropolitan Region and Implication for Policy and Planning

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Abstract

Carbon (iv) oxide (CO_2) is emitted majorly from fossil fuel combustion and industrial production. The sources, of interest, of carbon (iv) oxide in the study area are mining activities, transport system, and industrial processes. This study is aimed at building models that will help in monitoring the emissions within the study area. A statistical modelling approach was applied. The Orbiting Carbon Observatory-2 and -3 secondary data were used. Three scenarios were discussed, namely: pessimistic scenario; business-as-usual scenario; and the optimistic scenario. The results showed that there was a reduction in carbon dioxide concentration by approximately 50.5 ppm between March 2020 and January 2021 inclusive. From the models, the pessimistic, business-as-usual, and the optimistic scenarios gives CO_2 concentration of about 545.9 ppm, 415.0 ppm, and 360.1 ppm respectively on December 31st 2021. Also, the empirical CO_2 concentrations follows the business-as-usual scenario (BAU) path. This research helps paint the picture, to the policy makers, of the relationship between energy sources and CO_2 emissions. This research recommends investment in solar energy by energy-intensive companies, mine machinery and equipment maintenance, investment in electric vehicles, and doubling tree planting efforts to achieve the 10% cover.

Keywords: economic recovery, forecasting, greenhouse gas, green energy, energy-intensive.

1 Introduction

The increasing concentration of greenhouse gases (GHG) in the atmosphere has been verified as the most important cause of global warming, which is a major environmental concern [1]. Carbon (IV) oxide (CO_2) is the most important of the GHGs and is the greatest contributor to global warming [2]. The principal anthropogenic sources of CO_2 are fossil fuel combustion and industrial production, which are largely concentrated in urban areas [3] [4]. Ice core and instrumental measurements show that atmospheric CO_2 levels have risen by almost 40% in the last 150 years [5].

This research, therefore, will be part of decision support system for the stakeholders involved in the design of Kenya's Nationally Determined Contribution (NDC) to Paris Agreement and the long term low emissions and climate resilience strategy development. This is because the procedure used to estimate emissions for the NDCs is tedious and one that cannot be carried out monthly. Also, currently there are no near real-time mechanisms to monitor the Carbon (IV) Oxide concentrations within the study area and in Kenya at large, hence CO_2 concentration trends are not known. This makes it hard for policymakers to timely evaluating the policies put in place to reduce the CO_2 emissions. With the models in this study, it will be easy for policymakers to track the performance of policies they put in place.

The main objective of this research, therefore, is to monitor CO_2 concentrations trends in the study area by analysing the changes in the CO_2 concentrations due to COVID-19 containment measures and predicting the possible future concentrations through modelling and forecasting. This study answers questions such as:

i) What is the trend of CO_2 concentrations within the study area pre-and-during COVID-19?
ii) What is the drop in CO_2 concentrations due to COVID-19 mitigation measures? and
iii) What are the possible future CO_2 concentrations trends within the study area?

2 Materials and Methods

2.1 The Study Area

This study focuses on the Nairobi Metropolitan Region (NMR) comprising four out of the forty-seven counties in Kenya namely: Nairobi, Kiambu, Machakos, and Kajiado (Figure 2-1). The size of the study area is about 32514 km^2 with a population of about 9,354,580 people (Census 2019)

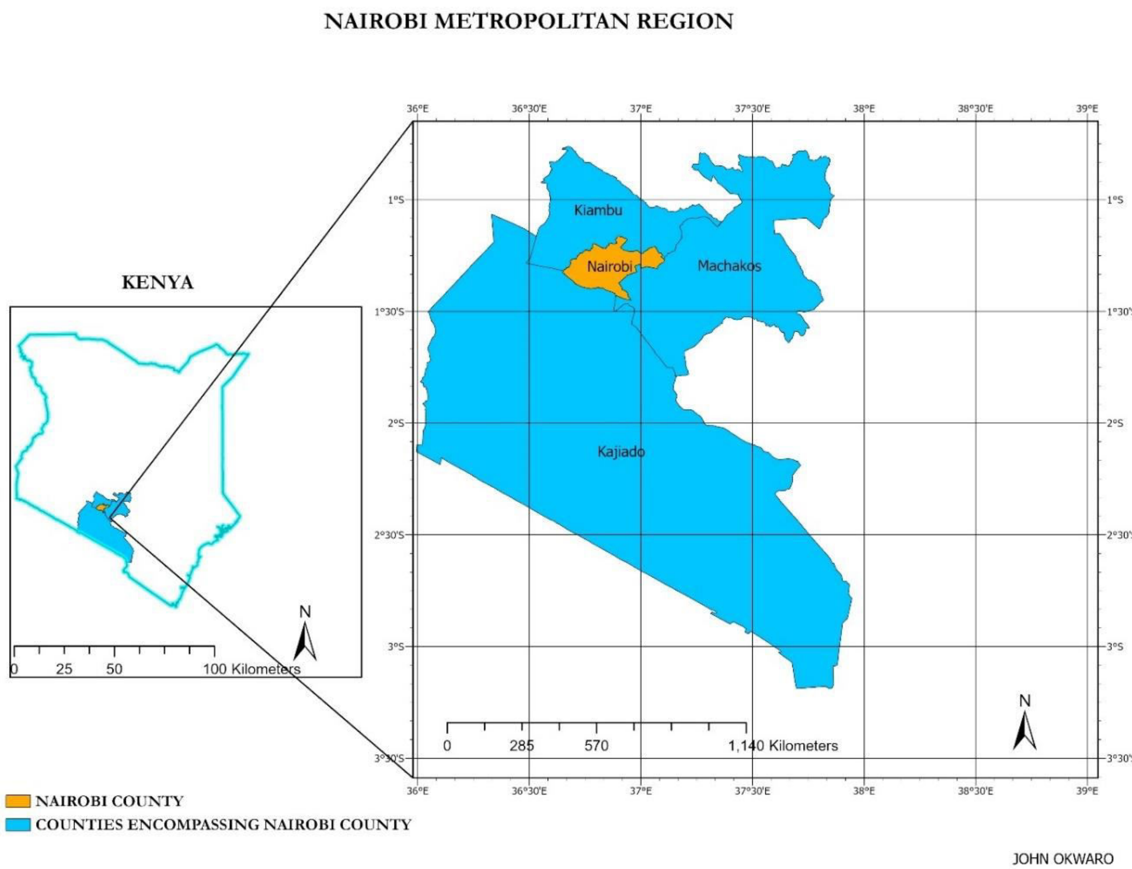

Figure 2-1 Study Area

2.2 Data

In this study, Arc GIS pro was used to create the map of the study area. Also, the OCO-2 and OCO-3 XCO_2 data from 15th January 2019 to 31st May 2021 were used. The data were downloaded from the OCO-2 and OCO-3 data centers on 4th June 2021. The data reported from 15th January to 31st May 2021 were used to test the predictive power of the models. The outliers on 31/01/2019 and 15/10/2019 reporting dates were removed before forecasting was done. This is because outliers are likely to affect the data distribution.

2.3 Methods

Data analysis was carried out in the MS Excel environment. The data were used to plot line graphs, which forms the models in this study.

2.3.1 Forecasting Future CO_2 Concentrations

To predict the possible future CO_2 concentrations, the pre-and-during COVID-19 (from 15th January 2019 to 31st December 2020) CO_2 concentration model was used as the baseline. Best-fit curves were then introduced to show the possible path the CO_2 concentrations are likely to follow in future. Three scenarios were discussed, namely: The Pessimistic scenario, the Business-as-usual scenario, and the Optimistic scenario.

2.3.1.1 Pessimistic Scenario

This scenario describes the highest level of emissions that can be reached. In this case, this research considered the part of the baseline curve that reported high rise in CO_2 concentrations trend. The period 15/01/2019 to 15/03/2019 inclusive was considered. The pessimistic scenario is described by the linear equation below.

$$y = 0.127x + 408.21 \tag{1}$$

The value of the $R^2 = 0.7621$.

2.3.1.2 The Business-as-usual Scenario

This scenario describes the status quo. This was described by the data set from 15/08/202 to 15/10/2020 inclusive. The business-as-usual scenario is therefore described by the linear equation below.

$$y = 0.0375x + 408.19 \tag{2}$$

The value of $R^2 = 0.7027$.

2.3.1.3 The Optimistic Scenario

This scenario was forecasted using data from 15/06/2020 to 15/08/2020 inclusive because this period describes a period where there was a drop in CO_2 concentration. The optimistic scenario is described by the linear equation below.

$$y = -0.0474x + 411.31 \tag{3}$$

The $R^2 = 0.8452$.

2.3.2 Model Calibration

Since the empirical data points follow the BAU scenario path, BAU model was calibrated using this data. The least square method was used in the calibration. The resulting equation was as below.

$$y = 0.003x + 411.8 \tag{4}$$

2.4 Assumptions

a) Since weather conditions such as wind and sunshine are likely to affect the dispersion of CO_2 gas, the research assumes that the weather conditions remained the same during data capture.
b) Secondly, this research assumes that the study area is a closed system with boundaries being the administrative boundaries, hence CO_2 concentrations measured are due to the emissions that occurred within the boundaries.
c) The research assumes that the decrease in CO_2 concentrations was brought about solely by the COVID-19 containment measures.

3 Results

3.1 Drop in CO_2 Concentration

Table 3-1 shows CO_2 concentration drop due to COVID-19 containment measures. The drop is about 50.3 ppm.

Table 3-1 CO2 concentration Drop due to COVID-19 Containment Measures.

	"2020/2021	"2019/2020	Diff. (ppm)
January	420	414.7	5.3
February	414.1	412.9	1.2
March	411.1	415.2	-4.1
April	412.5	414	-1.5
May	410.3	414.7	-4.4
June	410.8	414.3	-3.5
July	409.8	412.6	-2.8
August	408.8	414.7	-5.9
September	409.1	414	-4.9
October	410.8	419.4	-8.6
November	410.2	413.8	-3.6
December	412.3	414.2	-1.9
January	410.9	420	-9.1
February	414.9	414.1	0.8
March	412.6	411.1	1.5
April	416.5	412.5	4.0
May	413.1	410.3	2.8
Average	412.2	414.3	
		Sum	-34.7
		Sum (negative)	-50.3
		Diff. Average periods	-2.0
		Average	-2.0
		Diff. Start date (J-2019) - end date (M-2021)	1.6

[1]

[1] The negative values show drop in concentration. The total drop was calculated by adding the negative values.

3.2 Modelling Results

The equations that were generated for the three scenarios gave models shown in figure 3-2 after calibration and testing.

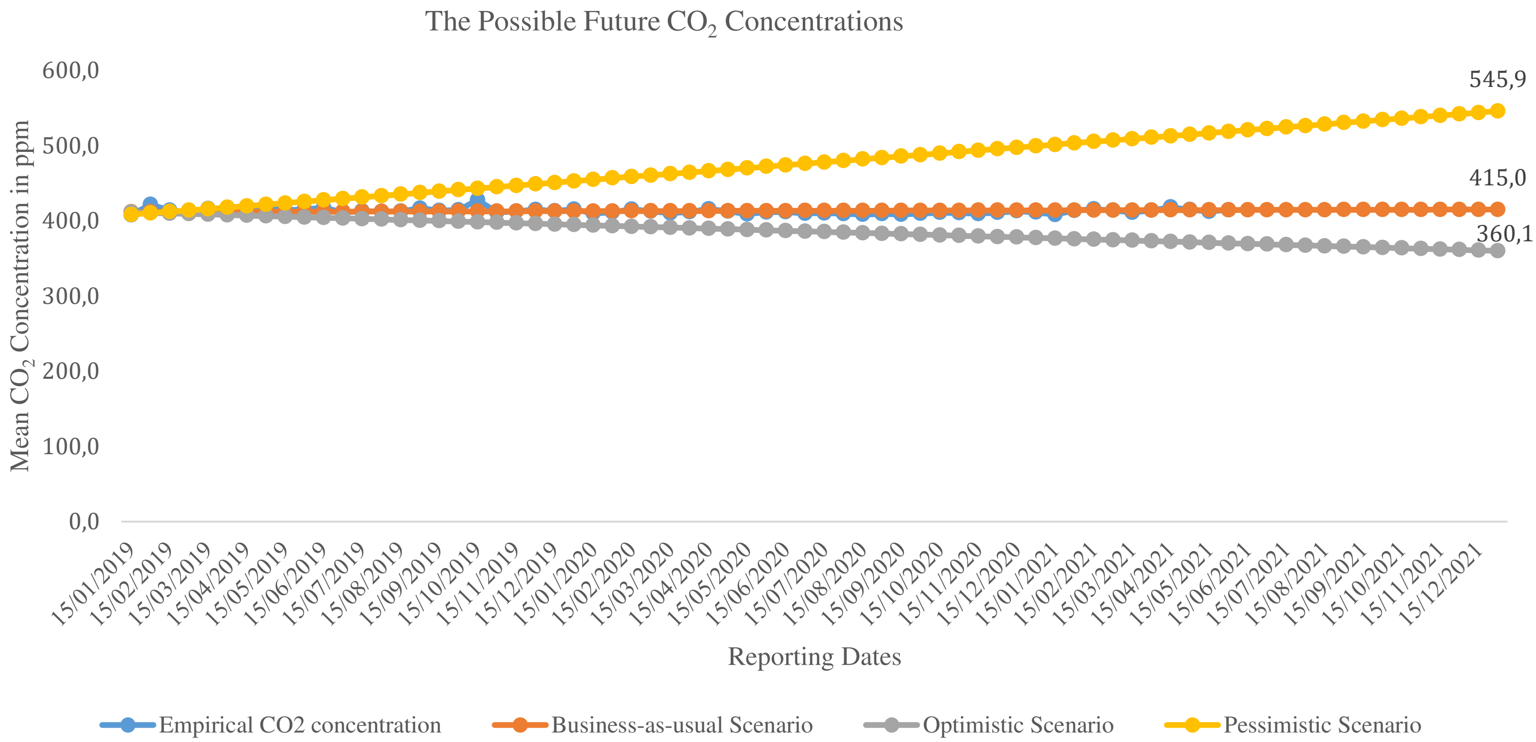

Figure 3-1 Models Showing the Possible Future Concentrations

4 Discussion

The models in this research have several limitations. Some of these limitations include:

i. The data points are obtained by averaging a large sum of individual readings which is likely to cause errors.

ii. The daily and weekly variations in CO_2 concentrations cannot be determined from the model.

4.1 Findings

From table 3-1, the drop in CO_2 concentrations is attributed to COVID-19 containment measures. These measures included partial lockdown that was in force from 6th April to 6th July 2020, grounding of aeroplanes that lasted up to 1st August 2020, and the curfew that is still in force to date. Secondly, from the models, it is clear that the CO_2 concentrations are high, well above 400 ppm. Also, it is clear that currently, CO_2 concentrations in the study area are following the business-as-usual scenario path. Further, the models show that the concentrations within the study area are rising. This means that mitigation measures put in place are not doing enough to combat CO_2 emissions. More mitigation measures, therefore, should be put in place. It is, however, important to note that emission reduction due to COVID-19 has very little effect on global CO_2 concentration.

4.2 Recommendation

To realise the optimistic scenario path, this research recommends the following mitigation measures: First, the mining and other high energy-intensive companies should install the solar PV system for electricity back-up instead of using the diesel generators. Secondly, the equipment, machines, and vehicles used in the mining site be well maintained to reduce emissions. Thirdly, the cement manufacturing companies should replace clinker in the cement mix with alternative low carbon materials or use carbon-capture technologies to cut on the CO_2 emitted. Fourth, the government should support the idea of electrifying motor vehicles where diesel/petrol engines are converted to electric engines, an idea that already exist in Nairobi city. Finally, tree planting efforts should be doubled so as to achieve the 10% tree cover sooner. This is because trees are natural sinks for CO_2 gas.

5 Conclusions

Models are integral part of the decision support systems for the policymakers. They help in the visualization of the current and future situations hence; they help in improving the accuracy of decision made concerning a situation. It is therefore prudent that more models be built around GHGs so as to help the policymakers improve the policies and measures put in place to reduce the emissions.

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