Regression and Correlation Analysis to Model Future CO2 Emission and Temperature in Jakarta

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Abstract:- This study aims to develop a methodical approach to investigate the impact of CO2 emission gasses on the temperature in Jakarta. Recently, the anomaly of temperature and climate has been one of the issues not understood by the public. People rely on weather forecasts without knowing the image at all. In this research, an analysis of the data on CO2 emission level and temperature is needed in order to design a non-linear regression model that depicts the relationship between both variables. Moreover, the proposed methodological approach is intended to be widely spread among the general public in order to understand the correlation and impact that CO2 emission gasses have on environmental aspects, namely temperature and climate change.

Keywords:- *Carbon dioxide; CO2 emissions; Temperature; Environmental; Climate change; Regression Analysis.*

I. INTRODUCTION

The anomaly of temperature and climate change is no longer a new thing because it is happening at the moment. Indonesia, as one of the tropical countries in the world, has experienced the effects of climate change as the temperature in some cities is drastically increasing. This graph is an overview of the temperature anomaly recorded by the Indonesian Agency for Meteorological, Climatological, and Geophysics.

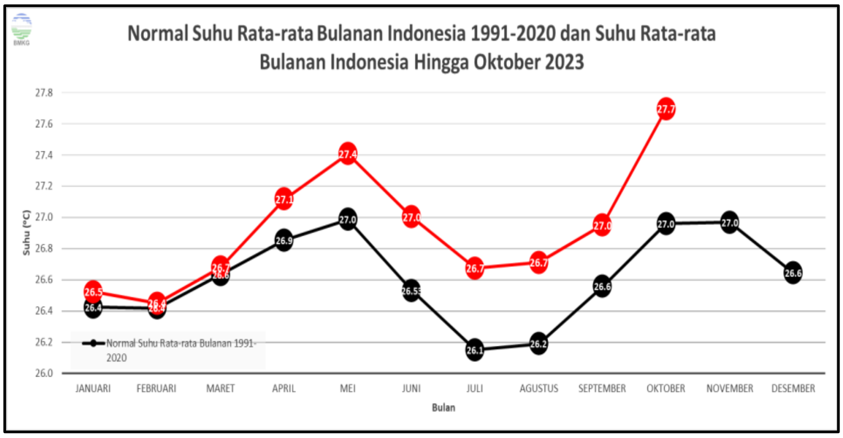

Fig. 1: Comparison of Average Temperature 1991-2020 and 2023

This study will focus on the changes happening in Jakarta, the capital city of Indonesia and one of the cities with the highest surge in temperature. Therefore, this study aims to investigate the major cause of this phenomenon, which is CO2 emission gasses.

This research involves the collection of data on temperature rates throughout the period 2022–2023 and CO2 emissions sources from combustion vehicles, power plants, residential, and industrial emissions within and surrounding Jakarta. The purpose of this paper is to develop a mathematical model as an approach to compare the amount of CO2 emissions and temperature increase rate to investigate the impact and the correlation between these two variables. With the regression model discussed in this paper, we will be able to predict the possible effect and outcome (in temperature) if the amount of CO2 emissions is increased or decreased.

II. LITERATURE REVIEW

This research emphasizes on the air temperature predictions in the ever warming city of Jakarta. In order to accurately predict the city air temperature, it's needed to determine the dominant factor that caused the increase of temperature. Based on recent studies, H2O, and CO2 is the most significant global warming contributor within the family of greenhouse gasses [30, 34]. This is due to those gasses that have a property of absorbing infrared radiation on several bands [34]. Meanwhile, in the city of Jakarta, there has been an increasing amount of industrialization, and land usage that has made the CO2 emissions increase drastically [21, 22, 26]. Ever since the 19th century, the levels of CO2 concentrations have increased by 40%. Combining this rise of CO2, added with the growing concentrations of other greenhouse gasses (CH4, N2O, etc.), has led to the increase of global temperatures by a rate of 0.08 degrees celsius per year [30].

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Based on the significance of CO_2 emissions, it is a possibility that the increase of temperature can be a local, or regional phenomenon. This is possible due to the differences of CO_2 concentration levels, and other factors that contribute to the absorption, and emission rates of heat, particularly from the sun, in different regions. This possibility is confirmed in the form of *Urban Heat Island* (UHI) phenomenon. Where, urbanized areas, such as large cities would have higher levels of greenhouse gasses emissions, and radiation absorption & re-emission rates, compared to more natural landscapes [20]. This phenomenon caused cities (highly urbanized areas) to have higher temperatures compared to the low-urbanized areas, or more natural areas surrounding it.

ZIn the megapolitan city of Jakarta, UHI regions can be defined as regions that have a temperature of more than 30 degrees celsius. UHI in the city of Jakarta has a drastic increase rate in the 21st century. From 36,5% of Jakarta in 2008, 84,7% of Jakarta in 2013, and 93,7% in 2018 [24]. The increase of UHI can be concluded as the increase of temperature in the city of Jakarta. In this research, this increase of temperature could be observed synchronizes with the increase of vehicle usage, and infrastructure in the city. Later on, this research will analyze the relationships between the increase of CO_2 emissions in Jakarta, and the increase of temperature observed. The mathematical model that is obtained from such regression would be used to predict the temperature of Jakarta in future months.

The fundamental theorem that is used to calculate the relation between CO_2 emissions, and temperature is the radiative forcing phenomenon, where the atmosphere emits less radiation than it absorbs, and causes an increase of temperature [34]. In which, the relation between CO_2 and temperature is described by a logarithmic graph [6, 34]. Due to the proportional relation between CO_2 and temperature, the CO_2 concentration and temperature data will be sorted from the lowest values, to the highest, before being analyzed.

III. METHODOLOGY

The Jakarta temperature prediction model would need three basic variables, including the temperature history, CO_2 emission estimation history, and the time period of the observed temperature & CO_2 behavior. Which would then be calculated in order to obtain mathematical expressions that are able to predict the average temperature of Jakarta, as a function of CO_2 emissions, in different time periods.

A. *CO2 Emission Prediction*

The property of CO_2 that is used for the emission estimation is the mass of CO_2 emissions, at a certain time period.

The method used for predicting CO_2 emissions that is developed in this research is called *yearly vehicle-based emission percentage prediction* (yearly VEPP). This method refers to the *Jakarta Bappeda* [7] report about the percentage of emissions from the transportation sector, compared to the total CO_2 emissions. Thus, the formula to predict the total CO_2 emissions from the vehicle emission percentage is:

$$yearly\ total\ emissions = \left(\frac{100\%}{vehicle\ emissions\ percentage}\right) * yearly\ vehicle\ emissions$$

The percentage of emissions per category from *Jakarta Bappeda* report in 2022 is 46% from the transportation sector, 31% from power plant sector, 8% from the industrial sector, 6% from the residential sector, and 5% from the garbage, and landfill sector [7].

B. *Vehicle Emission Calculation*

In order to predict the CO_2 emissions from transportation and vehicle sectors, we calculate the emission levels from the vehicle volume, vehicular emission rate per distance, and the average traveled distance of a vehicle in a single day. This action is done by using this formula:

$$M_{CO_2} = n * r * d$$

M_CO2 : CO_2 emission mass (grams)
n : yearly vehicle volume
r : CO_2 emission rate (grams/km)
d :average daily distance traveled by a vehicle (km)

The CO_2 emission mass is calculated on each different vehicle category, due to each unique respective volume (count), emission rate, and daily distance traveled. The vehicle category classification, and emission rate is based on a 2023 vehicle emission research in Hangzhou, China [33]. Another emission rate value is obtained from an emission distribution research in Tegal City, Indonesia [29]. The vehicle volume data used to calculate the total emissions is sourced from the *BPS* (Central Statistics Agency), and regional DKI Jakarta statistical data [2, 17, 31]. The variables are portrayed in this table:

Hangzhou (Z.Zhang et al, 2023)	Hangzhou (Z.Zhang et al, 2023)	Tegal (Unzilatirrizqi D., 2018)		Hangzhou (Z.Zhang et al, 2023)	
Vehicle Category	Emission Rate	Emission Rate	Av. Emission Rate	Av. Distance Travelled	Av. Emissions per day
	gr/km	gr/km	gr/km	km	gr
DHV-SPRV	235,2	306,3	249,1	66,4	4769,55
LCV	205,7	306,3	249,1	19,15	16537,76
LDV	249,8	306,3	249,1	18,9	5301,54
HCV	965,1	443,1	704,1	22,4	21618,24
HDV	1089,8	462,7	776,3	19,2	20924,16
Motorcycle	-	69,1	69,1	-	-

Fig. 2: Emission Rate of Vehicles

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Vehicle classification on this table is divided into 6 categories. Which include DHV, *Daily Household Vehicles*, and SPRV, *Spare Vehicles* (cars); LCV, *Light Commercial Vehicles* (taxis); *LDV, Light Duty Vehicles* (pickups); HCV, *Heavy Commercial Vehicles* (buses); HDV, *Heavy Duty Vehicles* (trucks); motorcycles. DHV daily distance travelled will be used for motorcycle's [33].

The predicted CO2 emissions using VEPP would then be compared to the CO2 emissions that are observed in a Greenpeace report [25].

C. Temperature and CO2 Emission Correlation

The relation between temperature and amount of CO2 emissions would then be calculated using regression analysis. The temperature data used is sourced from *Halim Perdana Kusuma* (HLP) International Airport weather station (East Jakarta) observations from 2010-2019 [16]. Temperature data from Tanjung Priok weather station will also be used for data range within 2020-2021, and for 2019 data that was not available in the previous database [3].The temperature used is a monthly average. While in order to calculate the relation between CO2 emission, and temperature, the observed CO2 emission within the range of 2010-2019 would be primarily used. Then, for the unobserved emissions of the future, emissions from the VEPP model would be used.

This research will provide various regression trend lines which include linear, logarithmic, exponential, 2nd, and 3rd degree polynomials. The regression has an aim of getting the R squared value of more than 0.90. The obtained regression variables would be combined with the VEPP emission model to achieve the final mathematical model that predicts the temperature of Jakarta in the future. The results would be a set of two mathematical models, one is *temperature as a function of CO2 emissions* which is the result of previous observations and another is *temperature at a certain timeline*, which uses the VEPP model for the CO2 emission value, to predict the temperature of Jakarta in the future.

IV. RESULTS AND DISCUSSION

A. CO2 Emission Analysis

The observed CO2 emission data has a range from 2010-2019. Meanwhile, the vehicle usage data for the VEPP calculation has a range from 2010-2022. In plotting the VEPP model with the real observation within the 2010-2019 range, the VEPP model has a significantly higher emission value. In order to synchronize the model, the difference of value of CO2 emission between the VEPP and the real observation is calculated from each year, and changed into a *percentage difference*. The percentage difference from different years has an average value of 17.4%, a median of 14.7%, and a middle value of 8.6%. Subtracting 100% with this percentage results in the *effective emission percentage*. After plotting the VEPP model with different effective percentages, the model with the most analogous results is the median effective percentage. This VEPP model has higher than real emissions in early years, near 2010. But, the model has a more matching trendline with the real emissions from the year 2016 onwards, with a value difference of less than 400 Ton CO2 emissions.

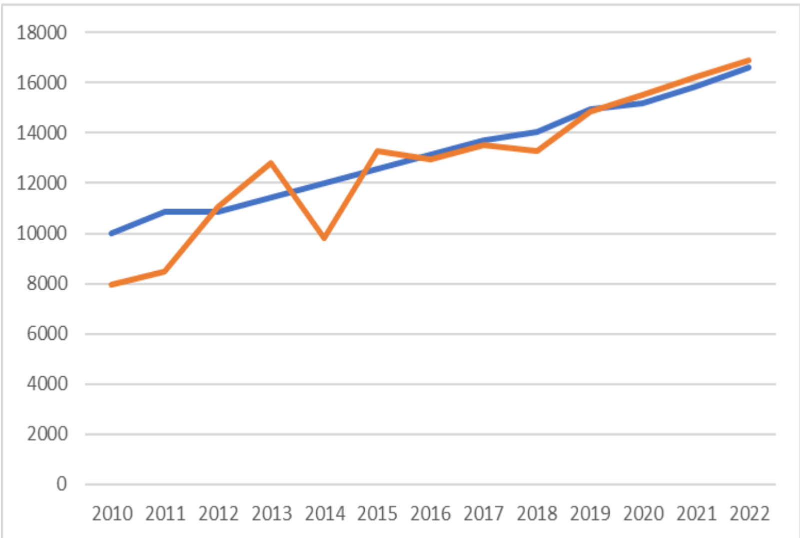

Fig. 3(a): the VEPP emission model (blue), plotted with the real observational data (orange). observational data is from 2010-2019, with the later orange graph is the trendline of observational data. While the VEPP model is plotted from the available vehicular data between 2010-2022.

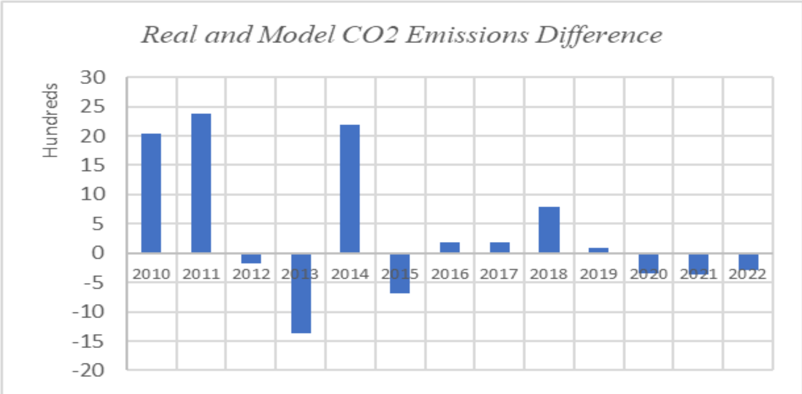

Fig. 3(b): the value of emission difference between the median-VEPP model, and the real observational data to measure accuracy of the model.

B. CO2 concentration analysis

The base relations between CO2, temperature, and radiative forcing, uses the CO2 in the form of concentration. To convert CO2 emission mass to concentration, we can use the basic ppmv formula of

$$C = \frac{M_{CO2}}{\rho\, V_{air}} * 1000000$$

C : CO2 concentration
M_CO2 : CO2 emission mass

rho : CO2 density
V_air : volume of atmospheric air

The air volume in this calculation refers to the volume of the earth atmosphere above Jakarta, from ground level, up to the stratosphere. The stratosphere is set to be the boundary, due to the highest radiative forcing effects that happen within the stratosphere, and troposphere beneath it [6].

In order to calculate the atmospheric volume, the atmosphere is modeled as the volume difference between two 3D spherical sectors, with the same solid angle, but different radius. The outer (higher radius) is a spherical sector from the stratosphere to the center of the earth. While the inner (lower radius) is a spherical sector from the altitude of Jakarta to the center of the earth. The deflection angle of the circular surface area on the sphere surface is calculated from the area of Jakarta. The corresponding formulas of the calculations are :

$$V_{sector} = \frac{2}{3}\pi r^3 (1 - \cos\theta)$$

$$V_{atm} = V_{stratosphere} - V_{Jakarta}$$

$$\cos\theta = 1 - \frac{A_{Jakarta}}{2\pi r^2}$$

By taking the area of Jakarta as 661.52 km^2 [1], the radius to the stratosphere as 6421 km (50 km above earth radius) [27], and the radius to the altitude of Jakarta as 6421.008 km (8m altitude above sea level) [4], the calculations would results as : theta equals to 0.130503665 degrees; Volume of stratosphere as 1.438184188E+15 m^3; Volume of Jakarta as 1.404853265E+15 m^3; and the volume of atmosphere for further calculations equals to 0.033330923E+15 m^3. While the density of CO2 that is used equals 1.87 kg m^(-3).

C. Regression Model of CO2 Emission and Temperature

By using those equations to convert the CO2 emission masses, to CO2 emission concentration, the regression between CO2 and temperature could be calculated. The regression done in this research includes the 3rd degree polynomial, 2nd degree polynomial, logarithmic, and exponential, which results are interpreted in the four graphs below, with the y-axis representing temperature, and the x-axis representing CO2 concentration in ppmv.

The regression model that best suits the temperature vs CO2 concentration is the 3rd degree polynomial, with a high value of R squared, reaching 0.98, figure 4a. Which is followed up by the 2nd degree polynomial with the R squared of 0.94. Even though both these regression models have a high R squared, it would not be logical to have such a steep increase of temperature for CO2 concentrations above 450 ppmv. This is not relevant because sharp increases in radiative forcing temperature would only happen in high ppm levels, above 2000ppmv [34].

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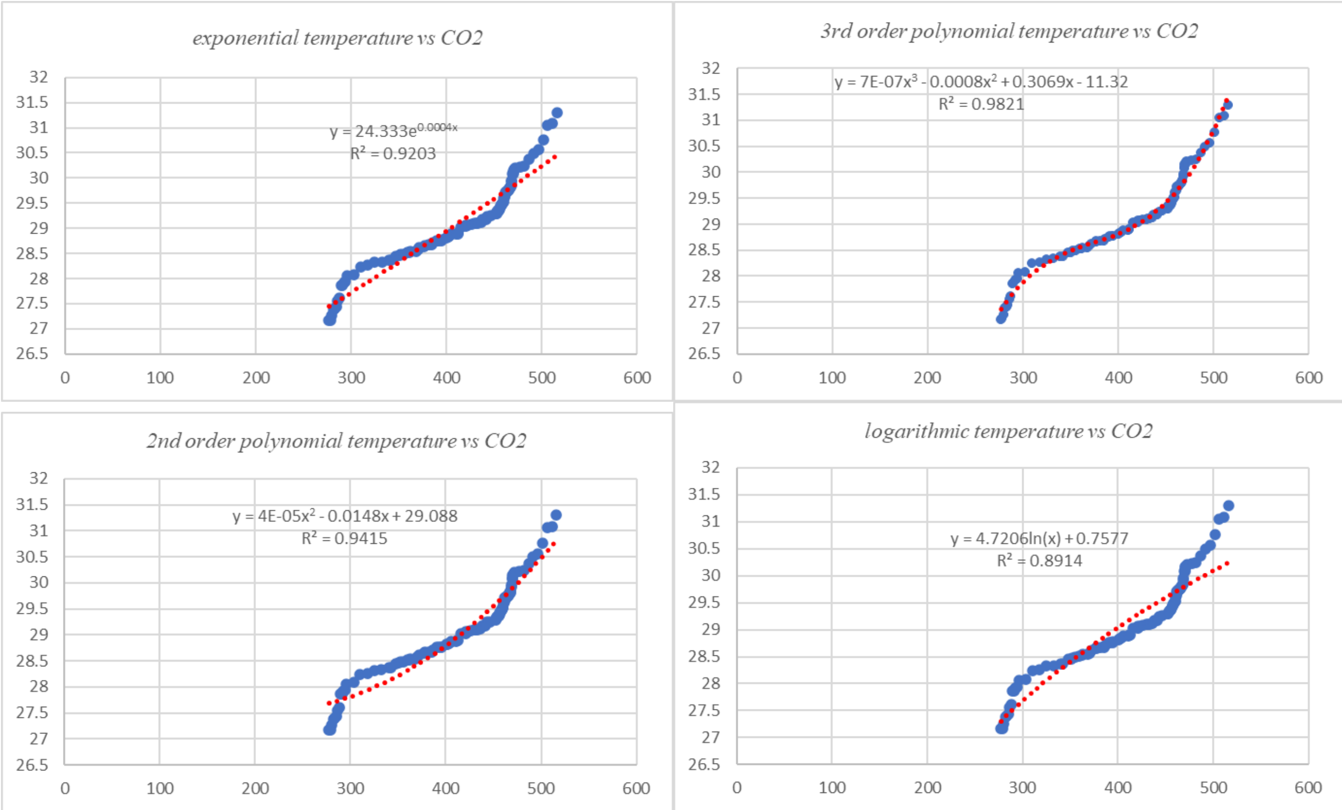

Fig. 4: Shows the trendlines of different regression equations on the sorted temperature-concentration data
From top to bottom: figure 4a. shows the exponential regression; 4b. shows the 3rd order polynomial regression; 4c. shows the 2nd order polynomial regression; 4d. shows the logarithmic regression.

Meanwhile, the exponential regression has a moderate value of R squared of 0.92, and for the theory based, logarithmic regression, has a R squared value of 0.89.

In order to get a logarithmic theory-based temperature prediction model, we did a qualitative analysis on the graph. It shows that at CO2 concentration levels above 450 ppmv, there is a sharp increase of temperature, which doesn't show a logarithmic increase. To counteract this, we limit the concentration levels for regression analysis up to 450 ppmv. This new prototype results in a higher R squared value of 0.943, which is represented in this graph.

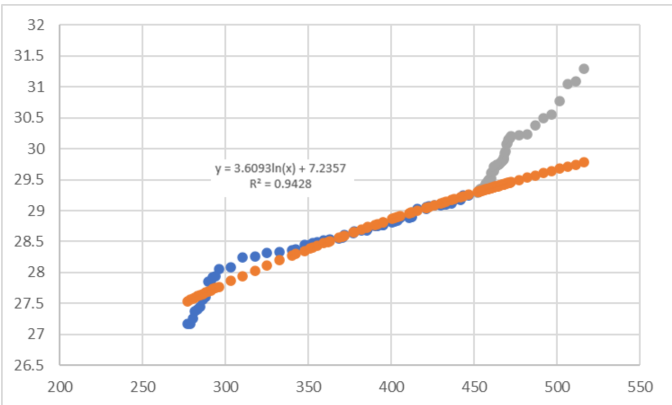

Fig. 5: Shows the logarithmic regression trendline (orange) of the temperature-concentration data which data range is limited to 450 ppmv (blue).

D. Future Predictions

Using our VEPP model, we can predict the CO2 emission in the future by using the vehicle count within the city of Jakarta. Equipped with future CO2 concentration prediction, we can use the values from the previous logarithmic temperature regression to predict the temperature of the city of Jakarta in the future. The graph below represents the comparison of temperature from the logarithmic prediction model, and the real observational temperature, within a range from 2010, up to the future in 2024.

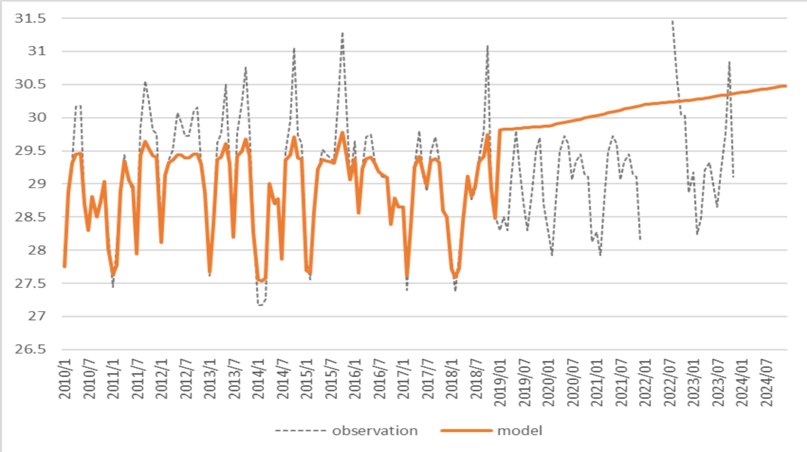

Fig. 6 shows the comparison between observed temperature (dotted line), with the predicted temperature from the regression model (orange). The observed data has a range from 2010-2023, while the model has a similar range added with future temperature predictions. The steadily increasing orange line after 2019 shows the temperature predicted from the VEPP model which emits a steady CO2 emission prediction that doesn't account for daily and monthly fluctuations.

Within the period of 2018-2023, observed temperature data is present, but the temperature model doesn't represent it's fluctuations. This is due to the usage of the VEPP algorithm for the CO2 concentration, which emits a steadily increasing emission prediction. This results in a steady temperature prediction that doesn't account for the daily fluctuations of CO2 concentration in a real city-wide environment. While in the future, for periods after 2024, observed temperatures no longer exist, the graph only represents the predicted temperature that's calculated from CO2 concentrations of the VEPP model.

This results in the average increase of temperature of 0.005809 degrees celsius in 2022, 0.009404 degrees in 2023, and 0.009119 in 2024. Looking to the future, the temperature in January 2024 is predicted to be 30.3792 degrees with predicted CO2 of 609 ppmv, and in December of 2024 with temperatures reaching 30.4795, with CO2 levels of 626 ppmv.

V. CONCLUSION

This study aims to derive a mathematical relationship between CO2 concentration and temperature in order to predict future temperature in Jakarta. By referring to the theories of radiative forcing, the temperature in Jakarta is obtained from a logarithmic function of CO2 concentration which is obtained from a logarithmic regression of Jakarta's CO2 concentration and temperature from 2010 to 2018. While the CO2 concentration is predicted by the VEPP model which is developed in this research.

The VEPP model of CO2 emission prediction is based on multiplying a vehicle CO2 emission factor, to the yearly vehicular volume, whose values vary between vehicle categories, and an statistical-obtained effective emission constant of 0.853. This model gives us a good approximation of the CO2 concentration in Jakarta, in which the predicted values of emission between 2016-2022 has a difference with real emissions of less than 400 Tons of CO2. The mass of CO2 emissions from this model is converted into CO2 concentration in ppmv by calculating an approximate volume of the atmosphere from Jakarta's altitude level, up to the stratosphere.

In calculating the regression, the data of CO2 and temperature is sorted, and matched, where the highest observed temperature is plotted with the highest observed CO2 concentration, and so on. This is done due to the property of logarithmic equations where the increase of y value in a ln(x) function is proportional to the increase of x value.

This results in 3rd and 2nd degree polynomial regressions having the most correlation with an R squared value of 0.98 and 0.94, while the logarithmic regression only has an R squared of 0.89. Even though the polynomial regressions have a high correlation, they are less accurate due to the sharp increase of temperature on higher CO2 concentrations that would only occur in levels above 2000 ppmv, much higher than that of the daily observations, or the VEPP prediction. Thus, the model sticks to the logarithmic regression.

In order to make the correlation of logarithmic regression higher, this research limits the analyzed values of only up to 450 ppmv of CO2. This new model results in a higher R squared value of 0.943. Plotting the temperature obtained from the model, with the observed temperature, the model is seen able to mimic the gradients of temperature from 27.5 to 29.5 degrees Celsius. But, the model isn't able to achieve peak values of temperature, below and above those levels.

For future predictions, we can use this model with CO2 concentrations obtained from the VEPP model. Due to the steadily increasing nature of VEPP emissions, the predicted temperature of Jakarta also increases in a steady manner. The predicted temperature has an average increase of 0.009119 degrees celsius in each month in 2024, reaching 30.47951 degrees celsius by the end of 2024.

This study is expected to be continued in order to obtain more accurate predictions of temperature in cities. The correlation between temperature with respect to the increase of CO2 concentration could become a meter of how CO2 pollution affects the climate condition, air content, and life quality in a certain city.

This study recommends organizations or decision makers to use the prediction of future city temperature with the estimated increase of CO2 emissions to plan future city development and create an eco-friendly city that supports the life-needs of its citizens while also being environmentally non damaging. The authors suggest several solutions to develop a greener city across sectors, as thus:

- **Transportation:** Replacement of fossil fuel vehicles with electric vehicles (EV) for within city transportations and hydrogen fuel cell for long distance travels [32].
- **Construction:** Using substitute material for cement, such as Ferrock that can trap carbon dioxide [11, 28].
- **Industrial:** Using heat-absorbing materials like concrete and ventilations to let heat escape [13, 18, 23].
- **Energy generation:** Increase the amount of WWS (wind, water, solar) electricity generator, i.e., solar photovoltaic/PV, wind turbine, hydroelectric power plant [8, 15].
- **Public policy:** Making Time-of-Use electricity rates policy [9, 12].

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The authors of this research declare that this research is purely academical, without any personal intentions.

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