# Forecasting of Carbon Dioxide Emissions in Indian context

Aseem Tuli[1,*], Girish Kumar[2]
[1]*Delhi Technological University, Delhi-110042*
[2] *Delhi Technological University, Delhi-110042*
*Contact: ast8995@gmail.com, phone +91-9650773468

*Abstract*— **Carbon Dioxide is a major component of Green House Gas (GHG) emissions, accounting for 81% of the total emissions. Released naturally (respiration, ocean drive, and decomposition) or as a consequence of human activity (cement production, burning of fossil fuels such as coal, oil and natural gas, etc.), carbon dioxide has played a significant role in Global Warming. It is a phenomenon whose existence can be found in the melting of polar ice caps or progressive rise in the annual global temperatures. India, an emerging economy is the fourth largest producer of $CO_2$ emissions, behind China, USA and the European Union. A nation, with the drive to become a leading superpower in the coming years, India's booming economy and development poses a serious challenge to the levels of carbon dioxide emissions. Overtaking Russia, to become the third largest producer of electricity, India still relies on coal as the biggest source of electricity, whose burning yields $CO_2$ into the atmosphere. Awaken by the adversities of $CO_2$ emissions, India has signed the Paris Agreement and pledged to reduce the $CO_2$ levels to 30-35% of the level in the year 2005. This agreement is set to be starting in 2020. To have a better understanding of what the challenge is going to be in the year 2020, prior to the implementation of the Paris agreement, this paper aims at forecasting the levels of $CO_2$ emissions and its constituents (solid, liquid and gaseous fuels) in India. The technique used in the forecasting is Exponential Smoothing. Starting from 1960, first two years data has been used for initialization and the value of model parameters (alpha and beta) has been optimized with data from 1962-2017 using Solver. The forecast is estimated for the years 2018-2020.**

***Keywords*: Predictive Analytics, CO2 emissions, Double Exponential Smoothing, Paris Agreement**

## I. Introduction

The planet Earth is home to millions of organisms found on land, water or air. Amongst various reasons for sustenance of life on the planet, one of them is the habitable temperature range. The presence of certain gases in the atmosphere insulates the Earth's surface against the chill of space. The capability of these gases to absorb the infrared radiations from sunlight in the day, and emit the same at night is what makes the planet warm and habitable. This phenomenon of absorbing and radiating the light at dayand night respectively is known as the Green House effect, and the gases which exhibit this phenomenon are called greenhouse gases (GHG). The primary greenhouse gases, found in the earth's atmosphere are: Carbon Dioxide, Ozone, Methane, Nitrous Oxide and Water Vapour. While greenhouse gases are vital for sustenance of life, their increasing concentration in the atmosphere has had a huge effect on climate change.

The average temperature of the Earth is on the rise, making some places already prone to drought, completely inhabitable. The melting of polar ice caps, the rising sea water levels, the unpredictability of seasons are some of the effects, which have the potential to cause a worldwide environmental catastrophe. Of all the greenhouse gas emissions, $CO_2$ emissions have played a major role in catalysing these hazardous environmental activities. Accounting for 81% of the total GHG emissions, the anthropogenic release of $CO_2$ into the atmosphere boils down to huge consumptions of fossil fuels such as oil, gas and coal.

India is the world's fourth largest emitter of $CO_2$, behind the United States, China and European Union. With the economy on the rise, the industry sector is booming, while at the same time, releasing millions of tonnes of $CO_2$ into the atmosphere. With the statistics reaching 2 million kilo tonnes [1] of $CO_2$ emissions, India needs a solution to curb the levels of $CO_2$, and reduce its fair share of global warming. One of the solutions India has adopted is the signing of Paris Agreement. Under this agreement, the nation has pledged to reduce the $CO_2$ levels to 30-35% of the level in the year 2005 [2]. With the agreement taking effect in 2020, the research done in the paper is aimed at predicting the level of $CO_2$ emissions in 2020 to proffer the foundation for the agencies to lay down subsequent socio-economic policies.

A number of researches have been carried out to estimate and forecast the $CO_2$ emissions. Berk Ayvaz et. al [3] applied grey model approach to forecast $CO_2$ emission in Turkey, Europe and Eurasia. M. A. Behrang et. al, [4] described an integrated multi-layer perceptron neural network with Bees Algorithm for examining world $CO_2$ emissions by using socio-economic indicators. Muhammad Alkassabeh et. al [5] predicted PM10 and TSP air pollution parameters using artificial neural network. A. Sangeetha et. al [6] proposed a novel bio framework for $CO_2$ emission forecast in India. The work described by A. Authors produced estimates and forecasts with MAPE (mean absolute percentage error) of

4.07. The goal is to achieve forecasts with a better accuracy. The approach adopted in this research is trend analysis for modelling and forecasting the carbon dioxide emissions in India.

## II. Carbon Dioxide emissions in India – overview

India's economic rise and efforts to become a leading superpower have resulted in high carbon dioxide emissions. India is third largest emitter of $CO_2$. India's continued reliance on thermal power as the largest source of electricity, which accounts for 64.3% of total installed capacity, implies that fossil fuels (coal, oil and gas), which are major sources of carbon dioxide emission, will continue to be mined, produced and utilized.

The three major sources of carbon dioxide emissions include:

1) *Solid Fuel Consumption:* Sources of solid fuel in India include coal, wood, coke, peat, biomass, etc. They are the biggest contributor of $CO_2$ emissions in India, accounting for more than 65% of the total emissions.

2) *Liquid Fuel Consumption:* Primarily petrol, diesel and kerosene (used for jet fuel), liquid fuels are the combustible liquids used as fuels in automobiles, power plants, generators, machinery, etc. Their high calorific value makes them an excellent fuel to be used in automobiles. Consumption of liquid fuel significantly adds to carbon dioxide emission, accounting for 23% of the total.

3) *Gaseous Fuel Consumption:* Gases like methane (Compressed Natural Gas), LPG (Liquefied Petroleum Gas) are the primary sources of gaseous fuel. The contribution of gaseous fuel is fairly low, nearly 10% of the total, with gaseous fuels chiefly used for domestic purpose (LPG) like cooking or automobiles (CNG) as a natural and cleaner alternative to petrol and diesel.

Of all the different types of fuel, coal is the most produced and utilized resource. Largely used in thermal power generation, steel industry, cement production, etc. Coal is a major stakeholder in the economy of India. 1,96,098 MW of the total installed capacity (3,44,689 MW) comes from coal, that is 56.9% of the total installed capacity. [7]

The Table I shows the quantity of coal produced in India (thousand tonnes) and Fig. 1 gives the trend for coal production in India.

TABLE I: Coal production in India (thousand Tonnes) [8]

| Year | Coal Production |
|---|---|
| 2000-01 | 313696 |
| 2001-02 | 327787 |
| 2002-03 | 341272 |
| 2003-04 | 361156 |
| 2004-05 | 382615 |
| 2005-06 | 407039 |
| 2006-07 | 430832 |
| 2007-08 | 457082 |
| 2008-09 | 492757 |
| 2009-10 | 532042 |
| 2010-11 | 532694 |
| 2011-12 | 539950 |
| 2012-13 | 556402 |
| 2013-14 | 565765 |
| 2014-15 | 609200 |
| 2015-16 | 639021 |
| 2016-17 | 662791 |

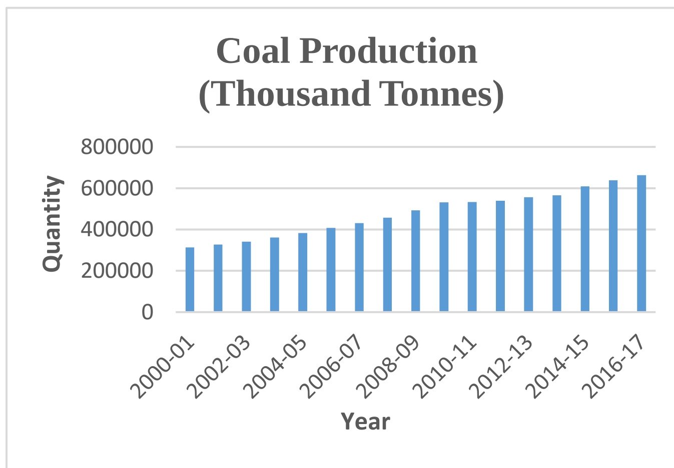


Fig. 1: A bar graph showing the trend of coal production in India from 2000-2017.

The large-scale production of coal is a consequence of its utilization in various industries such as steel, cement, textile, etc. 520 million tonnes alone were consumed in the year 2014-15 for electricity generation. Reducing the consumption of coal will greatly affect the levels of $CO_2$ emissions, thus calling for installation of more numbers of renewable energy plants across the nation.

Domestic sales of petrol and diesel in India, reach a new high every year, with net petroleum consumption reaching a record 204.95 million tonnes [9], a 5.3% growth compared to year 2016-2017 (194.6 million tonnes). This is accompanied by increasing sales of automobiles in India, with number of registered vehicles in India reaching 210 million [10] as of 2015, which contributes to the share of liquid fuel consumption in total $CO_2$ emissions.

The Table II shows year wise level of overall and sectional $CO_2$ emissions in India, from 1960 to 2017 in million tones.

TABLE II: YEAR WISE LEVEL OF OVERALL AND SECTIONAL CARBON DIOXIDE EMISSIONS IN INDIA (MILLION TONNES) [11]

| Year | Solid Fuel | Liquid Fuel | Gaseous Fuel | Overall |
|---|---|---|---|---|
| 1960 | 97.208503 | 19.460769 | 0 | 120.581961 |
| 1961 | 104.956874 | 21.327272 | 0.003667 | 130.402187 |
| 1962 | 114.22705 | 24.906264 | 0.011001 | 143.467708 |
| 1963 | 122.144103 | 27.128466 | 0.011001 | 154.083673 |
| 1964 | 117.167984 | 28.144225 | 0.022002 | 150.647694 |
| 1965 | 128.818043 | 30.83947 | 0.282359 | 165.972087 |
| 1966 | 129.404763 | 35.705579 | 0.311695 | 171.765947 |
| 1967 | 131.740642 | 32.724308 | 0.487711 | 172.23899 |
| 1968 | 136.973451 | 42.284177 | 0.751735 | 187.336029 |
| 1969 | 136.463738 | 45.386459 | 0.997424 | 190.724337 |
| 1970 | 136.66909 | 49.372488 | 0.924084 | 195.143072 |
| 1971 | 140.449767 | 55.489044 | 1.085432 | 205.869047 |
| 1972 | 148.641845 | 58.925023 | 1.206443 | 217.849136 |
| 1973 | 152.440857 | 61.799951 | 1.169773 | 224.343393 |
| 1974 | 161.102311 | 60.677849 | 1.360457 | 231.992755 |
| 1975 | 178.465556 | 61.887959 | 1.734491 | 252.201592 |
| 1976 | 186.855652 | 63.490438 | 2.295542 | 263.785645 |
| 1977 | 196.356849 | 68.613237 | 2.482559 | 279.051366 |
| 1978 | 193.236232 | 75.378852 | 2.742916 | 283.096067 |
| 1979 | 199.800162 | 82.731187 | 3.032609 | 296.891321 |
| 1980 | 218.289176 | 83.244567 | 2.489893 | 314.016211 |
| 1981 | 232.63448 | 89.786495 | 2.885929 | 338.838134 |
| 1982 | 235.75143 | 94.483922 | 4.36373 | 349.637449 |
| 1983 | 257.207047 | 99.251022 | 5.247477 | 378.669088 |
| 1984 | 256.073944 | 106.192653 | 6.175228 | 388.118947 |
| 1985 | 280.184469 | 116.856289 | 7.205655 | 426.673785 |
| 1986 | 302.175468 | 121.957086 | 10.318938 | 457.571927 |
| 1987 | 322.846347 | 127.776615 | 12.786829 | 488.48107 |
| 1988 | 350.847559 | 133.724489 | 15.21805 | 527.563956 |
| 1989 | 375.687817 | 150.838378 | 18.533018 | 579.008299 |
| 1990 | 405.430854 | 158.297056 | 21.114586 | 619.154615 |
| 1991 | 434.774188 | 166.558807 | 23.582477 | 658.18983 |
| 1992 | 455.096702 | 188.208775 | 27.278813 | 699.087881 |
| 1993 | 479.108218 | 187.031668 | 27.018456 | 723.697118 |
| 1994 | 504.106157 | 199.1181 | 29.024305 | 764.730848 |
| 1995 | 521.810433 | 216.459343 | 39.082886 | 811.562105 |
| 1996 | 558.066062 | 243.360455 | 39.779616 | 882.324204 |
| 1997 | 583.753397 | 244.401883 | 46.061187 | 917.685085 |
| 1998 | 579.774702 | 263.10725 | 47.63433 | 936.22177 |
| 1999 | 620.042029 | 285.483284 | 42.350183 | 995.766516 |
| 2000 | 633.701604 | 303.752278 | 43.908658 | 1031.85346 |
| 2001 | 643.881196 | 298.068428 | 43.604297 | 1041.15297 |
| 2002 | 662.153857 | 284.834225 | 47.172288 | 1054.25883 |
| 2003 | 692.344268 | 293.851378 | 50.028881 | 1099.59762 |
| 2004 | 741.104367 | 296.858318 | 49.625511 | 1154.32026 |
| 2005 | 798.071212 | 300.011938 | 50.479922 | 1222.56313 |
| 2006 | 855.698117 | 316.90214 | 49.482498 | 1303.71750 |
| 2007 | 931.927713 | 335.739519 | 52.738794 | 1407.60728 |
| 2008 | 1007.49724 | 403.403003 | 63.098069 | 1568.37956 |
| 2009 | 1088.42060 | 454.836345 | 91.245961 | 1738.64571 |
| 2010 | 1093.53240 | 414.257323 | 100.318119 | 1719.69098 |
| 2011 | 1210.83973 | 417.726305 | 91.443979 | 1841.77641 |
| 2012 | 1365.78515 | 437.836133 | 78.151104 | 2018.50381 |
| 2013 | 1329.93289 | 461.172921 | 101.883928 | 2034.75229 |
| 2014 | 1492.751359 | 514.109733 | 92.694426 | 2238.377137 |
| 2015 | 1628.547 | 539.815186 | 97.3291413 | 2350.29585 |
| 2016 | 1706.096 | 547.4552858 | 98.70665778 | 2383.56 |
| 2017 | 1729.906 | 572.638284 | 103.247174 | 2493.204 |

The graph in Fig. 2 shows the trend of overall carbon dioxide emissions in India.

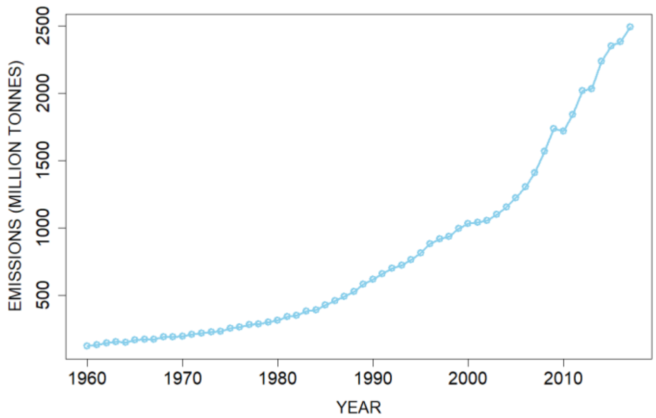


Fig. 2: A graph showing overall carbon dioxide emissions in India (million tonnes) 1960-2017

The Fig. 3, Fig. 4 and Fig. 5 show the trend of carbon dioxide emissions from solid, liquid and gaseous fuel consumption in India respectively.

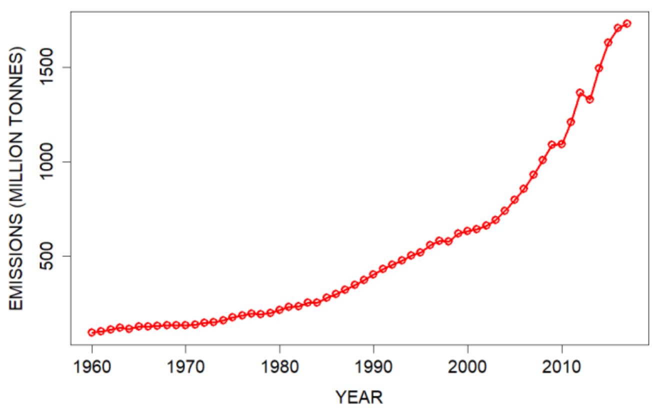


Fig. 3: A graph showing carbon dioxide emissions in India, from solid fuel consumption (million tonnes) 1960-2017

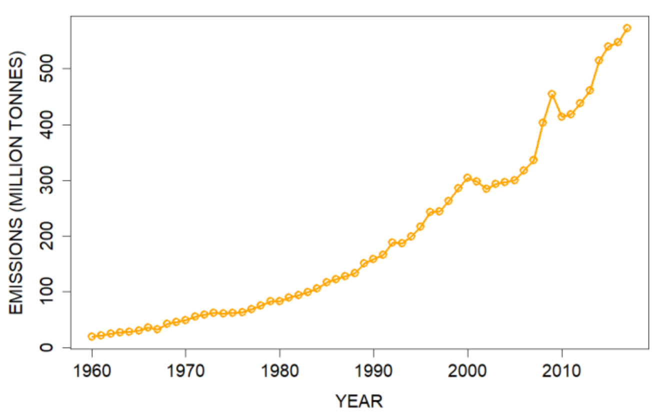


Fig. 4: A graph showing carbon dioxide emissions in India, from liquid fuel consumption (million tonnes) 1960-2017

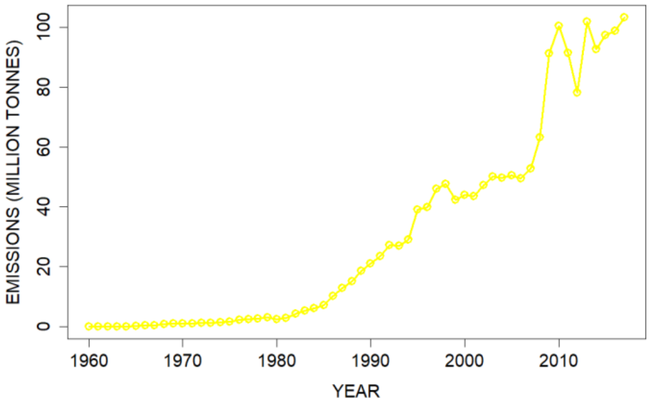


Fig. 5: A graph showing carbon dioxide emissions in India, from gaseous fuel consumption (million tonnes) 1960-2017

## III. Methodology

The data used for analyzing the carbon dioxide emissions, is varying with time, as the emissions in million tonnes, are progressively increasing every year, from 1960 to 2017. Therefore, it is considered as a time series, and subsequent forecasts are produced, using time series analysis.

The approach used in the research trend analysis using exponential smoothing. Exponential smoothing is a method of producing forecasts using weighted averages of past information, with the weights decaying exponentially as the observations get older. The selection of the method is usually based on analyzing the key components of the time series, i.e Trend, Seasonality and Error.

1) *Trend:* Trend is the nature of variability of data over a period of time, whether it is increasing or decreasing with time.

2) *Seasonality:* Seasonality is the presence of fluctuations in data that occur at specific regular intervals of time.

3) *Error:* Error is the presence of irregularities in data that occur randomly at any time interval.

Based on the data graphs above, it is observed that the data exhibits an increasing trend with no seasonal or error component. Therefore double exponential smoothing or Holt's linear trend method is used for forecasting.

Double exponential smoothing is an effective method to produce forecasts when the data exhibits a certain trend, in this case an increasing trend. It introduces two equations to calculate the forecasts, taking into account the level and trend both.

The forecasting equation becomes:

$$F_{t+1} = A_t + B_t$$

Where

$F_{t+1}$ = Forecast at time t+1

$A_t$ = level at time t

$B_t$ = trend at time t

Level A at time t is calculated using the equation:

$$A_t = \alpha D_t + (1-\alpha)F_t$$

Where

- $D_t$ = Observation at time t
- $F_t$ = Forecast at time t
- $\alpha$ = Smoothing level parameter whose value lies between [0,1]

Trend B at time t is calculated using the equation:

$$B_t = \beta(A_t - A_{t-1}) + (1-\beta)B_{t-1}$$

Where

- $A_t$ = Level at time t
- $A_{t-1}$ = Level at time (t-1)
- $B_{t-1}$ = Trend at time (t-1)
- $\beta$ = Smoothing trend parameter whose value lies between [0,1]

An error function E is defined as the root mean square (RMSE) of difference between the observation D and forecast F over a time period t. That is

$$E = \sqrt{[\{\textstyle\sum_0^t (D_i - F_i)^2\}/n]}$$

Where, n is the number of observations from 0 to t.

The values of smoothing parameters $\alpha$ and $\beta$ are determined by minimizing the error function. The values of the smoothing parameters are optimum, when the error function E is minimum. The optimization of error function to select two model parameters ($\alpha$ and $\beta$) is done using solver in Excel. The values of these parameters are then used in level and trend equations, and subsequent forecasts are produced.

## IV. Illustration

The values of smoothing parameters $\alpha$ and $\beta$ are determined using solver on excel. The data of first two years is used for initialization, for initial level and trend. The initial values of $\alpha$ and $\beta$ are taken as 0.2 and 0.1 respectively. The forecast is evaluated as the sum of level and trend.

Level and trend are calculated using the equations:

$A_t = \alpha D_t + (1-\alpha)F_t$

$B_t = \beta(A_t - A_{t-1}) + (1-\beta)B_{t-1}$

The error is evaluated as the difference between an observation and its corresponding forecast. A variable E is defined as the root mean square error (RMSE), and is a function of $\alpha$ and $\beta$. E is minimized using solver, and the corresponding values of α and β obtained are then used to produce forecasts.

The Table III shows the value of RMSE obtained after setting the initial values of α and β as 0.2 and 0.1 respectively. Note that, the data in Table II is used for all estimation and forecasting purpose.

TABLE III: ROOT MEAN SQUARE AND MEAN ABSOLUTE PERCENTAGE ERROR FOR INITIAL VALUES OF SMOOTHING PARAMETERS

| S. No | Emission | (α) | (β) | RMSE | MAPE |
|---|---|---|---|---|---|
| 1 | Overall | 0.2 | 0.1 | 1063.001 | 7.47% |
| 2 | Solid Fuel Consumption | 0.2 | 0.1 | 84.86122 | 8.68% |
| 3 | Liquid Fuel Consumption | 0.2 | 0.1 | 23.8602 | 8.28% |
| 4 | Gaseous Fuel Consumption | 0.2 | 0.1 | 7.751836 | 26.50% |

Mean absolute percentage error (MAPE) is the mean of the ratio of absolute error (absolute difference between forecast and observation) and the observation, in percentage value.

Error 'E' (root mean square error variable) is minimized using solver and the values of α and β are obtained as shown in the Table IV.

TABLE IV: ROOT MEAN SQUARE AND MEAN ABSOLUTE PERCENTAGE ERROR FOR OPTIMIZED VALUES OF SMOOTHING PARAMETERS

| S. No. | Emission | (α) | (β) | RMSE | MAPE |
|---|---|---|---|---|---|
| 1 | Overall | 0.67178 | 0.42371 | 37.0429 | 2.48% |
| 2 | Solid Fuel Consumption | 0.35328 | 0.80602 | 28.6670 | 3.23% |
| 3 | Liquid Fuel Consumption | 1 | 0.094681 | 15.21778 | 4.36% |
| 4 | Gaseous Fuel Consumption | 0.937734 | 0.049441 | 6.081291 | 14.43% |

The forecasts for the years 2018-2020, based on the optimized values of α and β, obtained by minimizing the RMSE using solver, are produced in the Table V.

TABLE V: FORECAST VALUES OF CARBON DIOXIDE EMISSIONS IN INDIA FROM 2018 TO 2020, IN MILLION TONNES

| Year | Solid Fuel | Liquid Fuel | Gaseous Fuel | Overall |
|---|---|---|---|---|
| 2018 | 1870.683 | 590.5097 | 105.7312 | 2594.664 |
| 2019 | 1962.009 | 608.3812 | 108.3372 | 2689.947 |
| 2020 | 2053.336 | 626.2526 | 110.9431 | 2785.231 |

To check whether the trend analysis approach fits well, the forecast values are compared with actual observations and the two lines, one depicting the actual observation and one showing forecast values are plotted on the graph and analysed.

The graph in Fig. 6 compares the actual observations against forecast values for overall $CO_2$ emissions.

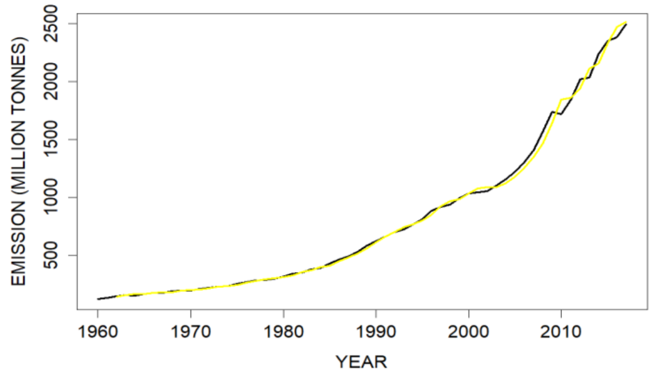


Fig. 6: A graph comparing the forecast values against the actual observation for overall $CO_2$ emissions: Yellow line depicts the forecast values, against observations shown using black line.

The graphs in Fig. 7, Fig. 8 and Fig. 10 compare the actual observations against forecast values sectional $CO_2$ emissions:

1) *Solid Fuel Consumption:*

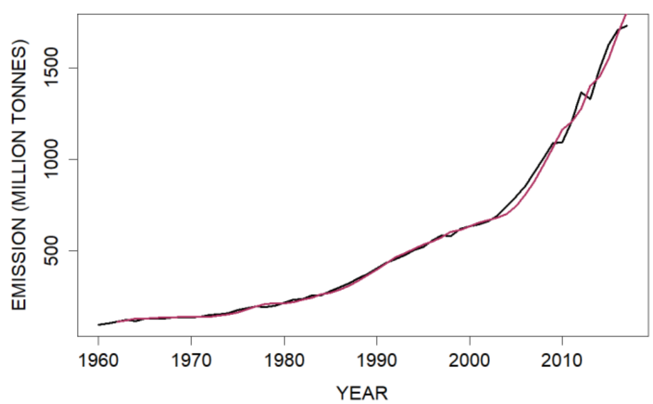


Fig. 7: A graph comparing the forecast values against the actual observation for $CO_2$ emissions by solid fuel consumption: Maroon line depicts the forecast values, against observations shown using black line.

2) *Liquid Fuel Consumption:*

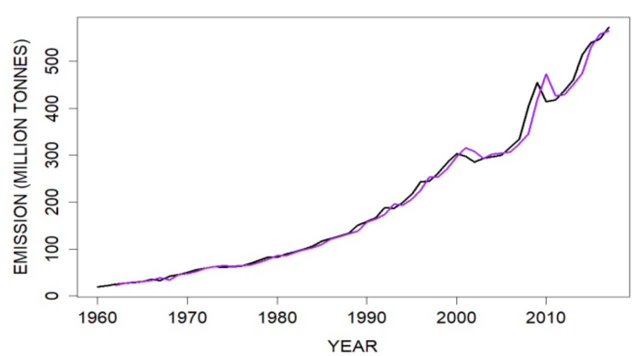


Fig. 8: A graph comparing the forecast values against the actual observation for $CO_2$ emissions by liquid fuel consumption: Violet line depicts the forecast values, against observations shown using black line.

3) *Gaseous Fuel Consumption:*

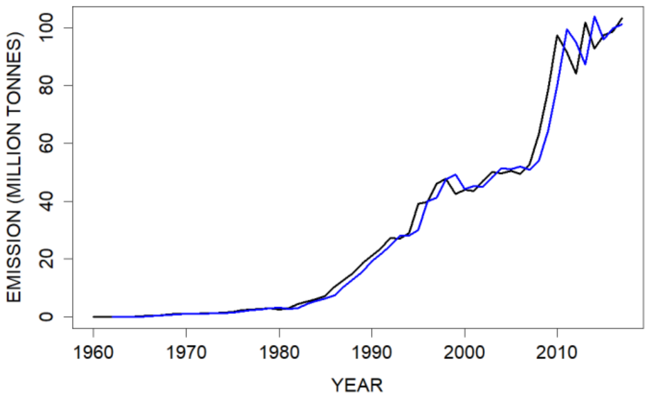


Fig. 9: A graph comparing the forecast values against the actual observation for $CO_2$ emissions by gaseous fuel consumption: Blue line depicts the forecast values, against observations shown using black line.

The graphs in Fig. 7, Fig. 8 and Fig. 10 show that the trend analysis approach fits well. With the mean absolute percentage error equal to 2.4989 and mean absolute scaled error equal to 0.533, the trend analysis approach has produced reliable forecasts.

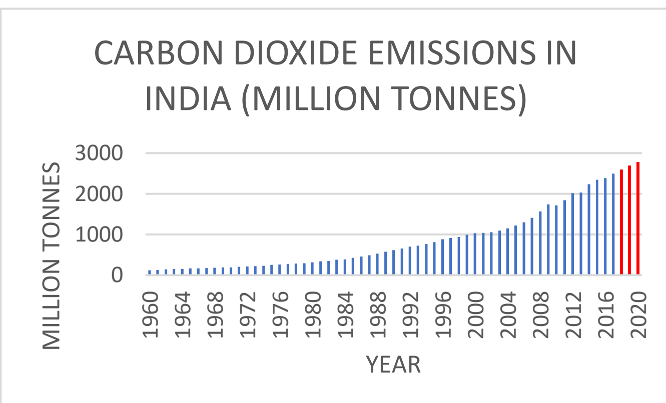


Fig. 10: A bar graph showing $CO_2$ emissions in India from 1960-2017 and predicted values from 2018-2020 in red.

## V. Conclusion

The overall $CO_2$ emissions in India, are projected to rise upto 2785 million tonnes by 2020. The graph in Fig. 10 shows the trend upto 2020.

Emissions from consumption of solid fuel are projected to rise upto 2053 million tonnes, increasing their share to 73%, implying the continued reliance on solid fuels for energy and other uses, while liquid fuels and gaseous fuel adding 626 million tonnes and 111 million tonnes respectively. The research is done to analyse the increase of $CO_2$ emissions in India, and place great emphasis on making efforts to curb the levels and switching to alternative sources of energy, as increased greenhouse gas emissions are detrimental to sustenance of life on this planet. As a future work, it is intended to propose a model that can analyse the explicit relation between factors such as economy, population, GDP, etc. and $CO_2$ emissions, and increase the accuracy of the forecasts.

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