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An analytical study of emission dynamics of carbon dioxide in India

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Abstract: *Global warming is a serious concern to the scientists over the globe due to its alarming situation to the inhabitants and also to the existence of life on earth over the last fifty years. The causes for the situation are too many. One of the major causes for global warming is the uncontrolled emission of green house gases mainly carbon-dioxide (CO_2). In India, this emission rate varies in different regions depending on several features, namely, industrialization, population and economic growth. In this paper, an attempt has been made to build up a state-wise analytical differential model of CO_2 emission using the data set of 21 years from 1980 to 2000. A search technique is utilized to identify the exact differential model. The model has been utilized experimentally to forecast carbon dioxide emission for 2015 and 2020.*

Keywords: *Carbon dioxide emission, Coefficient of determination, PRESS statistic, Residual analysis, Standard Error.*

I. INTRODUCTION

In recent times, climate change is a serious concerns today all around the world. One of the main reasons for the climate change is global warming and it attracts considerable attention to scientists, researchers and academicians. Different green house gases are responsible for this unwanted situation. An uncontrolled emission of one of the green house gases, namely carbon dioxide (CO_2) from different sources is the most important one [1] and alarming for the last fifty years. It may be mentioned here that India is the fourth largest CO_2 emitter in the world [2].

Solid fuels, liquid fuels, gaseous fuels, cement industry and gas flaring are the main sources of CO_2 worldwide. The major global sources of CO_2 are liquid fuels whereas solid fuels come second in importance; whereas, solid fuel is more important than liquid fuel in India. The state-wise emission of CO_2 in India for last three decade is quite frightening. So far the mean CO_2 emission is concerned during the last three decades; Uttar Pradesh tops the list followed by Madhya Pradesh, Maharastra and Bihar. Major sources for emission of CO_2 are coal, motor gasoline and high speed diesel. State-wise CO_2 emission from cement manufacturing reveals that Andhra Pradesh topped the list, followed by Rajasthan, Madhya Pradesh and Gujarat. The total CO_2 emission for India in 2000 (from fossil fuel and cement manufacturing) became 334431000 M.T. of carbon of which contribution of CO_2 from cement manufacturing is 3.11 per cent which is in conformity with the percentage of CO_2 emission from cement manufacturing (3 per cent) at the global level [3].

The dynamics and mathematical modeling of emission of CO_2 has been undertaken region wise by several researchers all over the world but in Indian context, hardly any study is undertaken. Tokos et al [4] made a study on the modeling of CO_2 emission with a system of differential equations for six attribute variables for the continental United States from 1950 to 2005. Peterson [5] developed an empirical model depending on economic growth and per capita income on United States. Kram et. al. [6] studied on global and regional emissions scenarios and introduced key sources and parameters in greenhouse gas emissions. Similarity, Fenhann [7] studied on industrial non-energy resources for greenhouse gas emissions. Ritter et al. [8] recommended methodologies for consistent estimation of greenhouse gas emissions from oil and gas industry facilities. The dynamic greenhouse and feedback processes that may influence future concentrations of atmospheric trace gases like CO_2 and corresponding climatic change has been studied by Lashof [9]. Climate processes and Climate Sensitivity due to greenhouse gases has been studied by Hansen and Takahashi [10].

In the Indian context, Singh et. al. [11] elaborated the trends of energy consumption and consequent emissions of greenhouse from the road transport sector in India. Parikh et. al. [12] described CO_2 emission structure of Indian economy based on fuel type, sector wise, final demand and expenditure classes.

This paper provides models of differential equations for the state-wise distribution of emissions of CO_2 in India considering the emission data for twenty one years (1980-2000) [2, 5]. The states considered here are Maharashtra, West Bengal and Punjab. From our model, short term state-wise CO_2 emission can be estimated.

Dynamical formulation:

Our dynamical formulation of CO_2 emissions in Indian perspective has been established on the basis of model recommended for other countries by Goreau [13], Tokos et. al. [4] and Bunce [14]. The survey [4, 14] reveals that without loss of generosity, we can express the change of CO_2 emissions as a function of time. Namely, the emission of CO_2 in a region is well represented by a differential equation in the form:

$$G(t) + dG(t)/dt = C_1 + C_2.t + C_3.t^2 + C_4.t^3 \qquad \ldots(1)$$

where G represents total emission of CO_2, C_1 is a constant, C_2, C_3, C_4 are coefficients and t is time variable (year).

The solution of the equation is comprehensively extracted as

$$G(t) = D_1 + D_2.t + D_3.t^2+D_4.t^3 \qquad \ldots (2)$$

where D_1 is a constant and D_2, D_3, D_4 are the coefficients.

The magnitudes of D_1, D_2, D_3 and D_4 are naturally region and time-specific. Utilizing the state-wise data set of 21 years (1980-2000), the numerical values of the coefficients relevant for a specific state are searched to generate dynamical models (2) for a specific state.

Quality of estimates:

Thus, one can utilize equation (2) above to obtain the estimates of the CO_2 emission for short and medium terms of time for a specific state. However, the question arises about the quality of these estimates. The judgment rests on the quality of the developed analytical models using the raw data.

For testing the quality of the proposed analytical models, we use three statistical criteria, the coefficient of determination R^2 (adjusted R^2) [15, 16], the PRESS statistic [17] and residual analysis [18]. The value of R^2 (adjusted R^2) defined as the proportion of the total response variation, provides an overall measure of how well the model fits and small value of residual attest goodness of the selected model.

Analysis

Maharastra

The differential equation for emission of CO_2 for the state of Maharastra is given by

$$G(T) + \frac{dG(T)}{dT} = 5152214110 - 7804116\,T + 3940.011\,000036T^2 - 0.662999988T^3 \qquad \ldots (3)$$

The solution is given by

$$G(T)= 5160026110 - 7812000T + 3942T^2 - 0.662999988T^3 \qquad \ldots(4)$$

Here, T is time in years.

A graphical display of the actual data and the solution (4) of the differential equation (3) for Maharastra is presented in fig 1.

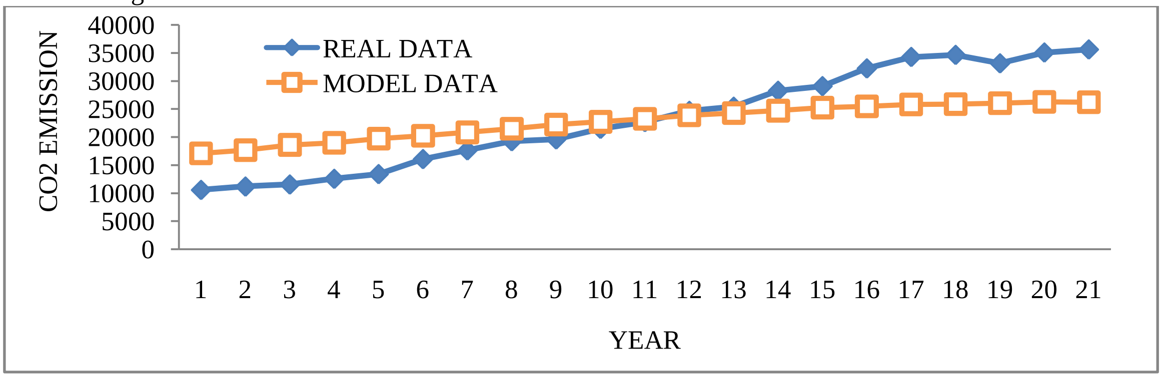

Figure 1Emission of CO_2 in Maharastra

In Fig. 1, the change of CO_2 emission is compared with the model data and it is evident from the figure that CO_2 emission model match reasonably well with the actual status of CO_2 emission in Maharastra. The increasing tendency of the emission persists right from 1980 and finally a decreasing tendency is observed form 1998.

However, it is now very much justifiable to quantify the goodness of the estimates. The answer depends on the quality of developed models using the raw data. Intermediately, the regression sum of square (SSREG), in other words the variation explained by the model is computed. The residual sum of squares (SSERR) indicating the variation that is left unexplained is calculated. The total sum of square (SSTOT), proportional to the sample variance and equals the sum of SSERR and SSREE is worked out. The coefficient of determination R^2 defined as the proportion of the total response variation explained by the model is worked out. It provides an overall measure of how well the model fits and Adjusted R^2 will adjust for degree of freedom of the model that works better when we have a lot of parameters, is also worked out. The prediction of residual error sum of squares (PRESS) that evaluates how good the estimation will be if each time we remove one data is also computed.

The calculated values for R^2 (adjusted R^2) and PRESS statistics for the Maharastra model are given by Table 1.

Table 1Statistical Evaluation Criteria

R Square	R square adjusted	PRESS	FVU
0.554330349	0.475682765	36602928.	0.445669651
SSTOT	SSREG	SSERR	
1.55796851E+009	193464304.	694339264.	

The values of R^2 (adjusted R^2) reflect that we have identified a reasonably good model along with a PRESS statistic value that is the smallest of several models. Moreover, the residual analysis we performed on the proposed differential equation of Maharastra is given in Table2.

Table 2 Residual Analysis ('000 MT)

Year	Observed Data	Model Data	Residual	Year	Observed Data	Model Data	Residual
1980	10564.2305	17069.8047	-6505.57422	1991	24651.4609	23877.2891	774.171875
1981	11166.8203	17614.7031	-6447.88281	1992	25387.3906	24245.4531	1141.9375
1982	11534.1602	18575.5684	-7041.4082	1993	28229.3594	24690.1289	3539.23047
1983	12544.6904	18934.0352	-6389.34473	1994	29056.75	25211.3164	3845.43359
1984	13382.9805	19708.4688	-6325.48828	1995	32216.8809	25469.5605	6747.32031
1985	16059.5898	20219.959	-4160.36914	1996	34255.3281	25804.3164	8451.01172
1986	17613.0703	20807.9609	-3194.89063	1997	34626.2305	25876.1289	8750.10156
1987	19243.1504	21472.4766	-2229.32617	1998	33120.7891	26024.4531	7096.33594
1988	19564.25	22213.5039	-2649.25391	1999	35051.8594	26249.2891	8802.57031
1989	21449.6895	22691.5859	-1241.89648	2000	35595.4297	26211.1816	9384.24805
1990	22660.1191	23246.1816	-586.0625				
				Mean of residual			560.041016
				Standard deviation of residual			5864.09717
				Standard error of residual			1279.65088

It is evident from the table that the residuals, standard deviation and standard error are reasonably small compared to the actual and empirical data indicating the good quality of the proposed model for emission of CO_2 in Maharastra. The total CO_2 emissions in Maharastra can be estimated for 2015 and 2020 as 15811.4941and 6552.61963 ('000 MT) respectively.

Punjab

The differential equation for emission of CO_2 for the state of Punjab is given by

$$G(T) + \frac{dG(T)}{dT} = 3045084.601 - 5223.985559\,T + 2.705389521\,T^2 - 0.000425809529T^3\,, \qquad \dots (5)$$

T representing time in years. The solution of (5) is given by

$$G(T) = 3050314 - 5229.398893T + 2.70666695T^2 - 0.000425809529T^3 \qquad \dots (6)$$

A graphical display of the actual data and the solution of equation (6) for Punjab is presented in Fig. 2.

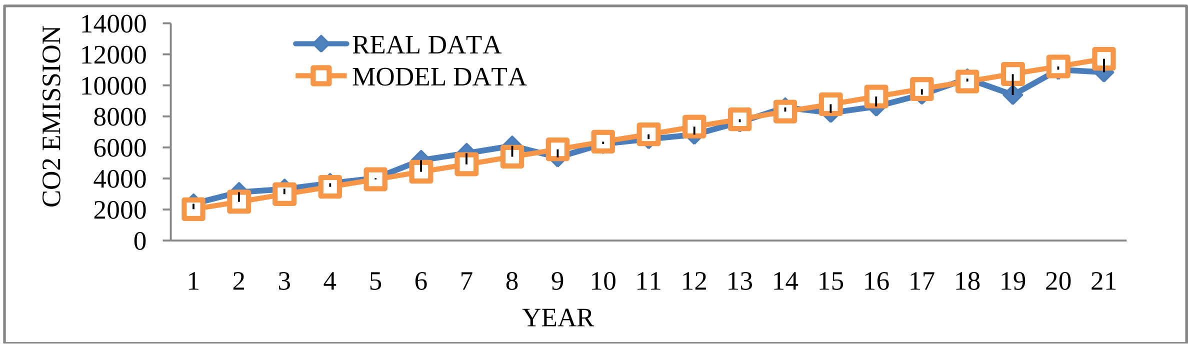

Figure 2 Emission of CO_2 in Punjab

In the Fig. 2, the change of CO_2 emission is compared with the model data and it is evident from the figure that CO_2 emission fits well with the actual CO_2 emission in Punjab. The growth of CO_2 follows almost a linear trend from the beginning of the data period.

The values of R^2 (adjusted R^2) and PRESS statistic indicates that we have identified a very good model (Table 3). Moreover, the residual analysis we performed on the proposed differential equation of Punjab is given in Table 4 below

Table 3 Statistical Evaluation Criteria

R Square	R square adjusted	PRESS	FVU
0.953682899	0.945509315	6425129.5	0.0463171005
SSTOT	SSREG	SSERR	
139519968.	180731696.	6462160.	

Table 4 Residual Analysis (‘000 MT)

Year	Observed Data	Model Data	Residual	Year	Observed Data	Model Data	Residual
1980	2377.12012	2020.71753	356.402588	1991	6830.77979	7332.38525	-501.605469
1981	3114.92993	2501.79956	613.130371	1992	7629.27979	7817.20215	-187.922363
1982	3332.82007	2983.49878	349.321289	1993	8572.62988	8302.41797	270.211914
1983	3694.71997	3465.16064	229.559326	1994	8235.86035	8788.0332	-552.172852
1984	4026.67993	3947.43994	79.2399902	1995	8646.74023	9273.8291	-627.088867
1985	5185.3999	4429.8999	755.5	1996	9408.62012	9760.02441	-351.404297
1986	5638.12988	4912.75879	725.371094	1997	10434.6396	10246.4004	188.239258
1987	6109.5	5396.01709	713.48291	1998	9392.08984	10733.1758	-1341.08594
1988	5370.00977	5879.67432	-509.664551	1999	11012.5498	11220.3496	-207.79980
1989	6225.66016	6363.51221	-137.852051	2000	10845.7197	11707.7051	-861.98535
1990	6544.85986	6847.74902	-302.88916				
				Mean of residual			-61.9529495
				Standard deviation of residual			564.869873
				Standard error of residual			123.264709

It is evident from the table that the residuals, standard deviation and standard error are reasonably small indicating the good quality of the proposed model for emission of CO_2 in Punjab. The estimated CO_2 emissions for 2015 and 2020 in Punjab are 19053.7012 and 21516.1406 (‘000MT) respectively.

West Bengal

The differential equation for emission of CO_2 in West Bengal is given by

$$G(T) + \frac{dG(T)}{dT} = 5152207220 - 7733160\,T + 39418.011\,T^2 - 0.663T^3 \qquad \ldots (7)$$

Here, T represents years in the above equation. The solution of the equation (7) is given by

$$G(T) = 5160019460 - 7812000T + 3942T^2 - 0.662999988T^3 \qquad \ldots (8)$$

A graphical display of the actual data and the solution of equation (8) are given by Fig. 3 below.

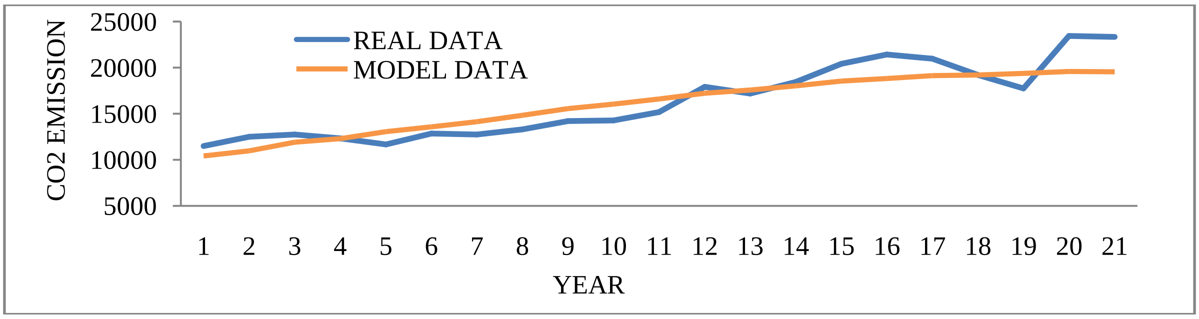

Figure 3 Emission of CO_2 in West Bengal

From Fig. 3, we can find out that our carbon emissions dynamic model of West Bengal matches well with the actual status of carbon emissions, presenting from smooth growth to rapid growth and almost stabilize at last.

The increasing trend prevails year-wise starting around 1985 except a decreasing tendency from 1995 to 1999. One can utilize either equation (8) on the above graph to obtain the estimate of emission of CO_2 in West Bengal for short or medium terms of time.

Table 5 Statistical evaluation criteria

R Square	R square adjusted	PRESS	FVU (Frac. Var. Unexplained)
0.795602262	0.759532094	56910220.	0.204397738
SSTOT	SSREG	SSERR	
315834048.	189219520.	64555760.	

The values of R^2 (R^2 adjusted) reflect the fact that we have identified a good model along with a PRESS statistic value that is the smallest of several models that are tested. The residual analysis performed on the proposed model of emission of CO_2 for the state of West Bengal State is presented Table 6 below. As seen from the table, the residuals are extremely small compared to data and so is the standard error. These results attest to the good quality of the proposed model for emission of CO_2 in West Bengal. Thus, we have predicted total CO_2 emissions in West Bengal for 2015 and 2020 as 19155.49414 and 9896.61945 ('000 MT) respectively.

Table 6 Residual Analysis ('000 MT)

Year	Observed Data	Empirical Data	Residual	Year	Observed Data	Empirical Data	Residual
1980	11499.3301	10413.8047	1085.52539	1991	17909.1504	17221.2891	687.861328
1981	12501.4902	10958.7021	1542.78809	1992	17197.9297	17589.4531	-391.523438
1982	12753.5	11919.5684	833.931641	1993	18439.5391	18034.1289	405.410156
1983	12313.3301	12278.0342	35.2958984	1994	20435.9004	18555.3164	1880.58398
1984	11663.2305	13052.4688	-1389.23828	1995	21432.4199	18813.5605	2618.85938
1985	12848.3203	13563.959	-715.638672	1996	20984.9199	19148.3164	1836.60352
1986	12742.4199	14151.9619	-1409.54199	1997	19212.7305	19220.1289	-7.3984375
1987	13307.9697	14816.4766	-1508.50684	1998	17753.2402	19368.4531	-1615.21289
1988	14190.1904	15557.5039	-1367.31348	1999	23457.0508	19593.2891	3863.76172
1989	14268.2695	16035.5869	-1767.31738	2000	23363.7109	19555.1816	3808.5293
1990	15175.4102	16590.1816	-1414.77148				
					Mean of residual		333.9375
					Standard deviation of residual		1763.71716
					Standard error of residual		384.874634

II. CONCLUSION

The emission of CO_2 is a major concern in different parts of the country. Some parts of country are severely affected due to mainly deforestation, growing of industry, growing of population and uncontrolled emission. However, the pattern of growth is diversified in time and area. This pattern changes from less industrial and less populated area to rapidly industry oriented and densely populated parts of the country. It is therefore essential to have study of emission of CO_2 in different parts of the country.

In the present study, we have developed a model of differential equations that characterize the behavior of emission of CO_2 for each of the three states in different zones of India considering all attributes. We observe that CO_2 emissions in different states keep on increasing year to year starting from 1980 except a nominal drop at certain years and certain states such as Punjab in 1988, Maharastra in 1988 and West Bengal in 1988.That only may be statistical fluctuation or reduction in energy consumption. Sometimes, the increment leads from smooth growth to rapid growth and finally stabilizing. Those instances are West Bengal in 1993 and 1998 and also Maharastra in 1994.The states being India's economic cores, its rapid economic development leads to the consumption of energy and a significant growth. Because of the CO_2 emissions of the states mentioned mainly depend on coal and petroleum product, the sources of consumption differs for various states of different zones. That investigation needs further study.

As a remedial measure of growth of $CO_{2,}$ we need a policy comprising of CO_2 emissions prediction, control strategy, policy implementation and technical innovations to achieve the goal of low CO_2 emissions.

That would lead the system to the ideal direction, reflecting the low carbonization development with high carbon energy and consequent economic growth.

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