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A Comparative Evolutionary Analysis and Prediction of Carbon Dioxide Emission in Different Countries

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Abstract

Climatic change in recent times is one of the serious issues throughout the world which is mainly due to the cause of global warming. Global warming is much alarming to the human beings and also to the existence of life on earth. The main cause for global warming is uncontrolled anthropogenic emission of green house gases like carbon dioxide, methane, chlorofluorocarbons etc. Among the green house gases, carbon-dioxide contributes a major share in this aspect. The rate of carbon-dioxide emission varies in different countries like India, USA, China, Japan and also in European countries depending on several conditions mainly industrialization, population explosion and economic growth. In this paper, an attempt has been made for the quantification of carbon dioxide emission in different countries using historical data of hundred years around the globe. Here, we formulate an evolutionary gas emission model using non-linear least square method and regression analysis has been done based on the above data for quantification of the emission. Finally, we predict the long term evolutionary trend of gas emission using instantaneous rate of change (IROC) in the subjected countries along with a comparative study of the carbon dioxide emission in different countries.

Keywords: Global warming, least square, regression analysis, carbon dioxide, IROC.

Introduction

Change of climate is one of the most serious concerns today all around the world. One of the important issues of climate change is global warming which attracts considerable attention to scientists, researchers and academicians throughout the world. Different green house gases like carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4), ozone (O_3) etc. are responsible for this unwanted situation but the uncontrolled emission of CO_2 from different sources is the most important one[1] and the amount of emission of CO_2 for the last fifty years from fossil fuels is tremendous[2]. The concentration of CO_2 in earth's atmosphere was about 280±10 parts per million by volume (ppmv) in 1750[3]. By 1999, it was 367 ppmv and rising by about 1.5 ppmv per year. If emission continues, the concentration will reach 500 ppmv at the end of twenty first century which is very much alarming for the existence for life on earth[4].

The uncontrolled emission of CO_2 from different sources is increasing in different parts of the continent. Some countries or parts of country are severely affected due to mainly deforestation, growing of industry, population explosion and increasing use of automobiles. However, the pattern of growth is time and area dependent. This pattern changes from less industrial and less populated area to rapidly industry oriented and densely populated part of the country. It is therefore essential to have study of emission of CO_2 in different parts over the globe. Main sources for the emission of CO_2 are solid fuels, liquid fuels and gaseous fuels. Source wise, India is significantly different from global averages. The major global sources of CO_2 are liquid fuels whereas solid fuels come second in importance. Emission of CO_2 in different countries is much fear-provoking. Several studies have been done by different researchers for the emission of CO_2 in India[5-7]. Country wise, India leads as far as mean CO_2 emission between 1980 and 2000. It is closely followed by China[8]. USA, Japan and European countries also contribute a major share for the increasing amount of CO_2 in the atmosphere from different sources. General trends in all these countries are high proportion of emissions from coal and automobiles.

Emission of CO_2 by mathematical modeling has been done region wise by several researchers all over the world. Mathematical understanding of CO_2 emission for different countries like Japan[9,10] China[8,11] and USA[12,13] have been done by some researchers also. Tokos et al.[13] 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. But in Indian context, very few studies are undertaken. Authors studied total CO_2 emission in Indian perspective as well as based on attributes[14,15]. Parikh et al.[16] described CO_2 emission structure of Indian economy based on fuel type, sector wise, final demand and expenditure classes.

In the present study, we developed mathematical models using non linear least square regression for the emission of CO_2 in different countries of the world. The countries considered here are India, China, Japan, USA and European countries for about hundred years (1890-1985). Emission data are collected from different literatures[2,17]. Using real historical data, analytical form of the equations are developed. Instantaneous Rate of Change (IROC) of emission has been derived from the developed equation which is utilized for the estimation of CO_2 emission for different countries for short and long range of time.

Methodology

In order to generate mathematical model of carbon dioxide emission, we visualize the works of Tokos et al.[13], Jin. et al.[18] and Basak and Nandi[15]. The authors suggest a third degree polynomial model for emission of the gas namely,

$$Y = a + b.x + c.x^2 + d.x^3 \qquad (1)$$

where Y is the emission of CO_2 and x represents time in years.

Least Square method: Given data $(x_1,y_1), (x_2,y_2),\ldots,(x_N,y_N)$, an error associated may be presented as

$$E(a,b,c,d) = \sum_{i=1}^{n} (y_i - a - bx_i - cx_i^2 - dx_i^3)^2 \qquad (2)$$

The equation (2) above is the N times variance of the data set (error) $\{y_1 - (a + bx_1 + cx_1^2 + dx_1^3)\},\ldots, \{y_N - (a + bx_N + cx_N^2 + dx_N^3)\}$ and is a function of four variables a, b, c and d. The goal is to estimate a, b, c and d with a view to minimize the error. Equating to zero, the partial derivatives with respect to a, b, c, d can be written as

$$\frac{\partial E}{\partial a}=0=-2\sum (y_i - a - bx_i - cx_i^2 - dx_i^3)$$

$$\frac{\partial E}{\partial b}=0=-2\sum x_i(y_i - a - bx_i - cx_i^2 - dx_i^3)$$

$$\frac{\partial E}{\partial c}=0=-2\sum x_i^2(y_i - a - bx_i - cx_i^2 - dx_i^3)$$

$$\frac{\partial E}{\partial d}=0=-2\sum x_i^3(y_i - a - bx_i - cx_i^2 - dx_i^3)$$

The corresponding normal equations are

$$\sum y_i = na + b\Sigma x_i + c\Sigma x_i^2 + d\Sigma x_i^3$$

$$\sum x_i y_i = a\Sigma x_i + b\Sigma x_i^2 + c\Sigma x_i^3 + d\Sigma x_i^4$$

$$\sum x_i^2 y_i = a\Sigma x_i^2 + b\Sigma x_i^3 + c\Sigma x_i^4 + d\Sigma x_i^5$$

$$\sum x_i^3 y_i = a\Sigma x_i^3 + b\Sigma x_i^4 + c\Sigma x_i^5 + d\Sigma x_i^6 \qquad (3)$$

For given set of points (x_i, y_i); (i=1,2,…,N), the equation (3) can be solved for a, b, c, d; whereas equation (3) is the third degree polynomial best fit. It has been observed that in all the cases, the values of the 2nd order derivatives viz. $\frac{\partial^2 E}{\partial a^2}$, $\frac{\partial^2 E}{\partial b^2}$, etc. come out to be positive at the points a, b, c. d indicating minimization of E.

Thus, the third degree fitted polynomial of CO_2 emission is estimated as

$$Y= \hat{a}, +\hat{b}.\,x + \hat{c}.x^2 + \hat{d}.x^3 \qquad (4)$$

Instantaneous Rate of Change of emission (IROC): In order to compute the rate of change of emission of the CO_2, the derivative of equation (4) is computed in the form

$$dY/dx= \hat{b}.+ \hat{c}.x + \hat{d}.x^2 \qquad (5)$$

The equation (5) at a particular time is utilized for prediction of the emission of the concerned gas.

Results and Discussions

Emission of CO_2 in Asian countries like India, China and Japan: For the analysis of emission of CO_2 in Asian countries like India, China and Japan, the dynamic models utilizing the data set of about hundred years are expressed in the following way

$$Y_{IND} = 23713.918\text{-}3.88413596.x\text{-}0.0155114625.x^2\text{+} 5.78179652E\text{-}006.x^3 \qquad (6a)$$

$$Y_{CHN} =37716.7383\text{-}7.90331459.x\text{-}0.0253356863.x^2\text{+} 1.00364778E\text{-}5.x^3 \qquad (6b)$$

$$Y_{JPN} =25853.957\text{-}4.52507401 .x\text{-}0.017040059 .x^2\text{+} 6.45304863E\text{-}6 .x^3 \qquad (6c)$$

where x represents time in years.

A graphical display of the actual data and the solution of the above models by least square method are compared in figure 1a, 1b and 1c for India, China and Japan respectively. These shows CO_2 emissions have a power series growing trend.

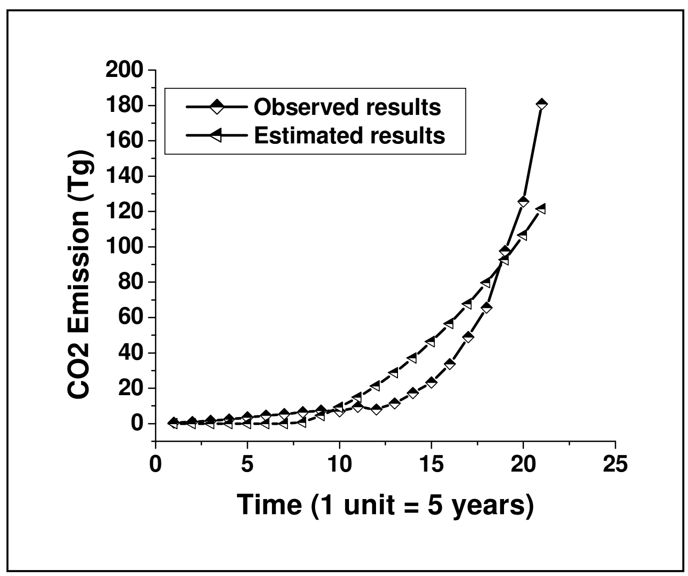

Figure-1a
CO_2 Emission in India

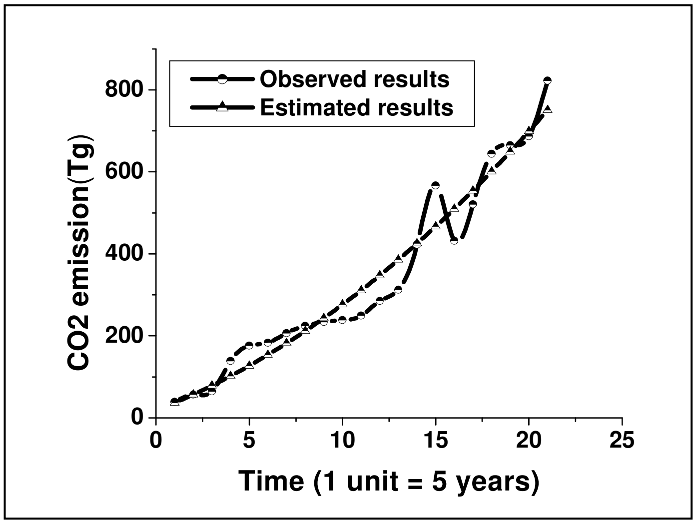

Figure-1b
CO_2 Emission in China

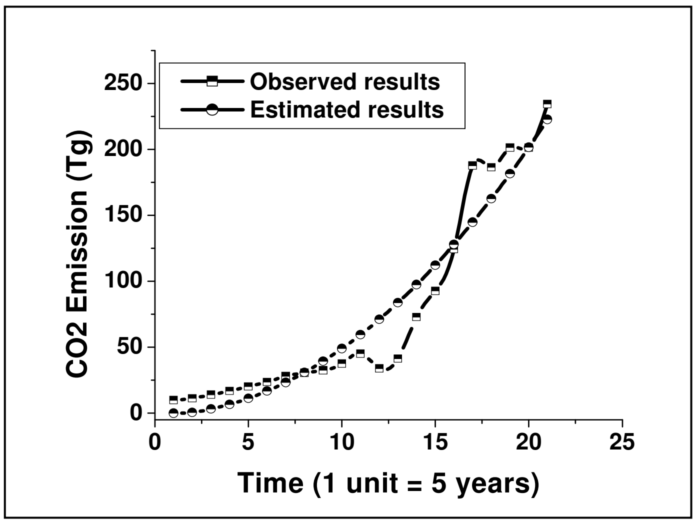

Figure-1c
CO_2 Emission in Japan

It has been observed from the graphical display that emission of CO_2 in China is much higher than India and Japan for the last hundred years. In recent years, the rapid growth leads to rapid consumption of fuels in automobiles and industry in these three countries. The goodness of the analytical model can be measured by utilizing the statistical criteria R^2 (R^2 adjusted). The calculated values of R^2 (R^2 adjusted) for three Asian countries are presented in table-1.

Table 1
Statistical Evaluation Criteria for CO_2 Emission

Country	R^2	R^2 adjusted
India	0.8534	0.8276
China	0.9574	0.9499
Japan	0.9307	0.9185

The value of R^2 (R^2 adjusted) reflect the fact that good models have been identified for the emission of CO_2 in India, China and Japan.

IROC of CO_2 emission in India, China and Japan: IROC is an important parameter which is useful for the prediction of future emission of gas. Here, IROC of CO_2 emission in India, China and Japan as a function of time are given analytically by

$$dY/dx \text{ (India)} = -3.88413596 - 0.031022925.x + 0.00001734538.x^2 \quad (7a)$$

$$dY/dx \text{ (China)} = -7.90331459 - 0.05066713726 .x + 3.01094334364778E\text{-}5.\ x^2 \quad (7b)$$

$$dY/dx \text{ (Japan)} = -4.52507401 - 0.034080118 . x + 19.35914589E\text{-}6 .x^2 \quad (7c)$$

A graphical display of expression 7a, 7b and 7c are given by figure 2a, 2b and 2c for India, China and Japan respectively.

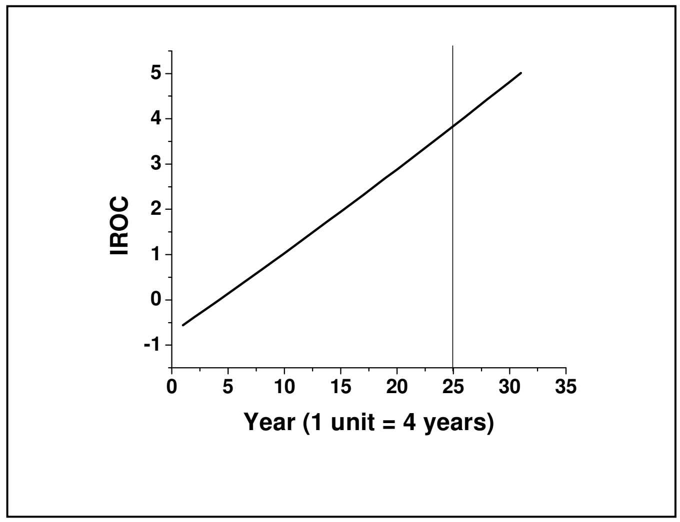

Figure-2a
IROC of India

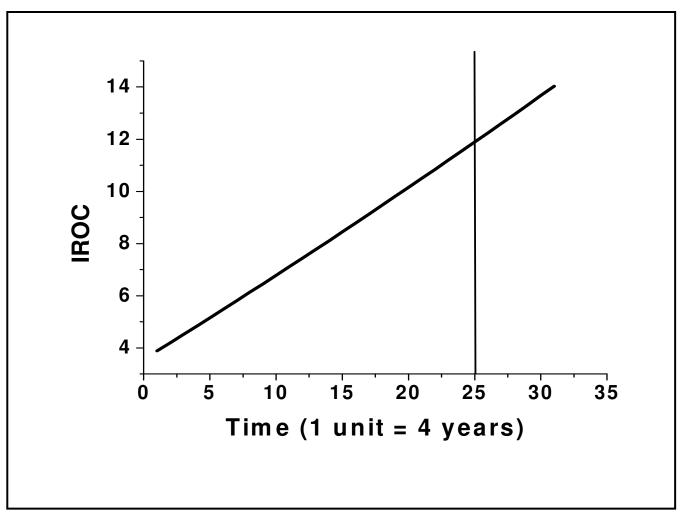

Figure-2b
IROC of China

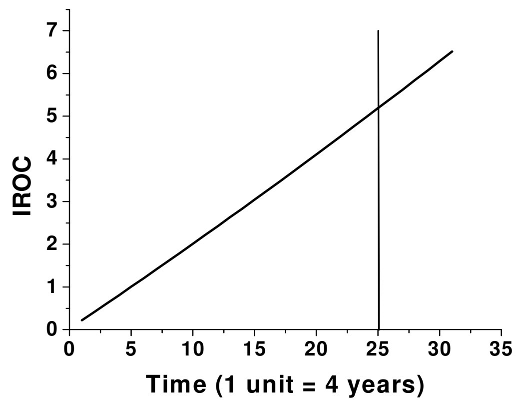

Figure-2c
IROC of Japan

One can utilize equation 7a, 7b or 7c or the graph to estimate the rate of change of CO_2 emission in India, China and Japan respectively for short and long term of time. For India, it is negative before 1905 and the decreasing trend in India was gradually slower before 1905. After 1905, CO_2 emission instantaneous variation is positive and emission grows rapidly. For all the countries especially in China, rapid increasing trend of IROC value signifies that uncontrolled emission of CO_2 into atmosphere from different sources occurs for the last hundred years which is very much alarming. The vertical lines in figure 2a, 2b and 2c indicate completion of hundred years of estimated IROC values for the emitted gas. Now, if we go beyond the vertical lines, we can easily predict the future IROC for the gas from where the future emission of CO_2 can be done for short and long range of time in the three countries. Increasing trend of IROC in future indicates continuous uninhibited emission of CO_2 from different sources which must be controlled for the sake of mankind.

Table-2
Details of residual analysis for CO_2 emission

Year	India			China			Japan		
	Empirical IROC	DF IROC	Residual	Empirical IROC	DF IROC	Residual	Empirical IROC	DF IROC	Residual
1890	0.7547	2.0825	-1.3278	0.4454	0.5485	-0.1031	0.1482	-1.6363	1.7845
1895	0.6989	0.4277	0.2712	0.1430	0.3819	-0.2389	0.2325	4.1713	-3.9387
1900	0.5063	0.1236	0.3827	1.1511	0.2967	0.8545	0.2030	1.1201	-0.0171
1905	0.4832	-0.0461	0.5293	0.2717	0.2444	0.0273	0.2063	0.6757	-0.4694
1910	0.2946	-0.2137	0.5083	0.0396	0.2091	-0.1695	0.1676	0.4921	-0.3245
1915	0.1707	-0.4827	0.6534	0.1283	0.1834	-0.0550	0.1858	0.3895	-0.2037
1920	0.2019	-1.3425	1.5444	0.0840	0.1639	-0.0799	0.0899	0.3234	-0.2335
1925	0.1431	5.1258	-4.9827	0.0433	0.1485	-0.1052	0.0665	0.2773	-0.2108
1930	-0.0571	1.0337	-1.0908	0.0186	0.0186	-0.1174	0.1532	0.2429	-0.0896
1935	0.3636	0.6058	-0.2421	0.0460	0.1257	-0.0797	0.2000	0.2163	-0.0163
1940	-0.1555	0.4382	-0.5937	0.1431	0.1170	0.0261	-0.2479	0.1950	-0.4429
1945	0.4386	0.3473	0.0913	0.0957	0.1095	-0.0138	0.2195	0.1776	0.0418
1950	0.5069	0.2895	0.2174	0.3517	0.1030	0.2486	0.7617	0.1632	0.5984
1955	0.3485	0.2493	0.0993	0.3429	0.0973	0.2455	0.2727	0.1510	0.1217
1960	0.4440	0.2194	0.22461	-0.2378	0.0923	-0.3301	0.3415	0.1405	0.2010
1965	0.4550	0.1963	0.2586	0.2048	0.0878	0.1170	05094	0.1314	0.3779
1970	0.3382	0.1779	0.1603	0.2371	0.0838	0.1532	-0.0071	0.1234	-0.1305
1975	0.4884	0.1628	0.3256	0.0325	0.0802	-0.0477	0.0804	0.1164	-0.0359
1980	0.2863	0.1501	0.1362	0.0320	0.0769	-0.0449	-0.0009	0.1101	-0.1110
1985	0.4398	0.1394	0.3004	0.1979	0.0738	0.1240	0.1651	0.1045	0.0606
Mean of Residual			0.1207	0.0196			-0.1875		
Standard deviation of Residual			1.2625	0.2397			1.0016		
Standard error of Residual			0.2823	0.0535			0.2239		

The goodness of the Instantaneous rate of changes is presented in table-2. In the table, the empirical or instantaneous rate of change for the emission of CO_2 in India, China and Japan, the corresponding instantaneous rate of change using the developed differential equation, DF IROC along with the residual being the difference of the two have been presented. It has been observed from the table that mean residual for India, China and Japan are 0.1207, 0.0196 and -0.1875 respectively which very are small and so the standard error. This certainly indicates that we have identified good models for emission of CO_2 for these three Asian countries.

Now, we can predict instantaneous variation of CO_2 emissions in future from the IROC graphical display for these three countries. Table-3 shows prediction of empirical IROC and future emission of CO_2 in India, China and Japan. We can see that in the year 2040, total CO_2 emission from all sources in India, China and Japan will be 323.28, 1363.30 and 493.11 Tg respectively if proper care to curb the emission is not be taken.

Emission of CO_2 in USA and Europe: For the analysis of emission of CO_2 in USA and Europe, the dynamic models utilizing the data set of about hundred years are expressed in the following way

$$Y_{USA}=101644.961-17.6519642.x-0.06658917484.x^2+2.51649053E-5.x^3 \quad (8a)$$

$$Y_{EUR}=57773.9727-11.2152081\ .x-0.0379425883\ .x^2+1.46929851E-5\ .x^3 \quad (8b)$$

where x represents time in years.

A graphical display of the actual data and the solution of the equation 8a and 8b are given in figure 3a and 3b for USA and Europe respectively.

Table-3
IROC and prediction of CO_2 in future

Year		2020	2025	2030	2035	2040
IROC in future	India	4.2256	4.4213	4.6179	4.8153	5.0137
	China	12.5990	12.9546	13.3118	13.6703	14.0305
	Japan	5.6261	5.8473	6.0693	6.2924	6.5165
Emission Prediction (Tg)	India	230.9174	252.5343	275.1341	298.7168	323.2881
	China	1097.0525	1160.9355	1226.6041	1294.0583	1363.3085
	Japan	371.7101	400.3929	430.1863	461.0902	493.1113

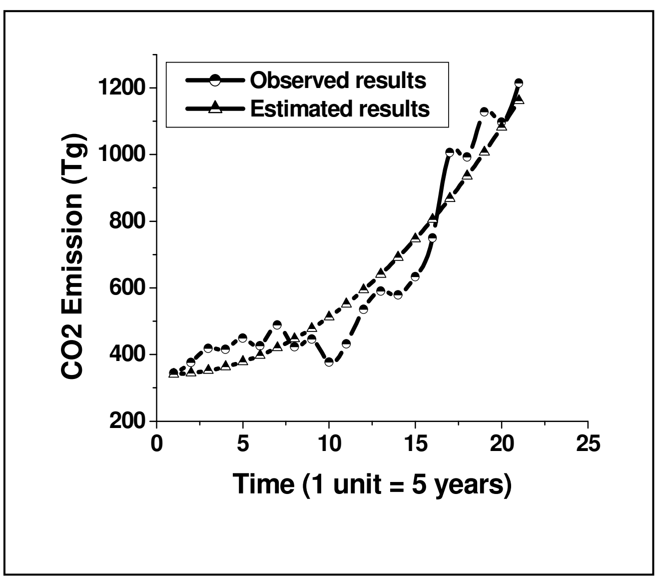

Figure 3a
CO_2 Emission in USA

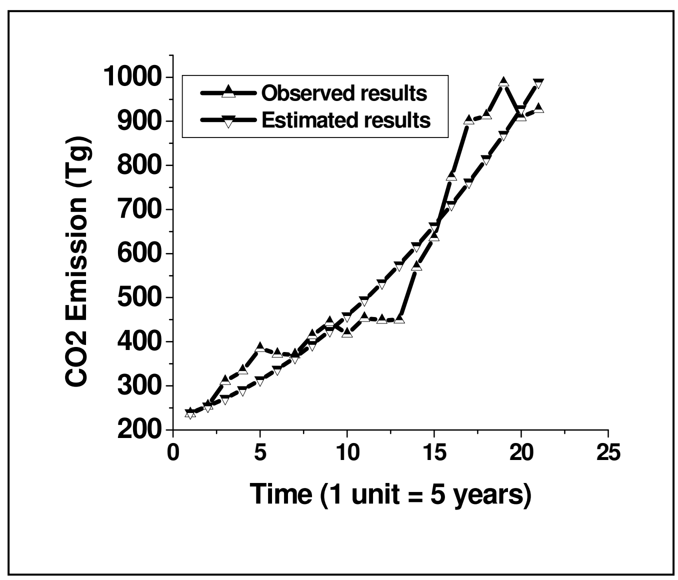

Figure 3b
CO_2 Emission in Europe

Figure 3a and 3b show the comparative study of the emission of CO_2 in USA and Europe and displayed that pattern of emissions dropped near the 1940 in both the cases. This may be due to the Second World War when a huge devastation occurred. The rapid growth of emission for the last fifty years may be due to rapid increase in the use of automobiles and enhancement of industrialization and urbanization in USA and European countries. For understanding the quality of the proposed analytical model, the statistical criteria such as R^2 (R^2 adjusted) are evaluated. The calculated values of R^2 (R^2 adjusted) are presented in table 4.

Table 4
Statistical Evaluation Criteria for CO_2 Emission

Country	R^2	R^2 adjusted
USA	0.9212	0.9073
Europe	0.8747	0.8525

The value of R^2 (R^2 adjusted) attest the fact that good models for both the cases have been identified.

IROC of CO_2 emission in USA and Europe: IROC of CO_2 emission in USA and Europe as a function of time are given analytically by

$$dY/dx\ (USA) = -17.6519642 - 0.1331634968\ .x + 7.54947159E\text{-}5\ .x^2 \quad (9a)$$

$$dY/dx\ (Europe) = -11.2152081 - 0.0758851776\ .\ x + 4.40789553E\text{-}5\ .x^2 \quad (9b)$$

A graphical display of expression 9a and 9b are given in figure 4a and 4b as follows

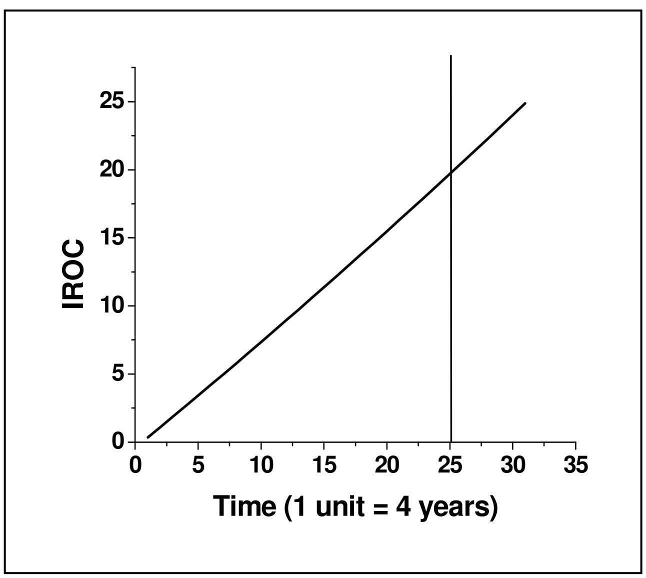

Figure-4a
IROC of USA

The rate of change of CO_2 emission in USA and Europe for short and long term of time can be obtained from the above displayed figure 4a and 4b respectively. Again future prediction for IROC and emission can be done from the above graphical display. Furthermore, residual analysis is performed on the proposed differentials and is presented in table-5. As seen from the table, the residuals and standard error are extremely small leading to identification of a good model.

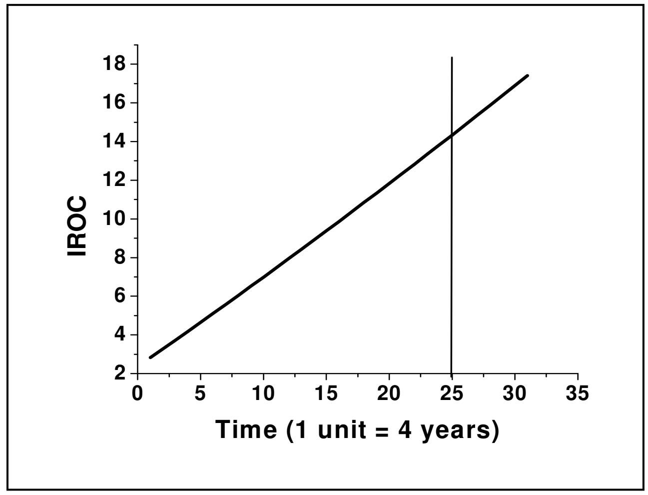

Figure-4b
IROC of Europe

Table-6 shows the future IROC and emission prediction for USA and European countries in the next twenty five years. It has been observed from the table that emission prediction of CO_2 are 2189.94 and 1731.57 Tg for USA and European countries respectively in the year 2040 if emission continues in the present rate.

Conclusion

In the present study, we have developed equations using non linear least square method that characterize the behavior of emission pattern of CO_2 for five major parts of the globe like India, China, Japan, USA and Europe utilizing the data set of about 100 years from 1890 to 1985. Sources of emission of CO_2 considered here are different attributes namely, fossil fuels, cement industry and gas flaring. In addition to the given analytical expression for emission in each case, we have utilized three different statistical procedures, namely R^2, R^2 adjusted and residual analysis to evaluate the quality of the proposed analytical methods. In all the cases, the statistical procedures attest the good quality of the proposed evolutionary systems. Finally, we have used these models to predict CO_2 emissions by deriving IROC for the next twenty five years in the respective countries /part of continent. This study may be the theoretical basis for the future researchers of CO_2 emission in different regions of globe and our model may be utilized for functional and efficient planning and strategic applications for the declining of appalling global warming in near future.

Table 5
Details of residual analysis for CO_2 emission

Year	USA			Europe		
	Empirical IROC	DF IROC	Residual	Empirical IROC	DF IROC	Residual
1890	0.0913	0.0106	0.0806	0.1482	0.0637	0.0105
1895	0.1134	0.0216	0.0919	0.2201	0.0688	0.1512
1900	-0.0064	0.0321	-0.0384	0.7661	0.0729	0.0037
1905	0.0799	0.0417	0.0382	0.1523	0.0758	0.0765
1910	-0.0509	0.0502	-0.1012	0.0333	0.0779	-0.1112
1915	0.1452	0.0577	0.0875	0.0047	0.0791	-0.0839
1920	-0.1327	0.0638	-0.1965	0.1179	0.0797	0.0382
1925	0.0531	0.0688	-0.0157	0.0723	0.0798	-0.0074
1930	-0.1538	0.0726	-0.2264	- 0.0597	0.0794	-0.1392
1935	0.1452	0.0755	0.0697	0.0861	0.0787	0.0073
1940	0.2388	0.0774	0.1614	-0.4513	0.0766	-0.5291
1945	0.1025	0.0786	0.0239	0.8055	0.0776	0.7288
1950	-0.0190	0.0792	-0.0981	0.2678	0.0754	0.1924
1955	0.0936	0.0792	0.0144	0.1151	0.0740	0.0411
1960	0.1841	0.0788	0.1053	0.2181	0.0725	01455
1965	0.3420	0.0782	0.2638	0.1644	0.0711	0.0934
1970	-0.0134	0.0772	-0.0906	0.0133	0.0696	-0.0562
1975	0.0135	0.0761	0.0596	0.0813	0.0685	0..0132
1980	-0.0269	0.0748	-0.1018	-0.0794	0.0665	-0.1460
1985	0.1067	0.0735	0.0332	0.0204	0.0651	-0.0447
Mean of Residual			0.0076	0.0183		
Standard deviation of Residual			0.1162	0.2200		
Standard error of Residual			0.0260	0.0492		

Table 6
IROC and prediction of CO_2 in future

Year		2020	2025	2030	2035	2040
IROC in future	USA	21.4064	22.2674	23.1323	24.0009	24.8733
	Europe	15.3565	15.8686	16.3828	16.8993	17.4180
Emission Prediction (Tg)	USA	1727.2422	1836.4239	1949.9299	2067.7602	2189.9404
	Europe	1403.8922	1481.9531	1562.5855	1645.7893	1731.5796

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