ISSN 1749-3889 (print), 1749-3897 (online)
International Journal of Nonlinear Science
Vol.18(2014) No.2,pp.104-109

The Dynamic Evolutionary Analysis of Carbon Emissions of the EU-27

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(Received 8 April 2014, accepted 5 October 2014)

Abstract: Based on the status quo of carbon emissions in the EU-27, this paper introduces control index and critical time of carbon emissions to find a new dynamic evolutionary model of carbon emissions of the States, deducing relative theories, such as Change Trends Theorem and Evolutionary Theorem. Least-square method is used to analyze the dynamic evolutionary system of carbon emissions in the four time intervals with data provided by the international energy agency(IEA). Based on the nonlinear dynamic evolutionary model, the paper predicts carbon emissions by means of control index and control function, which facilitates carbon policy regulation and the systems external influence, and creates unique dynamic evolutionary factors of carbon emissions corresponding with the real situation of the EU-27.

Keywords: carbon emissions; dynamic evolutionary system; dynamic evolutionary factor

1 Introduction

Climate change mitigation and prevention of global warming have become the consensus of the international community, and countries should bear much carbon emission reduction obligation, which become a hot debate. On January 8, 2014, energy, transport and climate change set up under the European commission jointly issued the report ”2050 trends in energy, transport and ”greenhouse gas emissions in the European Union”, which puts forward the forecast of carbon reduction of the EU,clean energy development and unconventional energy development: about long-term goals to reduce emissions, scientists and the European Union leaders agreed that the European Union should be based on the 1990 emissions reduced by 80% -95% to avoid catastrophic climate change and ensure that by 2050 the average global temperature levels than before the industrial revolution less than 2 degrees Celsius. On clean energy development, the report predicts that by 2050,natural gas wind energy, nuclear energy will each account for a quarter of Europe’s energy supply.

Now there are a lot of researches on carbon dioxide emissions in many countries.Lin S J et al. explored the interrelationships among economy, energy and CO2 emissions of 37 industrial sectors in Taiwan, which is insightful for sustainable development policy making [1]. Shuwen Niu et al. evaluated the causality between energy consumption, GDP growth and carbon emissions for eight Asia-Pacific countries from 1971 to 2005 by using the panel data. The researches aroused our attention to both the status quo and the potential problems of the CO2 emissions in China [2]. Youguo Zhang carried out a structural decomposition analysis (SDA) of production-related carbon emissions in China from 1992 to 2005 by adopting the Ghosh input-output model. The results suggest optimizing the supply-side structure and lowering the forward carbon multipliers to control carbon emissions in the future[3]. Chris P. Tsokos and Yong Xu forecast and analyze some carbon dioxide emissions and total carbon emissions of the United States by the dynamic evolutionary model with six variables[4]. L.X.Zhang,et al. use systematic accounting with a life cycle perspective to estimate both the direct CO2 emissions from fuel combustion and the indirect emissions from the production and provision of rural energy carriers. The results indicate that the total direct CO2 emissions resulting from rural energy consumption have nearly tripled,which provide substantial information for policy makers[5]. Shiwei Yu et al. propose a PSO-FCM-Shapley approach for carbon emission reduction target allocation and find provinces with large total emissions and high emission intensity are under more pressures than others. The results show fifteen provinces should exceed the national average decrease rates (30.8%) in coming 10 years[6]. Lin-Sea Lau et al. investigate the role of institution on the CO2 emission-growth nexus in Malaysia and find that an increase in carbon dioxide emission will increase economic growth and well-developed institution system

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IJNS.2014.10.15/827

would reduce the emission of carbon dioxide. The results show that to reduce CO2 emission, regulators must ensure the efficiency of institutions[7]. E.T.Lau,Q.Yang,A.B.Forbes,P.Wright and V.N.Livina model carbon emissions in electric systems and estimate emissions in generated and consumed energy with UK carbon factors, then model demand profiles with novel function based on hyperbolic tangents. Datasets of UK Elexon database, Brunel PV system and Irish Smart-Grid are studied and Ensemble Kalman Filter is applied to forecast energy data in these case studies[8]. Liwei Liu et al. used PSO-optimized combined model to predict the CO2 emission from thermal power in China and thought that CO2 emission intensity goal achievement by 2020 is a big challenge for China and reduction from coal-fired thermal power plays a key role in CO2 intensity reduction in China. The results show that thermal power generation of 2020 should be between 3801.45 and 4492.62 billion kW h for satisfying goals and Shanghai, Jiangsu, Zhejiang, Shandong and Fujian are key areas for reduction from thermal power[9]. Travis Roach estimates two models that account for the dynamic nature of emissions of carbon dioxide emissions at the state-level from 1980-2010 while taking account of scale, technique, and composition effects. The results show that there is an environmental Kuznets curve relationship with a feasible turning point for carbon dioxide emissions when stochastic trends are taken account of[10]. Ugur Soytas et al. investigate the Granger causality relationship between income, energy consumption, and carbon emissions, including labor and gross fixed capital formation in the model. They find that income does not cause carbon emissions in the US in the long run, but energy use does[11]. Wei Min Hao et al. examine how wildland fire information gathering has changed over the past decade and discuss Satellite and ground based systems for detecting and reporting fires. Then Knowledge gaps are identified including the potential for future improvements[12]. Lixin Tian et al. established the dynamic evolutionary system model of China's carbon emissions between 1980 and 2010, making evolutionary analysis and forecast for China's carbon emissions and scenario analysis of the four different circumstances[13]. All the above researches may provide theoretical and methodological support for this study.

2 The analysis of the model

With the data from international energy agency (IEA)[14],the carbon dioxide emissions(shortly called carbon emissions) from the consumption and burning of fossil fuels in the EU-27 during 1980-2011 can be obtained(Table1,Fig.1). Also the evolutionary control dynamic model of carbon emissions during this economic period come forward as follows:

$$\overset{\bullet}{E}(t) = rE(t)(1-\frac{E(t)}{cK})^{\alpha} + cf(t), T_0^* \le t \le T^* \tag{1}$$

where $E(t)$ represents carbon emissions in the time t; T^* is the critical time of carbon emissions during 1980-2013; r is carbon reduction coefficient; c is the evolutionary coefficient of carbon emissions, $c > 0$; α is the control index, $\alpha \ge 1$; $T^* = \{1980, 1990, 1999, 2002, 2011\}$,assuming$T_0^* = 1980$,$T_1^* = 1990$,$T_2^* = 1999$,$T_3^* = 2002$, $T_4^* = 2011$;thus,the range of I is $[T_0^*, T_1^*]$,$[T_1^*, T_2^*]$,$[T_2^*, T_3^*]$, $[T_3^*, T_4^*]$;
Control function $f(t)$ is

$$f(t) = \begin{cases} (-8.517279t^2 + 3.382152 \times 10^4 t - 3.357566 \times 10^7) - r(-2.839093t^3 + \\ 1.691076 \times 10^4 t^2 - 3.357566 \times 10^7 t + 2.222104 \times 10^{10})(1- \\ \frac{-2.839093t^3+1.691076\times10^4t^2-3.357566\times10^7t+2.222104\times10^{10}}{K})^{\alpha}, T_0^* \le t \le T_1^* \\ \\ (-6.876204t^2 + 2.743692 \times 10^4 t - 2.736914 \times 10^7) - r(-2.292068t^3 + \\ 1.371846 \times 10^4 t^2 - 2.736914 \times 10^7 t + 1.820101 \times 10^{10})(1- \\ \frac{-2.292068t^3+1.371846\times10^4t^2-2.736914\times10^7t+1.820101\times10^{10}}{K})^{\alpha}, T_1^* \le t \le T_2^* \\ \\ (-65.57364t^2 + 2.623262 \times 10^5 t - 2.623576 \times 10^8) - r(-21.85788t^3 + \\ 1.311631 \times 10^5 t^2 - 2.623576 \times 10^8 t + 1.749260 \times 10^{11})(1- \\ \frac{-21.85788t^3+1.311631\times10^5t^2-2.623576\times10^8t+1.749260\times10^{11}}{K})^{\alpha}, T_2^* \le t \le T_3^* \\ \\ (5.949024t^2 - 2.390032 \times 10^4 t + 2.400491 \times 10^7) - r(1.983008t^3 - \\ 1.195016 \times 10^4 t^2 + 2.400491 \times 10^7 t - 1.607322 \times 10^{10})(1- \\ \frac{1.983008t^3-1.195016\times10^4t^2+2.400491\times10^7t-1.607322\times10^{10}}{K})^{\alpha}, T_3^* \le t \le T_4^* \end{cases}$$

Table 1: Carbon Dioxide Emissions from the Consumption of Energy in EU-27,1980-2011(The unit is Million Metric Tons).

1980	1981	1982	1983	1984	1985	1986
4414.02306	4247.65732	4155.5128	4116.14619	4145.4937	4223.53681	4247.76792
1987	1988	1989	1990	1991	1992	1993
4294.52999	4237.82056	4277.89341	4177.7299	4097.87551	4061.52695	4033.06767
1994	1995	1996	1997	1998	1999	2000
3989.41832	4039.48113	4150.98362	4137.08013	4113.54193	4066.30781	4102.29396
2001	2002	2003	2004	2005	2006	2007
4169.83931	4137.79641	4260.09631	4292.97938	4284.62421	4297.67976	4257.65355
2008	2009	2010	2011			
4191.26404	3866.56662	3940.24239	3838.54976			

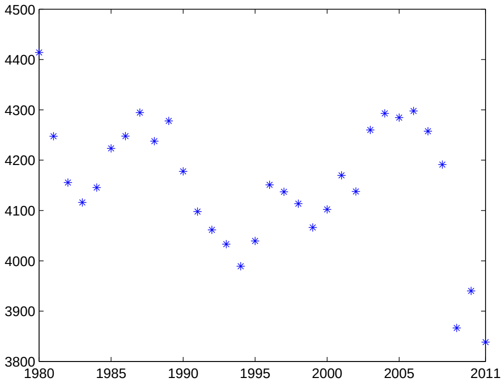

Figure 1: Carbon dioxide emissions from the consumption of energy in EU-27 (Million metric tons).

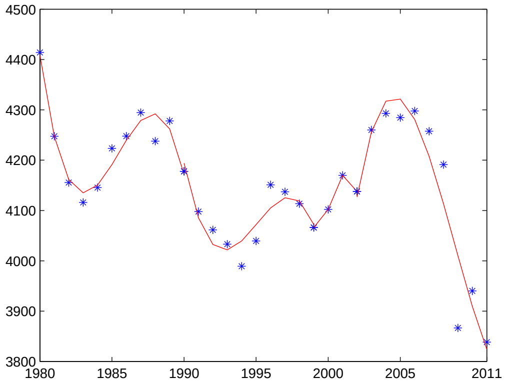

Figure 2: Carbon dioxide emissions from the model ($c = 1$)(Million metric tons).

The solution of Eq.(1) is

$$E(t) = \begin{cases} (-2.839093t^3 + 1.691076 \times 10^4 t^2 - 3.357566 \times 10^7 t + 2.222104 \times 10^{10}) \times c, T_0^* \le t \le T_1^* \\ (-2.292068t^3 + 1.371846 \times 10^4 t^2 - 2.736914 \times 10^7 t + 1.820101 \times 10^{10}) \times c, T_1^* \le t \le T_2^* \\ (-21.85788t^3 + 1.311631 \times 10^5 t^2 - 2.623576 \times 10^8 t + 1.749260 \times 10^{11}) \times c, T_2^* \le t \le T_3^* \\ (1.983008t^3 - 1.195016 \times 10^4 t^2 + 2.400491 \times 10^7 t - 1.607322 \times 10^{10}) \times c, T_3^* \le t \le T_4^* \end{cases} \tag{2}$$

The dynamic evolutionary factor of carbon emissions is as follows (Fig. 3):

$$F_E(t) = \frac{dE(t)}{dt} = \begin{cases} (-8.517279t^2 + 3.382152 \times 10^4 t - 3.357566 \times 10^7) \times c, T_0^* \le t \le T_1^* \\ (-6.876204t^2 + 2.743692 \times 10^4 t - 2.736914 \times 10^7) \times c, T_1^* \le t \le T_2^* \\ (-65.57364t^2 + 2.623262 \times 10^5 t - 2.623576 \times 10^8) \times c, T_2^* \le t \le T_3^* \\ (5.949024t^2 - 2.390032 \times 10^4 t + 2.400491 \times 10^7) \times c, T_3^* \le t \le T_4^* \end{cases} \tag{3}$$

The fig.3 shows that the dynamic evolutionary factor of carbon emissions $F_E(t)$ has a series of positive and negative irregular changes:

When $t \le 1982$,$F_E(t) < 0$,which is the dynamic evolutionary factor of carbon emissions, which shows that the rate of change over time of carbon emissions is negative in the EU-27 before 1982 years, namely, the carbon emissions are decreasing year by year;

When $1982 \le t \le 1988$,$F_E(t) > 0$,which is the dynamic evolutionary factor of carbon emissions, which shows that the carbon emissions are increasing year by year in this time interval in the EU-27;

When $1989 \le t < 1993$,$F_E(t) < 0$,which is the dynamic evolutionary factor of carbon emissions, which shows that the carbon emissions are decreasing year by year in this time interval in the EU-27;

When $1993 \le t \le 1997$,$F_E(t) > 0$,which is the dynamic evolutionary factor of carbon emissions, which shows that the

carbon emissions are increasing year by year in this time interval in the EU-27;
When $1997 < t < 1999$,P_E,which is the dynamic evolutionary factor of carbon emissions, which shows that the carbon emissions are decreasing year by year in this time interval in the EU-27;
When $1999 \leq t \leq 2004$,$F_E(t) > 0$,which is the dynamic evolutionary factor of carbon emissions, which shows that the carbon emissions are increasing year by year in this time interval in the United States;
When $2005 \leq t \leq 2011$,$F_E(t) < 0$,which is the dynamic evolutionary factor of carbon emissions, which shows that the carbon emissions are decreasing year by year in this time interval in the EU-27;
But the dynamic evolutionary factor of carbon emissions will be the trend, $F_E(t) > 0$, which shows that the carbon emissions of the EU-27 will also have a growth trend.

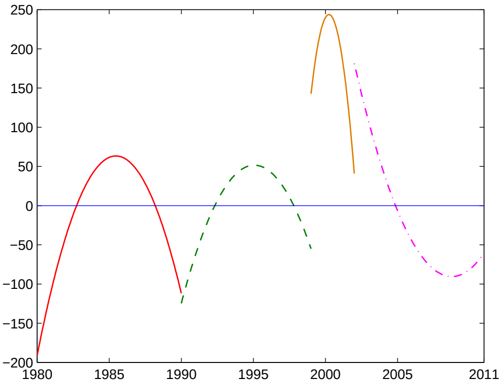

Figure 3: The dynamic evolutionary factor F_E of cumulative carbon emissions($c = 1$).

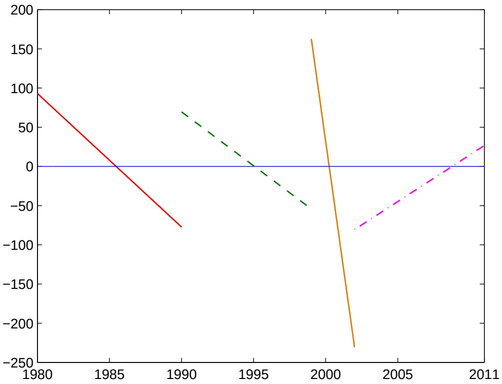

Figure 4: The dynamic evolutionary factor P_E of cumulative carbon emissions($c = 1$).

The dynamic evolutionary factor advance rateP_E of carbon emissions is as follows:

$$P_E = \overset{\bullet}{F_E}(t) = \begin{cases} (-17.034558t + 3.382152 \times 10^4) \times c, T_0^* \leq t \leq T_1^* \\ (-13.752408t + 2.743692 \times 10^4) \times c, T_1^* \leq t \leq T_2^* \\ (-131.14728t + 2.623262 \times 10^5) \times c, T_2^* \leq t \leq T_3^* \\ (11.898048t - 2.390032 \times 10^4) \times c, T_3^* \leq t \leq T_4^* \end{cases} \tag{4}$$

Some results are as following from Fig.4:
When $1980 \leq t \leq 1985$,$P_E > 0$, the dynamic evolutionary factor advance rate of carbon emissions is positive, the cumulative carbon emissions dynamic evolution factor$F_E(t)$changes from 1980 to 1985 increased gradually slow down;
When $1986 \leq t \leq 1990$,$P_E < 0$, the dynamic evolutionary factor advance rate of carbon emissions is negative, the cumulative carbon emissions dynamic evolution factor$F_E(t)$changes from 1986 to 1990 decreased faster and faster;
When $1990 < t \leq 1995$,$F_E(t)$, the dynamic evolutionary factor advance rate of carbon emissions is positive, the cumulative carbon emissions dynamic evolution factor$F_E(t)$changes from 1990 to 1995 increased gradually slow down;
When $1996 \leq t \leq 1999$,$P_E < 0$, the dynamic evolutionary factor advance rate of carbon emissions is negative, the cumulative carbon emissions dynamic evolution factor$F_E(t)$changes from 1996 to 1999 decreased faster and faster;
When $1999 < t \leq 2000$,$P_E > 0$, the dynamic evolutionary factor advance rate of carbon emissions is positive, the cumulative carbon emissions dynamic evolution factor$F_E(t)$ changes from 1999 to 2000 increased gradually slow down;
When $2001 \leq t \leq 2009$,$P_E < 0$, the dynamic evolutionary factor advance rate of carbon emissions is negative, the cumulative carbon emissions dynamic evolution factor$F_E(t)$changes from 2001 to 2009 decreased gradually slow down;
When $2009 < t \leq 2011$,$P_E > 0$, the dynamic evolutionary factor advance rate of carbon emissions is positive, the cumulative carbon emissions dynamic evolution factor$F_E(t)$ changes from 2009 to 2011 increased faster and faster;
Therefore carbon reduction strategy and policy must be regulated to suppress the rapid growth of the dynamic evolutionary factor of the cumulative carbon emissions, and makes the factor negative, and the evolutionary factor advance rate positive all the time, thus carbon emissions reduced speedily to implement reduction targets of carbon emissions(as Fig. 4).

3 Evaluation of the model

Table 2: Residual analysis of the Model

year	Empirical rate of change	The dynamic evolutionary factor of carbon emissions	Residual
1981	-0.037690274	-0.006158983	0.031531291
1982	-0.021693021	-0.002996791	0.01869623
1983	-0.009473346	-0.000514726	0.00895862
1984	0.007129851	0.001258084	-0.005871767
1985	0.018826011	0.002308978	-0.016517033
1986	0.005737161	0.002636988	-0.003100173
1987	0.011008622	0.002247671	-0.008760951
1988	-0.013205038	0.001147873	0.014352911
1989	0.009456004	-0.000659357	-0.010115361
1990	-0.023414214	-0.003179783	0.020234431
1991	-0.019114302	-0.003535998	0.015578304
1992	-0.008870099	-0.001396594	0.007473505
1993	-0.00700704	0.000226023	0.007233063
1994	-0.010822866	0.001319905	0.012142771
1995	0.0125489	0.001881085	-0.010667815
1996	0.027603171	0.001910839	-0.025692332
1997	-0.003349445	0.00141285	0.004762295
1998	-0.005689568	0.000390383	0.006079951
1999	-0.011482591	-0.001156462	0.010326129
2000	0.008849834	0.001266114	-0.00758372
2001	0.016465263	0.001462263	-0.015003
2002	-0.007684445	0.000839116	0.008523561
2003	0.029556771	0.005832133	-0.023724638
2004	0.007718856	0.003021866	-0.00469699
2005	-0.00194624	0.000725266	0.002671506
2006	0.00304707	-0.001080855	-0.004127925
2007	-0.009313446	-0.002408811	0.006904635
2008	-0.015592981	-0.003262695	0.012330286
2009	-0.077470046	-0.003640718	0.073829328
2010	0.019054571	-0.003537439	-0.02259201
2011	-0.025808724	-0.00294601	0.022862714
		The average residual	0.004065736
		Determination coefficient R^2	0.98457712

Table 2 shows that the residuals between the empirical rate of change and the dynamic evolutionary factor of carbon emission are very small. That means a good model has been identified.

Some results can be seen above from the analysis and research of the dynamic evolutionary factor and the evolutionary factor advance rate of carbon emissions as follows: the dynamic evolutionary factor and the evolutionary factor advance rate of carbon emissions of the EU-27 indicate the tendency of being positive and negative cross the each stage, which means that carbon emissions of the EU-27, though sometimes fall, but data shows a growth in 2012,and 2013.

4 Conclusions

Based on the present situation of carbon emissions, the evolutionary rules of carbon emissions are researched with the method of dynamic system in this paper. On the basis of concepts such as the dynamic evolutionary factors of carbon emissions, the evolutionary factor advance rate, the critical time, the evolutionary coefficient and the reduction coefficient, the paper introduces the concept of control index of carbon emissions, to research the dynamic system model of carbon emissions in the EU-27.

According to the research, the carbon emissions have obvious phases:

When $t < 1983$, we have$F_E(t) > 0$, which is the dynamic evolutionary factor of carbon emissions, and$P_E > 0$, which is the evolutionary factor advance rate, so the carbon emissions were decreasing year by year fast;
when $1982 \leq t < 1985$,we have$F_E(t) > 0$ and $P_E > 0$, the carbon emissions were increasing year by year fast;
when $1986 \leq t < 1988$,we have$F_E(t) > 0$ and $P_E < 0$, the carbon emissions were slightly increasing year by year;
when $1986 \leq t < 1988$,we have $F_E(t) > 0$ and $P_E < 0$, the carbon emissions were slightly increasing year by year;
when $1988 \leq t < 1990$,we have $F_E(t) < 0$ and $P_E < 0$, the carbon emissions were slightly decreasing;
when $1990 \leq t < 1992$,we have $F_E(t) < 0$ and $P_E > 0$, the carbon emissions were decreasing year by year fast;
when $1992 \leq t < 1995$,we have $F_E(t) > 0$ and $P_E > 0$, the carbon emissions were increasing year by year fast;
when $1995 \leq t \leq 1998$,we have $F_E(t) > 0$ and $P_E < 0$, the carbon emissions were slightly increasing year by year;
when $1999 \leq t < 2000$,we have $F_E(t) > 0$ and $P_E > 0$, the carbon emissions were increasing year by year fast;
when $2000 \leq t \leq 2005$,we have $F_E(t) > 0$ and $P_E < 0$, the carbon emissions were slightly increasing year by year;
when $2005 < t < 2008$,we have $F_E(t) < 0$ and $P_E < 0$, the carbon emissions were slightly decreasing year by year;
when $2009 \leq t \leq 2011$,we have $F_E(t) < 0$ and $P_E > 0$, the carbon emissions were decreasing year by year fast.
But then the evolutionary factor will be a trend of $F_E(t) > 0$ and $P_E > 0$. Our purpose is to make the dynamic evolutionary factor and the evolutionary factor advance rate in the state of $F_E(t) < 0$ and $P_E > 0$ through policy regulation and various measures. It is difficult to realize that the dynamic evolutionary factor is negative, namely, $F_E(t) < 0$, so we can only make the dynamic evolutionary factor decrease as far as possible to achieve emission reduction targets.

Acknowledgments

The research is supported by the National Natural Science Foundation of China (No:51276081,11171135), Major Program of the National Social Science Foundation of China (No: 12&ZD062).

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