Second International Association for Energy Economics (IAEE) Asian Conference: Energy Security and Economic Development under Environmental Constraints in the Asia-Pacific Region

Environmental Impact of China: Analysis Based on the STIRPAT Model

Shoufu Lin[a,b], Dingtao Zhao[a], Dora Marinova[b]

[a] *School of Management, University of Science and Technology of China, Hefei City, 230026, Anhui Province, China*

[b] *Curtin University Sustainability Policy (CUSP) Institute, Curtin University of Technology, Perth, GPO BOX U1987, WA 6845, Australia*

Abstract

Assuming that energy consumption is the main source of emissions in China, this article considers the influence on the environment of the exhaust emissions produced in the process of consuming energy as China's environmental impact. It then analyzes the influence of population, urbanization level, GDP per capita, industrialization level and energy intensity on the environmental impact using the STIRPAT model with data from 1978 to 2006. The analysis shows that population had the largest influence on the environmental impact, followed by urbanization level, industrialization level, GDP per capita and energy intensity. Hence China's Family Planning Policy, which restrains rapid population growth, has been a very effective way of reducing the country's environmental impact. However due to the difference in growth rates, GDP per capita had a higher effect on environmental impact, contributing 38% of its increase (while population's contribution was at 32%). Finally, the rapid decrease in energy intensity (through optimizing industrial and energy structures, increasing the proportion of clean energy sources and improving energy efficiency) was the main cause of restraining the increase in China's environmental impact.

JEL classification: Q43, Q56

Key words: Energy consumption, GDP, Population, Ridge regression

1. Introduction

After the reformation and opening of China in the late 1970s, its economy set up on a long-term high-speed growth. It attracted global attention and was called a “growth miracle” (Lin et al., 1996; Wu, 2004). However, it also started to consume larger energy resources and negatively impact on the country’s natural environment. Presently, China is facing severe energy resource shortage (Kong, 2005) and environmental deterioration, including water and air pollution, soil erosion, land degradation, deforestation, destruction of grasslands and salinization (Harris, 2006). China joined the rest of the world in contributing significantly to the fast increasing greenhouse gas (GHG) emission concentration levels widely perceived as the consequence of human activities (IPCC, 2007).

The relationship between economic growth and the state of the natural environment has been a subject of serious economic enquiry in the past including modeling through environmental Kuznets curves (EKC). These curves show an inverted U-shaped relationship between levels of income and use of natural resources and/or emission of waste (Stern, 2004). They essentially claim that with development a country’s ecology is expected to deteriorate until a critical average income is attained, after which the use of natural resources and waste generation decline with the improved levels of income. The EKC is considered analogous to a similar pattern presented by Kuznets in the mid-1950s to describe economic inequality.

The EKC concept has also been applied to China (see for example Hayward, 2005) but suggestions have been made that exogenous factors, such as institutions and public demand may have a more significant impact on environmental performance than mere income levels. In addition, many claim that the EKC is unlikely to be an adequate model when it comes to pollution, including GHG concentrations and emissions (Stern, 2005; Copeland and Taylor, 2004). For example, besides economic growth other anthropogenic factors (often called “driving forces”) are also influencing energy consumption, causing pollution and having further negative environmental impacts. These include population, economic activity, technology, political and economic institutions as well as attitudes and beliefs (Stern, Young and Druckman, 1992). These forces are usually assumed to drive not just GHG emissions but also all anthropogenic environmental change.

In order to comprehend and provide solutions to the complicated environmental question, it is useful to understand the influence of such anthropogenic factors on the environment and select appropriate policy responses. The STIRPAT model, a statistical model for assessing environmental impacts (for further information please refer to http://www.stirpat.org/), is a good approach to analyzing the influences of individual anthropogenic factors. It has been used successfully in estimating the impacts of anthropogenic factors on GHG and other contaminating emissions. For example, Dietz and Rosa (1997) estimated the effects of population, affluence and technology on CO_2 emissions. Fan et al. (2006) used the STIRPAT model to analyze the impact of population, affluence and technology on the total CO_2 emissions of countries at different income levels over the 1975-2000 period. The list of further studies using the STIRPAT model includes: Rosa and York (2002), York, Rosa and Dietz (2003b), Shi (2003), Aurelia and Inmaculada (2006) and Inmaculada (2008).

The STIRPAT model has also been applied to analyze environmental impact in China. For example, Wang and He (2006) looked at energy consumption as the environmental impact and estimated the effect of population, affluence and energy intensity (energy use per unit GDP) while Long et al. (2006) described environmental impact as the water footprint, and used the STIRPAT model to analyze the impact of population, GDP per capita, crop transpiration demand per area and land demand per food yield in China.

The overall conclusion from the STIRPAT Research Program is that “(w)ith few exceptions… we find that national impacts increase with affluence, providing little support for the ‘environmental Kuznets curve’ hypothesis” while “(t)he program has helped to clearly specify the anthropogenic factors that drive environmental change and point to testable hypotheses” (Rosa, York and Dietz, 2004: 2). None of these studies however examined the impact of other significant transformations currently occurring in the Chinese economy, namely the constantly increasing levels of urbanization and changes in the contribution of industry to the generation of the country’s wealth. In view of this, the current paper employs the STIRPAT model to analyze the influences on the environment of population and its structure, industrialization level, affluence and technology.

As human activities influence the environment not only through emitting GHG, but also through other pollutants, such as carbon (C), Sulphur oxides (SO_X), Nitrogen oxides (NO_X), particulate and volatile organic compounds and so on, it is not enough to describe the environmental impact of just GHG emissions. However, statistical data on these pollutants is not always available in China. As energy consumption is the main cause of emissions in the country, it also gives an indication of the cumulative environmental impact of all these pollutants. The STIRPAT model is then further expanded to include two more variables – urbanization level and industrialization level, in order to analyze their influence on the environment. Urbanization level is represented by the proportion of people living in urban areas; industrialization by the share of industrial value added in the country's GDP, affluence by GDP per capita, and technology by energy intensity. The data for these variables are obtained from *China County Statistical Yearbook* of 1979 to 2007.

The remainder of the paper is structured as follows. Section 2 offers a brief introduction to the STIRPAT model used; Section 3 explains the data and analyzes the variables; Section 4 presents the estimation results and provides a comparative analysis, and Section 5 gives some concluding remarks.

2. Methodology

Ehrlich and Holdren (1971, 1972) were the first to use IPAT to describe how the growing population impacts on the environment. They proposed the form of an equation, known as I=PAT, combining environmental impact (I) with population size (P), affluence (A, per capita consumption or production) and the level of environmental damage caused by technology per unit of consumption or production (T). Throughout the years there have been multiple uses, variations and transformations of this model (see for example, Dietz and Rosa, 1994). More recent examples include ImPACT (Waggoner and Ausubel, 2002), ImPACTS (Xu, Cheng and Qiu, 2005) and IPBAT (Schulze, 2002). Waggoner and Ausubel's (2002) ImPACT model argued that environmental impact is influenced by population (P), income as GDP per capita (A), intensity of use as a consumer good(s), for example energy, per GDP (C), and efficiency ratios as environmental impact per consumer good (T). Hence in the ImPACT model, the T from IPAT is decomposed into C and T. Xu, Cheng and Qiu (2005) pointed out that social development and society's capability to decrease environmental impact were often ignored in the process of its evaluation. Consequently they developed the ImPACTS identity where S stands for social development and m for management. Despite the attempt of the ImPACTS identity to provide a link between the environment and society, social development has proven hard to quantify. Similarly, Schulze (2002) argued that human behavior is also a key driving force of environmental impact, and expanded IPAT to IPBAT, where human behavior is represented by B.

The series of I=PAT, I=PBAT, I=PACT and I=mPACTS models only allow to estimate the proportionate impact of environmental change by changing one factor and simultaneously holding constant the others. To overcome this serious limitation, Dietz and Rosa (1994) reformulated IPAT into a stochastic model, named STIRPAT (Stochastic Impacts by Regression on Population, Affluence and Technology), which can analyze the non-proportionate impact of variables on the environment. The standard STIRPAT model is:

$$I_i = aP_i^b A_i^c T_i^d e_i \qquad (1)$$

The multiplicative logic of the equation I=PAT is still kept in this model. Population (P), affluence (A) and technology (T) are regarded as the determinants of environmental impact (I). After taking logarithms, the model becomes:

$$\ln I_{it} = a + b(\ln P_{it}) + c(\ln A_{it}) + d(\ln T_{it}) + \ln e_i \qquad (2)$$

where the subscript i denotes the observational units; t the year; b, c, and d are respectively the coefficients of P, A, and T; e is the error term, and a is the constant.

York, Rosa and Dietz (2003a) indicated that sociological or other control factors could be added into Equation (2), as long as these additional factors are conceptually consistent with the multiplicative specification of the model. Hence this article revises Equation (2) by adding urbanization level (UL) and industrialization level (IL) to the set of factors, resulting in Equation (3).

$$\ln I_{it} = a + b_1(\ln P_{it}) + b_2(\ln UL_{it}) + c_1(\ln A_{it}) + c_2(\ln IL_{it}) + d(\ln T_{it}) + \ln e_i \qquad (3)$$

Furthermore, York, Rosa and Dietz (2003b) introduced the concept of elasticity coefficients. For example, in Equation (2) b is the population elasticity coefficient of environmental impact that refers to the responsiveness of an environmental impact to a change in population size. Similarly, c is the affluence elasticity coefficient of environmental impact that refers to the responsiveness of an environmental impact to a change in affluence; and d is the technology elasticity coefficient of environmental impact that refers to the responsiveness of an environmental impact to a change in technology. Through the elasticity coefficients, we can analyze the influence of the change of each driving force on the change of environmental impact. Moreover, the elasticity coefficient is not always 1, and this is the most significant difference between STIRPAT and the IPAT (or IPBAT, ImPACT, ImPACTS) models (which assume the elasticity coefficient as 1).

3. Data

The original intention of this article was to consider the influence of pollutant emissions as the environmental impact. However, as there is no reliable statistical data about pollutant emissions in China, the only way around this problem is to use indirect measures. As the rapid increase in energy consumption is the main reason behind China's fast environment deterioration, the main pollutant emissions and their impact on the environment can be estimated through energy consumption. When coal, oil and gas are used to produce 1MJ energy, they emit respectively: coal (c) – 23.9g C, 1.07g SO_X, 0.41g NO_X, 0.31g particulate and 0.0021g volatile organic compounds; oil (o) – 19.70g C, 0.73g SO_X, 0.16g NO_X, 0.34g particulate and 0.0039g volatile organic compounds; and gas (g) – 14.10g C, 0.00g SO_X, 0.06g NO_X, 0.0013g particulate and 0.0039g volatile organic compounds (Spash, 2002). Hydro-, nuclear and wind power (h) in general do not produce these pollutants (Spash, 2002). Hence the weights of the influences of C, SO_X, NO_X, particulate and volatile organic compounds are 0.6, 0.1, 0.1 and 0.1 (Wang and He, 2006). Supposed that the influence of pollutants emitted by coal for releasing 1MJ energy is 1, the influence coefficient vector B_i of pollutants emitted by the various energy sources is as follows (Wang and He, 2006):

$$B_i = 0.6\times\begin{bmatrix}\frac{23.9}{23.9}\\ \frac{19.7}{23.9}\\ \frac{14.1}{23.9}\\ \frac{0}{23.9}\end{bmatrix} + 0.1\times\begin{bmatrix}\frac{1.07}{1.07}\\ \frac{0.73}{1.07}\\ \frac{0}{1.07}\\ \frac{0}{1.07}\end{bmatrix} + 0.1\times\begin{bmatrix}\frac{0.41}{0.41}\\ \frac{0.16}{0.41}\\ \frac{0.06}{0.41}\\ \frac{0}{0.41}\end{bmatrix} + 0.1\times\begin{bmatrix}\frac{0.31}{0.31}\\ \frac{0.34}{0.31}\\ \frac{0.0013}{0.31}\\ \frac{0}{0.31}\end{bmatrix} + 0.1\times\begin{bmatrix}\frac{0.0021}{0.0021}\\ \frac{0.0039}{0.0021}\\ \frac{0.0039}{0.0021}\\ \frac{0}{0.0021}\end{bmatrix}$$

$$= \begin{bmatrix}1\\ 0.79\\ 0.55\\ 0\end{bmatrix}\begin{array}{c}\text{Coal}\\ \text{Oil}\\ \text{Gas}\\ \text{Hydro-, nuclear and wind power}\end{array}$$

The impact coefficient of total energy consumption B is:

$$B = W_i B_i = \left[W_c, W_o, W_g, W_h\right]\begin{bmatrix}B_c\\ B_o\\ B_g\\ B_h\end{bmatrix} = W_c B_c + W_o B_o + W_g B_g + W_h B_h$$

where W_i is the energy consumption structure.

The impact on the environment of the pollutants produced in the process of consuming energy resources is I=B×E, where I is the environmental impact and E is the total energy consumption.

China’s energy consumption structure from 1978 to 2006 is presented in Figure 1 and Figure 2 gives the impact coefficient of total energy consumption (B) for the same period. Due to optimization in the energy structure, namely relative decrease in coal consumption and increase of other clean energy sources, the impact coefficient of total energy consumption B declined by about 3.60% (about 0.032 units), which restrained the increase in its negative environmental impact. Although the change in B is relatively small, the resulting decline in I would have been very significant because of the large increase in China's energy consumption (Figure 3 shows a steep increase in energy use, particularly since 2002; the average annual growth rate of energy use was 12.86%). This implies that the change in human behavior expressed by the selection of a different energy mix (represented by B), is very important for the environmental impact. This explains why Schulze (2002) added human behavior into the model and in this particular case the environmental impact is described by I and not just with E. In other words, the impact on the environment of energy consumption can be reduced by decreasing the share of coal and increasing the share of clean energy resources. As the share of coal consumption is currently very high, there is a lot of room for improvement.

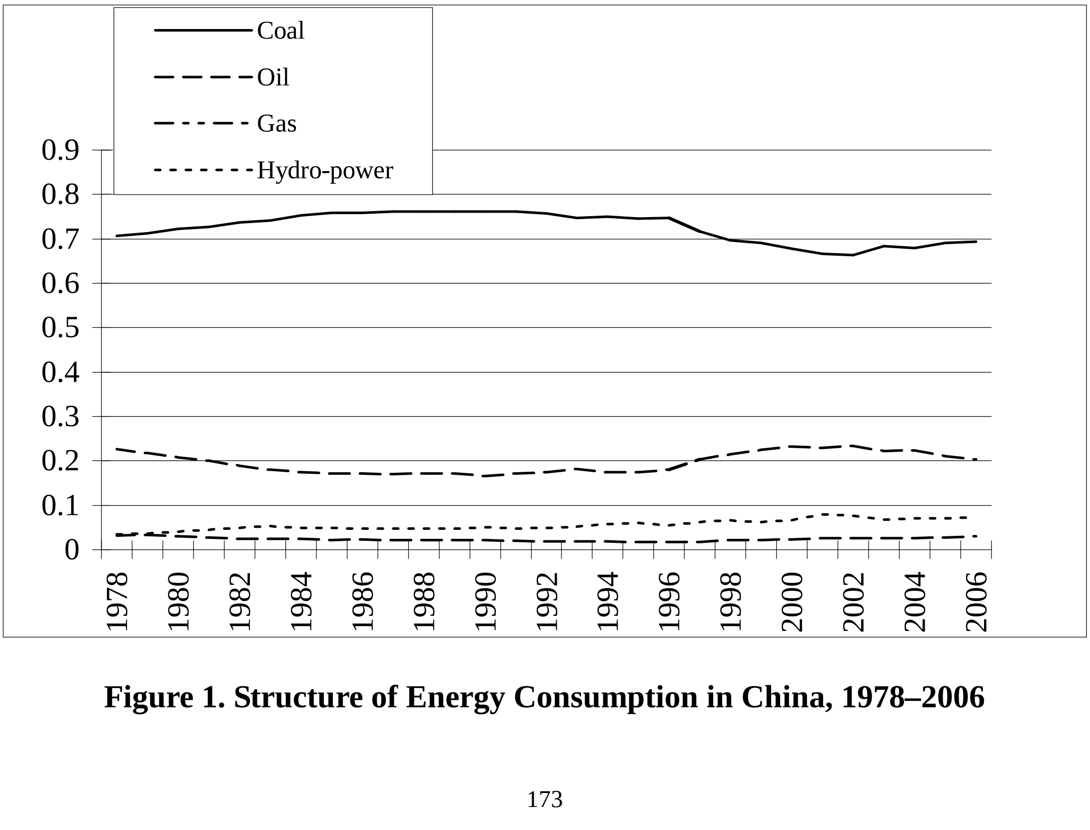

Figure 1. Structure of Energy Consumption in China, 1978–2006

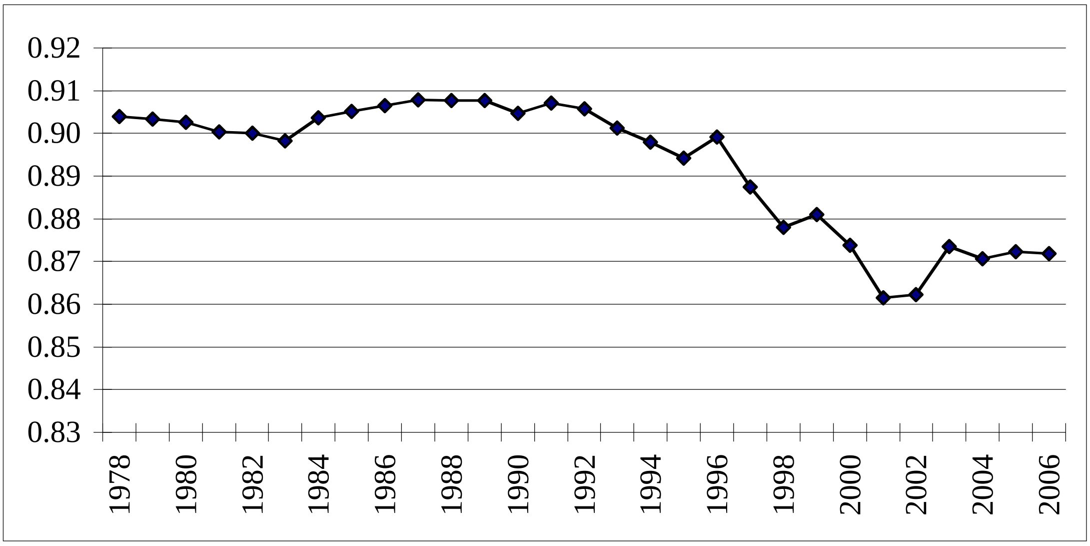

Figure 2. Impact Coefficient of Energy Consumption on the Environment (B) for China, 1978–2006

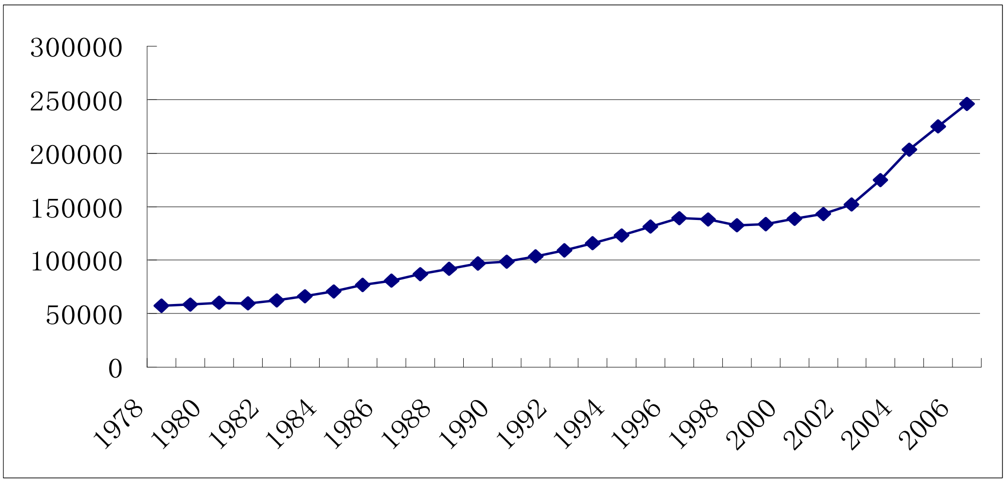

Figure 3. China's Energy Consumption ('0,000 tons of coal equivalent, tce), 1978–2006

Figures 3 and 4 show that both energy consumption and environmental impact increased rapidly on an upward trend with an average annual growth rate of 5.36% and 5.22% respectively, growing by 331% and 316% from 1978 to 2006. By comparison, Figure 5 shows that China's population changed slowly, increasing by around 37% from 1978 to 2006 and by 1.12% per annum. China's GDP per capita (see Figure 6) however increased very rapidly on a steady upward trend by 877% from 1978 to 2006 and by 8.48% per annum. During the same period, the country's energy intensity declined remarkably (see Figure 7) by 68% overall and by 3.96% per annum. The last few years (since 2002) however present a worrying trend as energy intensity has started to increase.

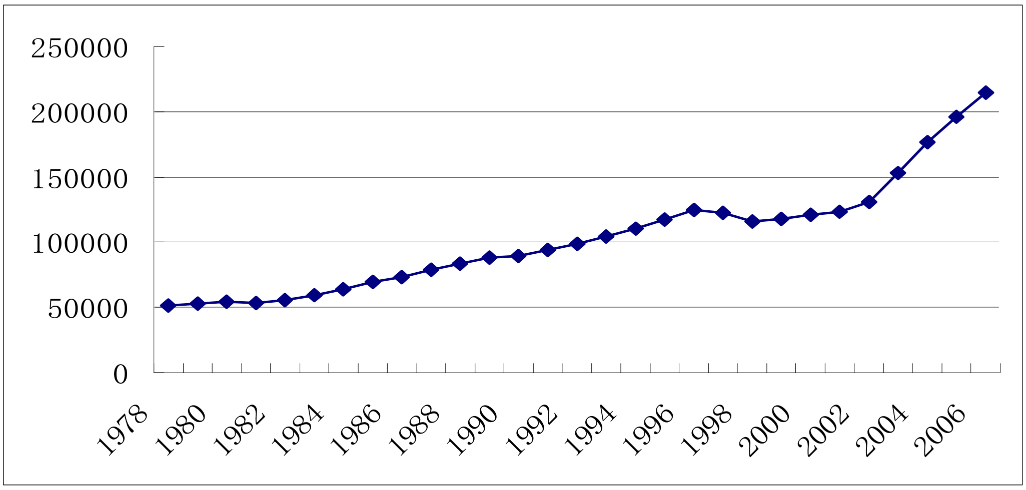

Figure 4. Environmental Impact (I＝B×E;'0,000 tce) of China, 1978–2006

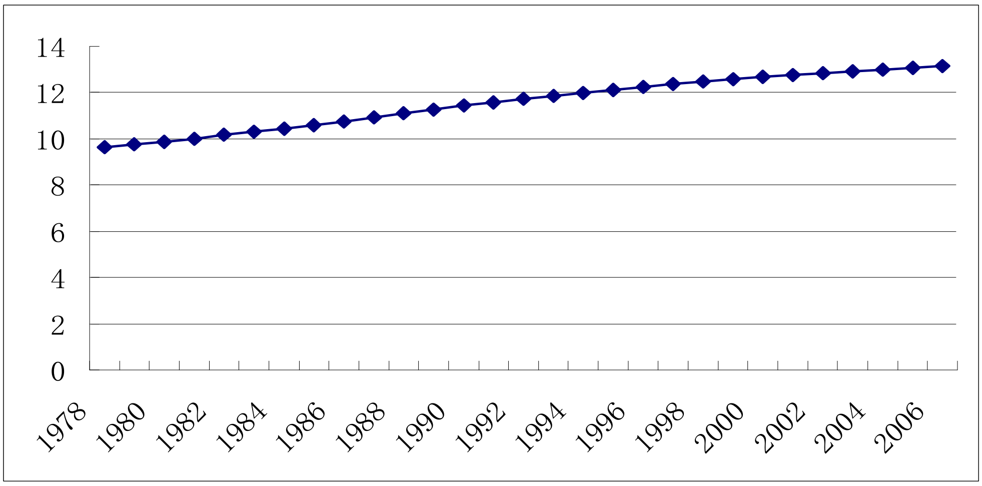

Figure 5. China's Population ('00,000,000), 1978–2006

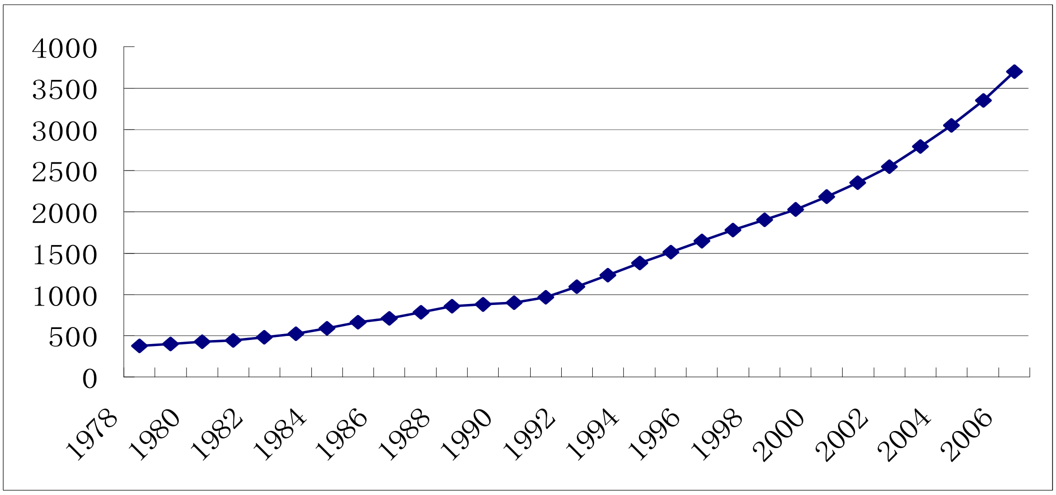

Figure 6. GDP per Capita (Yuan RMB, 1978 prices), China, 1978–2006

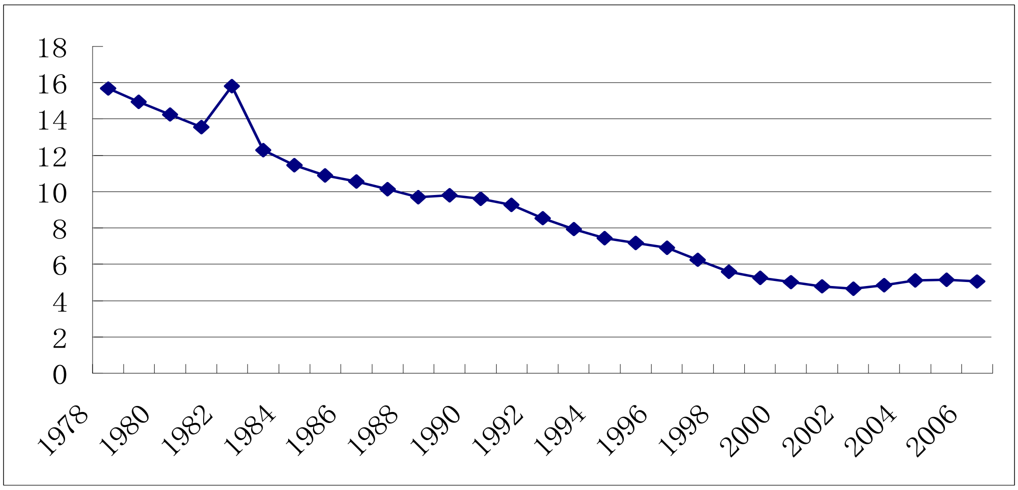

Figure 7. Energy Intensity (tce/10,000 Yuan), China, 1978–2006

In recent years China has experienced unprecedented levels of urbanization and industrialization. The size and the share of urban population grew extremely fast (see Figures 8 and 9) with an annual growth of 4.41% and 17.92% respectively. The proportion of urban population reached 44% in 2006. The industrial value added also grew by 9.26% per annum between 1978 and 2006 (see Figure 10). However, its share of GDP (i.e. industrialization level) has changed only slightly (see Figure 11) and it is just below 45% in 2006 (with an upward trend since 2002). Nevertheless, the share of tertiary industry increased to 39.40% in 2006 from 23.95% in 1978 (see Figure 12).

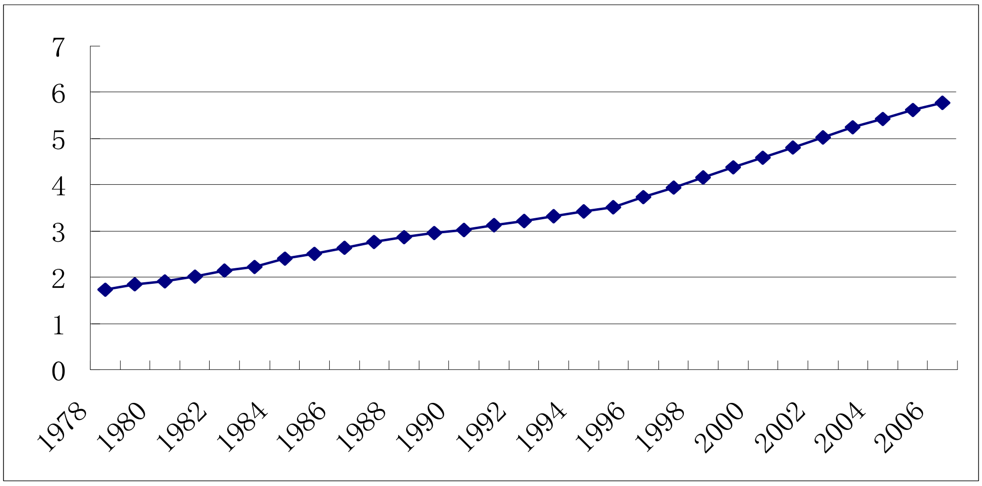

Figure 8. China's Urban Population ('00,000,000), 1978–2006

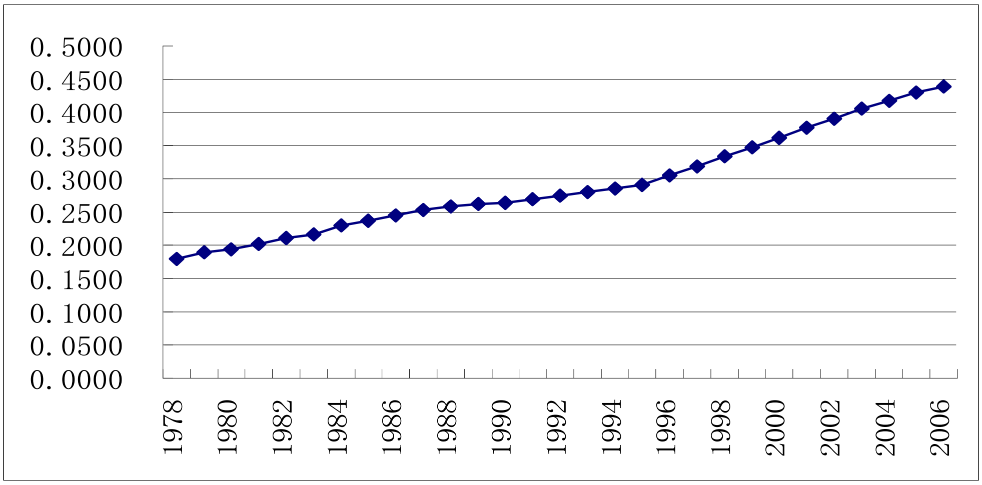

Figure 9.　China's Urbanization Level, 1978–2006

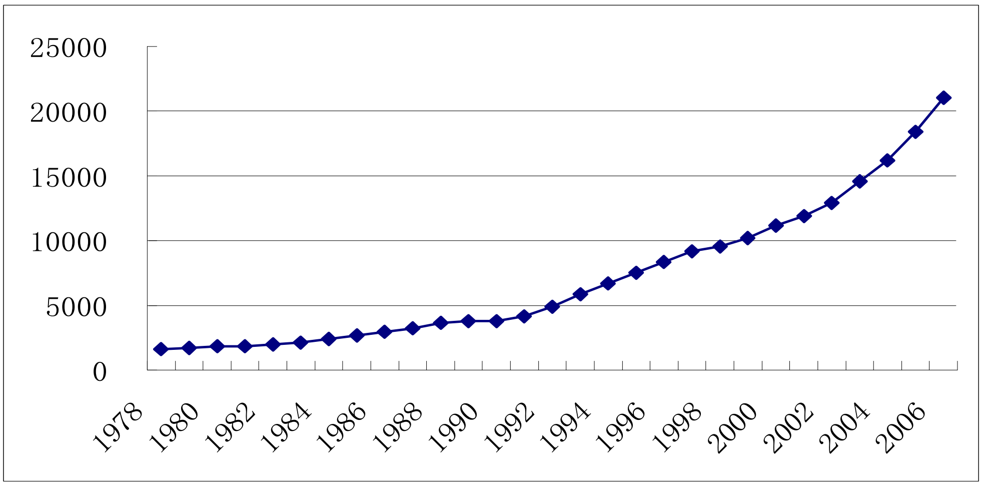

Figure 10. China's Industrial Value Added, 1978–2006

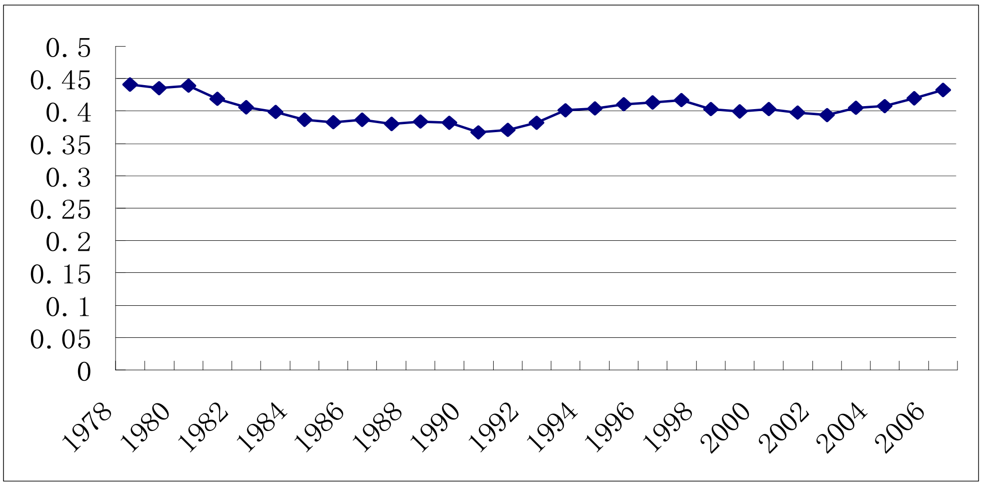

Figure 11. China’s Industrialization Level, 1978–2006

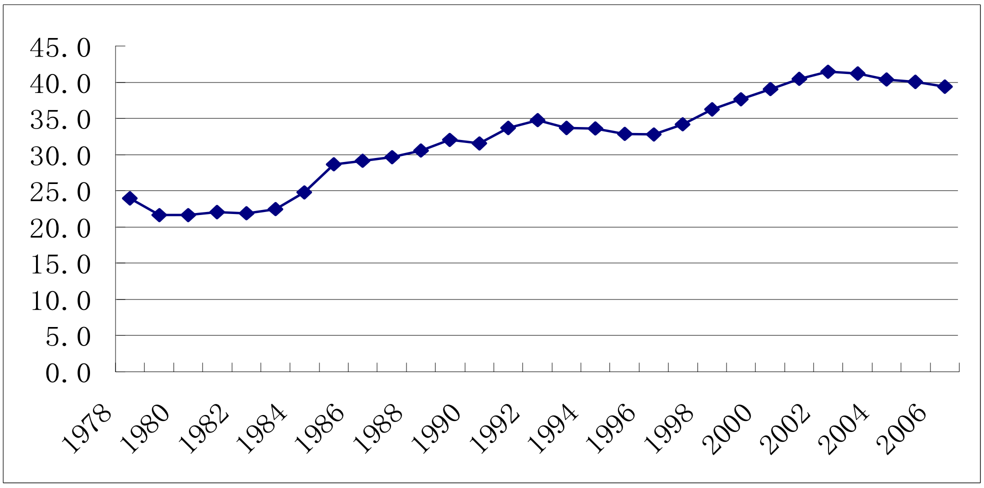

Figure 12. Share of Tertiary Industrial Value Added in China’s GDP, 1978–2006

With the sharp increases in industrial value added and urban population, energy consumption also rapidly increased. Between 1980 and 2006, energy consumption in industry grew by 5.95% per annum which is higher than the average annual growth rate of total energy consumption (5.56%). Industrialization and urbanization have had significant environmental influence and this is the main reason for analyzing their impact on the environment in this article.

Table 1 presents the growth rates for all variables between 1978 and 2006 and shows that GDP per capita had the fastest growth, followed by environmental impact, urbanization level and population. Energy intensity decreased very quickly, while industrialization level only slightly decreased. The analysis of these statistical data shows that the change in environmental impact is coincident with the changes in all variables except energy intensity and industrialization level. The growth of GDP per capita outpaces that of environmental impact, while the growth of the other variables is slower. What is the influence of these factors on the environmental impact? What is their contribution more specifically to the increase in environmental impact? These questions are analyzed using the STIRPAT model.

Table 1 Growth Rates of Variables, 1978-2006

Variables	**Total Growth Rate (%)**	**Average Annual Growth Rate (%)**
Environmental Impact	315.66%	5.22%
Population	36.56%	1.12%
Urbanization Level	144.98%	3.25%
GDP per capita	876.87%	8.48%
Industrialization Level	-1.78%	-0.06%
Energy Intensity	-67.69%	-3.96%

4. Empirical Analysis and Results

In the STIRPAT model, environmental impact is the dependent variable, while population, urbanization level, GDP per capita, industrialization level and energy intensity are independent variables. They are organized in the following Equation (4):

$$\ln I_{it} = a + b_1(\ln P_{it}) + b_2(\ln UL_{it}) + c_1(\ln A_{it}) + c_2(\ln IL_{it}) + d(\ln T_{it}) + \ln e_i \qquad (4)$$

The correlation test results for these variables are shown in Table 2. There are very high correlations between all variables with the exception of industrialization level. Hence multicollinearity is likely to be present. The OLS (Ordinary Least Square) regression estimate of the STIRPAT model (shown in Table 3) gives a VIF (Variance Inflation Factor) for population, urbanization level, GDP per capita and energy intensity much higher than 10. Therefore, there is serious multicollinearity between these variables. Hence, the STIRPAT model estimated by OLS regression cannot reflect the real relationships among the variables. To obtain the correct parameter estimation, this multicollinearity needs to be eliminated. However if certain highly correlated variables are deleted from the model, this will result in information loss and will affect the reliability of the estimation.

Table 2 Correlations of STIRPAT Variables

	Environmental Impact	Population	Urbanization Level	GDP per capita	Industrialization Level	Energy Intensity
Environmental Impact	1					
Population	.974(**)	1				
Urbanization Level	.971(**)	.981(**)	1			
GDP per capita	.983(**)	.992(**)	.992(**)	1		
Industrialization Level	.011	-.068	-.048	.008	1	
Energy Intensity	-.936(**)	-.982(**)	-.974(**)	-.982(**)	.038	1

** Correlation is significant at the 0.01 level (2-tailed).

Table 3 OLS Regression Results for the SIRPAT Model

	Coefficients		t	Sig.	Collinearity Statistics	
	B	Std. Error			Tolerance	VIF
Constant	-2.683	1.638	-1.638	.115		
Population	-.134	.097	-1.380	.181	.004	250.315
Urbanization Level	-1.122	.357	-3.140	.005	.006	179.977
GDP per capita	1.667	.264	6.307	.000	.001	714.554
Industrialization Level	-.867	.294	-2.948	.007	.236	4.240
Energy Intensity	.832	.095	8.744	.000	.032	31.053

Ridge regression is considered to be a better method to overcome multicollinearity (Hoerl, 1962; Björkström, 2001) as it does not require the deletion of variables and will not cause information to be lost. It requires a proper selection of an appropriate ridge regression coefficient K. As it is a biased estimation, K should be chosen as small as possible and simultaneously have small variance inflation factors (VIFs) and steady-going regression coefficients. The ridge regression coefficient K was calculated with a step length of 0.01 changing within [0, 1]. When K is 0.05, the coefficients of variables are steady going and the VIFs of variables are sufficiently small. This value of K (i.e. 0.05) is used to estimate the STIRPAT model. The results, calculated with SPSS 11.5 Software, are shown in Table 4.

Table 4 Ridge Regression Results (K=0.05)

	Coefficients		t	Sig.
	B	Std. Error		
Constant	6.9207	0.7722	8.9621	0.0000
Population	1.5068	0.2360	6.3854	0.0000
Urbanization Level	0.4783	0.0941	5.0812	0.0000
GDP per capita	0.2314	0.0170	13.6123	0.0000
Industrialization Level	0.4404	0.2916	1.5102	0.0723
Energy Intensity	0.1142	0.0675	1.6921	0.0521
Error term	0. 0787			
R^2	0.9688			
Adjust R^2	0. 9620			
F-statistic	142.9960			
Prob(F-statistic)	.0000			

The results in Table 4 show that the variables’ regression coefficients are significant at the 10% level, and population, urbanization level, GDP per capita, industrialization level and energy intensity have a remarkably positive relation with environmental impact. The calculated contributions of the various variables to the change in environmental impact from 1978 to 2006 are presented in Table 5.

Table 5 Contributions of Variables to the Change of Environmental Impact, 1978–2006

	Average Annual Growth Rate (%)	Regression Coefficient	Effect on the change of Environmental Impact (%)	Contribution degree to the change of Environmental Impact (%)
Environmental Impact	5.22			
Population	1.12	1.5068	1.69	32.30
Urbanization Level	3.25	0.4783	1.56	29.79
GDP per capita	8.48	0.2314	1.96	37.60
Industrialization Level	-0.06	0.4404	-0.03	-0.54
Energy Intensity	-3.96	0.1142	-0.45	-8.65
Other factors (a)		6.9207	0.50	9.50

Note: Effect on the change of Environmental Impact = Average Annual Growth Rate ×Regression Coefficient; Contribution degree to the change of Environmental Impact = Effect on the change of Environmental Impact ÷ Average Annual Growth Rate of Environmental Impact.

Tables 4 and 5 show that population has the highest regression coefficient of 1.51, followed by urbanization level, industrialization level, GDP per capita and energy intensity. Namely, the environmental impact increases 1.50% when population increases 1.00%. From 1978 to 2006, the population grew 1.12% per annum, so it contributed to a 1.69% increase of the environmental impact and had a contribution degree of 32.30%. The urbanization level's regression coefficient is 0.48 which is around one third of that of population. However, due to its high average annual growth (3.25%), it also had a strong effect on environmental impact and made it increse 1.56% per annum with a contribution degree of 29.79% in the 1978-2006 period. The regression coefficient of GDP per capita is small at 0.23, but as GDP per capita grew fast with an average annual rate of 8.48% (the highest), it had the biggest effect on environmental impact. Between 1978 and 2006, it made the environmental impact increase 1.96% with a contribution degree of 37.60%. Urbanization level has the third highest regression coefficient of 0.44, but as it changed only a little, its effect on environmental impact was small with a contribution degree of -0.54%. Energy intensity has the lowest regression coefficient of 0.11, but it decreased very rapidly with an average annual growth rate of -3.96%; hence its effect on environmental impact decreased by 0.45% and its contribution degree was -8.65%. In addition, other factors which are not explicit in the model made the environmental impact increase 0.50% and had the contribution degree of 9.50%.

The analysis above shows that the main driving forces of environmental impact are GDP per capita, population and urbanization level. They made the environmental impact increase by 5.21%. On the other hand, energy intensity and industrialization level restrained the increase of the environmental impact making it decrease by 0.48%.

5. Conclusions

The STIRPAT analysis using the a model which includes population, urbanization level, industrialization level, GDP per capita and energy intensity as driving forces, reveals the following findings about China’s development during the 1978–2006 period:

(1) Although it had a smaller degree of contribution than GDP per capita, population is the most important factor influencing China’s environmental impact. This conforms to the gist of the findings from the STIRPAT program where “population size has emerged as a persistent, major factor influencing the scale of national environmental impacts of all varieties” (Rosa, York and Dietz, 2004: 2).

Inevitably, the population of China will continue to contribute significantly to increasing the country’s environmental impact, as it is large in size, with a relatively young composition and cannot be reduced in the short term. The Family Planning Policy, known as One Child Policy, put in place by Deng Xiaoping in 1979 has consistently restrained rapid population growth. It is estimated that it had reduced population growth by as much as 300 million during its first twenty years (geography.about.com/od/populationgeography/a/onechild.htm). In this way it has also contributed towards reducing the influence of population on China’s environmental impact. Despite this positive outcome, the One Child Policy has been a draconian measure that has distorted sex ratios at birth and created a range of social problems.

It is clear that without these measures in place, the impact of population on the environment would have been even greater but the question is whether there are other ways of controlling population size. China's total fertility rate is already low at 1.7 (UN Statistical Office, 2008) and growth is driven mainly by what demographers describe as population momentum – the fact that the country's population has a relatively young structure and a large number of people are entering child bearing age. Controlling fertility levels is also creating a time bomb where the relatively small young section of the population will need to carry the burden of looking after the country's ageing people as well as after its deteriorating ecological environment (Guo and Marinova, 1999). Solutions need to be found elsewhere and policy makers will need to focus their attention on some of the other driving forces behind environmental impact.

(2) GDP per capita has a very small influence coefficient, but due to its rapid growth it largely drove the increase of China's environmental impact which resulted in its highest degree of contribution.

At present the most important and primary task for China is to achieve economic and social development including elimination of poverty. It is highly likely that in the future China will continue to invest in order to stimulate economic growth and that the Chinese economy will remain fast growing with raising energy consumption. This would increase pollutants and exhaust emissions and inevitably result in negative impacts on the environment.

In order to overturn this bleak scenario, the country will need to change its economic growth patterns with more consideration given to the environment. Despite the fact that our model shows GDP per capita as the main contributing force to environmental impact, it is the current type of GPD. An adjusted investment structure focused away from industries of high-energy consumptions, emissions and pollution can still contribute to an increased level of wealth without destroying the natural environment.

(3) China's urbanization level and industrialization level are two important factors driving the environmental impact increase.

The country is going through a fast urbanization and industrialization process. The population residing in urban areas is expecting to continue to increase steadily and the urban dwellers' ability and level of consumption will also increase. Industry will continue to grow generating more energy demand. Under this scenario, it is very important to reduce wastage in energy consumption and control luxury consumption which are major issues in China. Promoting efficiency in industrial energy utilization is also extremely important in order to arrest the increase in environmental impact.

(4) The rapid decline in energy intensity was the main factor restraining the increase of environmental impact.

Energy intensity in China decreased very rapidly from 1978 to 2006. However, compared to that of developed countries, China's energy intensity is still very high and has a large potential for reduction, particularly in view of the fact that since 2002 it has been on the rise. Optimization and adjustment of industrial structures as well as improvement in the energy utilization efficiency are effective measures to reduce energy intensity. Recent research shows that technological choices are the dominant contributor to the decline in energy intensity in China (Ma and Stern, 2006). Optimizing energy structure, decreasing the share of coal in energy consumption, and increasing the proportion of other energy sources, such as gas, hydro-, solar and wind, can reduce the GHG emissions produced in the process of consuming energy and finally reduce the environmental impact.

In summary, China is expected to continue its fast economic growth in the future, speeding up the rate of industrialization and urbanization and driving energy demand even further. These developments would cause the fast increase of energy consumption and pollution, further portraying China as the main culprit for the high emissions of greenhouse gases and environmental impact. This would make China face the stern challenges to balance environmental deterioration with economic and social development. The analysis of the 1978–2006 period of development clearly shows that the business as usual scenario is no longer an option as all factors driving environmental impact are likely to continue to rise. The only way this bleak situation can be improved is with significant changes in human behavior.

6. Acknowledgement

Work on this paper was supported by a grant from the National Natural Science Foundation of China (No: 70821001). The authors benefited from the discussions with Reiner Kummel and Geoff Glazier during the 2nd International Association for Energy Economics (IAEE) Asian Conference and are grateful for their suggestions.

They also want to acknowledge the help of two anonymous referees with useful and constructive comments. The third author is appreciative of the financial support from the Australian Research Council.

References:

Aurelia, B.M., Inmaculada, M.Z. (2006). The Impact of Population on CO_2 Emissions: Evidence from European Countries. FEEM Working Paper No. 98.06.

Björkström, A. (2001). Ridge Regression and Inverse Problems. Stockholm: Stockholm University, www2.math.su.se/matstat/reports/seriea/2000/rep5/report.pdf (26.08. 2008).

Copeland, B. R., Taylor, M. S. (2004). “Trade, Growth and the Environment”. Journal of Economic Literature 42: 7–71.

Dietz, T., Rosa E.A. (1994). “Rethinking the Environmental Impacts of Population, Affluence and Technology.” Human Ecology Review 1: 277-300.

Dietz, T., Rosa, E.A. (1997). “Effects of Population and Affluence on CO2 Emissions.” Proceedings of the National Academy of Sciences of the United States of America 94: 175-179.

Ehrlich P.R., Holdren J.P. (1971). “Impact of Population Growth.” Science 171: 1212-1217.

Ehrlich P.R., Holdren J.P. (1972). “One-dimensional Economy.” Bulletin of the Atomic Scientists 28(5): 16-27.

Fan, Y., Liu, L.C., Wu, G., Wei, Y.M. (2006). “Analyzing Impact Factors of CO2

Emissions using the STIRPAT Model.” Environmental Impact Assessment Review 26: 377– 395.

Guo, M.X, Marinova, D. (1999). “Population and Sustainability: Is There Hope for Coastal China?” Journal of Policy Studies 7: 31-48.

Harris, P.G. (2008). “Environmental Perspectives and Behavior in China: Synopsis and Bibliography.” Environment and Behavior 38(1): 5-21.

Harwood, S. (2005). “The China Syndrome and the Environmental Kuznets Curve”. American Enterprise Institute, http://www.aei.org/publications/pubID.23617/pub_detail.asp (27.12.2008).

Hoerl, A.E. (1962). “Application of Ridge Analysis to Regression Problems.” Chemical Engineering Progress 58, 54-59.

Inmaculada, M.Z. (2008). The Impact of Urbanization on CO_2 Emissions: Evidence from Developing Countries. FEEM Working Paper No. 50.2008.

Intergovernmental Panel for Climate Change (IPCC) (2007). Summary for Policymakers, in Climate Change 2007: The Physical Science Basis, Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge: Cambridge University Press, http://ipcc-wg1.ucar.edu/wg1/Report/AR4WG1_Print_SPM.pdf (17.07. 2008).

Kong, B. (2005). An Anatomy of China’s Energy Insecurity and Its Strategies. Oak Ridge, TN: Pacific Northwest National Laboratory, US Department of Energy.

Lin, J.Y., Cai, F. & Li, Z. (1996). The China Miracle: Development Strategy and Economic Reform. Hong Kong: Chinese University Press.

Long, A.H., Xu, Z.M., Wang, X.H., Shang, H.Y. (2006). “Impacts of Population, Affluence and Technology on Water Footprint in China.” Acta Ecologica Sinica 10: 3358-3365. (In Chinese)

Ma, C, Stern, D. (2006). China’s Changing Energy Intensity Trend: A Decomposition Analysis. Working Papers in Economics, Rensselaer Polytechnic Institute, http://www.economics.rpi.edu/workingpapers/rpi0615.pdf (31.12.2008).

Rosa, E.A., York, R. (2002). Internal and External Sources of Environmental impacts: A Comparative Analysis of the EU with Other Nation Groupings. National Europe Centre Paper No. 22. Presented to conference on The European Union in International Affairs, National Europe Centre, Australian National University, 3-4 July, 2002.

Rosa EA, York R, Dietz T. (2004). “Reflections on the STIRPAT Research Program”. Newsletter of the Section on Environment and Technology of the American Sociological Association, Summer: 1-2.

Schulze, P.C. (2002). “I=PBAT.” Ecological Economics 40(2): 149-150.

Shi, A. (2003). “The Impact of Population Pressure on Global Carbon Dioxide Emissions, 1975–1996: Evidence from Pooled Cross-Country Data.” Ecological Economics 44(1): 29-42.

Spash, C.L. (2002). Greenhouse Economics: Value and Ethics. London: Rutledge.

Stern, D.I. (2004). “The Rise and Fall of the Environmental Kuznets Curve”. World Development 32(8): 1419-1439.

Stern, P.C., Young, O.R., Druckman, D. (1992). Global Environmental Change:

Understanding the Human Dimensions. Washington, DC: National Academy Press.

United Nations (UN) Statistical Office (2008). Demographic Yearbook 2006. 58th ed. New York: Department of Economic and Social Affairs.

Waggoner P.E., Ausubel J.H. (2002). “A Framework for Sustainability Science: A Renovated IPAT Identity.” Proceedings of the National Academy of Sciences of the United States of America 99(12): 7860–7865.

Wang, L.M., He, K.L. (2006). “Analysis of Temporal Variation of Environmental Impact Based on STIRPAT Model – A Case Study of Energy Consumption in China.” Journal of Natural Resources 6: 862-869. (In Chinese)

Wu, Y. (2004). China’s Economic Growth: A Miracle with Chinese Characteristics. London and New York: Routledge Curzon.

Xu Z.M., Cheng G.D., Qiu G.Z. (2005). “ImPACTS Identity of Sustainability Assessment.” Acta Geographica Sinica 60(2): 198-218. (In Chinese)

York R., Rosa E.A., Dietz T. (2003a). “Footprints on the Earth: The Environmental Consequences of Modernity.” American Sociological Review 68(2): 279-300.

York, R., Rosa, E.A., Dietz T. (2003b). “STIRPAT, IPAT and ImPACT: Analytic Tools for Unpacking the Driving Forces of Environmental Impacts.” Ecological Economics 46: 351-365.