1 Growth and alkaline phosphatase activity of *Chattonella marina* and *Heterosigma akashiwo* in response to phosphorus limitation
Zhao-Hui Wang and Yu Liang

8 Distribution characteristics and indicator significance of Dechloranes in multi-matrices at Ny-Ålesund in the Arctic
Guangshui Na, Wei Wei, Shiyao Zhou, Hui Gao, Xindong Ma, Lina Qiu, Linke Ge, Chenguang Bao and Zwei Yao

14 Pretreatment of cyanided tailings by catalytic ozonation with Mn$^{2+}$/O$_3$
Yulong Li, Dengxin Li, Jiebing Li, Jin wang, Asif Hussain, Hao Ji and Yijie Zhai

22 Effects of different sludge disintegration methods on sludge moisture distribution and dewatering performance
Lingyun Jin, Guangming Zhang and Xiang Zheng

29 Removal of tetracycline from aqueous solution by a Fe$_3$O$_4$ incorporated PAN electrospun nanofiber mat
Qing Liu, Yuming Zheng, Lubin Zhong and Xiaoxia Cheng

37 Feasibility of bioleaching combined with Fenton oxidation to improve sewage sludge dewaterability
Changgeng Liu, Panyue Zhang, Chenghua Zeng, Guangming Zeng, Guoyin Xu and Yi Huang

43 Mg$^{2+}$ improves biomass production from soybean wastewater using purple non-sulfur bacteria
Pan Wu, Guangming Zhang and Jianzheng Li

47 Influence of zeta potential on the flocculation of cyanobacteria cells using chitosan modified soil
Liang Li, Honggang Zhang and Gang Pan

54 Effects of two polybrominated diphenyl ethers (BDE-47, BDE-209) on the swimming behavior, population growth and reproduction of the rotifer *Brachionus plicatilis*
Jingjing Sha, You Wang, Jianxia Lv, Hong Wang, Hongmei Chen, Leilei Qi and Xuexi Tang

64 Immmobilization of lead in anthropogenic contaminated soils using phosphates with/without oxalic acid
Xiaojuan Su, Jun Zhu, Qingling Fu, Jichao Zuo, Yonghong Liu and Hongqing Hu

74 Predicted no-effect concentrations for mercury species and ecological risk assessment for mercury pollution in aquatic environment
Meng Du, Dongbin Wei, Zhuowei Tan, Aiwu Lin and Yugo Du

81 Investigation of physico-chemical properties and microbial community during poultry manure co-composting process
Omar Farah Nadia, Loo Yu Xiang, Lee Yei Lie, Dzulkornain Chairil Anuar, Mohammed P. Mohd Afandi and Samsu Azhari Baharuddin

95 Cu(II), Fe(III) and Mn(II) combinations as environmental stress factors have distinguishing effects on *Enterococcus hirae*
Zaruhi Vardanyan and Armen Trchounian

101 Evaluation of biostimulation and Tween 80 addition for the bioremediation of long-term DDT-contaminated soil
Bibiana Betancur-Corredor, Nancy J. Pino, Santiago Cardona and Gustavo A. Peñuela

110 Hg$^0$ removal from flue gas over different zeolites modified by FeCl$_3$
Hao Qi, Wenqing Xu, Jian Wang, Li Tong and Tingyu Zhu

118 Preparation and evaluation of aminopropyl-functionalized manganese-loaded SBA-15 for copper removal from aqueous solution
Di Lei, Qianwen Zheng, Yili Wang and Hongjie Wang
<table>
<thead>
<tr>
<th>Page</th>
<th>Title</th>
<th>Authors</th>
</tr>
</thead>
<tbody>
<tr>
<td>128</td>
<td>Investigation of carbonyl compound sources at a rural site in the Yangtze River Delta region of China</td>
<td>Ming Wang, Wentai Chen, Min Shao, Shhua Lu, Limin Zeng and Min Hu</td>
</tr>
<tr>
<td>137</td>
<td>Low-carbon transition of iron and steel industry in China: Carbon intensity, economic growth and policy intervention</td>
<td>Bing Yu, Xiao Li, Yuanbo Qiao and Lei Shi</td>
</tr>
<tr>
<td>148</td>
<td>Synergistic effect of N- and F-codoping on the structure and photocatalytic performance of TiO₂</td>
<td>Jiemei Yu, Zongming Liu, Hailong Zhang, Taizhong Huang, Jitian Han, Yihe Zhang and Daohuang Chong</td>
</tr>
<tr>
<td>157</td>
<td>Pollution levels and characteristics of phthalate esters in indoor air of offices</td>
<td>Min Song, Chenchen Chi, Min Guo, Xueqing Wang, Lingxiao Cheng and Xueyou Shen</td>
</tr>
<tr>
<td>163</td>
<td>Characteristics and anthropogenic sources of carbonyl sulfide in Beijing</td>
<td>Ye Cheng, Chenglong Zhang, Yuanyuan Zhang, Hongxing Zhang, Xu Sun and Yujing Mu</td>
</tr>
<tr>
<td>171</td>
<td>Oxidation of diesel soot on binary oxide CuCr(Co)-based monoliths</td>
<td>Sergiy O. Soloviev, Andriy Y. Kapran and Yaroslava P. Kurylets</td>
</tr>
<tr>
<td>178</td>
<td>Effects of introducing energy recovery processes to the municipal solid waste management system in Ulaanbaatar, Mongolia</td>
<td>Kosuke Toshiki, Pham Quy Giang, Kevin Roy B. Serrona, Takahiro Sekikawa, Jeoung-soo Yu, Baasandash Choijil and Shoichi Kunikane</td>
</tr>
<tr>
<td>187</td>
<td>Toluene decomposition performance and NOₓ by-product formation during a DBD-catalyst process</td>
<td>Yufang Guo, Xiaobin Liao, Mingli Fu, Haibao Huang and Daiqi Ye</td>
</tr>
<tr>
<td>195</td>
<td>Changes in nitrogen budget and potential risk to the environment over 20 years (1990-2010) in the agroecosystems of the Haihe Basin, China</td>
<td>Mengmeng Zheng, Hua Zheng, Yingxia Wu, Yi Xiao, Yihua Du, Weihua Xu, Fei Lu, Xiaoke Wang and Zhiyun Ouyang</td>
</tr>
</tbody>
</table>
Low-carbon transition of iron and steel industry in China: Carbon intensity, economic growth and policy intervention

Bing Yu1,**, Xiao Li1,**, Yuanbo Qiao2, Lei Shi1,⁎

1. State Key Joint Laboratory of Environment Simulation and Pollution Control, School of Environment, Tsinghua University, Beijing 100084, China
2. School of Economics and Management, Tsinghua University, Beijing 100084, China

ARTICLE INFO

Article history:
Received 7 March 2014
Revised 14 April 2014
Accepted 22 April 2014
Available online 16 December 2014

Keywords:
CO₂ emission reduction
Iron and steel industry
Economic growth
China
Vector autoregression (VAR)

ABSTRACT

As the biggest iron and steel producer in the world and one of the highest CO₂ emission sectors, China’s iron and steel industry is undergoing a low-carbon transition accompanied by remarkable technological progress and investment adjustment, in response to the macroeconomic climate and policy intervention. Many drivers of the CO₂ emissions of the iron and steel industry have been explored, but the relationships between CO₂ abatement, investment and technological expenditure, and their connections with the economic growth and governmental policies in China, have not been conjointly and empirically examined. We proposed a concise conceptual model and an econometric model to investigate this crucial question. The results of regression, Granger causality test and impulse response analysis indicated that technological expenditure can significantly reduce CO₂ emissions, and that investment expansion showed a negative impact on CO₂ emission reduction. It was also argued with empirical evidence that a good economic situation favored CO₂ abatement in China’s iron and steel industry, while achieving CO₂ emission reduction in this industrial sector did not necessarily threaten economic growth. This shed light on the dispute over balancing emission cutting and economic growth. Regarding the policy aspects, the year 2000 was found to be an important turning point for policy evolution and the development of the iron and steel industry in China. The subsequent command and control policies had a significant, positive effect on CO₂ abatement.

© 2014 The Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences. Published by Elsevier B.V.
China’s iron and steel industry is undergoing a low-carbon transition accompanied by remarkable technological progress and investment adjustment, in response to the macroeconomic climate and policy intervention (Fujii et al., 2010; Hu et al., 2009; Kim and Worrell, 2002; Milford et al., 2013). This economic-environment interconnection shapes the profound transformation of the iron and steel industry. A variety of studies have addressed the drivers of CO₂ emissions in the iron and steel industry, as shown in Table 1, but the relationships between CO₂ abatement, investment and technological expenditure, and their connections with the economic growth and policy intervention in China, have not been conjointly and empirically examined. The most prominent part of the existing studies adopted index decomposition analysis (IDA) to explore the direct factors influencing the CO₂ emissions of the industry, including activity level, product structure, energy efficiency, fuel share, energy consumption and emission factor. They clearly calculated the contribution from each of these straight-forward factors, but they were weak in analyzing the underlying macroeconomic factors and policy influence. There were also a couple of studies that were able to accommodate a number of miscellaneous drivers with larger-size bottom-up models or integrated bottom-up/top-down models. They were good at analyzing the technology aspect from the bottom level and their possible influence on future CO₂ emissions with usually exogenous scenario settings on economic and policy dimensions. However, only limited implications can be drawn on the crucial bidirectional interactions between CO₂ emissions and the economic aspects. A few other studies also emphasized or briefly mentioned the importance of taking into account these interactions, especially for China (Milford et al., 2013), but did not provide answers.

To fill the knowledge gap, our study targets the key questions concerning the relationships between CO₂ abatement, investment and technological expenditure of the iron and steel industry, and

![Figure 1](image_url) - Output of iron and steel industry and economic growth in China from 1990 to 2010 (CISA, 1991–2011; EBCSY, 1991–2011; NBSC, 2013).

| Table 1 – Literature survey on drivers of CO₂ emissions of the iron and steel industry. |
|-------------------------------------------------|-------------------------------|-----------------|-----------------|
| Method                                          | Driver                        | Country or region | Literature       |
| Index decomposition analysis (IDA)              | Activity level                | Brazil, China, India, Mexico, South Korea, USA | Kim and Worrell (2002), Sheinbaum et al. (2010), Ozawa et al. (2002), Sun et al. (2011), Sun et al. (2012) |
| Product structure                               | Brazil, China, India, Mexico, South Korea, USA | Kim and Worrell (2002), Sheinbaum et al. (2010), Ozawa et al. (2002) |
| Energy efficiency                               | Brazil, China, Mexico, South Korea, USA | Kim and Worrell (2002), Sheinbaum et al. (2010), Ozawa et al. (2002) |
| Fuel share                                      | Brazil, China, Mexico, South Korea, USA | Kim and Worrell (2002), Sheinbaum et al. (2010), Ozawa et al. (2002) |
| Energy consumption                              | China                         | Sun et al. (2011), Sun et al. (2012) |
| Emission factor                                 | China                         | Sun et al. (2011), Sun et al. (2012) |
| Technological progress                          | Germany, China, Europe        | Pardo and Moya (2013), Lutz et al. (2005), Wang et al. (2007), Schumacher and Sands (2007) |
| Climate change policy models (bottom-up models, integrated bottom-up/top-down models) | Scale and direction of investment | Germany | Lutz et al. (2005) |
| Carbon tax, carbon price                        | Germany                        | Gielen and Moriguchi (2002a), Lutz et al. (2005), Schumacher and Sands (2007) |
| Trade barrier                                   | Japan                          | Gielen and Moriguchi (2002b) |
| Policy                                          | China                          | Wang et al. (2007) |
| Economic growth                                 | India                          | Das and Kandpal (1998) |
| Dynamic programming model                       | Scale and direction of investment | China, the world | Pauliuk et al. (2011), Milford et al. (2013) |
| Material flow analysis                          | Policy                         | China | Rock et al. (2013), Lv and Yang (2011) |
their connections with economic growth and policy intervention in China. In detail, we aim to answer the following three questions:

(1) What are the relationships among CO2 emission reduction, investment, and technological expenditure in the iron and steel industry?

(2) How does economic growth influence CO2 abatement, investment, and technological expenditure in the iron and steel industry? Conversely, how do CO2 abatement, investment and technology expenditure in the iron and steel industry affect the national economy?

(3) How have the policies affected CO2 emission reduction in China’s iron and steel industry? Has the evolving policy intervention led to structural change in the low-carbon transition of China’s iron and steel industry?

We provide an overview of the iron and steel industry in China in Section 1, and propose and illustrate a conceptual model and an econometric model in Section 2. Results are presented in Section 3, and discussed in Section 4. Finally, conclusions and policy implications are drawn in Section 5.

1. Overview of the development of the iron and steel industry in China

1.1. Carbon intensity

As shown in Fig. 2, CO2 emission intensity presented a downward trend due to several reasons, such as technological progress. CO2 emission intensity in physical terms (ton CO2 per ton of crude steel, abbreviated as ton/tcs) first decreased from 5.79 ton/tcs in 1990 to 5.37 ton/tcs in 1992, then increased to 6.36 ton/tcs in 1995, and finally dropped to 2.76 ton/tcs in 2010 with an average annual reduction rate of 5.4% from 1995 to 2010. CO2 emission intensity in monetary terms (ton CO2 per unit of gross industrial output value, abbreviated as ton/10^3 CNY) first decreased from 2.98 ton/10^3 CNY in 1990 to 1.37 ton/10^3 CYN in 1993, then increased to 1.80 ton/10^3 CNY in 1997, and finally dropped to 0.34 ton/10^3 CNY in 2010 with an average annual reduction rate of 12.0% from 1997 to 2010.

1.2. Investment

A major driver of the development of the iron and steel industry is the overall increasing investment during the past 20 years. Using the price level of 1990 as a baseline, the annual investment in fixed assets reached a peak of 167.3 billion CNY in 2009, compared with 12.7 billion CNY in 1990 (Fig. 3). The huge investment led to a tremendous expansion in production capacity, indicated by the striking increase of industrial output in Fig. 1. On one hand, it satisfied the high demand for iron and steel products required by the soaring economic growth in China; on the other hand, the high asset value from accumulated investment raised the risk of oversupply (Milford et al., 2013).

1.3. Technological progress

Remarkable technological progress is another characteristic of the development in the iron and steel industry. As shown in Fig. 3, there was an exponential increase in the annual internal expenditure on science and technology activities, which drove the upgrading of the industry in technological terms. From 1990 to 2000, new plants mainly adopted mature and advanced techniques and equipment, such as continuous thin slab casting and rolling technology, and high power direct-current electric arc furnaces, narrowing the technology gap between domestic and foreign steel industries. Meanwhile, backward technologies and equipment were eliminated step by step in an orderly way according to plan, such as open hearth furnaces, open-train mills, and pack-rolled sheet. In the 21st century, technological expenditure was focused on achieving high-class product quality, adoption of energy-saving technologies, introduction of international advanced techniques and equipment, and realizing the localization of key production equipment (Fujii et al., 2010; Li and Wang,
These technological improvements have greatly improved productivity and efficiency in the industry.

1.4. Economic growth

As shown in Fig. 1, the GDP of China expanded from 1854.8 billion CNY in 1990 to 13,459.5 billion CNY in 2010, with an average annual GDP growth rate of 10.2% (1990 as price base year) (NBSC, 2013). The continuous market reforms released tremendous productivity. Investment, consumption and export presented strong impetus in driving economic growth. The economy of China is also undergoing a transition. It is aiming to eliminate the backward growth pattern featured by low efficiencies and high costs in terms of resources, energy and the environment, and to build a new growth paradigm, with efforts on promoting innovation, adjusting economic structure, and enhancing environment-friendliness.

1.5. Policy intervention

Since the development and upgrading transition of the iron and steel industry was high on the governmental agenda, it has always been a target sector for policy interventions. Generally speaking, the policies encouraged extensive growth without much consideration of the environmental costs in the 1990s. After the Asian financial crisis broke out in 1997, there was a large amount of surplus production capacity in China’s steel industry, and most companies were in deficit. The government started to implement the working principle of ”controlling total quantity, adjusting structure, and improving efficiency”, and to promote the development strategy of “eliminating backward technologies, and speeding up industrial upgrading”. They set the tone for the policy interventions since then. The State Council published a notice on controlling blind investment in iron and steel, electrolytic aluminum and cement industries in 2003. In 2005 the National Development and Reform Commission issued an exclusive policy document, “Development Policy of the Iron and Steel Industry”, which aimed at technological upgrading, structural adjustment, competitiveness improvement, and pollution control for the industry. The policies afterwards further strengthened the environmental emphasis, and highlighted energy conservation and emission reduction, including differential power pricing, subsidies for energy-saving technological transformation, and preferential corporate income tax for comprehensive utilization of resources.

2. Methodology

2.1. Conceptual model

In order to answer the questions raised in Section 1, we proposed a corresponding conceptual model, as shown in Fig. 4. Five factors were included in the framework, i.e. the carbon intensity of the iron and steel industry, the investment in the iron and steel industry, the technological expenditure of the iron and steel industry, the economic growth, and the policies related to the iron and steel industry. The essence of the model is to extract and highlight these key aspects from a diverse array of factors and to conjointly examine the directions and magnitudes of their possible interconnections.
Within the domain of the iron and steel industry, investment may have mixed effects on CO2 emissions, mainly depending on the direction of investment. Investment in efficiency-improving or emission-cutting technologies and equipment as well as less-carbon-intensive but higher-value-added products can contribute to CO2 abatement. In contrast, blind investment in capacity expansion can increase the risk of oversupply and price fall, worsening corporate revenues and operating conditions, which is unfavorable for the low-carbon transition. Many technologies that enterprises are willing to develop or adopt can provide solutions leading to higher productivity and carbon friendliness. Thus, intuitively, technological expenditure will contribute to CO2 abatement. Nevertheless, the magnitude of the effect needs to be examined. There is more uncertainty when it comes to the effect from CO2 abatement on investment and technological expenditure. It is the government’s hope that CO2 emission reduction can impose pressure on enterprises and industry, forcing the upgrading of technologies and the optimization of investment. However, this desired effect may be not significant, or in the worst scenario, one-sided stress on CO2 emission reduction may become highly incompatible with profitability and undermine rational business calculations and the capacity for investment and technology innovation.

The relationship between the development of the iron and steel industry and economic growth has been studied (Das and Kandpal, 1998; Ghosh, 2006; Huh, 2011). However, the connections between economic growth and carbon intensity of the iron and steel industry are complicated. Economic growth causes increasing demand for iron and steel products. The magnitude of this effect is influenced by factors such as the economy’s dependence on iron and steel. Whether responses to the increasing demand for iron and steel will drive up the carbon intensity or not is determined by the technology and investment decisions of the industry. If the demand was met by production expansion with laggard and high-emission technologies, the carbon intensity of the iron and steel industry would probably rise. If the demand was met with increasing productivity by spending on technologies, especially carbon-friendly technologies, the carbon intensity would drop or stay relatively stable. Policies can certainly play a role in regulating the technology and investment decisions of the industry. Likewise, the effect of CO2 abatement of the iron and steel industry on economic growth is complicated by how the abatement is achieved. The transition of the iron and steel industry mirrors the transformations in the national economy. It is the government’s hope that the CO2 emission reduction can parallel the structural adjustment and technological upgrading of the industry, which will foster a more competitive iron and steel industry and provide sustaining impetus to economic growth. In light of the complexity, it is essential to empirically examine the bi-directional influences and carefully interpret the results and implications.

Policies are taken as an exogenous factor in the conceptual model. They can influence the other factors and provide external shocks to the system. Both of the two major types of policy instruments, i.e. command and control policies and market-based instruments, have played roles in regulating the iron and steel industry. Command and control policies mandate compliance with legislation. Market-based instruments provide incentives for corporate behavioral change. The effectiveness of these two types of policies needs to be examined. In addition, as reviewed in Section 1.5, the policies have been evolving, and during the evolution there may be turning points that mark structural change of the system.

### 2.2. Econometric model

The vector autoregression (VAR) model was used to explore the interrelationships among the factors that we identified in Fig. 4. A generic form of VAR model is illustrated below:

\[ Y_t = \mu + A_1 Y_{t-1} + \ldots + A_p Y_{t-p} + \varepsilon_t; \quad t = p + 1, p + 2, \ldots, T \]  

\[ Y_{t,i} = Y_{2,i}, i = 1, 2, \ldots, p, A_j = \begin{pmatrix} \alpha_{11} & \alpha_{12} & \ldots & \alpha_{1k} \\ \alpha_{21} & \alpha_{22} & \ldots & \alpha_{2k} \\ \vdots \cdots & \vdots \cdots & \vdots \cdots \end{pmatrix}, \quad j = 1, 2, \ldots, p \]

\[ \mu = (\mu_1, \ldots, \mu_k)^t; \varepsilon_t = (\varepsilon_{t1}, \varepsilon_{t2}, \ldots, \varepsilon_{tk})^t \]

where, \( Y_t \) is a vector of \( k \) endogenous variables; \( A_j \) is the coefficient matrix; \( \mu \) is a vector of the constants; \( \varepsilon_t \) is a vector of non-autocorrelated disturbances; \( p \) is the lag order; the sample size is \( T - p \).

VAR has become a widely used econometric model, especially in macroeconomics, since the 1980s. In model construction, it does not presume theoretical foundations that are usually difficult to prove satisfactorily. It has been used for analyzing and forecasting macroeconomic activities, testing Granger causality, and exploring the effects of policy and external stimuli through impulse response features (Greene, 2011). Greene (2011) summarized the merits of VAR models as follows: “researchers have found that simple, small-scale VARs without a possibly flawed theoretical foundation have proved as good as or better than large-scale structural equation systems”.

In addition to economic research, there have been various studies applying VAR models, or closely related representations, such as the autoregressive distributed lag model (ARDL) and the vector error correction model (VECM), at the interface of environment, energy and the economy. Zhang and Cheng (2009) used a VAR model to analyze the relationships among carbon emissions, economic growth, energy use, capital, and urban population at the national level of China from 1960 to 2007. They testified that GDP Granger-caused energy consumption, and energy consumption Granger-caused CO2 emissions, using Granger causality analysis. At the industry level, Zhao et al. (2013) applied the ARDL model, which is a single-equation model, to study the factors influencing the CO2 emissions of China’s power industry from 1980 to 2010. The CO2 emissions were the dependent variable, and the added value of the sector, structure of the sector, and the technological progress were the independent variables. Granger causality tests and impulse response analyses were usually done in such studies to investigate relationships among variables and their dynamic features.

In our study, the VAR model is very suitable for examining the potential bi-directional relationships between CO2 emissions, investment, and technology expenditure in the iron
and steel industry, and their connections with the economic growth in China, as described in the conceptual model. Accordingly, we constructed a VAR equation system as follows:

$$ Y_t = \mu + A_1 Y_{t-1} + \ldots + A_p Y_{t-p} + BX_t + \epsilon_t $$  \hspace{1cm} (4)

where, $Y_t = (\text{CO}_2, \text{GDP}, \text{Invest}, \text{Tech})'$ is a vector of endogenous variables; $X_t = (\text{Policy}_C, \text{Policy}_M)'$ is a vector of two exogenous, dummy variables; $A_p$ and $B$ are the corresponding coefficient matrices; $\mu$ is a vector of the constants; $\epsilon_t$ is a vector of non-autocorrelated disturbances; $p$ is the lag order. A detailed description of the variables was listed in Table 2.

### 2.3. Data

Energy-related $\text{CO}_2$ emissions of the iron and steel industry were calculated according to the World Steel Association (WSA, 2009). Direct emission factors were calculated on the basis of the conversion factor from the International Energy Agency and World Steel Association, and low calorific values were derived from the China Energy Statistical Yearbook (NBSC, 1991–2011). Indirect emission factors from electricity were derived from coal consumption for power supply in the China Energy Statistical Yearbook (NBSC, 1991–2011). The calculation results of $\text{CO}_2$ emissions showed similar trends compared with the studies done by Price et al. (2002), Wang et al. (2007), and Zeng et al. (2009).

The data of the gross industrial output value of the iron and steel industry and the GDP growth rate were obtained from the China Statistical Yearbook (NBSC, 1991–2011). The data of investment in the fixed assets of the iron and steel industry were obtained from the China Energy Statistical Yearbook (NBSC, 1991–2011) and China Statistical Yearbook (NBSC, 1991–2011). The data of internal expenditure on science and technology activities of the iron and steel industry were obtained from the China Statistical Yearbook on Science and Technology (NBSC and MSTC, 1991–2011) and China Statistical Yearbook (NBSC, 1991–2011). For data in monetary terms, the price inflation/deflation factor was eliminated by converting all values to the price level of 1990.

As for the value setting of the two dummy variables, we preselected two turning points, the years 2000 and 2006, in the policy evolution from 1990 to 2010, based on the characteristics of policies regarding the iron and steel industry. The year 2000 reflected the transition from encouraging policies that tolerated the extensive expansion of the industry to command and control policies that emphasized overall control, structural adjustment and efficiency improvement. The year 2006 marked the beginning of more stringent policies for the industry, and the emergence of market-based instruments functioning together with command and control instruments. Thus, the value of the two dummy variables were set as follows: Policy$_C$ (Year $\geq$ 2000) = 1; Policy$_C$ (1990 $\leq$ Year < 2000) = 0; Policy$_M$ (Year $\geq$ 2006) = 1; Policy$_M$ (1990 $\leq$ Year < 2006) = 0.

A logarithmic transformation was applied to the raw data. The data after the transformation were used in the model.

### 3. Results

#### 3.1. Stationarity of time series data

Stationarity tests were performed before the econometric estimation to avoid any spurious regression. The widely used KPSS test was adopted to examine the stationarity of the time series. The KPSS test of stationarity held a null hypothesis that the time series was stationary (Kwiatkowski et al., 1992). Table 3 presents the results of the test. The variables CO2, Invest, and Tech were non-stationary at the significance level of 5%, since their test statistic values were higher than 0.146. GDP was stationary at the significance level of 5%, since its test statistic value was lower than 0.146. The KPSS test was then applied to the first order differences of these variables. $\Delta$CO2 and $\Delta$Tech were stationary at the significance level of 5%, and $\Delta$GDP and $\Delta$Invest were stationary at the significance level of 2.5%. Thus the first order differences of the variables were used in the VAR model.

<table>
<thead>
<tr>
<th>Table 2 – Description of variables.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Variables</strong></td>
</tr>
<tr>
<td>CO2</td>
</tr>
<tr>
<td>GDP</td>
</tr>
<tr>
<td>Invest</td>
</tr>
<tr>
<td>Tech</td>
</tr>
<tr>
<td>PolicyC</td>
</tr>
<tr>
<td>PolicyM</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 3 – Results of KPSS test.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Variables</strong></td>
</tr>
<tr>
<td>CO2</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>GDP</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Invest</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Tech</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>

Critical value of the test statistic for accepting the null hypothesis at different levels of significance: 0.119 (10%), 0.146 (5%), 0.176 (2.5%), 0.216 (1%). $\Delta$ represents the first order difference.
3.2. Selection of lag order

Well-accepted criteria were used to examine the optimal lag order of the model. Given the length of the time series, variable numbers and the practical meanings, we set the second order as the maximum lag order. Longer lag length requires longer time series and greater sample size to make a valid estimation.

As shown in Table 4, the likelihood ratio (LR), Akaike’s information criterion (AIC), and Hannan and Quinn information criterion (HQIC) supported the selection of the second order as the optimal order. The Schwarz’s Bayesian information criterion (SBIC) supported a model without lagged variables, which did not conform to the basic idea of the model. So, we chose two as the lag order.

3.3. Regression results

The regression results are listed in Table 5. In Eq. (1), where ΔCO2 was the dependent variable, ΔCO2 and ΔGDP were significant at the 1% level; and ΔInvest and ΔPolicy were not statistically significant. In Eq. (2), where ΔGDP was the dependent variable, most variables were not significant except for PolicyC and PolicyM; the R-sq value showed that the goodness-of-fit of this equation was less satisfactory than other equations. The situation was similar for Eq. (3), where ΔInvest was the dependent variable. Only PolicyC and PolicyM were significant at the 5% and 1% significance levels, respectively. In Eq. (4), where ΔTech was the dependent variable, all variables were significant except ΔInvest and PolicyM; the R-sq value showed that the goodness-of-fit of this equation was less satisfactory than other equations.

Wald tests were performed to test the joint significance of coefficients. The results showed that coefficients in Eq. (1), Eq. (4) and the entire VAR model were jointly significant at the 1% level. All the eigenvalues were inside the unit circle, which indicated that the VAR model satisfied stability conditions. The results of Jarque-Bera tests, Skewness tests, and Kurtosis tests showed that the disturbances of Eqs. (1) and (4) were normally distributed. All the test results are shown in the Supporting materials.

3.4. Granger causality test

Granger causality was defined by Granger (1969) and Sims (1972) in the sense that time series variable \( x_t \) Granger-caused \( y_t \), if \( y_t \) can be better predicted by using the lagged values of both \( x_t \) and \( y_t \), than using the lagged values of \( y_t \) alone. The VAR can be used to test the Granger causality.

Granger causality results in Table 6 indicated that there was a bidirectional Granger causality relationship between ΔCO2 and ΔTech at the 1% significance level; ΔGDP and ΔInvest significantly Granger-caused ΔCO2 at the 1% and 10% significance levels, respectively; ΔGDP also significantly Granger-caused ΔTech at the 5% significance level. None of the variables had significant Granger causality effects on variables ΔGDP and ΔInvest.

3.5. Impulse response analyses

For VAR models, the regression coefficients are usually not much interpreted. Instead, impulse response analyses are adopted to examine the directions and magnitudes of the interactions among different variables in the VAR system. With a one-time impulse of a certain variable, all other variables will deviate from, and then return to their equilibrium (Greene, 2011; Hamilton, 1994). Fig. 5 shows the results of the impulse response functions.

With a one-unit increase in the innovation of variable ΔGDP at step 0 and all other innovations at all steps constant, the variable ΔCO2 will move away in the negative direction from the equilibrium at step 1, and gradually return to the equilibrium. This indicates that acceleration in GDP growth rate will first cause acceleration in CO2 emission reduction.
Likewise, the acceleration in technological expenditure increase will also bring about acceleration in CO2 emission reduction. In contrast, the acceleration in investment expansion will mainly cause the acceleration of CO2 emission increase. With a one-unit increase in the innovation of variable $\Delta CO2$ at step 0 and all other innovations at all steps constant, variable $\Delta Tech$ will move away in the positive direction from the equilibrium at step 1, and gradually return to the equilibrium. This indicates that the slowing down of CO2 emission reduction or the acceleration of CO2 emission increase will cause the acceleration of technological expenditure increase in future phases. The acceleration in GDP growth rate will accumulate an obvious negative impact on technological expenditure increase at step 3. There is a minor response of $\Delta Tech$ to the impulse of $\Delta Invest$.

**4. Discussion**

**4.1. CO2 abatement, investment, and technological expenditure in the iron and steel industry**

The VAR regression results, Granger causality test and impulse response analyses all indicated that in China’s iron and steel industry, technological expenditure significantly reduced carbon emissions, while investment expansion showed negative effects on carbon emission reduction. Meanwhile, CO2 emission reduction has a significant effect on technological expenditure of the industry: the pressure for CO2 abatement promoted the technological expenditure increase in the iron and steel industry. The impact of carbon intensity change on the scale of industrial investment was not significant.

CO2 emission reduction is usually connected with energy efficiency increase. In China’s iron and steel industry, the pressure from CO2 emission reduction will force a technological expenditure increase, because of the tightening of environmental regulation, the appraisal of governments based on energy conservation and emission reduction performance, and rising energy prices. The incentive-based measures and policies as well as other profitability considerations also strengthen the bi-directional connections between carbon emission reduction and technological innovation.

**4.2. Economic growth and the iron and steel industry**

VAR regression results, Granger causality test and impulse response analyses indicated that good economic conditions favored carbon emission reduction in China’s iron and steel industry.

<table>
<thead>
<tr>
<th>Dependent variable</th>
<th>Independent variable</th>
<th>$\Delta CO2$</th>
<th>$\Delta GDP$</th>
<th>$\Delta Invest$</th>
<th>$\Delta Tech$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Delta CO2$</td>
<td>–</td>
<td>51.3***</td>
<td>5.59</td>
<td>17.3***</td>
<td></td>
</tr>
<tr>
<td>$\Delta GDP$</td>
<td>–</td>
<td>(0.000)</td>
<td>1.87</td>
<td>1.69</td>
<td></td>
</tr>
<tr>
<td>$\Delta Invest$</td>
<td>2.00</td>
<td>(0.367)</td>
<td>(0.393)</td>
<td>(0.429)</td>
<td></td>
</tr>
<tr>
<td>$\Delta Tech$</td>
<td>1.47</td>
<td>2.17</td>
<td>–</td>
<td>0.168</td>
<td></td>
</tr>
</tbody>
</table>

$P$-Value is in parentheses.

***, **, and * indicate significance at the 1%, 5% and 10% levels, respectively.

**Fig. 5 – Results of impulse response analyses.**
industry, and had positive effects on its technological expenditure increase. At the current stage, maintaining a steady, rapid growth of the economy plays a positive role in carbon emission reduction and innovation for the iron and steel industry. \( \Delta CO_2 \) did not have a significant impact on \( \Delta GDP \), and it did not Granger-cause \( \Delta GDP \), indicating that achieving \( CO_2 \) emission reduction in this industrial sector did not necessarily threaten economic growth. This result suggested that a certain degree of decoupling emerged between China’s economic growth and the \( CO_2 \) emissions of the iron and steel industry.

The demand increase from economic growth did not exhibit a prominent influence on the carbon intensity of the iron and steel industry. This may be due to the effective transition from extensive growth to intensive growth in China’s economy. In addition, the iron and steel industry has reached a certain level of technology with plenty of spare capacity. The increase in steel demand from accelerating GDP growth is met by utilizing the spare capacity at a relatively stable and high level of technology, so that its impact on carbon intensity (rather than total \( CO_2 \) emissions) is not significant.

In China, GDP growth rate has long been regarded as one of the most important social and economic development goals, governmental objectives and the vane of the economic climate. It provides an important signal effect on industrial and corporate investment decisions and governmental policy adjustments. Economic upturn can provide richer resources and more favorable conditions for industrial technological innovation, leading to positive impacts on carbon emission abatement in industry.

### 4.3. Policy influence on \( CO_2 \) abatement in the iron and steel industry

Policy impacts on the development and carbon emission reduction of China’s iron and steel industry have shown different stages. The year 2000 was found to be a turning point, as we anticipated. Policy\( C_2 \) had a significant impact on changes in carbon intensity as well as investment scales and technological expenditure, indicating a positive effect on emission reduction and industrial innovation from policies after 2000. In contrast, Policy\( M_1 \) had a significant impact on investment scales, but its influences on the changes in technological expenditure and carbon intensity were not verified. The year 2006 was not verified as a turning point.

Before 2000, the government was maintaining an encouraging policy on the iron and steel industry, which tolerated the extensive expansion of the industry. The direction of policies started to turn in late 1999, when the government put forward a new approach on the iron and steel industry. It emphasized “overall control, structural adjustment, efficiency improvement”, and proposed the new strategy of “eliminating backward technology and accelerating industrial upgrading”. In 2000, it first introduced guiding policies on controlling small-scale steel mills, and carried out a series of policies on total control and stopping blind investment, which led the iron and steel industry into a new phase in terms of \( CO_2 \) abatement. Policies in the new stage had a positive influence on \( CO_2 \) emission cutting, and the increase of investment and technological expenditure. The government issued the first steel industry development plan in the second half of 2005, and for the first time included energy consumption per unit of GDP as a compulsory development target. In addition to continuously tightening the approval of new projects and adopting more stringent and intensive policies on eliminating backward production capacities and controlling pollution, market-based instruments were also introduced, such as subsidies for upgrading energy-saving technologies and differential power pricing. The policies in this new stage had obvious effects on controlling new projects and investment, but their impacts on promoting technological expenditure and lowering \( CO_2 \) intensity were less significant.

### 5. Conclusions and policy implications

Our study targeted the key question concerning the interrelationships between the \( CO_2 \) abatement, investment and technological progress of the iron and steel industry, and their connections with the economic growth and policy intervention in China. We put forward a concise conceptual model and an econometric model to conjointly and empirically examine the relationships.

The results of regression, Granger causality test and impulse response analysis indicated that technological expenditure can significantly reduce \( CO_2 \) emissions, and that investment expansion showed a negative impact on \( CO_2 \) emission reduction. It was also argued with empirical evidence that good economic conditions favored \( CO_2 \) abatement in China’s iron and steel industry, while achieving \( CO_2 \) emission reduction in this industrial sector did not necessarily threaten the economic growth. This shed light on the dispute over balancing emission cutting and economic growth. Regarding the policy aspects, the year 2000 was found to be an important turning point for the policy evolution and the development of the iron and steel industry in China. The subsequent command and control policies had a significant, positive effect on \( CO_2 \) abatement.

Policy implications can be drawn from our analyses. China’s iron and steel industry is at the stage of capacity adjustment, technology innovation and carbon emission reduction. Technological expenditure and upgrading should be highlighted, particularly in terms of the technologies having key impacts on carbon emission reduction, making it a major driver for meeting the \( CO_2 \) targets of the industry. The proportion of technology-related investment in total investment should be increased, and the industrial expansion mode should be optimized, in order to achieve more positive impacts of investment on carbon emission reduction. Meanwhile, the \( CO_2 \) emission reduction targets at the industrial sector level must be strengthened, to force the transformation and upgrading of the industrial sector.

At the current stage, maintaining steady, rapid economic growth of the economy is still of great importance. Therefore, blind restriction on economic growth in the name of industrial transformation and environmental constraints, in fact may turn out to have a negative influence on industrial upgrading and carbon emission reduction. This complicated relationship suggests a more cautious approach in policy design. It requires more attention and discussion from the government, industry and academia.
The coordination and relative stability of various types of policies and objectives will help further strengthen the positive effect from economic growth on technological innovation and carbon emission abatement. A stable expectation should be consolidated. The government should carry out measures to encourage and facilitate industrial innovation and carbon emission reduction, and barriers to fostering innovation should be removed from the system. In this way, sustained economic growth will provide impetus to innovation and CO₂ emission reduction of the iron and steel industry.

Different development stages of the economy and the iron and steel industry have different features and interactions among the studied factors. Full attention should be paid to this stage difference in policy setting and the structural change of the system. The virtuous cycle among investment, technological expenditure and CO₂ abatement should be strengthened through improved institutional arrangements. There are fewer and fewer low-hanging fruits within the current policy setting. Well-crafted market-based instruments, which can provide incentives for further emission reduction and help achieve a win-win between the economic growth and emission cutting, should be put into practice quickly.

This research focused on the macro level; further studies can be done at the micro-level of iron and steel companies, to explore the possible influences of the GDP growth rate on corporate investment and innovation decisions, and their connections with corporate CO₂ emission reduction. China is continually enacting new policies and tightening existing regulations associated with emission reduction in the iron and steel industry. In particular, the government is now determined to carry out iron-fist measures to fight against air pollution. Facilities in steel mills are forced to shut down, and the elimination of backward production capacity is accelerated. This will have direct and substantial impacts on the development and carbon emission reduction of the industry and the whole economy. Future research should give full attention to the new trends of influential policies.

Acknowledgments

This work was supported by the National Natural Science Foundation of China (No. 41071352), the National Social Science Foundation of China (No. 13BYY030) and the National Science and Technology Support Program (No. 2012BA03B01). The authors are very grateful to Professor Yi QIAN at Tsinghua University and the anonymous reviewers for their helpful comments.

Appendix A. Supplementary data

Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.jes.2014.04.020.

REFERENCES


Kwiatkowski, D., Phillips, P.C.B., Schmidt, P., Shin, Y., 1992. Testing the null hypothesis of stationarity against the alternative of a unit root: how sure are we that the economic time series have a unit root? J. Econ. 54 (1–3), 159–178.


Sheinbaum, C., Ozawa, L., Castillo, D., 2010. Using logarithmic mean Divisia index to analyze changes in energy use and carbon dioxide emissions in Mexico’s iron and steel industry. Energy Econ. 32 (6), 1337–1344.


Editorial Board of Journal of Environmental Sciences

Editor-in-Chief

X. Chris Le
University of Alberta, Canada

Associate Editors-in-Chief

Jiuhui Qu
Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, China

Shu Tao
Peking University, China

Nigel Bell
Imperial College London, UK

Po-Keung Wong
The Chinese University of Hong Kong, Hong Kong, China

Editorial Board

Aquatic environment

Peijun Li
Institute of Applied Ecology,
Chinese Academy of Sciences, China

Daqiang Yin
Tongji University, China

Maohong Fan
University of Wyoming, USA

Zhongtang Yu
The Ohio State University, USA

Baoyu Gao
Shandong University, China

Jingwen Chen
Dalian University of Technology, China

Zhifeng Yang
Beijing Normal University, China

Jianying Hu
Peking University, China

Maohong Fan
University of Wyoming, USA

Zhiwu Wang
The Ohio State University, USA

Tsuyoshi Nakanishi
Gifu Pharmaceutical University, Japan

Chihpin Huang
National Chiao Tung University

Studies on the Environment and Health of China

Willie Peijnenburg
University of Leiden, The Netherlands

University of Technology, Taiwan, China

Huijun Wang
Research Center for Eco-Environmental Sciences,

A. C. K. Liu
University of Hawaii at Manoa, USA

Ralph T. Yang
University of Michigan, USA

Nanyang Environment &

Environmental catalysis and materials

Water Research Institute, Singapore

Hong He
Research Center for Eco-Environmental Sciences,

Hannong Huang
National Chiao Tung University

Chinese Academy of Sciences, China

Environmental analysis and method

Zichuan Wang
Peking University, Canada

Hong He
Shanghai Jiao Tong University, China

Zhou Wang
Research Center for Eco-Environmental Sciences,

Hong Shi
China

Zouming Zhen
University of Texas, USA

Qihua Shi
Research Center for Eco-Environmental Sciences,

National Tsing Hua University

Green chemistry

Liu Ping
China

Jianmin Chen
Fudan University, China

Qingcai Feng
Shanghai Jiao Tong University, China

Environment and Technology of China,

University of Science & Technology of China,

Chunxia Wang
National Natural Science Foundation of China

China

Zixuan Wang

Terrestrial environment

Yong Cai
Florida International University, USA

Zixuan Wang

Guibin Jiang
Research Center for Eco-Environmental Sciences,

Qinhuangdao Agricultural University, China

Research Centre Juelich, Agrosphere Institute

Chunxia Wang
National Natural Science Foundation of China

Research Centre Juelich, Agrosphere Institute

Germany

Junhua He
Tongji University, China

Christopher Anderson
Massey University, New Zealand

Environmental biology

Yong Cai
Florida International University, USA

Hong Kong

Zouming Zhen
University of Texas, USA

Huanhuan Hu
Hunan Normal University, China

Bojan Sedmak
National Institute of Biology, Slovenia

Haoqing Cai
Shanghai Jiao Tong University, China

Jianguo Li
Research Center for Eco-Environmental Sciences,

China

Zixuan Wang

Environmental catalysis and materials

Hong He
Research Center for Eco-Environmental Sciences,

Environmental analysis and method

Zouming Zhen
University of Texas, USA

Christopher Rensing
 University of Copenhagen, Denmark

Jiping Chen
Dalian Institute of Chemical Physics,

Chunxia Wang
National Natural Science Foundation of China

Shanghai Jiao Tong University, China

Zouming Zhen
University of Texas, USA

Jianguo Li
Research Center for Eco-Environmental Sciences,

China

Municipal solid waste and green chemistry

Zouming Zhen
University of Texas, USA

Zouming Zhen
University of Texas, USA

Jianguo Li
Research Center for Eco-Environmental Sciences,

China

Municipal solid waste and green chemistry

Zouming Zhen
University of Texas, USA

Jianguo Li
Research Center for Eco-Environmental Sciences,

China

Municipal solid waste and green chemistry

Zouming Zhen
University of Texas, USA

Jianguo Li
Research Center for Eco-Environmental Sciences,

China

Municipal solid waste and green chemistry

Zouming Zhen
University of Texas, USA

Jianguo Li
Research Center for Eco-Environmental Sciences,

China

Municipal solid waste and green chemistry

Zouming Zhen
University of Texas, USA

Jianguo Li
Research Center for Eco-Environmental Sciences,

China

Municipal solid waste and green chemistry

Zouming Zhen
University of Texas, USA

Jianguo Li
Research Center for Eco-Environmental Sciences,

China

Municipal solid waste and green chemistry

Zouming Zhen
University of Texas, USA

Jianguo Li
Research Center for Eco-Environmental Sciences,

China

Municipal solid waste and green chemistry

Zouming Zhen
University of Texas, USA

Jianguo Li
Research Center for Eco-Environmental Sciences,

China

Municipal solid waste and green chemistry

Zouming Zhen
University of Texas, USA

Jianguo Li
Research Center for Eco-Environmental Sciences,

China

Municipal solid waste and green chemistry

Zouming Zhen
University of Texas, USA

Jianguo Li
Research Center for Eco-Environmental Sciences,

China

Municipal solid waste and green chemistry

Zouming Zhen
University of Texas, USA

Jianguo Li
Research Center for Eco-Environmental Sciences,

China

Municipal solid waste and green chemistry

Zouming Zhen
University of Texas, USA

Jianguo Li
Research Center for Eco-Environmental Sciences,

China

Municipal solid waste and green chemistry

Zouming Zhen
University of Texas, USA

Jianguo Li
Research Center for Eco-Environmental Sciences,

China

Municipal solid waste and green chemistry

Zouming Zhen
University of Texas, USA

Jianguo Li
Research Center for Eco-Environmental Sciences,

China

Municipal solid waste and green chemistry

Zouming Zhen
University of Texas, USA

Jianguo Li
Research Center for Eco-Environmental Sciences,

China

Municipal solid waste and green chemistry

Zouming Zhen
University of Texas, USA

Jianguo Li
Research Center for Eco-Environmental Sciences,

China

Municipal solid waste and green chemistry

Zouming Zhen
University of Texas, USA

Jianguo Li
Research Center for Eco-Environmental Sciences,

China

Municipal solid waste and green chemistry

Zouming Zhen
University of Texas, USA

Jianguo Li
Research Center for Eco-Environmental Sciences,

China

Municipal solid waste and green chemistry

Zouming Zhen
University of Texas, USA

Jianguo Li
Research Center for Eco-Environmental Sciences,

China

Municipal solid waste and green chemistry

Zouming Zhen
University of Texas, USA

Jianguo Li
Research Center for Eco-Environmental Sciences,

China

Municipal solid waste and green chemistry

Zouming Zhen
University of Texas, USA

Jianguo Li
Research Center for Eco-Environmental Sciences,

China

Municipal solid waste and green chemistry

Zouming Zhen
University of Texas, USA

Jianguo Li
Research Center for Eco-Environmental Sciences,

China

Municipal solid waste and green chemistry

Zouming Zhen
University of Texas, USA

Jianguo Li
Research Center for Eco-Environmental Sciences,

China

Municipal solid waste and green chemistry

Zouming Zhen
University of Texas, USA

Jianguo Li
Research Center for Eco-Environmental Sciences,

China

Municipal solid waste and green chemistry

Zouming Zhen
University of Texas, USA

Jianguo Li
Research Center for Eco-Environmental Sciences,

China

Municipal solid waste and green chemistry

Zouming Zhen
University of Texas, USA

Jianguo Li
Research Center for Eco-Environmental Sciences,

China

Municipal solid waste and green chemistry

Zouming Zhen
University of Texas, USA

Jianguo Li
Research Center for Eco-Environmental Sciences,

China

Municipal solid waste and green chemistry

Zouming Zhen
University of Texas, USA

Jianguo Li
Research Center for Eco-Environmental Sciences,

China

Municipal solid waste and green chemistry

Zouming Zhen
University of Texas, USA

Jianguo Li
Research Center for Eco-Environmental Sciences,

China

Municipal solid waste and green chemistry

Zouming Zhen
University of Texas, USA

Jianguo Li
Research Center for Eco-Environmental Sciences,

China

Municipal solid waste and green chemistry

Zouming Zhen
University of Texas, USA

Jianguo Li
Research Center for Eco-Environmental Sciences,

China

Municipal solid waste and green chemistry

Zouming Zhen
University of Texas, USA

Jianguo Li
Research Center for Eco-Environmental Sciences,

China

Municipal solid waste and green chemistry

Zouming Zhen
University of Texas, USA

Jianguo Li
Research Center for Eco-Environmental Sciences,

China

Municipal solid waste and green chemistry

Zouming Zhen
University of Texas, USA

Jianguo Li
Research Center for Eco-Environmental Sciences,

China

Municipal solid waste and green chemistry

Zouming Zhen
University of Texas, USA

Jianguo Li
Research Center for Eco-Environmental Sciences,

China

Municipal solid waste and green chemistry

Zouming Zhen
University of Texas, USA

Jianguo Li
Research Center for Eco-Environmental Sciences,

China

Municipal solid waste and green chemistry

Zouming Zhen
University of Texas, USA

Jianguo Li
Research Center for Eco-Environmental Sciences,

China

Municipal solid waste and green chemistry

Zouming Zhen
University of Texas, USA

Jianguo Li
Research Center for Eco-Environmental Sciences,

China

Municipal solid waste and green chemistry

Zouming Zhen
University of Texas, USA

Jianguo Li
Research Center for Eco-Environmental Sciences,

China

Municipal solid waste and green chemistry

Zouming Zhen
University of Texas, USA

Jianguo Li
Research Center for Eco-Environmental Sciences,

China

Municipal solid waste and green chemistry

Zouming Zhen
University of Texas, USA

Jianguo Li
Research Center for Eco-Environmental Sciences,

China

Municipal solid waste and green chemistry

Zouming Zhen
University of Texas, USA

Jianguo Li
Research Center for Eco-Environmental Sciences,

China

Municipal solid waste and green chemistry

Zouming Zhen
University of Texas, USA

Jianguo Li
Research Center for Eco-Environmental Sciences,

China

Municipal solid waste and green chemistry

Zouming Zhen
University of Texas, USA

Jianguo Li
Research Center for Eco-Environmental Sciences,

China

Municipal solid waste and green chemistry

Zouming Zhen
University of Texas, USA

Jianguo Li
Research Center for Eco-Environmental Sciences,

China

Municipal solid waste and green chemistry

Zouming Zhen
University of Texas, USA

Jianguo Li
Research Center for Eco-Environmental Sciences,
Aims and scope

*Journal of Environmental Sciences* is an international academic journal supervised by Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences. The journal publishes original, peer-reviewed innovative research and valuable findings in environmental sciences. The types of articles published are research article, critical review, rapid communications, and special issues.

The scope of the journal embraces the treatment processes for natural groundwater, municipal, agricultural and industrial water and wastewaters; physical and chemical methods for limitation of pollutants emission into the atmospheric environment; chemical and biological and phytoremediation of contaminated soil; fate and transport of pollutants in environments; toxicological effects of terrorist chemical release on the natural environment and human health; development of environmental catalysts and materials.

For subscription to electronic edition

Elsevier is responsible for subscription of the journal. Please subscribe to the journal via http://www.elsevier.com/locate/jes.

For subscription to print edition

China: Please contact the customer service, Science Press, 16 Donghuangchenggen North Street, Beijing 100717, China. Tel: +86-10-64017032; E-mail: journal@mail.sciencep.com, or the local post office throughout China (domestic postcode: 2-580).

Outside China: Please order the journal from the Elsevier Customer Service Department at the Regional Sales Office nearest you.

Submission declaration

Submission of the work described has not been published previously (except in the form of an abstract or as part of a published lecture or academic thesis), that it is not under consideration for publication elsewhere. The publication should be approved by all authors and tacitly or explicitly by the responsible authorities where the work was carried out. If the manuscript accepted, it will not be published elsewhere in the same form, in English or in any other language, including electronically without the written consent of the copyright-holder.

Editorial

Authors should submit manuscript online at http://www.jesc.ac.cn. In case of queries, please contact editorial office, Tel: +86-10-62920553, E-mail: jesc@rcees.ac.cn. Instruction to authors is available at http://www.jesc.ac.cn.