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Green development performance and its influencing factors: A global perspective

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ABSTRACT

Green development has attracted increasing attention by the international community. This paper uses a green development performance index (GDPI) based on data envelopment analysis (DEA) and the panel data of 41 regions (including 165 countries/sub-regions) to estimate the global patterns of green development performance and its influencing factors. The results show that: (1) the patterns of the global green development are extremely imbalanced. Developed regions/countries have been leading in green development since the 21th century, while most of the developing regions/countries' GDPIs are relatively low and are following a descending path; (2) an U-shaped Environmental Kuznets Curve (EKC) exists between GDPI and economic development level and the inflection point is 2424 US $; (3) GDPI is positively related to living altitude, energy structure, and integrated oil prices while negatively related to ecological carrying capacity; (4) the financial crisis occurred since the second half of 2007 has a negative influence on the global green development.

1. Introduction

Since the industrial revolution, human productivity and people's material life have been greatly improved. Accompanied with this is that the accelerated depletion of natural resources and the ecological environment enormous destruction put human beings into the double oppression of resources and environment. Although sustainable/green development has been emphasized for years, the global use of natural resources (e.g., energy resources) and environmental emissions (e.g., CO_2) has dramatically increased and the world is still dominated by "brown economy" (Brand, 2012). Especially in recent years, the situation has become more serious and triggered off widespread concerns about energy security, environmental issues, and global climate change around the world.

Many studies have shown that there are close relationships between CO_2 emissions, economic growth, and energy consumption (Asafu-Adjaye, 2000; Lee and Chang, 2008; Zhang and Cheng, 2009; Chang, 2010; Belke et al., 2011; Wang et al., 2011). With the steady growth of the global economy, the only way to get rid of the dilemma is to improve resource utilization and emission reduction efficiencies without damaging the economic growth. As we can see, the United States has put forward a green New Deal and passed the American Climate and Energy Security Act (ACESA). Japan has formulated overall planning of "green development strategy". The European Union has announced its "2020 Strategy" and taken green growth as the core strategy of enhancing the competitiveness of European countries. Undoubtedly, green development has been the inevitable choice of human beings and in the foreseeable future the green economy will lead to a new pattern of the global economy.

In this context, the open question is what's the feature of the global green development performance in the past few years? And what's the difference of green development performances among the world's major countries and regions? Furthermore, what are the key influencing factors of green development performance? The answers to these questions are of vital significance for the sustainable/green development of the global economy. The purpose of this study is to apply a green development performance index based on data envelopment analysis for presenting the evolution of global green development since the 21st century. This can help us know the gains and losses of our world in green development and clarify strengths and weaknesses. Then, using the Tobit model we further empirically test the impact of influencing factors

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on green development performance. This can help us clarify what the focuses are and what human beings can do to realize global green development.

This study's main contributions are as follows: (i) its presentation of the evolution of the global green development performance during 2000–2014 using a DEA-based green development performance index. This could help us grasp the feature of the global green development performance, know the gains and losses of our world in green development, and clarify strengths and weaknesses; (ii) its reveal of the difference of green development performances among the world's major countries and regions. This could help us clarify the current patterns of global green development and know who are leading and who are impeding in global green development; and (iii) its analysis of the key influencing factors of global green development performance. This may be beneficial in forming a feedback mechanism to guide the adjustment and improvement of follow-up international policies.

The remainder of this paper is organized as follows. In Section 2, the relevant literature is reviewed. The extended DEA models for measuring green development performance and Tobit model for testing the impact of influencing factors on global green development are briefly introduced in Section 3. Section 4 describes the panel data used in the empirical study. The empirical results (i.e., green development performance estimation and Tobit regression results) are presented and discussed in Sections 5.1 and 5.2. Section 6 provides the conclusions and corresponding policy implications.

2. Literature review

As a rising share of total-factor productivity (TFP) in economic growth was generally regarded as a signal of the transformation towards a "sustainable" growth model (Solow, 1957; Krugman, 1994; Young, 1995; Chen and Golley, 2014), a number of scholars tried to analyse the sustainability of regions, countries, and industries based on TFP or production framework. Nishimizu and Page (1982) estimated TFP of Yugoslavia during 1965–1978 for analysing the reason of the slowdown in economic growth in Yugoslavia in the 1970s and found out that technological regress and technical inefficiency were two main factors responsible for this slowdown in economic growth. Wen (1993) applied a weighted total-factor performance index for evaluating TFP changes in China's farming sector during 1952–1989 and found that TFP in China's farming sector had increased significantly after the Household Responsibility System. Färe et al. (1994) proposed a nonparametric Malmquist index for analysing TFP of 17 OECD countries and found out Japan's TFP growth was the highest. Nehru and Dhareshwar (1994) examined TFP growth for 83 industrial and developing countries during 1960–1987 and found that rapid growth of developing countries' economies mainly relied on physical and human capital accumulation rather than TFP growth. Actually, there are numerous scholars who had explored sustainability-related problems based on TFP framework (e.g., Kalirajan et al., 1996; Chen, 1997; Menon, 1998; Maudos et al., 1999; Kim and Han, 2001; Wu, 2001&2003; Krüger, 2003; Coelli and Rao, 2005; Chen et al., 2008).

However, most of the above TFP-based studies simply ignored the importance of energy input and the "by-product" or environmental emissions (e.g., CO_2). In practical production process, when we get the outputs desired, there are always the undesired "by-product" accompanied (e.g., CO_2 emissions discharged by energy consumption). As environmental emissions have negative externality (Jaffe et al., 2005), the traditional TFP in which environmental emissions were ignored thus cannot reflect resource and environmental costs and are to some extent biased (Watanabe and Tanaka, 2007; Wang and Feng, 2014). In response, an increasing number of scholars have tried to take energy input and environmental emissions into consideration and analyse regions/countries/industries' sustainability-related problems within a "green" TFP framework. For readability and the ease of interpretation, the existing "green" TFP studies and their research objects are listed in Table 1.

Here, it should be pointed out that as resource conservation and emissions reduction are two main connotations of sustainable/green development, there are also numerous scholars focused on studying regions/countries/industries' resource efficiency and eco-efficiency or environmental efficiency based on total-factor framework (Zhou et al., 2008a; Song et al., 2012; Zhang and Choi, 2014). For example, Zhou et al. (2006, 2007, 2008b) proposed several environmental performance evaluation models based on data envelopment analysis (DEA) for the measurement of environmental performance of OECD countries and eight world regions. Zhang et al. (2008) treated chemical oxygen demand, nitrogen, sulfur dioxide, soot, dust, and solid waste as inputs and applied BCC-DEA model for analysing eco-efficiency of reginal industrial systems in China. The results show that provinces with higher economic development level are more likely to have higher eco-efficiency. Similar studies on regions/countries/industries' resource efficiency and eco-efficiency or environmental efficiency based on total-factor framework also can be found in the works listed in Table 2.

To sum up, the above studies focused on analysing sustainability-related problems in major regions (e.g., OECD and EU), countries (e.g., U.S. and China), and industries (e.g., electronic information and transportation industries). As it is known, nowadays economic development, resource utilization, and emissions reduction have been increasingly globalized. For example, among them the global climate warming caused by increasing concentrations of greenhouse gases (e.g., CO_2) has become one of the increasingly thorny problems around the world (Meehl et al., 2007). In this context, studying green development performance from a global perspective undoubted is of great significance. That's because studying from a global perspective can help us grasp the feature of the global green development performance in the past few years, the difference of green development performances among the world's major countries and regions, and the key influencing factors of green

Table 1
The "green" TFP studies and their research objects.

Studies	Research object	Studies	Research object
Chung et al. (1997)	Swedish pulp and paper industry	Chen and Golley (2014)	China's industrial sectors
Hailu and Veeman (2001)	Canadian pulp and paper industry	Li and Lin (2015a)	Chinese industrial sectors
Kumar (2006)	41 countries	Long et al. (2015)	China's cement manufactures
Cao (2007)	China's manufacturing sectors	Zhang (2015)	Cities in China's Anhui province
Mahlberg et al. (2011)	14 EU countries	Li and Song (2016)	China's provinces
Mahlberg and Sahoo (2011)	22 OECD countries	Li and Lin (2016a)	China's cities
Zhang et al. (2011)	China's provinces	Chiu et al. (2016)	G20 countries
Ahmed (2012)	China, Japan and South Korea	Wang and Feng (2015a,b)	China's provinces
Lin et al. (2013)	70 countries	Li and Lin (2016b)	China's manufacturing sector

Table 2
Energy and environmental efficiency studies and their research objects.

Studies	Research object	Studies	Research object
Korhonen and Luptacik (2004)	European country's' power plants	Robaina-Alves et al. (2015)	European countries
Kortelainen (2008)	20 European countries	Woo et al. (2015)	OECD countries
Bian and Yang (2010)	China's provinces	Yang et al. (2015)	China's provinces
Sueyoshi and Goto (2010)	US coal-fired power plants	Zhang and Wei (2015)	Chinese transportation sector
Wang et al. (2015)	China's cities	Li and Lin (2015b)	China's provinces
Wang et al. (2016b)	APEC countries	Halkos and Papageorgiou (2016)	Five European countries
Zhang and Choi (2013)	China's fossil fuel power plants	Meng et al. (2016)	China's provinces
Huang et al. (2014)	China's eight regions	Liao et al. (2016)	23 IEA countries
Song et al. (2014)	China's provinces	Long et al. (2016)	China's provinces
Wu et al. (2014)	China's provincial industry	Yu et al. (2016)	China's pulp and paper industry
Xie et al. (2014)	OECD and BRIC countries	Zhang et al. (2016a)	China's provincial industry
Xie et al. (2016)	China's provincial industry	Lahouel (2016)	French firms
Zhou et al. (2014)	China's transport sector	Mandal (2010)	Indian cement industry
Bian et al. (2015)	China's provincial industry	Zhang et al. (2016b)	Swedish industry
Zhang and Xie (2015)	China's electronic information industry	Wang et al. (2012a,b, 2013a,b,c, 2014, 2016a)	China's provinces
Ewertowska et al. (2016)	Electricity mix of the top European economies	Jiang et al. (2016)	Textile industry in China's Jiangsu Province

development performance. Undoubtedly, they are of vital significance for the further sustainable/green development of the global economy. However, to our knowledge few of the existing literature studied sustainability-related development performance based on a global perspective (i.e., most countries in the world included). In addition, there are already a number of literature studied influence factors of green TFP, energy efficiency, emission efficiency, and eco-efficiency (e.g., Song et al., 2013a,b; Wang and Wei, 2014; Li and Wang, 2014; Lin and Du, 2015). The influence factors selected in these studies are economic development level, degree of opening up, environmental regulation, fiscal decentralization, etc. In fact, the factors selected in these studies are more or less economic-related ones. Few of the existing research take factors (e.g., ecological carrying capacity and altitude) which may be much closed to green development into consideration. It is possible that lower altitude regions maybe are willing to pay more attention to global warming than higher altitude regions do. Thus, living altitude may be an important factor to be reckoned with.

In view of the above, this paper tries to analyse green development performance of the world regions and countries since the 21st century from a global perspective. To do this, a non-radial directional distance function (DDF) based on DEA is first proposed for measuring green development performance. Then, a Tobit model in which geographical and environmental factors are included is built for testing the impact of influencing factors on green development performance. What we are looking forward to is grasping the feature of global green development and its influencing factors much more macroscopically. Through this, we can obtain a comprehensive understanding of the current pattern of global green development and know what the gains and losses of our world in green development in the past few years are and what the prospect of our global green development in the future is.

3. Methodologies and data

3.1. The non-radial DDF measure for green development performance

DEA is a mathematic procedure proposed by Charnes et al. (1978) for measuring relative efficiency of decision making units (DMUs). In this study, it is used for the performance evaluation of green development in the world's regions/countries. In recent years, the world is facing increasingly serious crisis of resources and environment and the pressure from continuously downward of global economic growth. The connotation of green development therefore should contain three main aspects of resources-conserving, environmental-friendly, and economic development. Following Wang and Feng (2015a) and Li and Song (2016), a non-radial DDF measure for green development performance evaluation can be defined as follows:

$$\begin{aligned} & D\left(l^{k'}, k^{k'}, e^{k'}, y^{k'}, b^{k'}; g \middle| CRS\right) = \rho^{k'} \\ & = \max w_e \beta^e + w_y \beta^y + w_b \beta^b \\ & s.t.\ \sum_{k=1}^{K} z_k e_k \le e_{k'} - \beta^e g^e,\ \sum_{k=1}^{K} z_k y_k \ge y_{k'} + \beta^y g^y; \\ & \sum_{k=1}^{K} z_k b_k = b_{k'} - \beta^b g^b,\ \sum_{k=1}^{K} z_k l_k \le l_{k'}; \\ & \sum_{k=1}^{K} z_k k_k \le k_{k'},\ z_k \ge 0, for k = 1, ..., K \end{aligned} \tag{1}$$

Where $(l^{k'}, k^{k'}, e^{k'}, y^{k'}, b^{k'})$ respectively represents labour force, capital stock, energy consumption, economic output, and undesirable output of DMU k'; $D(l^{k'}, k^{k'}, e^{k'}, y^{k'}, b^{k'}; g|CRS)$ and $\rho^{k'}$ are the distance functions; CRS denotes constant returns to scale; β^e and β^b respectively are the reduction ratios of energy consumption and environmental emissions; β^y is the increase ratio of economic output; $g = (g^e, g^y, g^b)$ represents the directional vector of energy consumption, economic output, and undesirable output. And it is set to (e, y, b); $w = (w_e, w_y, w_b)$ represents the weight vector of (e, y, b). Following Wang et al. (2013b), Lin and Du (2015), Zhang et al. (2015), Wang and Feng (2015a), Li and Song (2016), we set the weight vector to $w = (1/3, 1/3, 1/3)$; z_k is the intensity variable for connecting the inputs and outputs by a convex combination; K is the number of DMUs. Here it should be pointed out the fact that resources and emissions include many types. However, it may be a little difficult to incorporate all types of resources and emissions into our DEA-based models. That's because DEA-based model has its own limitation that the number of inputs and outputs of decision making units should be as small as possible. Hence, we choose energy as the proxy of resources because in the modern society, energy has become an essential production factor. We choose CO_2 emissions discharged by energy consumption as one of the proxy of Greenhouse gas emissions mainly according to the practical production process. And we choose SO_2 emissions as a necessary proxy of environmental emissions.

From model (1), we can see that the objective function pursues the minimum of energy input and environmental emissions and the maximum of economic output simultaneously. This is in line with the main connotation of green development, i.e., resource-conserving, environmental-friendly, and economic development. Here, following Li and Song (2016) we define green development performance (GDPI) as follows:

$$GDPI = \frac{1}{2}\left[\frac{1-\beta^{e*}}{1+\beta^{y*}}\right] + \frac{1}{2}\left[\frac{1-\beta^{b*}}{1+\beta^{y*}}\right] \quad (2)$$

Where $(\beta^{e*}, \beta^{y*}, \beta^{b*})$ are the optimal values of $(\beta^{e}, \beta^{y}, \beta^{b})$. And as shown in Eq. (2), GDPI is an aggregative index in which resource-conserving, emission reduction, and economic development are fully reflected. Obviously, these three aspects are the main and the very necessary components of green development for all regions/countries/industries, no matter what growth patterns they have. We further define resource-conserving efficiency (RCE) and emission reduction efficiency (ERE) as follows:

$$RCE = \frac{1-\beta^{e*}}{1+\beta^{y*}}, ERE = \frac{1-\beta^{b*}}{1+\beta^{y*}} \quad (3)$$

As the evolution of global development performance is to be presented, the concept of global DEA is introduced here to make estimation results of different years comparable. The core of global DEA is forming a global production possibility set (PPS) in which all contemporaneous PPSs are enveloped and decision making units of all periods take the global PPS as reference. Let $P(x)$ denotes production possibility set and suppose there are T periods. Then, a contemporaneous $P(x)$ can be defined as follows:

$$P^t(x^t) = \{(y^t, b^t) | x^t \text{can produce} (y^t, b^t)\} \quad (4)$$

Where $P^t(x^t)$ denotes the contemporaneous PPS of period t. The global $P(x)$ envelops all contemporaneous$P(x)$ and can be defined as follows:

$$P^G(x) = P(x)^1 \cup P(x)^2 \cup \ldots \cup P(x)^T \quad (5)$$

Where $P^G(x)$ denotes the global PPS in which all contemporaneous PPSs are enveloped. In this study, the estimations of green development performance of DMUs in all periods are based on the global PPS, i.e., $P^G(x)$.

3.2. Tobit model

To test the impact of influencing factors on green development performance (GDPI), resource-conserving efficiency (RCE), and emission reduction efficiency (ERE), econometric model is needed here. Before the selection of econometric models, an understanding of the feature of estimated dependent variable is essential. From model (1)–(3), we can get the knowledge that dependent variables (i.e., GDPI, RCE, and ERE) are between 0 and 1. According to McDonald and Moffitt (1980), when dependent variables are truncated or censored, the Tobit model proposed by Tobin (1958) is the proper choice. So far, the Tobit model has been widely used for testing influence factors of energy and environmental efficiency (e.g., Zhang et al., 2011; Song et al., 2013a; Lv et al., 2015). Following them, we choose the Tobit model for analysing the influence factors of GDPI, RCE, and ERE. The theoretical model can be defined as follows:

$$\begin{cases} y_i = X_i\beta_i + u_i & if \quad y_i \in (0,1] \\ = 0 & if \quad y_i \in (-\infty, 0] \\ = 1 & if \quad y_i \in (1, +\infty) \\ i = 1, 2, \ldots, N \end{cases} \quad (6)$$

where N is the number of observations; y_i is dependent variable; X_i is the vector of independent variables; u_i is the independently distributed error term and is assumed to be normal with zero mean and constant variance δ^2.

Here, combining with the existing studies and considering the main focus of this study, we choose the following influence factors: (1) economic factors: economic development level (*edl*). The economic development level is measured by GDP per capita. Many studies have proved that there is Environmental Kuznets Curve (EKC) in many regions/countries (Stern, 2004); (2) geographical and environmental factors: ecological carrying capacity (*ecc*) and altitude (*alt*). The ecological carrying capacity is measured by the ratio of the forest area over regional territorial area. The variable *alt* is measured as the proportion of population whose living altitude is lower than 5 metres. As we have discussed, it is possible that regions/countries with lower altitude and weak ecological carrying capacity maybe are willing to pay more attention to global warming; (3) the dummy variable of financial crisis (*crisis*) is selected for testing the impact of financial crisis on global green development. The value of the dummy variable of financial crisis equals to 0 before 2008, and equals to 1 after; (4) other control variables: structural factors of industrial structure (*istr*) and energy structure (*enstr*) and energy price (*price*). The industrial structure is measured by the ratio of secondary industrial output over gross domestic product (GDP). The energy structure is measured by the ratio of non-fossil energy consumption over total energy consumption. Many studies had found that industrial structure and energy structure have impact on energy and carbon emission efficiencies (e.g., Fan et al., 2007; Liao et al., 2007; Ma and Stern, 2008). As the price variables often have lag effects, we choose lagged energy prices as the price variables. Here, it should be pointed out that as energy consumption used in this study is measured as oil equivalent, energy prices used in this study therefore are domestic integrated oil prices of countries/regions. According to the refining level of international crude oil, a ton of crude oil can refine 0.29 tons of petrol or 0.49 tons of diesel oil. Thus, the integrated oil prices can be obtained as a weighted price of petrol and diesel oil. Finally, the Tobit model for testing the impact of influencing factors on GDPI, RCE, and ERE are provided as follows:

$$\begin{aligned} Y_{i,t} = {} & \beta_0 + \lambda_1 \ln edl_{i,t} + \lambda_2 \ln edl_{i,t}^2 + \beta_1 instr_{i,t} + \beta_2 enstr_{i,t} \\ & + \beta_3 ecc_{i,t} + \beta_4 alt_{i,t} + \gamma crisis + \eta_{lag} price_{i,t-lag} + \varepsilon_{i,t} \end{aligned} \quad (7)$$

Where Y refers to GDPI, RCE, and ERE; β, λ, γ, η are the coefficients; i and t respectively represents region and year; *lag* denotes the lagged periods;ε is the stochastic disturbance item and is assumed to be normal with zero mean. It should be pointed out here that there are many factors influencing GDPI and it may be difficult for us to test all of them. Hence, the selection of influencing factors in this study is mainly based on our research focuses.

4. Data and descriptive statistics

According to the practical production process and following most of the existing studies, labour, capital stock, and energy consumption are chosen as inputs. Gross domestic product (GDP) is chosen as desirable output. CO_2 and SO_2 emissions are chosen as undesirable outputs. The energy consumption and CO_2 emissions data comes from 'BP Statistical Review of World Energy 2015'. Labour and GDP data (in 2000 constant price) comes from the World Bank Database (2000–2014). SO_2 emissions data is calculated according to the approach (i.e., Greenhouse gas-Air pollution Interactions and Synergies and bottom-up mass balance approach) suggested by Klimont et al. (2013). Considering the availability of data, our panel data covers 165 countries/sub-regions around the world since the 21st century (2000–2014). And to facilitate comparison when considering the availability of data for some small countries, we divide the 165 countries/sub-regions into 41 regions

Table 3
Regions and the countries/sub-regions they consist of.

Region	Sub-regions	Region	Sub-regions
East Asia	North Korea, Mongolia, Taiwan (China)	Other African Regions	sub-Saharan Africa, excluding South Africa
Middle East	Bahrain, Iran, Iraq, Syria, Israel, Jordan, Kuwait, Lebanon, Oman, Qatar, Saudi Arabia, the Republic of Yemen, the United Arab Emirates	Oceania	Australia, New Zealand
		South America	Argentina, Chile, Uruguay
		Central America	Other Central American regions
Southeast Asia	Afghanistan, Bhutan, Brunei, Kampuchea, Laos, Malaysia, Burma, Philippines, Singapore, Vietnam	Region of Ukraine	Ukraine, Belarus, Moldova
South Asia	Bangladesh, Nepal, Pakistan, Sri Lanka	Central Europe	Albania, Bosnia and Herzegovina, Bulgaria, Croatia, Serbia, Czech Republic, Hungary, Macedonia, Montenegro, Poland, Romania, Slovakia, Slovenia
Central Asia	Armenia, Azerbaijan, Georgia, Uzbekistan, Turkmenistan, Kazakhstan, Kyrgyzstan	Baltic States	Estonia, Latvia, Lithuania
North Africa	Republic of Egypt, Algeria, Libya, Morocco, Arabia, Tunisia	Western Europe	Cyprus, Iceland, Malta, Norway, Switzerland
Other regions: China (mainland China, Hong Kong, and Macao), South Korea, Japan, Thailand, Indonesia, India, South Africa, Brazil, Mexico, Canada, the United States, Turkey, Russia, the European Union 15 countries			

according to the practice of Klimont et al. (2013) [1] The 41 regions and the countries/sub-regions they consist of are shown in Table 3.

As there is no official capital stock data for the 165 countries/sub-regions or the 41 regions, we calculated it by using the approach (i.e., the perpetual inventory method) suggested by Hall and Jones (1999). The perpetual inventory method suggested by Hall and Jones (1999) can be defined as follows:

$$K_{i,t} = \frac{I_{i,t}}{p_{i,t}} + (1 - \delta_{i,t})K_{i,t-1} \tag{8}$$

Where $K_{i,t}$, $I_{i,t}$, $p_{i,t}$, and $\delta_{i,t}$ respectively represents capital stock, fixed asset investment, price index of fixed asset investment, and depreciation rate of region i in year t. Following Hall and Jones (1999), capital stock in the base period is calculated as follows:

$$K_{i,0} = \frac{I_{i,0}}{\delta_0 + g_{i,r}} \tag{9}$$

Where $K_{i,0}$ $I_{i,0}$, and δ_0 denotes capital stock, fixed asset investment, and depreciation rate of region i in the base period. $g_{i,r}$ is the average annual growth rate of GDP in region i. In this study, depreciation rate used in Eq. (8) and Eq. (9) are the arithmetic mean of the depreciation rate of all countries/sub-regions. The original data of depreciation rate on countries/sub-regions during 2000–2011 comes from the Penn World Table P.W.T 8.1, and the depreciation rate data on countries during 2012–2014 are obtained via trend extrapolation. The fixed asset investment and its price index data come from the World Bank Database (2000–2014). All the monetary variables are converted into 2000 constant price.

To be brief, the sample used in this study consists of 41 regions (covers 165 countries/sub-regions) for the period of 2000–2014. And the summary statistics of inputs and outputs is presented in Table 4. In addition, original data of influencing factors mentioned in Section 3.2 comes from 'BP Statistical Review of World Energy 2015' and the World Bank Database (2000–2014). And the summary statistics of these influencing factors is presented in Table 5.

Table 4
Summary statistics of inputs and outputs.

Index	Unit	Observations	Min	Max	Mean	Std.dev
Energy	1 million tons	615	14	3000	270.47	470.11
Labour	10,000 persons	615	177	81,060	7334.15	14,030.65
Capital	1 billion dollars	615	49	53,981	4112.85	8054.49
GDP	1 billion dollars	615	25	13,172	976.20	1940.58
SO_2	thousand tons	615	11	33,262	2274.05	4835.91
CO_2	1 million tons	615	37	9851	749.48	1440.13

5. Empirical results and discussion

In this Section, green development performances of the world regions and countries since the 21st century are shown in our analysis. Then, an empirical analysis of influencing factors on green development performance is employed. It should be pointed out that as resource input and environmental emissions in this study respectively are energy and CO_2 and SO_2 emissions, the resource-conserving efficiency and emission reduction efficiency in fact refer to energy-conserving efficiency (ECE) and CO_2 and SO_2 emissions reduction efficiencies (i.e., CRE and SRE).

5.1. The global green development performance since the 21st century

To make the estimation results of difference years comparable, the concept of global DEA is introduced into our study. The evolution of the global development performance (GDPI), energy-conserving efficiency (ECE), and CO_2 and SO_2 emissions reduction

Table 5
Summary statistics of influencing factors.

Index	Observations	Min	Max	Mean	Std.dev
ecc	615	0.0046	0.7374	0.3045	0.1937
lnedl	615	6.1137	10.6289	8.9466	1.3337
istr	615	0.1080	0.5395	0.3043	0.0766
alt	615	0.0166	0.4030	0.0870	0.0614
enstr	615	0.0042	0.6753	0.1600	0.1443
price	615	0.1013	2.4077	1.0643	0.5036

[1] Here, it should be pointed out that geographical factor is not the only standard for this regional classification. In order to make the grouped regions comparable, Klimont et al. (2013) deliberately put some small countries/sub-regions together into one region while each of the remaining major countries become a sole region themselves. Admittedly, there also are many other proper adopted regional classifications. However, as the basic data on global SO_2 emissions and the corresponding measurement adopted in this study come from the work of Klimont et al. (2013), the global countries/sub-regions are divided into regions according to the practice of Klimont et al. (2013).

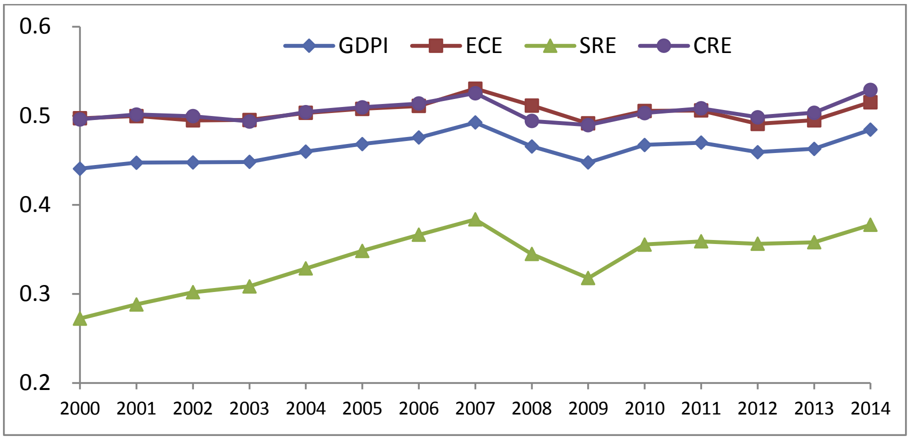

Fig. 1. Global green development performance, energy-conserving efficiency, and CO_2 and SO_2 emissions reduction efficiencies during the period of 2000–2014.

efficiencies (i.e., CRE and SRE) is presented in Fig. 1. It can be seen from Fig. 1 that the global GDPI, ECE, CRE, and SRE are relatively very low. On one hand, this indicates that green developments among the world' regions are uneven. This is mainly because DEA-based efficiency measures the relative efficiency of decision making units (DMUs). The global inefficiency, to some extent, measures the gap between the benchmarking regions (DMUs whose efficiency equals to 1) and the inefficient regions (DMUs whose efficiency is lower than 1). On the other hand, this also suggests that there is considerable potential of improvement. GDPI, ECE, CRE, and SRE have almost the same change tendency, i.e., an increase during 2000–2007, a decrease during 2008–2009, and a fluctuant increase since 2010.

The relatively sharp decrease during 2008 and 2009 may partly due to the financial crisis occurred since the second half of 2007. That's to say, the financial crisis maybe have a certain impact on the global green development. To illustrate this more clearly, Fig. 2 is drawn for revealing the relationship between the global green development performance and economic growth during the period of 2000–2014. As seen, GDPI and economic growth have similar changing trends during the sample period. Before 2007, both GDPI and the global economic growth were following an ascending path (except for 2001, in which economic growth declined). And during the period of 2007–2010, the global economic growth had ridden a roller coaster of booms and busts, while GDPI also experienced a V-shaped trend. Since the year 2011, both of them were forward in the wave. On this basis, we can speculate that the international financial crisis has a strong impact on GDPI. And we will further discuss it in the following influencing factors analysis (Section 4.2).

Table 6 shows the regional mean values and fluctuations in GDPI, ECE, SRE, and CRE during the period of 2000–2014. It can be seen from Table 6 that regions/countries whose GDPI is higher than 0.7 are Japan, Western Europe (Rest of), South America (Rest of), United States, Austria, Denmark, Ireland, Sweden, and United Kingdom. Without exception, the regions/countries with high GDPI are all developed ones. Also, as we can see, their green development performances have increased during the sample period. Here, we take United Kingdom and Japan for example. As two of the countries who are committed to developing low carbon economy, they never stop moving on the path to a low-carbon economy. As early as in 2003, the UK government formally issued the concept of low-carbon economy and CO_2-reduction targets in its Energy White Paper. And in 2009, the UK government further passed the Climate Change Act. This makes the UK the first country to introduce legally-binding carbon budgets (cut emissions by 34% by 2020 and 80% by 2050 based on their 1990 levels) around the world. As is known to all, Japan is an island country whose natural resources are relatively deficient. Japan also is one of the countries who are committed to developing low carbon economy. So far, the Japanese government has issued a series of policies on low-carbon/sustainable development. The Japanese Ministry of Economy, Trade and Industry (METI) launched the "Top Runner scheme" for

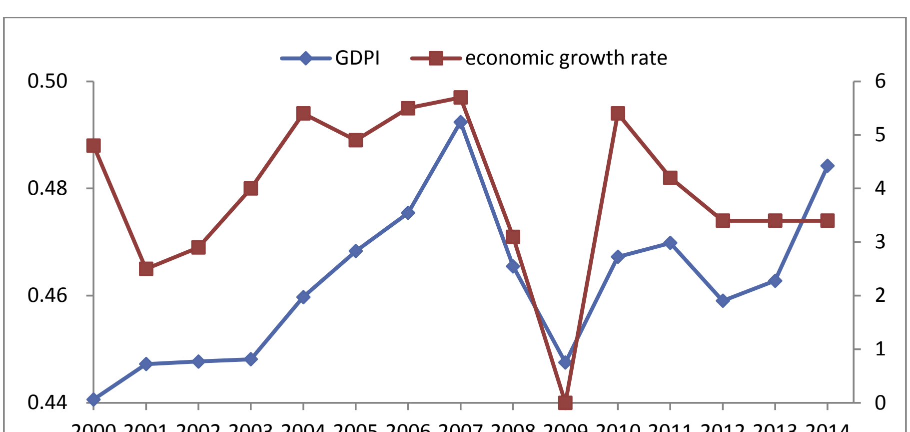

Fig. 2. Global green development performance and economic growth during the period of 2000–2014.

Table 6
Regional mean values and fluctuations in GDPI, ECE, SRE, and CRE during the period of 2000–2014.

Regions	Mean values				Fluctuations			
	GDPI	ECE	SRE	CRE	△GDPI	△ECE	△SRE	△CRE
China	0.2480	0.3130	0.1519	0.2139	0.0547	0.0173	0.1510	0.0331
East Asia (Rest of)	0.5256	0.5453	0.5205	0.4916	0.3818	0.3047	0.6427	0.2750
Japan	0.8863	0.8841	0.8389	0.9380	0.2013	0.1737	0.3319	0.1260
Republic of Korea	0.2972	0.3090	0.2793	0.2913	0.0836	0.0333	0.2002	0.0677
Southeastern Asia (Rest of)	0.3293	0.4096	0.1886	0.3092	−0.0898	−0.1143	−0.0272	−0.1034
Thailand	0.3029	0.3445	0.2154	0.3072	−0.1157	−0.1735	0.0262	−0.1421
Indonesia	0.2220	0.2788	0.0964	0.2339	−0.1146	−0.1380	−0.0802	−0.1021
India	0.2777	0.3568	0.1237	0.2735	−0.2103	−0.2105	−0.2573	−0.1631
South Asia (Rest of)	0.4599	0.5633	0.1512	0.5616	−0.1129	−0.1523	−0.0634	−0.0836
Australia & NZ	0.3041	0.3961	0.0869	0.3372	0.0343	0.0291	0.0140	0.0651
Central Asia	0.4199	0.4663	0.3353	0.4117	−0.8004	−0.7202	−0.9500	−0.8113
Russian Federation	0.1519	0.1456	0.1702	0.1462	−0.2368	−0.0995	−0.5907	−0.1575
Ukraine+	0.0930	0.1080	0.0561	0.1001	0.0706	0.0885	0.0181	0.0873
Baltic States	0.1809	0.1881	0.1184	0.2288	0.0038	0.0184	0.0327	−0.0543
Western Europe (Rest of)	0.8667	0.9017	0.6634	1.0000	0.2619	0.2555	0.5368	0.0000
Central Europe (Rest of)	0.1749	0.2281	0.0361	0.2075	0.0467	0.0557	0.0232	0.0524
Turkey	0.4718	0.5968	0.1658	0.5276	−0.1593	−0.2368	−0.0286	−0.1349
Northern Africa	0.2880	0.3435	0.1412	0.3240	−0.1352	−0.1797	−0.0324	−0.1489
Other Africa	0.2637	0.3449	0.0202	0.3449	0.0521	0.0701	−0.0017	0.0701
South Africa	0.2322	0.3223	0.0742	0.2098	0.0232	0.0256	0.0151	0.0265
Middle East	0.1823	0.2180	0.0881	0.2051	−0.0720	−0.0950	−0.0345	−0.0636
Brazil	0.5602	0.5451	0.4270	0.7236	−0.3227	−0.3162	−0.2538	−0.4045
South America (Rest of)	0.8607	0.8898	0.7394	0.9238	0.0239	−0.0970	0.3774	−0.0877
Central America	0.4868	0.5434	0.2649	0.5953	−0.2105	−0.2245	−0.1945	−0.1984
Mexico	0.3886	0.4644	0.1761	0.4495	−0.0170	−0.1237	0.2919	−0.1125
Canada	0.2752	0.2900	0.1342	0.3866	−0.0204	−0.0365	0.0286	−0.0372
United States	0.7442	0.8536	0.5324	0.7370	0.5594	0.3444	0.9193	0.6294
Austria	0.7191	0.6662	0.8328	0.7111	0.1516	0.1854	0.1552	0.0802
Belgium	0.3958	0.3828	0.3865	0.4310	0.1549	0.1060	0.2679	0.1396
Denmark	0.8485	0.8446	0.8561	0.8488	0.2801	0.2715	0.2892	0.2883
Finland	0.4472	0.4459	0.3034	0.5935	0.1273	0.1248	0.0499	0.2098
France	0.6198	0.5490	0.4833	0.8979	0.1854	0.2049	0.1080	0.2236
Germany	0.5639	0.5717	0.5044	0.6080	0.1206	0.1417	0.0534	0.1454
Greece	0.3312	0.4420	0.0810	0.3599	0.0807	0.0779	0.0701	0.0971
Ireland	0.8139	0.8996	0.5912	0.8650	0.2500	0.1293	0.4818	0.2595
Italy	0.5496	0.6207	0.3255	0.6316	0.2009	0.1510	0.3617	0.1401
Netherlands	0.5918	0.5749	0.7842	0.4334	0.4781	0.4754	0.3663	0.5953
Portugal	0.3578	0.4703	0.0232	0.4675	0.0388	0.0079	0.0102	0.1293
Spain	0.3848	0.4507	0.1427	0.4953	0.0932	0.0724	0.0804	0.1475
Sweden	0.9183	0.9423	0.8472	0.9414	0.1982	0.1407	0.3875	0.1241
United Kingdom	0.9223	0.9365	0.8930	0.9231	0.2482	0.1552	0.5351	0.1474

improving its energy efficiency in 1998 and further proclaimed Japan as a "recycling oriented economic system" for promoting the development of circular economy in 2002. In 2007 and 2008, "Cool Earth 50" as a Japanese plan to reduce global CO_2 emissions by 50% by 2050 was first put forward by the Japanese president of Shinzo Abe and then discussed at the 34th G8 summit. As we can see, these green-oriented policies and schemes have already achieved remarkable effects and have made the UK and Japan walking in the forefront of the world in green development.

The countries/regions whose GDPI is relatively low have very different changing trends. Most of the developing countries/regions (e.g., Indonesia, Thailand, and India) are of relatively low GDPI and are following a descending path. While some of them (e.g., China) also have relatively low GDPI, but their GDPI are increasing. Here, we take China and India for example. During the sample period, mean values of GDPI in China and India are both lower than 0.3. But the difference is GDPI in China is following an ascending path while that in India is decreasing. Concretely, the growth of GDPI in China was mainly because of the improvement in SRE. This may due to the obligatory set forth of environmental pollution (e.g., SO_2) reduction targets since the "11th five year plan (2006–2010)". According to National Bureau of Statistics of China, during the period of 2000–2014 China's GDP (in 2000 constant price) increased by nearly 2.5 times while its energy consumption, SO_2 emissions, and CO_2 emissions increased respectively by 1.94 times, 11.33%, and 1.76 times. It is not difficult to find that China has performed well on the improvement of SRE while its improvements of ECE and CRE are not particularly optimistic. This indicates that the Chinese economy still relies heavily on energy and CO_2 emissions and the situation has not been fundamentally changed. The Chinese government should pay more attention to promoting its energy efficiency and CO_2 emissions reductions so as to be a big responsible nation. The relatively low ECE, SRE, and CRE also suggest that there is still a long way to go on the path to green development. On the contrary, during the same period, India's GDP (in 2000 constant price) increased by 1.65 times while its energy consumption, SO_2 emissions, and CO_2 emissions also increased respectively 1.16 times, 1.18 times, and 1.19 times. As we can see, the rapid growth of India's economy growth is accompanied by significant increase of energy consumption and environmental pollutants. It is therefore not difficult to understand that India appears to have deviated from the green development orbit (△GDPI<0).

In summary, the global green development has been in twists and turns. The financial crisis occurred since the second half of 2007 seems to have strong impact on global green development. In addition, the patterns of the global green development are extremely imbalanced. Developed countries of Japan, United States, Austria, Denmark, Ireland, Sweden, and United Kingdom have been leading in green development since the 21th century. While most of the developing countries/regions' GDPIs are relatively low and are following a descending path. As mentioned, there remain the questions to be answered: (1) whether the financial crisis have impact on global green development?; (2) as shown in Table 6, the developed and developing countries/regions have quite different GDPI. Then there is the further question whether economic development level is one of the key factors influencing green development?; (3) few of the existing research take geographical and environmental factors (e.g., altitude) which may be much closed to green development into consideration. As we have discussed, it is possible that lower altitude regions maybe are willing to pay more attention to global warming than higher altitude regions. That's to say, altitude may be an important factor to be reckoned with. In this context, a test is very essential.

5.2. Analysis of the influencing factors of green development performance

The main purpose of this Section is testing the impact of the factors we concerned on green development performance. GDP per capita (*edl*) is chosen as the proxy variable of economic development level for testing the relationship between the level of economic development and green development. To verify whether the financial crisis have impact on global green development, the dummy variable of financial crisis (*crisis*) is set and the value of *crisis* equals to 0 before 2008 and equals to 1 after. What's more, ecological carrying capacity (*ecc*) and altitude (*alt*) respectively are selected for testing the impact of environmental and geographical factors on green development. Industrial structure (*istr*), energy structure (*enstr*), and lagged integrated oil prices (*price*) are the control variables.

As dependent variables (i.e., GDPI, ECE, CRE, and SRE) are truncated, the Tobit model is selected as the theoretical model. To test the lagged effects of integrated oil prices on green development performance, integrated oil prices with one and two lagged periods (i.e., price_t1 and price_t2) are stepwise introduced into the regression models. The results of Tobit regression are listed in Table 7. It can be seen from Table 7 that when separately introduced into the regression models, both price_t1 and price_t2 can pass the significance test at 1% (as shown in the results of model (1) and model (2)), and both of them cannot pass the significance test at 10% when they are simultaneously introduced (as shown in model (3)). What's more, the coefficients of price_t1 and price_t2 in model (1) and model (2) are very close. A Pearson test shows that Pearson correlation coefficient between price_t1 and price_t2 is 0.987 which passes the significance test at 1%. This can be treated as a signal of strong multicollinearity. Thus, it is not reasonable to simultaneously incorporated both price_t1 and price_t2 into regression models. For this consideration, price_t2 is removed from the regression models (4)–(6). The considerable values of log likelihood statistics indicate that the model (1)–(6) as a whole is highly significant. And the considerable values of "LR chi2(n)" denotes that the models (1)–(6) carry no heteroscedasticity.

From the regression results of model (1), we can see that there is U-shaped Environmental Kuznets Curve (EKC) relationship between GDP per capita (ln *edl*) and GDPI. As reported in the first column of Table 7, a negative coefficient for ln *edl* associated with a positive coefficient for its quadratic term implies a performance decrease at the early stage of income growth and then followed by a performance increase once a certain level of income is reached. According to the characteristics of a quadratic equation, the inflection point of the U-shaped EKC is $\ln edl = 7.7932$ or $edl = 2424$. This result suggests that GDPI decreases with the rising of economic development level when this level is less than 2424 US $. And when *edl* exceeds 2424 US $, GDPI will increase with the rising of economic development level. Also, the U-shape EKC relationships can be seen between GDP per capita and ECE, CRE, and SRE. And the corresponding inflection points of these U-shaped EKCs respectively are 2638, 2151, 2380 US $. In 2014, there are only several regions/countries (i.e., India, South Asia (Rest of), and Other Africa) whose economic development level is lower than the inflection point of the U-shaped EKC. That's to say, for most regions/countries they are expected to realize the "win-win" situation between economic and green developments.

The positive correlation coefficient between *alt* and GDPI is as much as 0.6513, indicating that geographical factor, measured by the proportion of population whose living altitude is lower than 5 m in this study, is one of the key factors influencing green development. The fifth assessment of the Intergovernmental Panel on Climate Change (IPCC) pointed out that there is significant signal of accelerated global warming, which is caused by increasing concentrations of global greenhouse gases (GHGs). The report shows that in the past century, the global sea-level has risen by 10–20 cm and will accelerate in the future. If it cannot be efficiently restrained, areas with low living altitude may be swamped. Thus, people whose living altitude is very low are likely to pay more attention to promoting green development (energy-conserving and emissions reduction) so as to mitigate global warming. Considering this fact, it is therefore not difficult to understand that the variable

Table 7
Results of Tobit regression.

Independent variables	GDPI			ECE	SRE	CRE
	Model (1)	Model (2)	Model (3)	Model (4)	Model (5)	Model (6)
lnedl	−0.7575***	−0.7535***	−0.7581***	−0.7862***	−0.7643***	−0.6935***
$(\text{lnedl})^2$	0.0486***	0.0483***	0.0486***	0.0499***	0.0498***	0.0446***
alt	0.6513***	0.6518***	0.6516***	0.4569***	1.4293***	0.2622**
ecc	−0.1688***	−0.1680***	−0.1690***	−0.1918***	−0.1008*	−0.1908***
crisis	−0.0435**	−0.0434**	−0.0428**	−0.0445**	−0.0380*	−0.0468**
istr	0.0851	0.0755	0.0845	−0.0358	0.4758***	−0.0637
enstr	0.3937***	0.3944***	0.3942***	0.2639***	0.3566***	0.6902***
price_t1	0.0796***		0.0959	0.0680***	0.1205***	0.0621**
price_t2		0.0791***	−0.0176			
cons	3.1114***	3.1013***	3.1133***	3.3913***	2.7036****	2.9593***
log likelihood	179.9989	179.4586	180.0161	165.2694	71.9423	147.6560
LR chi2(n)	440.4200	439.3400	440.4500	368.9100	440.9200	451.2300
Pseudo R2	5.4763	5.4629	5.4768	9.6141	1.4844	2.8941

Note: symbols of ***, **, and * respectively denotes 1%, 5%, and 10% significant levels; price_t1 and price_t2 represents integrated oil prices with one and two lagged periods; 'n' inside the parentheses denotes degrees of freedom.

of *alt* has significant impact on GDPI. The positive correlation coefficients between *alt* and ECE, SRE, and CRE in regression results of model (4)–(6) denote that areas with low living altitude are likely to promote their green development through both energy-conserving and emissions reduction.

As shown in the second column of Table 7, the correlation coefficient between *ecc* and GDPI is −0.1688, indicating that the ecological carrying capacity plays a negative role in promoting green development. It implies that regions/countries who are of weak ecological carrying capacity may like to pay more attention to green development. It can be seen from the fifth, sixth, and seventh columns of Table 7, correlation coefficients between *ecc* and ECE, SRE, and CRE are negative. This suggests that the way of regions/countries with weak ecological carrying capacity realizing green development is promoting energy-conserving and emissions reduction. The influencing mechanism of ecological carrying capacity on green development is a little like that of living altitude on green development. For the regions/countries with weak ecological carrying capacity, their ecosystems are more fragile and more vulnerable to damage caused by climate change and environmental pollution. Thus, they have incentives and pressures to develop green economy and promote energy-conserving and emissions reduction.

The negative correlation coefficient between the dummy variable *crisis* and GDPI suggests that the financial crisis occurred since the second half of 2007 had a negative influence on the global green development. Concretely, the financial crisis may have induced a decrease of nearly 0.04 percent in GDPI. This is a not huge but significant enough impact. To promote a rapid return to economic recovery, many regions/countries enlarged their investment and there was short-lived impact of financial crisis on emissions due to strong emissions growth in emerging economies, a return to emissions growth in developed economies, and an increase in the fossil-fuel intensity of the world economy (Peters et al., 2012). The work of Peters et al. (2012), to some extent, indicates that in the economic depression, people may prefer to promote economic development rather green development.

For the structural factors, the correlation coefficient between *istr* (measured by the ratio of secondary industrial output over GDP) and GDPI is positive but not significant, while that between *enstr* (measured by the ratio of non-fossil energy consumption over total energy consumption) and GDPI is positive and significant. Actually, around the world the secondary industry is not exactly labeled with "high energy consumption and high emissions". For example, the secondary industry has the highest energy and emission intensity and produces more than 70% of the total CO_2 emissions in China, while the "Green Industrial Revolution" originates from U.S., Japan, and Germany is leading their second industry in the direction of the green development. In a word, the non-significant correlation between *istr* and GDPI may be due to uneven levels of global industrial development. Non-fossil energy is a kind of clean energy. Increasing the proportion of non-fossil energy can effectively reduce emissions. The impact of lagged integrated oil prices (*price_t*1) on GDPI is positive, indicating that a rise of integrated oil prices is conducive to green development. The positive correlation coefficients between *price_t*1 and ECE, SRE, and CRE further suggest that high integrated oil prices will promote energy-conserving as well as emissions reduction. It is generally known that an increase in integrated oil prices will induce an increase in production and consumption costs. To cut the costs, producers will actively introducing or developing new energy and energy-conserving technologies, and consumers will pay more attention to energy-conserving in their daily lives. That's to say, high integrated oil prices are conducive to green development.

6. Conclusions

In recent years, the issues of energy security, environmental pollution, and global climate change have received more attentions. Promoting green development is the only way to walk out of the current resources and environmental dilemma. This study tries to analyse green development performance of the world regions and countries since the 21st century from a global perspective. To do this, a non-radial DDF based on DEA was first proposed for measuring the global green development performance. Then, a Tobit model is built for testing the impact of influencing factors on green development performance. To operate the empirical analysis from a global perspective, we then sorted out a panel data of 41 regions (including 165 countries/sub-regions) for the period of 2000–2014. Conclusions and the corresponding implications are as follows:

(1) The current global green development performance, energy-conserving efficiency, and CO_2 and SO_2 emissions reduction efficiencies are relatively very low and have been in twists and turns, i.e., an increase during 2000–2007, a decrease during 2008–2009, and a fluctuant increase since 2010. And the current patterns of the global green development are extremely imbalanced. Developed countries of Japan, United States, Austria, Denmark, Ireland, Sweden, and United Kingdom have been leading in green development since the 21th century. While most of the developing countries/regions' GDPIs are relatively low and are following a descending path. The relatively low global green development performance suggests that there is considerable potential of improvement. Narrowing the gaps between the developed and developing regions/countries is one of the most important ways for realizing this considerable potential. It calls for the joint efforts of everyone. For these developing regions/countries, they should realize the importance of green development as soon as possible, pay more attention to promoting green development, and actively introduce and develop energy-conserving and emissions reduction technologies. For these developed countries, they should ease restrictions on technologies exports, especially energy-conserving and emissions reduction technologies exports, to developing countries. Only in this way, can the developing countries catch-up with the developed ones and realize this considerable potential of improvement.

(2) The U-shaped Environmental Kuznets Curve (EKC) exists between GDP per capita and green development performance. That's to say, along with an increase of GDP per capita, there would be a performance decrease at the early stage of income growth and then followed by a performance increase once a certain level of income is reached. Concretely, the inflection point is 2424 US $. Also, there are U-shape EKCs between GDP per capita and energy-conserving efficiency and CO_2 and SO_2 emissions reduction efficiencies. The corresponding the inflection points respectively are 2638, 2151, 2380 US $. So far, there are only several regions/countries (i.e., India, South Asia (Rest of), and Other Africa) whose economic development level is lower than these inflection points. For most regions/countries, their economic developments are conducive to green development. That's to say, they are expected to realize the "win-win" situation between economic and green developments. Although the world is remain dominated by "brown economy", with the continuous development of the global economy, the prospect for the global green development is promising.

(3) Green development performance, energy-conserving efficiency, and CO_2 and SO_2 emissions reduction efficiencies are positively related to factors of altitude (measured by the proportion of population whose living altitude is lower than 5 metres), energy structure (measured by the ratio of non-fossil energy consumption over total energy consumption), and integrated oil prices while negatively related to factor of ecological carrying capacity (measured by the ratio of the forest area over regional territorial area). In addition, the financial crisis occurred since the second half of 2007 has a negative impact on the global green development. In the future, the regions/countries should actively promote energy structure adjustment. Concretely, they should vigorously develop and promote the use of clean energy. Reasonably increases of fossil energy prices can also be made to stimulate the global green development. In addition, it is necessary to strengthen the consensus that climate change is a global problem. These regions/countries whose living altitudes are relatively high and whose ecological carrying capacities are relatively strong should also pay enough attention to green development because no one can be alone in the global climate change.

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