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Model-based assessment of the pattern differences and the equity of national carbon emissions in China during 2000–2010

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ABSTRACT

Land cover information of China was extracted using the supervised classification of remote sensing data and the carbon sink and carbon emissions of each province were calculated by combining the statistical data with the method of the Intergovernmental Panel on Climate Change (IPCC) 2006 listing. With the newly built 3E model, the three indexes of ESI (ecological support index), EDI (equitable distribution index) and EEI (economic efficiency index) were calculated and their spatial pattern characteristics and regional differences over time were analyzed. The research results indicated that as the forest coverage rate increased, the carbon sink of the ecosystem in China also increased. ESI in the central and western China was tending to decrease, while ESI in the eastern coast was growing. Although the EEI gap between eastern China and western China was large, their EDI value gap was becoming shrinking as the economic growth shifted towards the central China and western China. The 3E values which were calculated with the consideration of ecology, equity and efficiency for China's carbon emissions indicated that the carbon emissions in half provinces of China were in good conditions, with benign ecosystem circulation, fairness and high economic efficiency in the recent 11 years. These results could act as references for China's low carbon economic development and also could provide guidance for the spatial pattern planning of China's carbon emissions.

1. Introduction

Currently, global warming has a significant influence on the earth's environment and human life, and it has been a popular topic of global change researches. The increase in carbon dioxide emissions is considered to be one of the most important causes of global warming, in which human activities play an important role in the terrestrial carbon library (Qin et al., 2007, IPCC, 2007, 2008). As a result, researchers in all countries of the world have attached great importance to the study of carbon emissions since the 1980s and have proposed different simulation methods from different perspectives to understand more accurately the effects of carbon emissions and to control carbon emissions to slow global warming trends (Cox et al., 2002; Leemans et al., 2002; Powlson et al., 2011). As a developing country, China has experienced rapid economic growth since the economic reform and encouraging foreign investment, which has inevitably led to an increase in carbon dioxide emissions (Energy research institute, 2003). In 2007, China became the world's largest country in terms of energy consumption and carbon emissions (International Energy Agency, 2010). As a responsible power, China formulated and implemented a series of policies and measures to promote energy savings and emissions reduction. During the period of the "11th five-year plan", China's primary energy consumption growth rate was approximately 6.7%, which corresponds to a 3.4% drop compared to the period of the "10th five-year plan" (Liao and Wei, 2011). China's efforts regarding energy conservation and the reduction of carbon emissions have resulted in a 20% drop in energy intensity. In 2009, China proposed the goal of reducing the intensity of carbon emissions by 45% by 2020 compared to that in 2005, the realization of which requires the joint effort of all the provinces, autonomous regions and municipalities directly under the central government in China. Then the problem comes. Shall all the provinces pay equal efforts for the goal since each province has different carbon emissions according to its own natural and social conditions? What's the regional difference for carbon emissions? It is difficult to solve this problem because there is no unified model in the world now, and there are still different sounds among different countries. The developed countries tend to ignore the history of

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carbon emissions, focusing on the research of how to allocate the world's future carbon emissions credits (J. A. Duro, 2013), while the developing countries try their best to emphasize the fairness. In China, scholars were more likely to adopt the cumulative emissions of a certain historical period Ding et al., 2009, Li and Qi, 2011] or the gini coefficient (Huang and Yang, 2011) for studying the regional carbon emissions based on fairness. As to the study of the pattern of differences, most scholars consider it in absolute quantity with different calculation methods. In large scale research, the IPCC listing method (IPCC, 2006) is often used to calculate carbon emissions for its acknowledgment in worldwide. In China, Some scholars like Shu (2012), Lu et al. (2012), Xiong et al. (2012), Zou et al. (2013) analyzed China's energy carbon emissions by using it. In recent years, the factor decomposition method is also used in China to performed quantitative analyses for regional carbon emissions which maybe more complicated and may have more uncertainty. For example researchers of Li and Sun (2011), Li and Li (2010), Zha and Zhou (2007), Xu et al. (2006), used the IPAT model (Impact = Population * Affluence * Technology), the STIRPAT model (Stochastic Impacts by Regression on PAT), Kaya factorization, and LMDI (Logarithmic Mean Divisia Index) method respectively in the study of China's carbon emissions, and their results varied. As to the smaller region, the scholars at home and abroad often use carbon flux which has been tested by Static box – gas chromatography or by Eddy covariance technique (Wang et al., 2008) which may be very accurate in a little place but it is very hard for applying them in a large scale. Overall consideration, our study used the IPCC listing method. However, the absolute amount of carbon emissions does not correspond to the size of the regional carbon libraries, which means that some high carbon emissions in certain provinces may be offset by their higher carbon sink capacities. Thus, it is unfair for some provinces only considering their absolute carbon emissions or historical cumulate amount regardless their different ecological conditions and social economic development levels. It is particularly important to perform research on carbon emissions under fair conditions to enable proper comparisons.

Based on the above consideration and inspired by Chen et al. (2012), the authors tried to set up a 3E model which includes ecology, equity and efficiency under the frame of ecological economics and can reflect the pattern differences of China's provincial carbon dioxide emissions on fairness comprehensively. With Y_{3E} values for the years of 2000, 2005 and 2010 in China, we can see the reasonable trends of carbon emissions of each province clearly besides the absolute quantity changing trends. Thus we think that Y_{3E} will not only provide a new way for the study of regional spatial differences in carbon emissions but also give fundamental references for the future distribution of carbon dioxide emissions among different provinces of China on fairness.

2. Methods

2.1. Data sources

The paper considered the three periods of NDVI (Normalized Difference Vegetation Index) data of 2000, 2005 and 2010 from SPOT NDVI data with 36 VGT-S10 files each year. The Annual Stacking images were synthesized from the annual NDVI data set of the time series with 36 bands. This study used the DEM (Digital Elevation Model) data from SRTM3 (Shuttle Radar Mission) to assist in the Topography processing after land cover classification, whose spatial resolution is 90 m × 90 m. At the same time, the study used the land use data from the Chinese resources and environment remote sensing data base of 2000 and 2005 as the accuracy references, which were extracted through the TM(Thematic Mapper)/ETM(Enhanced Thematic Mapper)/ETM + data by computer based artificial interpretation.

The data on fossil fuels used in this paper are from the fossil fuels Chinese energy statistical yearbook (NBS, 2001–2012a), and the cement production comes from the Chinese cement yearbook (NBS, 2001–2012b); the Chinese population, the Gross Domestic Product (GDP) and other social and economic data are from China statistical yearbook (NBS, 2001–2012c), and the carbon emissions parameters of energy and cement are from the IPCC 2006 listing.

2.2. Extraction methods for the classification information of land cover

There are six land cover types in the Chinese land use maps of 2000 and 2005, which include Cropland, Woodland, Grassland, Water body, Built-up area and Unused land. All six land cover types have obvious characteristics on the NDVI time series, according to which we can classify the land cover (Peng et al., 2009). In the NDVI classification, the method of spectral angle mapping (SAM) in supervised classification was used (De Carvalho et al., 2006) according to equation (1) (Tang et al., 2005).

$$\cos(ta) = \frac{\mathrm{F_p}^*\mathrm{F_{roi}}}{|\mathrm{F_p}||\mathrm{F_{roi}}|} = \frac{\sum_{i=1}^{n}\mathrm{F_p}i\mathrm{F_{roi}}i}{\sqrt{\sum_{i=1}^{n}\mathrm{F_p}i\mathrm{F_p}i}\sqrt{\sum_{i=1}^{n}\mathrm{F_{roi}}i\mathrm{F_{roi}}i}} \tag{1}$$

Among the classification items, ta denotes the angle between the pixel curve and the curve of the ROI (Regions of Interest), and Fp and $\mathrm{F_{roi}}$ denote the time sequence vectors of the pixel and the ROI, respectively, with $i = 1 \ldots n$, $n = 36$.

Then with the expert model once used by William and Maik (2005) the post classification process was performed and we got the land use classification graphs which were shown in Figs. 1 and 2, respectively. Based on the validation of the classification accuracy, we calculated the total carbon sinks of different provinces with the land classification data from the three periods in combination with the carbon exchange rates of different vegetation (e.g., woodland and grassland).

2.3. Calculation methods for determining China's CO_2 emissions

According to the fourth assessment report of the IPCC in 2007, the main source of increased greenhouse gases is the burning of fossil fuels (IPCC, 2007a). And carbon dioxide emissions resulting from the burning of fossil fuels was nearly 95.13% of the world total emissions in 2004. Worldwide, the emission inventory method of the IPCC2006 is often used according to 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2007b), so we likewise used it to calculate the carbon emissions of fossil fuels and cement consumption in China.

1) Calculation method for determining CO_2 emissions for fossil fuels

To avoid larger errors made by the direct use of the primary energy data, the data used for this article are from the energy statistical yearbook of China pertaining to eight classes of final energy data: raw coal, coke, crude oil, gasoline, kerosene, diesel oil, fuel oil and natural gas. And with formula 2 we could calculate each kind of carbon emissions.

$$Y_e = \sum_{ij} F_{ijy} {*} EF_i \tag{2}$$

In formula 2, Y_e denotes the CO_2 emissions for the various fuels and its unit is tons of CO_2. F_{ijy} is the activity intensity, which denotes