



# The evolution and a temporal-spatial difference analysis of green development in China

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## ABSTRACT

According to the dissipative structure theory, this study establishes an indicator system and information entropy model to analyze the evolution of green development. The integrated weighting method is used to assess the level of green development. Finally, we analyze the level of green development from temporal and spatial perspectives. The results show that the total entropy of almost all provinces and cities in China has been reduced, indicating that the degree of order of the green development system has been strengthened. The level of green development has increased from 2000 to 2014 but overall was not high. From a temporal view, the level of green development converges with a big gap. From a spatial view, there are tremendous differences among the eastern, central, and western areas. Based on these findings, we put forth reasonable suggestions for promoting the level of green development in China.

## 1. Introduction

Development is the theme and common pursuit of human society, while the natural environment is the basic prerequisite for the survival and development of human society; understanding the challenges that exist between supporting the environment and development economics are very important (Barbier, 2014). Since the start of the 21st century, warming of the global climate has become increasingly prominent. Ecological, environmental, resource, and climate crises and other phenomena, such as the “greenhouse effect,” atmospheric ozone depletion, soil erosion, deforestation, land desertification, and water pollution, occur frequently, exacerbating shortages of global environmental resources. As observed in Brown (2004), losses caused by climate change were estimated by the United Nations to be \$150 billion a year by 2010. In 2008, the world was faced with multiple crises (fuel, food, and finance). Facing such new energy and climate crises, human beings must adapt to the future “green prospect” and develop green, low-carbon technologies (Makower & Pike, 2008). In this context, the idea of a “green economy” has become more prominent internationally, particularly in developed countries (Ciocoiu, 2011). In both Europe and Asia, developed economies upgrade their technology, transform their industrial structures, and formulate regulations to control energy prices and inflation, gradually mitigate energy dependency, and lower carbon emissions; developing countries take on the challenge of designing their

own climate change governance at a standard comparable to that of developed countries (Tsai, Lee, Yang, & Huang, 2016).

Green development has a long history. Pearce, Markandya, and Barbier (1989) explained that the green economy advocated for an “affordable economy” and proposed including the costs of harmful activities and exhausted resources in the national balance sheet. Further, they stated that economic development should take the capacity of the natural ecological environment into account fully as the green economy first began to appear worldwide. With economic growth as its goal, the Organization for Economic Cooperation and Development (OECD Indicators, 2011) designed an indicator system that included environmental and resource productivity, natural asset base, quality of life, and policy response. Over time, the theory of green development has gradually matured. The goals of the green economy have evolved from achieving an ecological or economic-ecological system to achieving an economic-social-ecological system, which has laid a solid theoretical foundation for the further study of green development (Shen, Ma, Xie, & Wang, 2014). Economic activities, all of which are subject to the constraints of ecological parameters, take place within a social network (Malone et al., 2014), and an understanding of the relationship between the socio-economic and natural ecological environment has long been an important goal in the process of green development. The link between exergy (Sciubba & Wall, 2007) and entropy is a thermodynamic approach to the analysis of the unavailability of economic, productive,

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or social systems (Lucia, 2016), and the unavailability percentage can be used to support sustainable development (Lucia & Grisolia, 2017).

As green development is a highly intricate system composed of economic, social, and ecological environments, many factors should be considered in its evaluation. Many studies have developed complex and multi-target integrated index systems to analyze the level of green development. Nevertheless, they still remain limited. In a report on China's green development index, a relatively complete green economy evaluation index system was set forth, and the differences in the green economy of 30 provinces and cities in China were analyzed. While the method of assigning weights has some limitations, it almost entirely uses the subjective analysis of the Delphi method for weighting and, with only one year of data, could not achieve a dynamic comparison (Scientific Development and Economic Sustainable Development Research Base of Beijing Normal University, Green Economy and Economic Sustainable Development Research Base of Southwestern University of Finance and Economics, and China Economic Monitoring and Analysis Center of National Bureau of Statistics, 2015). Guo, Mi, and Zhao (2015) used an entropy method, improved TOPSIS model, and obstacle degree model to assess the spatial differentiation of and factors influencing the green development level of Ningxia but could not analyze it in terms of the time dimension. Zhao, Lin, and Chen (2011) took California as an example and introduced foreign countries that established a measurement of the green economic development index system, but they too heavily emphasized the low-carbon economy, ignoring the economic base and the support of natural resources.

According to the World Bank (2009), China has become the world's second largest energy consumer and the largest emitter of carbon dioxide. Current studies generally agree that China's energy consumption and carbon emissions have played a significant role in global carbon dioxide emissions (Geng & Shi, 2014). Since 2007, a series of papers has been published on the implementation of the green economy, while the concept of "greenization" as a national strategy was proposed for the first time in 2015. China's green development faces serious problems. Resource-intensive and labor-intensive products are the major driving forces of the rapid growth of China's economy, aggravating resource scarcity and environmental degradation (Li, 2014). Furthermore, Qian and Liu (2014) showed that the pollution control coefficient in the country is negative but not significant, indicating that the government has not achieved its expected improvements despite its environmental control measures. The implementation of green development is not a short-term process. In order to get results, we must carry out long-term evolution analysis.

Green development is a system consisting of society, the economy, and the natural environment, but few studies have analyzed its evolutionary mechanisms from the perspective of a complex system. In previous studies, the use of information entropy and dissipative structure theory in the urban ecosystem (Lin & Xia, 2013), utilization and protection of cultivated land resources (Xun, Liu, & Wu, 2007), land use structure (Zhao, Xu, Mei, Wu, & Zhou, 2004), and urban landscape patterns (Antropy, 2004) made the application of information entropy and dissipative structure theory in the green development system possible. Based on the information entropy model and dissipative structure theory, this study establishes an evaluation index system, which includes a sustaining input index, imposed output index, destructive metabolism index, and regenerative metabolism index, to study the change in the entropy of the system of green development in China. The green development level of each province and city is calculated via integrated weighting methods. Our discussion focuses on temporal and spatial analyses and directly determines the main influencing factors. Subsequently, we put forward some valuable suggestions for the government.

## 2. Materials and methods

### 2.1. Study area

China is the largest developing country, encompassing 31 mainland provinces, as well as the Hong Kong, Macau, and Taiwan districts. China's total area of land is 9.6 million km<sup>2</sup>, accounting for about 1/15 of the world's total land area. On the whole, China is rich in resources but has a large population and a fragile ecological environment. Thus, the per capita strategic resources that can support development, such as arable land, water, iron ore, coal, petroleum, and natural gas, is far below the global average (SDESDRBBNU et al., 2015). In addition, the natural resources of China are distributed unevenly. Compared with the abundant natural resources in western regions, the resources in most of the eastern coastal areas are limited, and these areas are faced with resource shortages. Since the implementation of the "reform and opening up" policy, China's rapid economic development has made major achievements with a milestone in the history of world economic development of the GDP ranking second in the world for several years. However, the extensive development mode of high growth, high energy consumption, and high emissions has put increasing pressure on the ecological environment. For example, air pollution problems in Beijing, the capital of China, have seriously affected the competitiveness of the city and its national image. According to the national monitoring of air quality of 161 prefecture-level and above cities, 16 cities met the average annual air quality standards, while the urban air quality of 145 cities exceeded the normal standard (SDESDRBBNU et al., 2015). China is not only short on water, but water pollution is also very serious. As a large developing country in the pursuit of modernization, China has faced numerous ecological dilemmas and neglected ecological and environmental problems. For example, there are more than 150 million acres of cultivated land pollution, and more than 40% of cultivated land is degraded. The soil erosion area accounts for nearly one third of the land area, and serious degradation of the forest ecosystem, land desertification, and rocky desertification pose threats to people's lives and property. More urgent is that China has long been in the low end of the global value chain, with the most highly polluting, energy-consuming industries. Historical environmental problems have not been resolved, and the new environmental problems have followed. Therefore, concerning China's current problems, the implementation of a green development strategy is needed. Owing to a lack of data availability, the objects of research in this paper include 30 provinces and cities in mainland China, excluding Tibet.

### 2.2. Methods

The green development system is similar to the urban ecosystem, which is composed of economic, social, and ecological environments. They are of the dissipative structure, which must obtain materials and energies from the outside world and continuously produce products and wastes to maintain a stable and orderly state. At the same time, the system is like a complex organism with constant metabolism that can achieve system optimization and regeneration (Zhang, Yang, & Li, 2006). According to the dissipative structure, the entropy of the system can be divided into two parts. The first is entropy flow ( $\Delta_e S$ ), which is produced when the socioeconomic system exchanges material and energy with the external environment and which can express the co-ordination of the system. The other is entropy production ( $\Delta_i S$ ), which is generated in the socioeconomic system owing to the degradation of the internal environment and the construction of the eco-environment (Depew & Weber, 1988) and which can express the vigor of the system. The total entropy change ( $\Delta S$ ) is the green development status of the overall system and can describe the system as orderly and healthy. The formula can be expressed as follows:

$$\Delta S = \Delta_e S + \Delta_i S. \quad (1)$$

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