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Identifying a pathway towards green growth of Chinese industrial regions based on a system dynamics approach

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ABSTRACT

Green growth is considered a new growth mode to achieve sustainable development worldwide. There are existing studies that analyze the question of how to effectively configure resources, and balance economic development and environmental protection to achieve green growth. However, these studies are mainly focused on discussing effects of three elements on green growth, namely, economy, resources, and environment, without considering dependent interactions among the three elements themselves, and other essential elements, such as population, policy and so on. This paper develops a system dynamics model integrated with five subsystems including economy, population, resources, environment, and policy to investigate pathways towards green growth in a typical Chinese traditional industrial region, Liaoning province. Based on the current policy tools, five path scenarios are considered for policy makers, namely, business as usual scenario, technical innovation scenario, environmental regulations and management scenario, growth demand management scenario, and comprehensive optimization path scenario. Considering respective development objectives of these scenarios, this paper summarizes and analyzes characteristics of the five scenarios by examining long-term prospects of green GDP, energy consumption, and CO_2 emissions. According to the ranking results for these five scenarios, with respect to energy consumption per GDP, energy consumption mix, CO_2 emissions per GDP, cost of resources and environment, and green GDP per capita, the comprehensive optimization path scenario is identified as the most appropriate and effective to achieve green growth in Liaoning province. Finally, policy implications are offered based on the simulation results.

1. Introduction

In order to address resource shortage and climate changes, an increasing number of countries start seeking out new growth modes to realize sustainable development. The governments of the countries, especially developing countries, try to find effective methods to reduce energy consumption and CO_2 emissions, and improve environmental conditions. Many countries started to implement green growth (GG) strategies on country levels, and the "Global Green New Deal" has been introduced worldwide.

GG, as a new mode of economic growth, was first proposed by the United Nations Economic and Social Commission for Asia and the Pacific (UNESCAP) in 2005 (ESCAP, 2005). It was defined as a strategy to promote "win-win" approaches and policies for reconciling conflicts between two important Millennium Development Goals on poverty reduction and environmental sustainability (ESCAP, 2006). Subsequently, the Organization for Economic Cooperation and Development (OECD) described GG as "fostering economic growth and development while ensuring that natural assets continue to provide resources and environmental services on which our well-being relies" (OECD, 2011), where "to do this, it must catalyze investment and innovation which will underpin sustained growth and give rise to new economic opportunities" (OECD, 2011). A consensus view of these two different definitions is that GG fully meets transformation objectives and requirements of conventional economic growth patterns. Since the introduction of GG, the concept was widely accepted by many countries, especially developed countries. For example, South Korea (Mathews, 2012), the UK (HM Government, 2009), Germany (Jänicke, 2012) and Canada (Webb and Esakin, 2011) adopted certain GG practices in order to achieve economic sustainability and low-carbon development.

Since the opening and reforms, China's average annual growth rate of GDP reached 9.81%, far above the world average level of

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2.87%. However, rapid development also caused severe natural resource depletion and environmental pollutions. For instance, the total energy consumption in China increased by 207% from 1.36 billion tce in 1997 to 4.17 billion tce in 2013 (China's National Bureau of Statistics, 2014a); waste water discharge increased by 1572% from 41.58 billion tons in 1997 to 695.44 billion tons in 2013; industrial waste gas emissions increased by 525% from 10.7 trillion cubic meters in 1998 to 66.9 trillion cubic meters in 2013; and industrial solid waste generation increased by 212% from 1.06 billion tons in 1997 to 3.31 million tons in 2013 (China's National Bureau of Statistics, 2014b). In fact, according to experience in developed countries, the coordination of economy and environment can be greatly improved by implementing GG strategies (HM Government, 2009; Jänicke, 2012). Inspired by these significant achievements, Chinese government started to launch its own GG strategy in 2012 (The Eighteenth CPC National Congress, 2012). In the bulletin of the fifth plenary sessions of the 18th Central Committee of the Communist Party (Chinese Communist Party, 2015), the government specifically proposed to implement the green development idea during the 13th Five Year Plan, which demonstrates the government's determination in pursuing GG. Therefore, the identification of effective pathways towards GG becomes significantly important for Chinese regions, especially traditional industrial areas suffering most serious natural resources exploitation and environmental pollutions. For these areas, it is crucial to implement the country's GG strategy.

Currently, there are several studies on the achievement of GG (OECD, 2010; Ploeg and Withagen, 2013). Based on successful GG experience in OECD member countries, OECD (2010) found that good policies had positive effects on improving regional green growth. Ploeg and Withagen (2013) indicated that the combination of R&D subsidies and carbon taxes was the best pathway to achieve green growth. Grover (2013) investigated India's GG strategy, and discovered that there was a significant relationship between green innovations and GG. Lee and Kim (2016) indicated that the momentum from local governments and active citizen participation played key roles in implementing Korea's green energy strategy.

However, most studies focused on some specific pathways towards GG, such as a policy, R&D subsidies, innovation and so on. Only several attempts were made to integrate some pathway factors in a methodology framework by adopting theories and methods, such as the game theory (Carfì and Schilirò, 2012), statistical analysis (Kim et al., 2014; Zaman et al., 2016) and CGE models (Dai et al., 2016). Carfì and Schilirò (2012) devised an appropriate game theory model to address relationships among climate change policies, low-carbon technologies, and green economy, where a fair Kalai-Pareto solution of the competitive model for a win–win scenario was developed. Zaman et al. (2016) adopted econometric modeling techniques to examine effects of energy consumption, environment, health and wealth on BRICS countries' green growth in 1975–2013. Dai et al. (2016) used a dynamic computable general equilibrium (CGE) model to assess economic and environmental impact of large-scale development of renewable energy on green growth in Chinese power sector. The results indicate that large-scale renewable energy development has significant effects on green growth that benefits the development of upstream industries, reshapes the energy structure, and brings substantial environmental co-benefits. However, these existing studies are limited, since economy, resources and environment are major factors impacting the GG system. GG involves many complicate, dynamic and systematic activities, and is definitely influenced by various factors including population and policy (Musango et al., 2014). Therefore, it is extremely important to build an integrated system including economy, population, resources, pollution and policy to explore and identify pathways to achieve GG, which would make research results more close to the reality.

With this goal, a system dynamics (SD) method was applied to investigate the GG system. Our study is one of the first trails that explore dependent interactions among major influencing factors, discuss how the factors of economy, population, resources, environment and policies affect GG's implementation, and further analyze dynamic change characteristics of major influencing factors in order to identify appropriate and feasible pathways to achieve Chinese GG. Also, our research contributes to examining prospects of long-term green economic growth, energy consumption and structure, and CO_2 emissions in China. Using visual observations, the disparity between the current development mode and GG strategy can be confirmed.

Additionally, this study can provide decision-makers, local governments and managers with some implications from the following aspects. First, the effects of environmental policies on GG are discussed in this paper. Therefore, for those governors who intend to protect their countries or regions facing severe resource shortage and environmental pollution, a strategy for enhancing environmental laws and regulations is given in the process of GG implementation. Moreover, although the SD framework is used for the case of Liaoning province, China, the structure of the model is similar to GG systems in many regions. Therefore, by changing values of some parameters, the SD model becomes also appropriate for other regions of China.

The reminder of the paper is organized as follows. Literature review is presented in Section 2. The method is described in Section 3, including data and case background, problem analysis, and the SD model. Section 4 summarizes simulation results based on the model. Section 5 provides policy implications. Finally, Section 6 discusses main conclusions.

2. Literature review

Compared to other methodologies, a SD model is chosen in this paper to identify pathways towards GG for two reasons. First, the method has excellent advantages in dealing with nonlinear, high order complex system problems, especially in analyzing socio-economic-environmental systems (Sahin et al., 2015). Second, with the help of computer simulation techniques, the SD method can visually analyze relationships among various factors, simulate data, as well as describe information related to feedback structures, functions, and behavior of the system (Liu et al., 2015a,b). The model is much easier to apply to simulate various path scenarios to reveal dynamic evolution mechanisms of the GG system.

The SD method was first proposed by J.W. Forrester and his colleagues in 1956, and was specifically designed to analyze complex dynamic feedback systems (Liu et al., 2015a,b). SD models are widely used in various fields, including economic-environmental systems (Niedertscheider et al., 2014), energy management and pollution control (Liu et al., 2015a,b), industrial policy and planning (Ansari and Seifi, 2012) and others. For instance, for economic-environmental systems, F.J. Li et al. (2012) and F. Li et al. (2012) applied a SD model to analyze environmental and economic effects of the eco-agriculture system of Kongtong District, Pingliang City, Gansu Province, China, from 2009 to 2050. Zhang et al. (2014) built a SD simulation model for a regional ecological water carrying capacity to investigate the coordination development of social economy and water eco-environment in Siping area of Jilin Province, China.

For energy management and pollution control, the SD method was widely applied to investigate the performance of energy consumption and CO_2 emissions on the national, regional and industrial levels (Ansari and Seifi, 2013; Wang et al., 2016). Ansari and Seifi (2013) employed a SD model to study energy consumption and CO_2 emission under different production and export scenarios in Iranian cement industry. Their simulation results indicate