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The interactions between China's economic growth, energy production and consumption and the related air emissions during 2000–2011

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ABSTRACT

The growing conflict between economic growth, energy and environment in China has restrained the country's economic development. In this work we investigated the interaction among the Chinese economy, energy production and consumption and the impacts of concomitant air emissions from 2000 to 2011, using an indicator system based on energy, emergy and money units. The results show that China's rapid economic growth has promoted tremendous expansion in energy production and consumption, which have led to increasing the impact of emissions in this study period. During the time examined, energy production and use efficiencies and the structure of the energy sector improved slightly; the self-sufficiency of energy use fluctuated, as petroleum took on an increasingly strong dependence on imports; fossil energy, mainly coming from coal, still has a majority share in energy production and consumption of the nation; the environmental loading intensity of energy consumption decreased slightly while that of energy production increased; most of the impacts of energy-related emissions are derived from their impact on human health; the impact of emissions from energy production made an increasing contribution to the total impact. Generally speaking, China's economic growth still heavily depends on energy-intensive industries that put great pressure on energy supply and pollution control. Although China has made obvious progress in energy mix optimization to save energy and reduce emissions, the pace of improvement still fell behind that of economic growth. Finally, this paper discussed some related issues and presented corresponding suggestions to further coordinate the relationship between the economy, energy production and consumption and the environment.

1. Introduction

The world has seen China's enormous changes in its economic and social growth as well as serious resources and environment related issues, since Reform and Opening of China to international trade and investment beginning in 1978. China's gross domestic product (*GDP*) has continuously increased by an annual average growth rate of 9.83% during 1978–2012 based on constant 1978 prices; meanwhile, the country's energy production and consumption have also risen from 627.70 million tons of coal equivalent (tce) and 571.44 million tce, respectively, in 1978, to 3318.48 million tce and 3617.32 million tce in 2012, with an average annual growth rate of 5.02% and 5.58%, respectively (National Bureau of Statistics of the People's Republic of China (NBSPRC), 2014). Currently China has become the first energy producer and the second largest energy consumer in the world (National Bureau of Statistics of the People's Republic of China (NBSPRC), 2012).

Energy is the driving force for socio-economic development. With rapid economic development and improved standards of living, energy demand in China is continually rising and resource constraints have become more serious. Huge energy demand imposes great pressure on energy supply and raises the country's dependency on energy imports, especially on oil (Liu et al., 2009). China's degree of dependency on foreign oil has exceeded the international warning line and reached 59.1% in 2011. The huge gap between energy supply and demand is endangering China's energy security and has also become a bottleneck to the sustainable development of the country. In addition, low energy efficiency and heavy reliance on fossil fuel are challenging China's energy security (State Council of the People's Republic of China (SCPRC),

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2012a,b). Thus, solving the incongruous relation between energy supply and demand has become a critical strategic issue related to the sustainable development in China.

Moreover, waste emissions from both fossil energy production and consumption lead to all kinds of negative impacts, such as effects on environmental quality that cause human respiratory diseases, economic loss, etc (World Bank, 2007; Wang, 2010a; Matus et al., 2012). Along with the rapid expansion of energy production and consumption, pollution from emissions has become a more and more serious problem in China, because these pollutants have strongly influenced the regional and even the global atmospheric environment (British Petroleum (BP), 2008; International Energy Agency (IEA), 2011; Peters et al., 2007; Ohara et al., 2007). Confronted with growing environmental pollution and resource shortages, the Chinese government has been improving its environmental management systems and promulgating a series of policies and guidelines as support measures (State Development Planning Commission of the People's Republic of China (SDPCPRC), 1994; State Development Planning Commission of the People's Republic of China (SDPCPRC) et al., 1996; Ministry of Environmental Protection of the People's Republic China (MEPPRC), 1998–2005, 2002; State Council of the People's Republic of China (SCPRC), 2007, 2011). In 1983, environmental protection was adopted as one of the two basic state policies, and since 1996 China has formally regarded sustainable development as the fundamental national development strategy. In the 11th Five-Year-Plan (FYP, 2006–2010) (Xinhuanet, 2006), China's central government proposed to build a resources-saving and environment-friendly society and set restricted targets to decrease energy intensity and reduce major pollutant emissions. The work has achieved a remarkable success, though some goals were not fully completed (State Council of the People's Republic of China (SCPRC), 2012a,b). Next, more restricted targets have been set for the 12th FYP (2011–2015) (Xinhuanet, 2011), including a 16% reduction in energy intensity, an 8% reduction of SO_2 and a 10% reduction of NO_X emissions, and an 11.4% share of non-fossil energy in primary energy consumption by 2015 compared to the 2010 level (The central People's Government of the People's Republic of China, 2012). Recently, in order to manage the deteriorated regional conditions in atmospheres mainly derived from high concentrations of PM_{10} and $PM_{2.5}$ in the developed cities, the State Council of China issued an action plan for the prevention and control of atmospheric pollution ("Ten Regulations of the Atmosphere"). This plan presented the overall goal and specific measures for cutting air emissions, setting targets that decrease PM_{10} in the cities by more than 10%, and reduce coal-consumption to 65% of total energy consumption by 2017 compared to the 2012 level (State Council of the People's Republic of China (SCPRC), 2013).

Obviously, the expected growth of anthropogenic emissions depends on economic growth, energy policy and implementation of emission control measures, and all these will influence future environmental quality (Ohara et al., 2007). Meanwhile, the contradictions among economy growth, energy shortages, energy security and environmental protection have become the key issues weakening China's economic driving force and endangering human health (Li et al., 2011a; Zhang et al., 2013). Therefore, it is urgent for China to coordinate the relationship among its economic growth, energy production and consumption and environment.

Many scholars have carried out research on the Chinese economy, energy and environment related issues. Such as energy accounting (Chen and Chen, 2007a,b), energy structure and energy intensity as well as the related impact factors (Li et al., 2011a; Chen and Chen, 2007c); regional atmospheric pollution and control (Chan et al., 2008; Wang and Hao, 2012; Wang et al., 2010), impact of pollutant emissions on public health (Wang, 2010a; Wang and Denise, 2006), economic growth and environmental protection (Yu et al., 2013; Zhang and Wen, 2008), the interaction between energy consumption and economic performance (Midilli et al., 2006; Zhang and Xu, 2012; Wang et al., 2011; Chang, 2010); relationship between energy consumption and economic growth (Zhang and Xu, 2012; Wang et al., 2011; Chang, 2010), the relationship among energy consumption, environment and economic growth (Zhang et al., 2012, 2013; Xia and Xu, 2012), etc. However, few studies were found to address emissions' impact of energy production (especially primary energy production) as well as the interaction between economy, and energy and environment from an overall perspective through a systematic method.

Energy analysis, widely used in energy related fields, can evaluate the efficiency and structure of energy use. However, it cannot assess impact of emissions. Emergy analysis (EA), first proposed by Odum, can quantify impact of emissions. EA is a system evaluation method based on irreversible thermodynamics, ecology and systems theory. Emergy is defined as the available energy (exergy) of one kind that is used up directly or indirectly to make a product or service, and this makes it possible to measure energy with different natures using a common unit (Odum, 1988, 1996). EA has the ability to fully consider environmental contributions that are often neglected or underestimated by other methods, such as economic analysis, energy analysis, etc. Previous studies expanded the fields of study to which this method has been applied and promoted its development. EA has been applied to analyze systems at many different scales of organization, e.g., ecosystems, territories like cities, states, and nations, and the world as a whole (Ulgiati et al., 1995, 2011; Bastianoni et al., 2001; Vassallo et al., 2007; Lomas et al., 2008; Jiang et al., 2008; Brown et al., 2009; Brown and Ulgiati, 2011; Chen and Chen, 2011; Watanabe and Ortega, 2011; Zhang et al., 2011; Su and Fath, 2012; Pereira and Ortega, 2012; Lei and Zhou, 2012; Lin et al., 2013; Lou and Ulgiati, 2013; Giannetti et al., 2013; Song et al., 2013; Liu et al., 2014; Coscieme et al., 2014; Arbault et al., 2014, etc.). Hence, it can act as a feasible tool to assess efficiencies of environmental and social economic systems through considering energy hierarchy. However, some useful details of systems, which can provide beneficial references for decision-making, could be lost during the course of conversions of resources, energy, money and labor. Therefore, some other measurement tools such as money, energy, etc., may be combined with EA so as to provide a look at detailed information on the system from other perspectives, e.g., economics in the case of money.

This paper aimed to establish an indicator system based on energy, emergy and money units to describe the relationship among economic growth, energy production and consumption and air emissions. And then this system of indicators was applied to investigate the relationship among economic growth, energy production and consumption and the related air emissions in China during 2000–2011 so as to provide beneficial suggestions for decision-makers.

2. Materials and methods

2.1. Materials

In this paper, the basic data on the economy, energy production and consumption came from various national statistics yearbooks published by the National Bureau of Statistics of the People's Republic of China (data involved in this work came from China's National Statistics Yearbooks except for some specific illustrations), including the China Statistical Yearbook 2001–2012 (National Bureau of Statistics of the People's Republic of China (NBSPRC), 2002–2013a), China Energy Statistical Yearbook 2001–2012 (National Bureau of Statistics of the People's Republic of China (NBSPRC), 2002–2013b); the environmental data came