Available online at www.sciencedirect.com
ScienceDirect
Environmental Modelling & Software 22 (2007) 378–393
Environmental Modelling & Software
www.elsevier.com/locate/envsoft

A model for China's energy requirements and CO_2 emissions analysis ☆

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Received 17 December 2004; received in revised form 28 November 2005; accepted 9 December 2005
Available online 20 March 2006

Abstract

This paper introduces a model and corresponding software for modeling China's Energy Requirements and the CO_2 Emissions Analysis System (CErCmA). Based on the input–output approach, CErCmA was designed for scenario analysis of energy requirements and CO_2 emissions to support policymakers, planners and others strategically plan for energy demands and environmental protection in China. In the system, major drivers of energy consumption are identified as technology, population, economy and urbanization; scenarios are based on the major driving forces that represent various growth paths. The input–output approach is employed to compute energy requirements and CO_2 emissions under each scenario. The development of CErCmA is described in a case study: China's energy requirements and CO_2 emissions in 2010 and 2020 are computed based on the input–output table of 1997. The results show that China's energy needs and related CO_2 emissions will grow exponentially even with many energy efficiency improvements, and that it will be hard for China to maintain its advantage of low per capita emissions in the next 20 years. China's manufacturing and transportation sectors should be the two major sectors to implement energy efficiency improvements. Options for improving this model are also presented in this paper.

Keywords: Energy requirement; CO_2 emissions; Scenario analysis; Input–output model

1. Introduction

Global warming, caused by increasing emissions of CO_2 and other greenhouse gases as a result of human activities, is one of the major threats now confronting the environment. CO_2 accounts for the largest share of total greenhouse gases, and its impact on the environment is also the greatest. If anthropogenic CO_2 emissions are allowed to increase without limits, the greenhouse effect will further destroy the environment for humans and all other living beings, threatening the existence of humankind.

In order to control the continuous global warming and protect the living environment, the Kyoto Protocol to the United Nations Framework Convention on Climate Changes, signed in Kyoto, Japan in 1997, sets detailed emissions mitigation commitments for the 38 major industrialized countries.

Although the protocol did not set an explicit CO_2 reduction obligation for China and other developing countries, these nations still face great pressure from the environment. In 2003, CO_2 emissions caused by fuel combustion in China were about 0.849 billion tons of carbon (tC), accounting for 13.1% of the world's total, second only to the United States, the largest CO_2 emitter worldwide (IEA, 2003).

In addition to the current high CO_2 emissions is the probability that China's economy will continue to grow rapidly over the next 50 to 100 years (Development Research Center of the State Council of China, 2003). Since almost all of economic

☆ National Natural Science Foundation of China under grant Nos.70425001, 70573104 and 70371064, and the Key Projects of National Science and Technology of China (2001-BA608B-15, 2001-BA605-01).

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doi:10.1016/j.envsoft.2005.12.007

activities consume energy, energy needs, along with CO_2 emissions, will inevitably increase, which will likely create tensions between the country's need for economic growth, energy and environmental protections. These divergent pressures could hinder China's goal of sustainable development. To address this problem effectively, analysis tools are required so as to support energy and environmental policy decision making. For this purpose, this study investigated and developed China's Energy Requirements & CO_2 Emissions Analysis System (CErCmA) to assess how changing certain social and economic policies could impact China's future energy needs and CO_2 emissions.

Many studies have examined CO_2 emissions analysis tools including Silberglitt et al. (2003), Savabi and Stockle (2001), Roca and Alcántara (2001), Gielen and Moriguchi (2002), Clinch et al. (2001), Hsu and Chen (2004), Winiwarter and Schimak (2005), Galeotti and Lanza (2005), Pan (2005), Scrimgeour et al. (2005), Ball et al. (2005) and Sun (1999). Similar investigations into CO_2 emissions analysis tools geared for China include presenting forecasts of energy consumption and related emissions (Lu and Ma, 2004; Chen, 2005; Crompton and Wu, 2005; Gielen and Chen, 2001), analyzing strategies for developing a sustainable energy system (Qu, 1992; Wu and Li, 1995; Ni and Thomas, 2004; Xu et al., 2002), assessing impacts of driving forces on historical emissions (Wu et al., 2005 and Zhang, 2000), exploring various types of energy technology (Wu et al., 1994; Yan and Kong, 1997; Feng et al., 2004; Mu et al., 2004; Eric et al., 2003; Solveig and Wei, 2005), and energy efficiency standards (Lang, 2004 and Yao et al., 2005).

This study aims to extend current studies to obtain not just one scenario but several possible energy requirements and emissions scenarios under different growth paths of various driving factors (not just focusing on technology factors but also focusing on changes in social and economic factors).

The model and software for China's Energy Requirements and CO_2 Emissions Analysis System (CErCmA) were developed by combining the input–output model (I–O model) with the scenario analysis concept.

China's energy system is huge and complex with many uncertainties due to the driving forces of energy requirements. The traditional trend extrapolation approach works only when the changes in driving forces follow established paths, but can shed little light on the case of driving forces moving in a brand-new orbit, e.g., certain risks or challenges baffle economic development.

The current popular scenario analysis operates in a different way in that "it does not try to predict the future but rather to envision what kind of futures is possible" (Silberglitt et al., 2003). Through the description of various possible future scenarios representing different growth paths, driving force uncertainties can be taken into account. Under each scenario, the input–output model is employed to assess China's energy requirements along with its CO_2 emissions.

In recent years much attention has been given to these issues. Some of these studies perform sensitivity analyses on one or more social and economic factors. Others identify certain key factors affecting CO_2 emissions and evaluate their impacts (e.g., Lee and Lin, 2001; Paul and Bhattacharya, 2004; Yabe, 2004). Some focus on one factor, such as socioeconomic structural change (Kainuma et al., 2000), or consumption patterns (Kim, 2002).

Other researchers primarily analyze the impact of certain economic activities or governmental policies on energy consumption and related CO_2 emissions, such as the impact of international trade (Machado et al., 2001; Sánchez-Chóliz and Duarte, 2004; Kondo et al., 1998; Cruz, 2002), and the effects of certain policy reforms or frameworks (Bach et al., 2002; Christodoulakis et al., 2000).

Our study extends the sensitivity analysis and applies it to China's energy and environmental protection issues. Firstly, major energy consumption impact factors are identified: economic growth, technological changes, population growth, changing consumption and production patterns, and urbanization. Secondly, we construct a set of future scenarios describing different growth paths based on these factors; then we apply the I–O model to compute energy requirements along with CO_2 emissions under each scenario.

This paper is organized as follows:

In Section 1 the CErCmA modeling framework is described, along with its underlying rationale, design principles, model components and a case study.

Section 2 presents the rationale for using the I–O model to analyze China's energy requirements and CO_2 emissions along with the system components. Section 3 introduces software we developed based on the system explained in Section 2. Section 4 presents an application to assess China's energy requirements along with projected CO_2 emissions in 2010 and 2020; this is followed by conclusions and corresponding policy recommendations. Finally, strengths, research challenges and further work needed to improve the system are presented in Section 5.

2. CErCmA: approach and components

2.1. Basic approach: input–output model

The CErCmA system was established based on the input–output (I–O) model, an analytical framework developed by Professor Wassily Leontief in the late 1930s. The main purpose of the input–output model is to establish a tessellated input–output table and a system of linear equations.

An input–output table shows monetary interactions or exchanges between the economic sectors and therefore their interdependence. The rows of an IO table describe the distribution of a sector's output throughout the economy, while the columns describe the inputs required by a particular sector to produce its output (Miller and Blair, 1985).

The system of linear equations also describes the distribution of a sector's output throughout the economy mathematically, i.e., sales to processing sectors as inter-inputs or to