Engineering 3 (2017) 512–517

Contents lists available at ScienceDirect

Engineering

journal homepage: www.elsevier.com/locate/eng

Research
Clean Energy—Article

An Empirical Study on China's Energy Supply-and-Demand Model Considering Carbon Emission Peak Constraints in 2030

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A R T I C L E I N F O

Article history:
Received 28 April 2017
Revised 11 July 2017
Accepted 12 July 2017
Available online 15 August 2017

Keywords:
Carbon emission
Peak
Energy supply and demand
Model
Scenario

A B S T R A C T

China's energy supply-and-demand model and two related carbon emission scenarios, including a planned peak scenario and an advanced peak scenario, are designed taking into consideration China's economic development, technological progress, policies, resources, environmental capacity, and other factors. The analysis of the defined scenarios provides the following conclusions: Primary energy and power demand will continue to grow leading up to 2030, and the growth rate of power demand will be much higher than that of primary energy demand. Moreover, low carbonization will be a basic feature of energy supply-and-demand structural changes, and non-fossil energy will replace oil as the second largest energy source. Finally, energy-related carbon emissions could peak in 2025 through the application of more efficient energy consumption patterns and more low-carbon energy supply modes. The push toward decarbonization of the power industry is essential for reducing the peak value of carbon emissions.

1. Introduction

In the 2015 United Nations Climate Change Conference (COP21), all Parties unanimously adopted the Paris Agreement and proposed to keep the global average temperature rise within 2 °C and to control it within 1.5 °C. The Chinese government proposed to have China's carbon dioxide emissions peak by 2030, and strives to achieve that goal as soon as possible. As carbon dioxide emissions mainly come from fossil energy consumption, total carbon dioxide emissions as a new hard constraint will have a significant impact on total energy supply and demand, growth rate, and the structure of China's economy from now to 2030. The quantitative analysis of these effects has important theoretical and practical significance for the development of medium- and long-term energy planning and policies.

Existing carbon emission peak research primarily focuses on the carbon emission growth momentum, peak time, and peak level, as well as on the peak path of regions and sectors. Wang et al. [1] pointed out that GDP growth is the biggest driver of China's carbon emissions growth, and Chai [2] further suggested that industrialization is the primary factor determining whether carbon emissions will peak ahead of time. According to studies by Qu and Guo [3], Jiang et al. [4], and Ma and Chen [5], if the energy-saving and low-carbon mode is adopted for economic and social development, then energy-related carbon dioxide emissions will peak around 2030, with the emission peak coming as early as 2025. Yang et al. [6] and Liu et al. [7] have predicted the carbon emissions peak in Beijing, Chongqing, and other places. Cheng and Xing [8] and Guo [9] have studied the path toward peak carbon emissions in the fields of electric power and industry.

The existing research highlights the role of the energy industry in defining the peak impact and the path toward realization of a lower carbon path. However, the focus mainly lies on the total primary energy consumption. There is a lack of overall systematic optimization analysis regarding the primary energy supply structure, terminal energy consumption structure, power generation and power source structure, energy processing and conversion, and other major energy issues. As a result, it is difficult to answer questions regarding

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http://dx.doi.org/10.1016/J.ENG.2017.04.019

the energy supply-and-demand structure, carbon flow, and other important issues that are necessary for determining different peak scenarios. Bearing this in mind, this paper attempts to construct a model of China's energy supply and demand by considering constraints such as the carbon emission peak from the perspective of "energy-economy-environment" (3E) system simulation and to analyze the total energy supply and demand, growth rate, system structure, and detailed carbon emissions for different peak scenarios.

2. Model

Based on classical research methods and models such as MARKAL (Market Allocation Modeling Framework)/TIMES (The Integrated MARKAL-EFOM System) [10], NEMS (National Energy Modeling System) [11], MAED (Model for Analysis of the Energy Demand) [12], AIM (Asia-Pacific Integrated Model) [13], and LEAP (Long-Range Energy Alternatives Planning System) [14], the modeling ideas of "bottom up," "top down," and a 3E system are adopted. These ideas allow the design of China's energy supply-and-demand model to be based on a comprehensive consideration of economic development, technological progress, policies, resources, environmental capacity, and other factors. The model framework is shown in Fig. 1.

The model calculation is divided into two stages. In the first stage, a scenario designed for economic and social development and technological progress is conducted in order to estimate the GDP, population, urbanization rate, and other basic parameters of economic and social development. Econometrics, elastic coefficient, and other methods are then applied to predict the energy service demands required by residential areas and by various industries, including construction, transportation, commerce, and other sectors. Next, the unit consumption method of output value, the unit consumption method of product, the turnover analysis method, and other methods are used to determine the terminal energy demand of different sectors. On this basis, the time series, energy price ratio, and other methods are used to predict the variety of fuel sources used to meet the required energy demand. Varieties include coal, oil, natural gas, electric power, heating power, and other energy sources. In the second stage, by considering power generation, heating, oil refining, coking, gasification, and other processing and conversion links, the total amount and structure of the primary energy supply are obtained through an energy system simulation calculation. This allows proper attention to be paid to both the total carbon emissions (as the main constraint) and the energy supply-and-demand balance, taking into consideration energy resources, processing, conversion capacity, proportion of non-fossil energy, and other constraints (balance). The energy-related carbon dioxide emissions are calculated based on the input-output relations and related physical energy efficiencies of primary energy sources, terminal energies within various links of the supply side, several sectors of the demand side, and the Intergovernmental Panel on Climate Change (IPCC) carbon emission factor.

The main constraints (balance) involved in the second stage of the energy system simulation are as follows.

(1) Constraints of carbon emission peak:

$$Ca_t \le Ca_{\mathrm{T}} \tag{1}$$

where t is the year in the planning period (t = 1, ..., 15 represent 2016, ..., 2030, respectively), T represents the peak year of the planning period, and Ca_t represents the energy-related carbon dioxide emissions in the tth year.

$$Ca_t = \sum_{i=1}^{3}\Big(\big(EP_{it} + IM_{it} - EM_{it}\big) \times RLO_{it} + \big(EP_{it} + IM_{it} - EM_{it}\big) \times \big(1 - RLO_{it}\big) \times RTP_{it} + TG_{it} \times EG_{it} + TH_{it} \times EH_{it} + FD_{it}\Big) \times Emi_i \tag{2}$$

where i is the type of fossil energy (i = 1, 2, and 3 represent coal, oil, and natural gas, respectively); EP_{it}, IM_{it}, EM_{it}, RLO_{it}, RTP_{it}, and FD_{it}

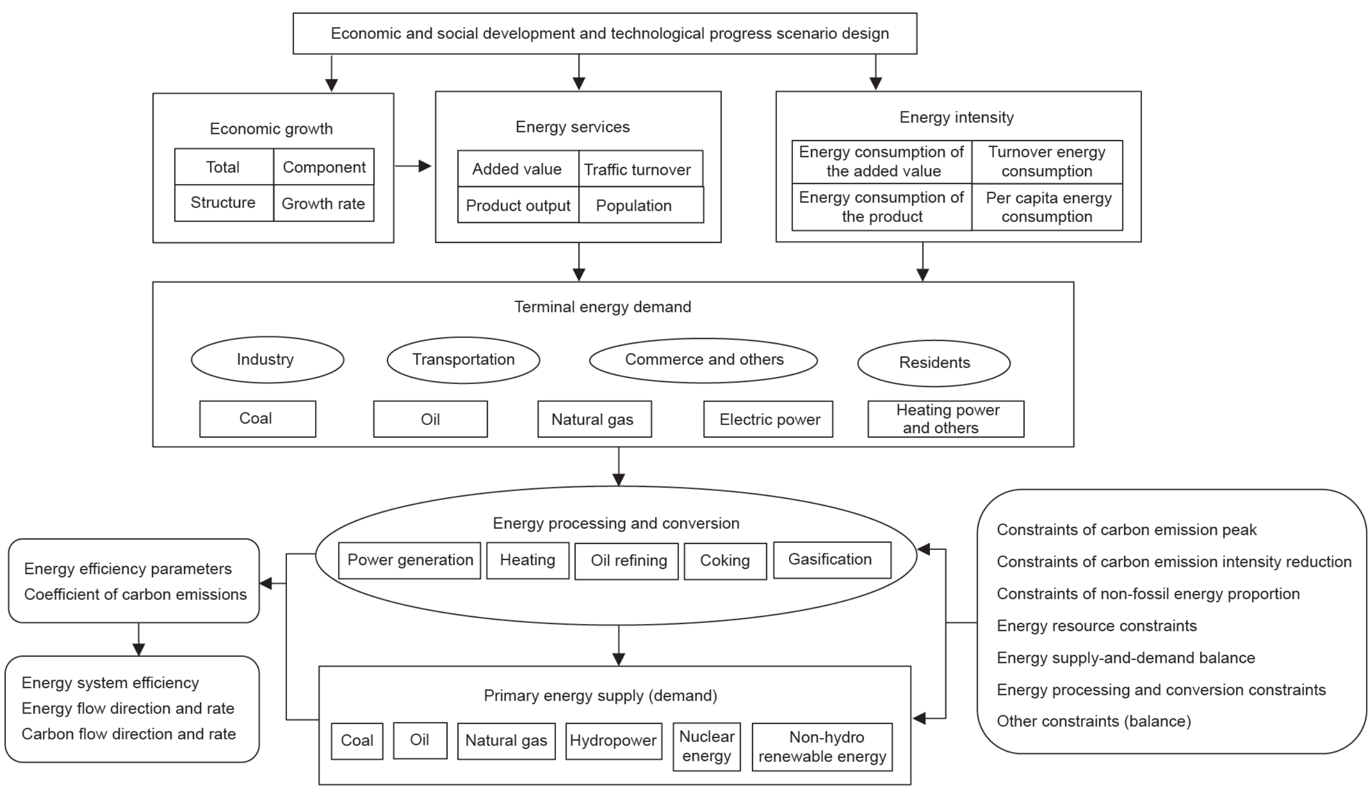

Fig. 1. China's energy supply-and-demand model framework.