Energy Policy 68 (2014) 508–523

Contents lists available at ScienceDirect

Energy Policy

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

Peak energy consumption and CO_2 emissions in China

Jiahai Yuan [a,*], Yan Xu [a], Zheng Hu [b,**], Changhong Zhao [a], Minpeng Xiong [a], Jingsheng Guo [a]

[a] School of Economics and Management, North China Electric Power University, Beijing, China
[b] Center for Energy and Environmental Policy, University of Delaware, DE, USA

HIGHLIGHTS

- A framework for modeling China's energy and CO_2 emissions is proposed.
- Scenarios are constructed based on various assumptions on the driving forces.
- Energy consumption will peak in 2035–2040 at 5200–5400 Mtce.
- CO_2 emissions will peak in 2030–2035 at about 9300 Mt and be cut by 300 Mt in a cleaner energy path.
- Energy consumption and CO_2 emissions per capita will peak soon after China steps into the high income group.

ARTICLE INFO

Article history:
Received 14 November 2013
Received in revised form
27 December 2013
Accepted 16 January 2014
Available online 4 February 2014

Keywords:
Energy consumption
CO_2 emissions
long-term scenario
China

ABSTRACT

China is in the processes of rapid industrialization and urbanization. Based on the Kaya identity, this paper proposes an analytical framework for various energy scenarios that explicitly simulates China's economic development, with a prospective consideration on the impacts of urbanization and income distribution. With the framework, China's 2050 energy consumption and associated CO_2 reduction scenarios are constructed. Main findings are: (1) energy consumption will peak at 5200–5400 million tons coal equivalent (Mtce) in 2035–2040; (2) CO_2 emissions will peak at 9200–9400 million tons (Mt) in 2030–2035, whilst it can be potentially reduced by 200–300 Mt; (3) China's per capita energy consumption and per capita CO_2 emission are projected to peak at 4 tce and 6.8 t respectively in 2020–2030, soon after China steps into the high income group.

1. Introduction

The pattern of energy consumption plays an essential role in social-economic development. The growth of per capita energy consumption and per capita CO_2 emissions shows an approximately inverted “U” curve, namely Environmental Kuznets Curve (EKC) (Selden and Song, 1994; Grossman and Krueger, 1995). There are debates on whether EKC could be found in developed countries' CO_2 emissions/energy consumption pattern (Iwata et al., 2011; Jakob et al., 2012). The global achievement of ambitious climate targets particularly requires radical reduction of CO_2 emissions in industrialized countries as well as control of emissions in developing countries (IPCC, 2007). However, there have been opposite trends, for instance, Raupach et al. (2007) found that in 2000–2004, economic growth in developing and less developed countries were the main driver for increasing global CO_2 emissions.

China became globally the largest CO_2 emitter since 2009. The Chinese government proposed to address the emission issue by releasing several energy targets: 20% reduction of energy intensity of the economy by 20% during 2005–2010, 40–45% reduction of GDP CO_2 intensity during 2005–2020, and a 15% clean energy share target by 2020 (Yuan et al., 2011; State Council of China, 2013). In the 18th National Congress of CPC, China's new administrative government released stronger targets of doubling total GDP and per capita income by 2020 on the 2010 levels (Hu, 2012). Meanwhile, the concept of “ecological civilization and beautiful China” was firstly proposed, which indicates Chinese Government's high attention to the environmental and ecological impact of energy consumption.

China is currently in the process of industrialization and urbanization. The following questions are proposed: “what is the expected growth of China's future energy consumption?”, “would CO_2 emissions reach a peak (or a plateau) or would it be monotonously increase in the long run?”, and “when and what is the peak of China's CO_2 emission?” This paper seeks to address these questions, from the perspective of China's recently-declared social-economic policies and related energy and environmental impacts.

The paper is organized as follows: Section 2 reviews literatures of current discussions. Section 3 presents the methodology. Section 4 provides the historical trajectory of driving factors and sets assumptions for the scenarios. Section 5 presents the

* Corresponding author. Tel.: +86 10 61773 091.
** Corresponding author.
E-mail addresses: yuanjh126@126.com (J. Yuan), brucehu06@gmail.com (Z. Hu).

0301-4215/$ - see front matter
http://dx.doi.org/10.1016/j.enpol.2014.01.019

scenarios from the perspective of international comparative study. Section 6 concludes the paper.

2. Literature review

2.1. Environmental Kuznets curve

The EKC hypothesis implies environmental issues would be concerned only when economic growth reaches a certain level (Grossman and Krueger, 1991; IBRD, 1992). According to Stern (2004), The EKC seeks to expound and prove a two-track argument: (1) whether there is an inflection point in the curve of per capita CO_2 emissions vs. GDP per capita; and (2) whether there is a reflection of convergence on per capita CO_2 emissions. Regarding inflection point, Richmond and Kaufmann (2006) found limited evidence of EKC in OECD countries. Jaunky (2011) found no inflection point in 36 high-income countries for the period 1980–2005 but indicated that over time CO_2 emissions would be stable. For developing countries, no inflection point has been found, which is consistent with the EKC hypothesis (Jakob et al., 2012; Jaunky, 2011).

Regarding convergence, Some scholars argued that CO_2 emissions of the OECD countries showed a significant sign of convergence, according to Strazicich and List (2003), Aldy (2006), Lee and Chang (2008), Romero-Ávila (2008), Westerlund and Basher (2008), and Meng et al. (2013); while on the other hand, Barassi et al. (2008) suggested an opposite argument. Van (2005), Stegman (2005), Panopoulou and Pantelidis (2009), and Jobert et al. (2010) found strong evidence of global convergence; however, some others proved the divergence of per capita CO_2 emissions; e.g., Aldy (2006). Lin and Li (2013) found an absolute convergence of per capita CO_2 emissions over the period of 1971–2008 within subsamples grouped by income level. Furthermore, there was an argument of lacking evidence of absolute convergence in the full sample containing 110 countries.

Methods of data and variable selection are key determinations of various EKC results. For instance, due to changes in fuel composition's direct impacts on emissions, per capita energy consumption is more appropriate than CO_2 emissions per capita as the dependent variable. But for a sample of 113 countries covering the period 1971–2004, no evidence of EKC was detected in the world as a whole or in single country level (Luzzati and Orsini, 2009). However, Jakob et al. (2012) found the existence of EKC in the panel data of 21 industrialized countries over the period of 1971–2005.

Sun (1999) argued that CO_2 EKC merely reflects the theory of peak-value for energy intensity. What is behind is the structure shifts from the higher energy intensity of heavy industry to the lower intensity of light industry; and the product structure changes from general value-added to higher value-added, from material production to knowledge production. Therefore, we believe that CO_2 EKC is a reflection of the historical pattern of energy intensity; it is not the guidance to determine when a country's environment starts to improve. What's interesting is that inflection points of both energy intensity curve and CO_2 EKC occurred in China in 1977, where per capita GDP was 250US$. Jalil and Mahmud (2009) also found the evidence of EKC for China during 1975–2005.

2.2. Peak energy consumption and CO_2 emissions in China

Various scenarios show that China's future energy consumption and GHG emissions have been largely improved (Vuuren van, et al., 2003; Wang and Waston, 2009, 2010; McKinsey and Company, 2009; Steckel et al., 2011; Rout et al., 2011; Zhou et al., 2013). Jiang et al. (2009) analyzed China's long-term scenarios of energy consumption and GHG emissions in 2000–2050. Accordingly, energy consumption will continue to increase, whilst under the reinforcement of low-carbon scenario, CO_2 emissions is estimated to reach the peak in 2030. Lin and Jiang (2009) applied the original CO_2 EKC simulation model to predict China's emission and found that inflection point is likely to happen in 2020.

In addition, International Energy Agency (IEA) set an aggressive "450 Scenario" by 2030 with China-specific policy assumptions and outlook (IEA, 2009a). Lawrence Berkeley National Laboratory (LBNL) projects China's primary energy demand would rise continuously and approach a plateau around 2040. CO_2 emissions will approach a plateau in 2025 or 2030 depending on the underlying assumptions.

Energy Research Institute (ERI) of National Development and Reform Commission (NDRC) published a 2050 China Energy and CO_2 Emissions Report in2009, which described the potential energy and emissions scenarios in 2050 (CEACER, 2009), where energy demand in 2050 is expected to reach 6690 Mtce in the baseline scenario and 5560 Mtce in the low-carbon scenario. Moreover, Chinese Academy of Engineering proposed a "scientific, green and low-carbon" energy strategy and projecting CO_2 emission to reach 9 billion tones in 2030 (CAE, 2011).

To sum up, firstly, EKC can be used as an important tool to observe the income-pollutant relationship for developing countries. Secondly, due to the complexity of CO_2 emissions, some additional factors would be essential to model CO_2 emissions. Thirdly, complexity of modeling structuring and variables would result in difficulty of understanding scenarios. Furthermore, subjective assumption of parameter/scenario settings could lead to incommensurable results and misleading policy.

3. Methodology of the study

The Kaya identity states that total emission level can be expressed as the product of four inputs: population, GDP per capita, energy use per unit of GDP, and carbon emissions per unit of consumed energy (Kaya and Yokobori, 1997). In order to adopt the Kaya identity to capture China's characteristics, firstly, residential energy consumption accounts for only 10% of primary energy but the share would be substantially increasing. It is important to differentiate energy consumption for production and for daily life. Secondly, due to the severe gap between rural and urban household energy consumption, it is essential to model the impact of urbanization process. Thirdly, since China's economic structure is transmitting to service-based economy and China's energy efficiency is still low, we want to model the impact of economic output as well as energy efficiency improvements. Accordingly, we adapt the equation as follows:

$$EI_{GDP} = \frac{E}{GDP} = \frac{E_P + E_R}{GDP} \tag{1}$$

$$\frac{E_P}{GDP} = \frac{E_{PP} + E_{PS} + E_{PS}}{GDP} = \sum_{i=1-3} (S_i I_i) \tag{2}$$

$$E_R = E_{UR} + E_{RR} = \frac{e_U}{I_U} \times \frac{I_U}{gdp} \times P \times R_U + \frac{e_R}{I_R} \times \frac{I_R}{gdp} \times P \times (1 - R_U) \tag{3}$$

$$CI_{GDP} = \frac{CO_2\ \text{Emissions}}{GDP} = \frac{E}{GDP} \times \frac{CO_2\ \text{Emissions}}{E} = EI_{GDP} \times EF_E \tag{4}$$

$$EF_E = \sum_i (E_s ef) \tag{5}$$

$$CO_2\ \text{emissions} = GDP \times CI_{GDP} \tag{6}$$

According to the model, primary energy consumption (E) is decomposed into production use (E_P) and household use (E_R). The productive factor can be expressed as the sum of products of all output shares (primary, secondary and tertiary, S_i) and their corresponding energy