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Exploring potential pathways towards fossil energy-related GHG emission peak prior to 2030 for China: An integrated input-output simulation model☆

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A B S T R A C T

This study develops a dynamic integrated input-output simulation model to explore potential pathways towards GHG emission peak prior to 2030 for China. Dynamic energy consumption intensities and GHG emission intensities (GHGEIs) of sectors (household), as well as various levels of economic growth are set in 4 scenarios (each containing 4 sub-scenarios). The impacts of changes in the added value (reflected as industrial restructuring) and changes in GHGEIs (reflected as technological advancement and intensified policies) of 10 target sectors including both promoted and constrained ones on the peak are elaborated. In the Business-as-Usual scenario, no emission peak could appear before 2040 along the historical trends without taking further intensified emission reduction policies. In Scenario 1 and 2, when economic growth is maintained at higher levels, sole dependence on changes in either added value or GHGEIs of sectors could curb GHG emissions, however without contributing to a peak timing before 2030. The peak timing could be advanced to 2026 (10.85×10^9 t CO_2-e), 2025 (10.77×10^9 t CO_2-e), 2024 (10.69×10^9 t CO_2-e) and 2023 (10.65×10^9 t CO_2-e) corresponding to different levels of economic growth in Scenario 3, where industrial restructuring and intensified energy and GHG emission reduction policies are involved. The results are expected to provide references to future planning of energy utilization and GHG emission reduction from the perspective of both the country and sectors.

1. Introduction

The fifth assessment report released by Intergovernmental Panel on Climate Change (IPCC) analyzed the causal relationships between anthropogenic activities and global climate change, and emphasized the necessity to reduce greenhouse gas (GHG) emissions and mitigate the effects of climate change (IPCC, 2014). As the largest energy consumer and GHG emitter being responsible for about 20% of global GHG emissions, China has been confronting the urgent pressure to actively address climate change. The control of its total GHG emissions and relevant policies are of great importance to assess the likelihood of achieving the 2 °C climate goal (Elzen et al., 2016). A series of reduction targets have been announced officially, including increasing the consumption proportion of new and renewable energy to 15% and reducing its carbon emission intensity by 18% below 2015 levels by the year 2020 (NDRC & NEA, 2016). The pledge of peaking its GHG emissions around 2030 made in The U.S.-China Joint Announcement on Climate Change in November 2014 was again stated and reinforced in The Paris Agreement under the United Nations Framework Convention on Climate Change in December 2015 (Shen and Sun, 2016; Zheng et al., 2017). Such a goal of emission peaking is a tough challenge reflected in the nexus among economic growth, energy consumption and GHG emissions. Soaring energy consumption and the subsequent increased GHG emissions are inevitable results of economic growth, which in turn has to be dependent on energy consumption to maintain a certain level.

The task of emission peaking incorporates determining both the timing and magnitude of the peak. Economic growth and energy consumption, definitely fossil energy consumption, are the key interactional determinants of the peak. Owing to lower energy

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Nomenclature

Variables

X	total output
x	industrial intermediate requirements
a_{ij}	input coefficients from sector i to j
Y	household income
H	household consumption
G	government consumption
ΔK	capital formation
N	net export
V	added value
η	income rate
τ_d	direct tax rate
α	share of household consumption
β	household saving rate
τ	indirect tax rate
S	savings
I	net investment
K	capital stock
δ	depreciation rate
γ	capital stock rate
V	added value
v	added value rate
ε	comprehensive energy production coefficient
ς	comprehensive energy consumption intensity (CECI)
φ	comprehensive energy import (export) coefficient
ω	greenhouse gas emission intensity (GHGEI)
g	average growth rate of added value

Subscripts

i,j,m,n:	industrial sectors
h	household consumption
g	government consumption
t	time (year) (denoting an endogenous variable determined by the model)

consumption, GHG emissions would peak earlier with smaller magnitude in a sluggish or slow-growing economy. Contrastively, in a prosperous economy with greater growth in energy consumption, the magnitude of the peak would be larger and the timing would likely be delayed (Wang et al., 2014). China undoubtedly pertains to the latter case, confronted with the dilemma of pursuing a smaller magnitude and an earlier timing of the peak whilst keeping the economic growth at a relatively high level to meet the demand of a tremendous population. Traditional pathways towards high-speed industrialization and urbanization have led to lower energy efficiency and remarkable impacts on China's natural resources and environment, entailing sustainable strategies targeting stringent emission reduction, energy conservation and structure adjustment (Wang and Zou, 2014). This leads to much interest in researches to explore the driving factors of the historical and current GHG emissions, and to project future GHG emissions including the emission peak, both for more targeted policy proposals.

Widely adopted as a tool to represent the relationship between environment and development, Environmental Kuznets Curve (EKC) theory is frequently utilized to examine the relationship between GHG emissions and economic growth from regional and sectoral level, always combined with panel data and regression analysis (Chang, 2015a; Li et al., 2016; Riti et al., 2017). Some additional factors are often introduced to extend the EKC model for examining their impacts on GHG emissions (Kang et al., 2016; Wang et al., 2017b). Besides, decomposition techniques are a tool to decompose the changes of energy-related GHG emissions into their driving factors, among which LMDI is the most adopted and favorable one (Wang et al., 2017a). Main influencing factors are found to be energy intensity, energy mix, industrial structure, GDP structure, GDP itself, etc (Jiang et al., 2017; Ye et al., 2017; Zhang et al., 2016a). Some scholars also employs the IPAT for both investigating the driving factors (Wang et al., 2016; Shuai et al., 2017) and forecasting future GHG emissions (Xu et al., 2017; Yuan et al., 2014; Yue et al., 2013). The drivers are further extended to the level of population, technology, urbanization etc.

In addition to the IPAT model, System Dynamics Model (Liu et al., 2015b; Xiao et al., 2016) and China-in-Global Energy Model (Qi et al., 2016; Zhang et al., 2016b) and the LEAP model (Tian et al., 2016) are also commonly adopted tools for forecasting GHG emissions. The predictions are generally conducted in different scenarios set based on various affecting factors and optimal measures for GHG emission reduction. Beyond these methods, some studies have been carried out applying integrated modeling approaches through proposing new indicators, embedding more variables, and setting more potential scenarios and policy proposals (Rout et al., 2011; Wang and Ye, 2017; Peng et al., 2017). For example, Niu et al. (2016) set three variables (economic growth, energy intensity, and multiple emission intensity) to the combinations of high, medium and low levels, and calculated the annual total emission index for each combination by the unitary regression model, the compound growth model and the gray forecasting model. Elzen et al. (2016) provided emission projections for China up to 2030 given current policies and a selected set of enhanced policies and estimated the impacts of these policies on GHG emissions by two different methods: an IEA and US EPA-based bottom-up framework and an integrated FAIR/TIMER model. Guo et al. (2015) constructed a bottom-up model to estimate the trends in energy-related GHG emissions by 2050 in typical projected scenarios for energy supply and demand and examine how low-carbon technologies and electrification would affect future energy-related GHG emission trends. Affected by various intricate factors, the results of the projection of China's GHG emission peak are distinct, estimated either conservatively or excessively.

These existing studies illustrate an overview of the efforts China could make to achieve the emission peaking goals and discover the potential driving factors of energy-related GHG emissions. The findings are helpful in understanding the characteristic and trends in energy system changes and technological innovations and in uncovering the interactions of economic growth and energy consumption.

Created by Leontief in 1936, the traditional input-output (I-O) model focuses on the economic situation of one country or region and has been developed subsequently into the environmental I-O analysis to reveal the environmental emissions of the whole economy (Leontief, 1985; Miller and Blair, 2009). Compared with the methods in the above reviewed studies, I-O analysis is better at describing the interactions among sectors and therefore is capable of accounting for GHG emissions of various economic agents from different perspectives (based on production or consumption) (Liu et al., 2015a). Extensive studies have been conducted to analyze