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Carbon emission and abatement potential outlook in China's building sector through 2050

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ABSTRACT

The carbon dioxide generated by building sector accounts for approximately 30% of the total CO_2 emissions in China. The building sector plays a significant role in Chinese low-carbon development. This study develops the CAS bottom-up model system to predict the future trend of carbon emissions in China's building sector. Firstly, we sets three scenarios: business as usual (BAU), policy scenario, and synergistic emission reduction (SER) scenario, which consider the influence of low-carbon building policies and emission factors (i.e. power and heat emission factor (PEF and HEF)). Then we develop an emission reduction potential model to assess the CO_2 abatement potential of the building sector in 2016–2050. The results reveal that low-carbon policies of building sector in policy scenario can only slow down but not curb the CO_2 emission completely. The CO_2 emissions will reach its peak before 2030 in the SER scenario, taking into account the impact of PEF and HEF. The analysis demonstrates that the synergistic reduction effect of inter-department will be better than that of one sector. Furthermore, green buildings, renewable energy building and energy conservation policies for district heating have a great influence on emission abatement in the building sector.

1. Introduction

Global climate change and energy crises have increasingly impeded the sustainable development of society and the global economy, which posing the largest threats to environment and ecology. Energy consumption in the building operational sector accounts for one-third of the world's total energy consumption, and energy demand in the building sector will grow by nearly 50% by the year 2050 if it is not controlled (IEA, 2013). Subramanyam et al. (2017) analyze the carbon reduction potential in 80 countries by 2020. They conclude that the building sector could cost-effectively cut approximately 29% of building-related global CO_2 emissions, the largest among all sectors reported by the IPCC. Especially in developing countries, the building sector has 52% of emission-reduction potential. In those context, the carbon emission in building operational stage accounts for 60–70% of total life-cycle emission in China building sector, which account for 15–30% of total energy consumption in China (Zhang et al., 2015; Cai et al., 2009). With the development of urbanization and the improved standard of living of the residents, the energy consumption and carbon emission of building sector will increase rapidly in the future (Lin and Liu, 2015). In June 2015, China officially released the 'Intended Nationally Determined Contribution' (INDC) document that announced the goal to peak its emission around 2030 and to lower the carbon intensity of GDP by 60–65% below 2005 levels by 2030. To achieve this goal, the building sector needs to improve in energy saving and emission reduction. Thus, it is essential to analyze the CO_2 mitigation potential of the key policy in the building sector.

An increasing amount of literature has paid attention to the CO_2 mitigation potential analysis, which mainly focuses on two aspects. On one hand, some scholars build mathematical models by analyzing the correlation of variables and then use a scenario analysis to forecast the carbon emission and abatement in the building sector. For example, Merkel et al. (2017) use a times-heat-power optimization model and decentralised energy system optimization model to discuss Germany's thermal power sector energy consumption and emission reduction in the future. Lin and Ahmad (2017) analyze and forecast the carbon emission and abatement of all sectors in Pakistan based on an LMDI model and scenario analysis. Ma et al. (2017) evaluate building energy efficiency and calculate carbon emission reductions for the building sector by using the IPAT-LMDI model. Guo et al. (2016) use the Kastovich decision model to discuss CO_2 reductions of energy-efficient equipment in Xiamen.

On the other hand, other scholars apply engineering economic model which evaluate technologies or policies based on their principle

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and scenario to forecast carbon emission and its reduction. Mata et al. (2013) and Subramanyam et al. (2016) use the bottom-up model to analyze the CO_2 reduction potential of the building policy for the EU-21 countries and Canada's Alberta area, respectively; the policy measures include: heating and cooling envelope reconstruction and lighting and equipment efficiency. Delmastro et al. (2015), Khanna et al. (2013) and D. Yang et al. (2017) provide various scenarios with which to discuss the medium-term and long-term carbon emission and policy emission abatement in the Chinese building sector. The policies considered include (1) improvement of energy-efficient standards; (2) heating metering system installation and price reform; (3) promotion of efficient household appliances; (4) renewable energy building applications; and (5) public building renovations. McKinsey (2007) and Xiao et al. (2014) consider the rural building policies based on the research of Delmastro et al. (2015) and Khanna et al. (2013), such as household methane tanks and passive solar houses. As a whole, the policy quantification model is more specific than the mathematical models. And the policy analysis can clarify the specific emission abatement path and guide future policy formulation.

Above all, scholars have paid emphasis on the policy of the building sector itself. Such single- departmental analyses are very valuable in themselves but they do not take into account the possibility of synergistic effects, especially for the terminal energy consumption sector. The carbon emissions of one sector not only affects by its final energy consumption and but also by other sectors (Liu et al., 2012; Alcantara and Padilla, 2009). Most studies mainly focus on the policies analysis in building sector and ignore the low-carbon development in the upstream sector, such as the power and heat sector (Yuan et al., 2018). There has been a significant shift from primary energy consumption to electricity and heat in urban residential during the periods of 1996–2012, the proportion of indirect CO_2 emission to residential emission increased, and urban building electricity consumption increased fivefold (Jiang, 2016). With an accelerated process of urbanization and improved standards of living, the indirect emissions of building sector will increase year by year. T. Yang et al. (2017) analyze the carbon emission of building sector and find out that the most important factors are the building area, energy intensity and carbon emission factor. From 2000–2014, the annual average power emission factor (PEF) fell by 24.7% and the heat emission factor (HEF) fell by 3.7% (NSO,2000–2016). Meanwhile, the power sector will continue to implement low-carbon development strategies that are bound to bring greater reductions in emissions in the future (National Development and Reform Commission, 2016, 2014). Hence the impact of the PEF and HEF on the building sector cannot be ignored.

Above all, the PEF and HEF will continue to maintain a downward trend, which not only affects the carbon emissions of the building sector, but also emission-abatement policy. Therefore, in this paper, the PEF and HEF are added into the emission-reduction potential analysis of the building sector. We evaluate the integrated emission abatement of 18 building low-carbon policies and the PEF/HEF by using the emission reduction potential (ERP) model. This paper is divided into five parts. Following this introduction, Section 2 describes the research method and model. Section 3 examines the energy consumption and CO_2 emission performance of the building sector and compares it with other researchers' results. Section 4 discusses the current policies and provides policy recommendations for the building sector in China. Section 5 summarizes the paper.

2. Methodology

This paper uses the Chinese building sector as the research object and divides it into four sub-sectors: urban district heating, urban buildings, commercial buildings and rural buildings. We discuss the building sector's carbon emissions and emission reduction by establishing a bottom-up model, emission reduction potential (ERP) model and considering factors such as low-carbon policy and emission factor.

2.1. Border and data sources of CO_2 emission in building sector

China has vast territory and complex climate. Because of its different regions and functions, the energy consumption of buildings has their own characteristics (Xiao.et.al, 2014). It is very necessary to classify the building and count their energy consumption. Therefore, according to the characteristics of the building emission, this paper divides the building sector into four types of buildings: urban district heating, commercial buildings, urban buildings and rural buildings.

(1) The urban district heating is those provinces, autonomous regions and municipalities which adopt various central heating modes, but does not include individual heating in northern cities and towns.[1] (2) The energy of urban residential is the energy consumed by urban residential buildings, excluding the urban district heating and including individual heating in northern area and hot-summer and cold winter zone (i.e. electrical air conditioner, gas furnace, electrical heater, and so on) and other end-users (i.e. lighting, home appliances, hot water, and so on).(3)The energy of commercial building, which is all non-residential buildings excluding industrial production rooms, excluding the urban district heating and including individual heating (i.e. gas boiler, electrical boiler, and so on) and other end-users (lighting, office appliances, heating, ventilation and air-conditioning (HVAC) system, elevator etc.).(4) The energy of rural buildings include individual heating (i.e. electrical heater, biomass heater, and so on) and other end-users (i.e. lighting, home appliances, stove, etc.). The main energy type of rural buildings is electricity, coal and biomass (straw and firewood). The biomass energy have been merged into "other" according to consultation with the National Bureau of statistics.

This paper mainly studies the operational stage of carbon emissions in the building sector. Because China's energy statistics yearbook does not provide building energy consumption directly (Yang. D. et al., 2017a), we need to merge and adjust the energy data of the primary, secondary and third industry sector as well as residential sector. The specific accounting boundaries are shown in Table 1. All values have been adjusted by 2010's constant price. The reduction item is part of energy consumption of the transport sector and heat.

2.2. CAS bottom-up model system

We develop a CAS bottom-up model system based on models of Delmastro et al. (2015) and McNeil et al. (2016). The system can be used to estimate the CO_2 abatement policy within and outside the building sector, and to predict energy consumption and carbon emissions through the year 2050 by using M1 and M2 (Fig. 1). Also it can provide a reference for the government with which to formulate energy planning and policy measures.

The system consists of four modules: social-economic factor (M1), the prediction model for building's energy consumption (M2), CO_2 reduction potential analysis model (M3) and results (M4).

As shown in Fig. 1, social-economic factor include population, urbanization rate, GDP and other parameters. M2 is determined by the scale and the building energy intensity, which applied the population and urbanization rate from M1 as the input data. The BAU scenario is calculated into M2 and its results are presented in Section 3. The formula of M2 are as follows:

$$EC_n = P_i{*}PEC_i + ECUA_j{*}AREA_j. \tag{2-1}$$

Here, EC denotes the total energy consumption in the nth year; i = 1,2, expressed as urban and rural, respectively; P_i and PEC_i represent the population and energy intensity per capita, respectively; $ECUA_1$ and $ECUA_2$ denote the urban district heating and the energy consumption per unit area in public buildings', respectively; $AREA_1$ and

[1] Including Beijing, Tianjin, Hebei, Shanxi, Inner Mongolia, Liaoning, Jilin, Heilongjiang, Shandong, Shannxi, Gansu, Qinghai, Ningxia, Xinjiang, Tibet and Henan.