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# Low carbon transition of global building sector under 2- and 1.5-degree targets

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## HIGHLIGHTS

- Building's energy transition pathways under 2- and 1.5-degree targets are generated.
- High income region would take the lead in building sector's $CO_2$ mitigation.
- Cumulative building $CO_2$ mitigations may be doubled from 2-degree to 1.5-degree.
- Electrification is critical in building sector's low-carbon energy transition.

## ARTICLE INFO

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## ABSTRACT

Building sector accounts for nearly 30% of global final energy usage, and its energy demand is expected to keep growing with the increasing population and expanding tertiary industry in the coming decades. To achieve global climate mitigation goal, building sector will need to fully tap its potential on energy conservation and $CO_2$ reduction. This paper simulated the transformation pathways of global energy system under 2-degree and 1.5-degree climate targets with Global TIMES model, classified the 14 model regions into high, middle and low income region, and analyzed the main features and key challenges of each region's building sector transition pathways. Modeling results show that: (1) For global building sector, 32 Gt of $CO_2$ emissions reduction is required between 2010 and 2050 by 2-degree target, additional 28 Gt of reduction would be essential to achieve 1.5-degree target; (2) High income region would take the lead in building sector's $CO_2$ mitigation, while low income region may be increasingly important when the carbon constraint gets more stringent; (3) Electrification is a critical approach in building sector's low carbon transition, by 2050, the share of electricity in final energy consumption is expected to reach 44%, 54% and 59% in reference, 2-degree and 1.5-degree scenarios respectively.

## 1. Introduction

With the growing energy demand, building sector is expected to play a critical role in low-carbon transition of global energy system. Building sector's energy demand has been rising for the last decades, the average annual growth rate between 1990 and 2015 is 1.4%, and the total energy consumption of building sector reached 117 EJ in 2015, accounting for 30% of global final energy consumption [1]. In future, global building energy demand is expected to experience further increase, mainly coming with the rapid development of developing countries, one driver is their growing population and the basic needs in daily life including lighting and cooking, another driver is the growing economy and new demands in commercial buildings, such as hospitals, schools, office buildings and shopping malls.

Great potential of both energy saving and $CO_2$ mitigation exists in building sector, thusly significant contribution may be achieved in short to medium term if effective and timely mitigation measures are to be taken. Building sector is by far the biggest final energy consumer, and its energy service demand is expected to grow rapidly with the increasing population for the rigid demand in residential building, building sector will continue to play an important role in global energy system. Besides, large amount of energy waste is caused by the utilization of poor envelope and low-efficient equipment, and if wide deployment of best available technologies can be realized, the increase rate of building energy demand between 2010 and 2050 can be controlled within 10% [2], significant amount of final energy saving can be achieved, and so as to $CO_2$ emissions.

Building sector's unique importance in energy transition and

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climate governance has become a consensus in recent years, and research findings on its current and future energy-using features and on related policy implementation have been published. However, most existing researches are limited on a narrow scope with only one or a few more countries, the few studies involving global perspective only focused on current or short term situation, or took the world as a whole with little concerning on regions' features.

Major regions have always attracted extensive attentions, several targeted analyses on their building sector have been conducted. Berardi compared energy consumption trends between America, European Union and BRIC countries, and pointed out BRIC countries' total energy consumption is higher than developed countries in building sector, and they are expected to have large growth potential for in the increasing building stock [3]. Allouhi updated global energy consumption data in both residential and commercial buildings, discussed the historical, current and future situation of selected countries including America, European Union and China [4]. Took the world as a single region, Fujimori analyzed the $CO_2$ mitigation potential brought by energy service demand reduction, and concluded that building sector has a higher effectiveness of this reduction than other sectors [5].

Besides, a few other studies focused on detailed analysis of a single region, including America, Denmark, China, Japan, etc.

Multiple analyses on building energy consumption and CO2 emissions for a single region or country have been published, which could provide valuable references for domestic policy-making. China is the biggest developing country with large energy consumption and CO2 emission, a lot of researches have been conducted to analyze the overall energy-saving potential of its building sector [6–8], the performance evaluation of advanced technologies including PV and heat pumps [9–12] and etc., and some of these researches involved detailed comparison on building energy using features in different climate zones [13–15]. And for other countries, the researches focused on building sector are relatively limited, and publications for less developed countries are especially lacking. Lee et al analyzed the influences energy sources and prices may bring to building sector's CO2 emissions for America, and found that mitigation efforts in commercial sector can be especially important [16]; Evan proposed a recommendation that building commissioning should be applied in America to ensure buildings construction can obey the energy efficiency rules in their designing [17]; Connolly proposed a roadmap for European Union, on the basis of projection on district heating and renewable heat's potentials, and stated district heating application can effectively reduce energy consumption and CO2 emissions with low expenses [18]; Murakami outlined building sector's trend in energy consumption and CO2 emissions for Japan, and proposed several policy instruments on building energy saving including standards system [19].

Other studies may hold their attention on the assessment of actual measures such as energy-saving policies in building sector. Based on the evaluation of 20 existing policy instruments' effectiveness in reducing $CO_2$ emissions based on over 60 ex-post policy evaluation reports, appliance standards, building codes and voluntary labeling are proved to be the most effective [20]. As for carbon trading mechanism, certain barriers existed in building sector for the small energy-saving potential of a single building and wide variety of available technologies [21]. Building renovation is expected to be one of the most effective energy-saving measures in near future, the barriers and possible solutions are analyzed in several studies [22–24]. For some developed countries such as European Union and United Kingdom, although they have taken the lead in exploring variety of policy instruments including standards and pricing mechanism, the effectiveness of standards and the coverage of market and pricing will need to be further improved [25].

However, the existing researches on building sector's energy transition under the global climate targets are relatively lacking, and challenges for regions with different income levels have not been analyzed in detail. Based on 14-region energy system modeling results, this paper takes a global perspective, classifies the whole world as high income, middle income and low income regions, and analyzes building sector's energy consumption and CO2 emission features for these three regions under 2-degree and 1.5-degree targets. Under these stringent carbon constraints, all countries would have to establish a low-carbon energy system in building sector, thusly this paper proposes key challenges and possible strategies for regions with different income levels between 2010 and 2050, which could provide reference on both policy making and technology roadmap for building sector.

The ideas and methods used in this research would be introduced in Section 2, including model structure and scenario design. Section 3 will present the main results, each region's contribution to promote global building sector's mitigation will be analyzed, energy system feature and major changes in future of three regions will be analyzed, together with policy recommendations in low-carbon energy transition. Section 4 will contain the key conclusions from this research, and discuss the current limitations and future improvements.

## 2. Methodology

### 2.1. Global TIMES model and its building sector

This research conducted dynamic energy system optimization with the application of Global TIMES model [26], a bottom-up integrated assessment model from 2010 to 2050 with the interval of five-year period, although model base year is set to be 2010, calibration considering major indicators and key technologies has been conducted for 2015, on the basis of IEA database [27]. This model was developed by Tsinghua University, experience from former modeling researches with China Markal and China TIMES model on structure design idea, data foundation and model platform development have been used as Refs. [6,28–37]. The whole world is divided into 14 regions in the model according to social development level and geographical distribution, and this paper has classified the 14 regions into three classes of region: high income region, middle income region and low income region, since the development of building sector is closely related to income level, details on region classification are shown in Table 1.

Global TIMES model is an optimization model with abundant technologies, and a least-cost mix of technologies and fuels to satisfy the energy service demands would be generated during the scenario run. The whole energy system is constructed by 2 sections: supply side section including upstream and power sectors, demand side section including agriculture, building, industry and transportation sectors, the whole process of energy extraction, processing, transformation, transport and end-use are described in detail, with various technologies in each sector. For all technologies, technical and economical parameters have been added, in order to make reasonable descriptions on the regional differences of technical progress, several researches have been taken as references for the key parameters' determination [38–40]. However, due to the limitations on data availability, data assumption and processing have been applied for regions where related data is relatively scarce, existing data in other regions with similar income level has been used as reference in this work. Driving by energy service demand of end-use sectors, the model would generate technology and fuel mix in both supply side and demand side sections and CO2 emissions from energy consumption in each sector. Global TIMES model would reach a partial equilibrium in energy system after the scenario

**Table 1**
Region classification.

| Class name | Regions included |
|---|---|
| High income region | The United States, Western Europe, Japan, Korea, Oceania, Canada |
| Middle income region | Eastern Europe, Russia, the Middle East, Latin America, China |
| Low income region | Africa, India, Other regions |