

# Impact Analysis of Developing Net Zero Energy Buildings in China

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## ABSTRACT

China consumes approximately 20% of primary energy in its building sector, and this share is estimated to continue to grow in the future due to fast urbanization. The Chinese government has developed many policies to regulate energy uses in buildings. Recently, China has developed a roadmap to continue reducing energy consumption in its building sector and promote nearly zero energy buildings.

This paper analyzes the energy and CO<sub>2</sub> impacts of different scenarios of adoption of net/nearly zero energy buildings in China from now to 2050. First, it analyzes the technical potential for Chinese urban residential buildings to reach net zero energy through modeling and survey of current Chinese building energy use patterns. The feasibility study is done by investigating both efficiency measures and renewable energy integration in buildings. Then a detailed bottom-up model is applied to all of China's residential and commercial building stock where it is feasible to achieve net zero energy through 2050 under several scenarios of renewable energy utilization in buildings. The impact of net zero energy buildings development in China is compared with a business as usual case where there is little efficiency gain and no renewable integration in Chinese building sector. For all buildings, we find overall feasible annual primary energy savings ranging from 270 to 320 Million tonnes of coal equivalent (Mtce) annually in 2030 and from 740 Mtce to 1060 Mtce annually in 2050 across the three scenarios, with the majority of savings from energy efficiency measures.

## Introduction

Buildings consume 20% of primary energy in China in 2010 (Zhou et. al. 2015). Due to the fast urbanization process, and increased needs of built environment comfort levels, the energy use in buildings is expected to grow dramatically (Eom et. al. 2012). A recent study shows that total building floor space will increase to 86 billion m<sup>2</sup> 2050 from 55 billion m<sup>2</sup> in 2010, and the building sector is going to double its energy use in China by 2050 compared to its 2010 level (Zhou et. al. 2015). Reducing energy use in buildings becomes a critical issue for China's future low carbon development.

Many countries have developed their policies and targets to reduce energy use in building sector by developing Net Zero Energy (NZE) buildings (Zhang et. al 2016). Recently, the Chinese Ministry of Housing and Urban Rural Development (MOHURD) developed a long term energy efficiency improvement plan. In the plan, developing net (or nearly) zero energy buildings become a key action item. MOHURD's target is to achieve an overall efficiency level of 82% in residential buildings and 79% in commercial buildings by 2030 compared to the

1980's baseline performance (Wu et.al. 2015)<sup>1</sup>. This is the first time the Chinese government has developed a long-term plan to conserve energy in its building sector. Therefore, paper investigates the high-level technical feasibility of developing NZE buildings, and the energy savings and CO<sub>2</sub> mitigation impact for buildings in China.

## Methodologies

To quantify the long-term energy and carbon savings of developing net zero energy buildings, we developed a long-term bottom-up energy analysis model. This model is built upon our previous study “Reinventing Fire: China” conducted in collaboration with China Energy Research Institute and the Rocky Mountain Institute. The detailed model structure and some key assumptions can be found in LBNL “Reinventing Fire: China” (Zhou et. al. 2015) project which is not introduced here. Figure 1 below gives a general overview of the building sector model which was adopted and used in this study.

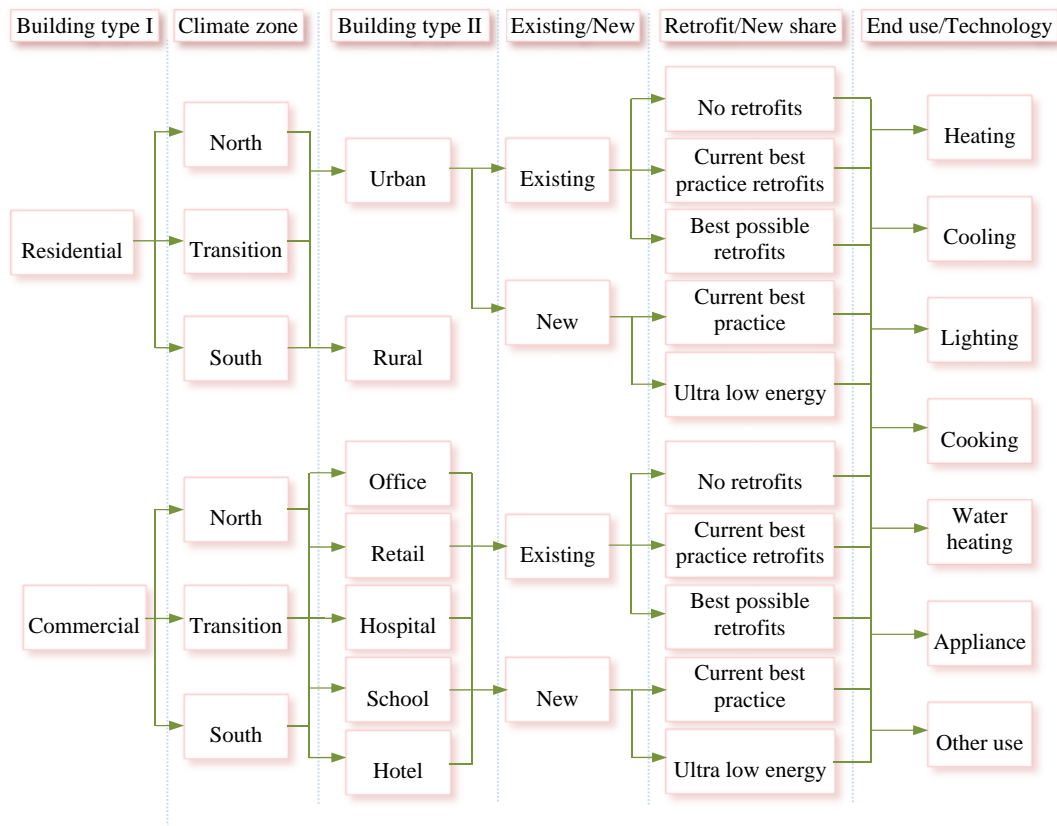


Figure 1. Building Sector Model Structure

There are many discussions of the net zero energy buildings definition (Torcellini et. al. 2006, Marszal et.al. 2011, U.S. DOE 2015). For this study, we use a relatively stringent definition of net zero energy meaning that buildings' final energy consumption is equal or less

<sup>1</sup> The current Chinese national level standard has achieved efficiency level of 62% for commercial buildings and 65% for residential buildings compared to the 1980s' baseline performance.

than its on-site renewable energy generation<sup>2</sup>. This is slightly different from other definitions mentioned in China such as “nearly zero energy buildings”. This means that the building stock used in the net zero potential analysis follows the site energy net zero definition. If the source energy net zero definition was used instead, the analysis will yield slightly different results<sup>3</sup>.

In order to evaluate the potential savings of developing net zero energy (NZE) buildings, the first question that needs to be answered is how buildings can achieve net zero energy. A feasibility study of achieving net zero energy buildings in China was conducted. A few residential and commercial building prototype models were developed in order to understand how to achieve net zero energy buildings. The prototype building models were developed for the North (cold and severe cold climate zones), Transition (hot summer cold winter climate zone) and South climate (hot summer and warm winter climate zone) zones of China by using the climate conditions in the representative cities of Beijing, Shanghai and Shenzhen, respectively<sup>4</sup>. The building models are also developed in accordance with Chinese national level residential and commercial building codes. To take building energy usage, comfort and occupant behavior into account, energy survey data on plug load, lighting and appliance were used when developing the prototype building models. Finally, the models were simulated in EnergyPlus to get results. Figure 2 below shows the reference urban residential building model developed in EnergyPlus (PNNL 2015).

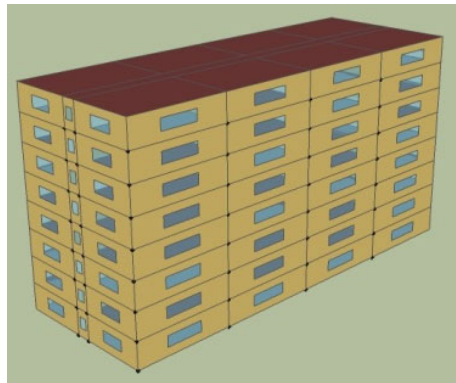


Figure 2. Residential Building Energy Model Prototype

### Modeling of Net Zero Energy Building

In order to develop net zero energy buildings, it requires that buildings 1) improve energy efficiency performance and reduce site energy demand, and 2) have renewable energy installations made on them. The simulation analysis shows that Chinese buildings have great potential to improve their energy efficiency. The climate conditions in each location are kept

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<sup>2</sup> The on-site generation here means that generation comes from within buildings' footprint. Local renewable generation that is produced outside of building's footprint is not considered in this study. Renewable generated remotely and transmitted to buildings are also not considered here.

<sup>3</sup> The non-electric energy use in heating in China is mainly met by coal. If a building achieves NZE in final energy definition, it will achieve NZE in source energy definition considering the non-electrical energy use portion in buildings.

<sup>4</sup> The cities are chosen based on their climate zones and Heating Degree Days (HDD) and Cooling Degree Days (CDD) numbers. The climate zones for Beijing (CDD18= 848, HDD18 = 2830), Shanghai (CDD18 = 1158, HDD18 = 1599) and Shenzhen (CDD18 = 2141, HDD18 = 272) are: Cold, Hot Summer Cold Winter, Hot Summer Warm Winter climate zones respectively.

same from 2010 to 2050. The energy efficiency improvement in residential and commercial buildings mainly come from the following building systems:

- Improve building envelope performance by having better insulation on wall and roof, high performance windows and shades, and air tightness construction (e.g. Beijing, wall U value is improved to 0.14 kW/k-m<sup>2</sup>)
- Install high performance HVAC system; use outdoor air ventilation system to reduce opening windows in conditioning seasons (e.g. air conditioner COP value is improved to 4)
- Use high efficiency lighting system with efficient light source, fixtures and control; maximize the use of daylight (lighting power density = 1 W/m<sup>2</sup>)
- Use high efficiency appliance and plug load equipment; manage the use of equipment effectively, and reduce stand-by power.
- Control building lighting, HVAC, and plug load energy use efficiently.

After evaluating the potential for net zero energy buildings to reduce energy demand, it is important to understand how renewable energy technologies, especially solar PV, can contribute to the development net zero energy buildings. Three solar PV utilization scenarios are analyzed in this study and the key assumptions for each scenario is summarized in

Table . Scenario 1 assumes that PV is only installed on buildings’ rooftop. Scenario 2 assumes that PV is installed on the roof and the East, West and part of the South walls. Scenarios 1 and 2 both assume that the solar PV panels’ generation efficiency is constant from now through 2050 and stays at the current efficiency level of around 15%. Scenario 3 assumes that PV is installed on the rooftop only, but assumes that PV panels’ efficiency will gradually increase from 15% installed now to 30% installed in 2050. We use these three scenarios to analyze solar PV’s contribution and compare electricity generation in buildings with the prototype building energy demand under the Reference scenario.

Table 1. Scenario Assumptions for Net Zero Energy Building Impact Analysis

Scenario	Energy Efficiency Measures	Solar PV Installation	Solar PV Efficiency	Impacted Building Stocks in Analysis
<b>Reference</b>	Modest adoption of efficiency measures consistent with autonomous change	Not considered	Not considered	All building stocks
<b>Scenario 1</b>	Aggressive adoption of all efficiency measures (discussed above)	Rooftop installation	Fixed efficiency: 15% efficiency through 2050	Buildings with fewer than 6 stories have the potential to achieve net zero
<b>Scenario 2</b>	Aggressive adoption of all efficiency measures (discussed above)	Rooftop and 100% East and West + 50% South facade installation	Fixed efficiency: 15% efficiency through 2050	Buildings with fewer than 10 stories have the potential to achieve net zero
<b>Scenario 3</b>	Aggressive adoption of all efficiency measures (discussed above)	Rooftop installation	Improving efficiency: 15% efficiency in 2010 rising gradually to 30% in 2050	Buildings with fewer than 12 stories have the potential to achieve net zero

## Results

### NZE Building Feasibility Analysis

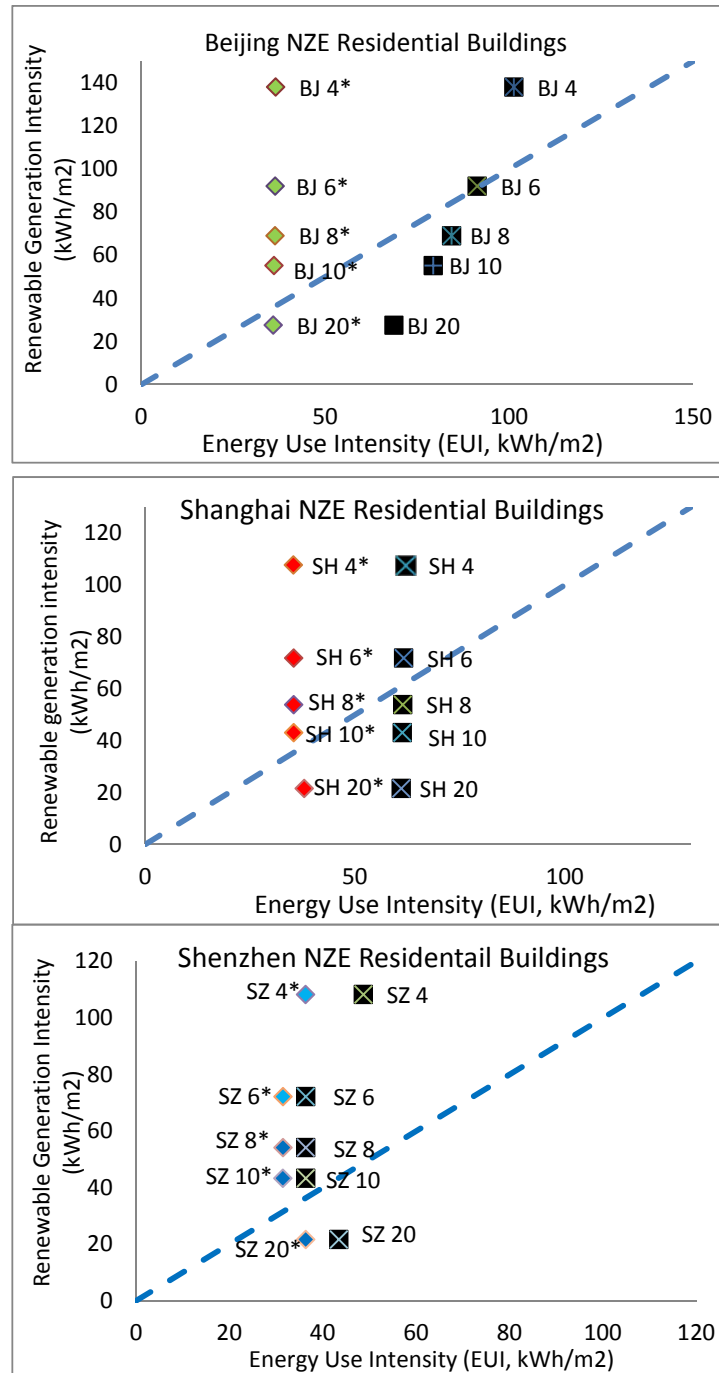


Figure 3. Net Zero Feasible Building Performance in Three Representative Chinese Cities under Scenario 2 (green, red, blue dots mean energy use in Beijing-BJ, Shanghai-SH and Shenzhen-SZ respectively for net zero energy buildings; black represents buildings energy use based on current standards level in the three cities; number next to letters indicates number of floors )

By employing these measures in developing net zero energy buildings, the energy demand in Chinese high rise residential buildings can be significantly reduced. Figure 3 shows the total site energy intensity including heating, cooling, ventilation, lighting, plug load and appliance energy use in Beijing (green), Shanghai (red) and Shenzhen (blue), the three representative typical climate regions in China. It shows that total site energy use in buildings can be significantly reduced to a level of around 30 to 40 kWh/m<sup>2</sup>-yr by adopting various energy efficiency measures.

Figure 3 also shows the relationship between PV energy generation and building final energy demand at different levels/height of buildings under the second scenario. We find that PV's contribution to building energy generation per floor area varies by the numbers of floors in the given building. For tall buildings with a greater number of floors, PV generation intensity per m<sup>2</sup> of floor space expressed in units of kWh/m<sup>2</sup>-yr is less than that of buildings with fewer numbers of floors. This is because PV is mainly installed on rooftop and parts of the facades, and the taller a given building is, the greater the ratio of total floor space to PV installation area is.

We also found that in general, under scenario 2, buildings with 10 stories or less have the potential to achieve the net zero energy buildings following the definition of this study. This is achieved through energy efficiency and renewable energy utilization. There are some minor differences across different climate zones, but the general conclusion holds.

We used the same methodology to analyze Scenario 1 and Scenario 3. For Scenario 1, buildings with fewer than 6 floors can achieve net zero and for Scenario 3, buildings with fewer than 12 floors (given the improving PV efficiency to 30% by 2030) can achieve net zero. A similar feasibility study was also conducted for the commercial building sector.

Given the feasibility study results, the next question is to determine how many buildings in China have the potential to achieve net zero, and what savings these buildings can bring to China's building sector. We know that for the residential sector, buildings of fewer than 6, 10 and 12 floors, respectively, in our three different scenarios have the potential to achieve net zero energy by combining energy efficient measures and renewable technologies. It is necessary to assess the total floor space in China that can meet the NZE requirement under each of the three scenarios.

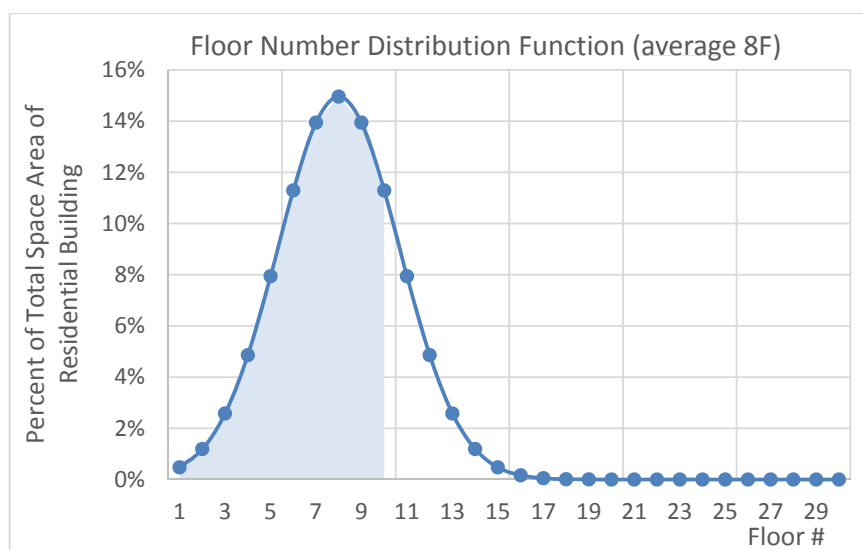


Figure 4. Urban Residential Building Floor Area Distribution

The building floor number varies from one building to another. In general, this study assumes that the average Chinese urban residential building has approximately 8 floors in 2010 and the floor number distribution follows a nearly normal distribution pattern as shown in Figure 4 below. Based on the previous analysis of net zero energy potential, the shaded area shows the fraction of building floor space with number of floors of equal to or fewer than can achieve net zero energy status, according to the assumptions in Scenario 2. Similarly, we can also determine the net-zero-energy feasible stock for Scenario 1 and Scenario 3. The distribution curve analyzed above for the net-zero-energy feasible stock is not fixed over time. We assume that with continued urbanization, the average height of high-rise buildings will increase from 8 floors in 2010 to 12 floors in 2050, but the distribution of heights will follow the same distribution function as shown in Figure 4. Thus, the possible share of buildings that can achieve net zero energy decrease over time.

We took these results and incorporated them into the “Reinventing Fire China” building model. The building stock share which is net-zero-energy possible was applied to the branches of “ultra low energy buildings” for new construction and “best possible retrofit” for existing buildings in the model structure shown previously in

Figure 1.

## Urban Residential Energy Results

Figure 5 shows that developing net zero energy building can bring significant energy savings to China in the long run. The Reference Scenario results as shown by the thick black solid line represents a scenario in which urban residential building energy use is expected to continue increasing over time due to urbanization and rising comfort levels given modest or autonomous efficiency measures adoption. The results of Scenarios 1, 2, and 3 are represented by the blue, green and red lines, respectively. The solid lines for Scenarios 1, 2, and 3 represent the total primary energy consumption after introducing building energy efficiency measures to the NZE feasible building stock. Although the same energy efficiency measures are deployed in all three scenarios, the total primary energy consumption of the three scenarios differ because the applicable NZE feasible building stock changes under the three scenarios. Efficiency savings from Scenario 3 are greater than Scenario 1 because it covers a larger NZE feasible building stock (with efficiency measures) of all urban residential buildings with fewer than 12 floors versus buildings with fewer than 6 floors under Scenario 1. The dashed lines represent the total annual consumption of non-site-generated energy, taking into consideration energy savings from efficiency measures as well as the reduction in grid purchased electricity from adopting different levels of solar PV installation.

Figure 6 compares the annual total primary and non-site-generated energy consumption of urban residential buildings in 2050 (Zhou et. al. 2015). Incorporating efficiency measures into NZE feasible buildings only under the three scenarios significantly reduce the 2050 total primary energy consumption of urban residential buildings by 30% to 40%, as shown by the lower solid bars compared to the Reference scenario without full adoption of efficiency measures. If the reduction in non-site-generated energy consumption from different levels of PV generation are taken into consideration, then the 2050 total annual energy consumption of urban residential buildings are further reduced by 2% to 12%, depending on the scenario and assumed PV installation and efficiency. For example, adopting efficiency measures and PV generation for all urban residential buildings with less than 12 floors that are considered NZE feasible under scenario 3 with increasing solar PV efficiency can result in a 52% reduction in non-site-generated energy consumption compared to the Reference scenario.

The annual energy savings impact of NZE feasible buildings can be decomposed into two parts as seen in Figure 7. The first part of energy savings comes from these NZE feasible buildings adopting energy efficiency measures, as represented by the solid bars for Scenarios 1, 2, and 3 savings in Figure . In 2030, adopting energy efficiency measures in NZE feasible buildings can produce 110 to 130 million tonnes of coal equivalent (Mtce) in primary energy savings in Scenarios 1, 2, and 3. By 2050, the primary energy savings will triple to approximately 350 Mtce to 450 Mtce in Scenarios 1, 2, and 3. For scenarios with higher PV penetration (such as Scenarios 2 and 3), the NZE feasible building stock increases, resulting in higher savings from efficiency measures than Scenario 1. In all three scenarios, energy efficiency measures produce more primary energy savings than the reduction in grid purchased energy achieved by renewable energy utilization in buildings. In Scenario 1 and 2, utilizing PV generated energy in urban residential buildings can result in reductions of less than 40 Mtce in 2030 and less than 100 Mtce in 2050 in grid purchased, non-site energy, as seen in the striped bars in Figure . This is much lower than the primary energy savings of over 130 Mtce in 2030 and over 400 Mtce in 2050 from efficiency measures alone. Scenario 3 has more aggressive PV utilization with higher PV efficiency which can reduce grid purchased, non-site energy consumption by 130 Mtce annually by 2050. The 2050 annual efficiency and PV savings under Scenario 3 is 48 times the primary energy equivalent of the annual electricity generated by the Three Gorges Dam<sup>5</sup>.

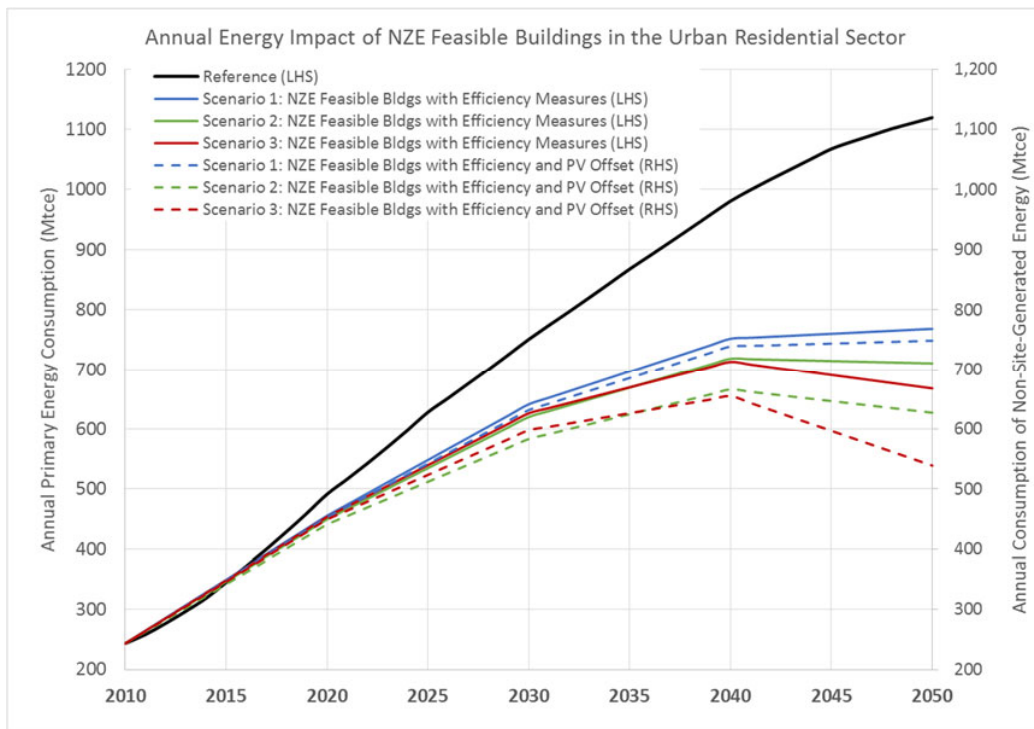


Figure 5. Annual Energy Impact of NZE Feasible Buildings in Urban Residential Sector

It is necessary to point out that the savings from energy efficiency measures and

<sup>5</sup> We assume 50% load factor for the 22.5 GW generating capacity for the Three Gorges Dam. Electricity output is converted to primary energy equivalent assuming 100% conversion efficiency, at 0.1229 kgce per kWh.



renewable energy results calculated by this study only represent savings coming from buildings which can achieve the definition of site net zero energy based on the previous discussion. However, there are buildings which may not be able to achieve net zero (e.g. super high-rise buildings) but still produce savings through employing energy efficiency measures and renewable energy technologies. The energy savings associated with energy efficiency and renewable energy technologies for these buildings are not included in the analysis above.

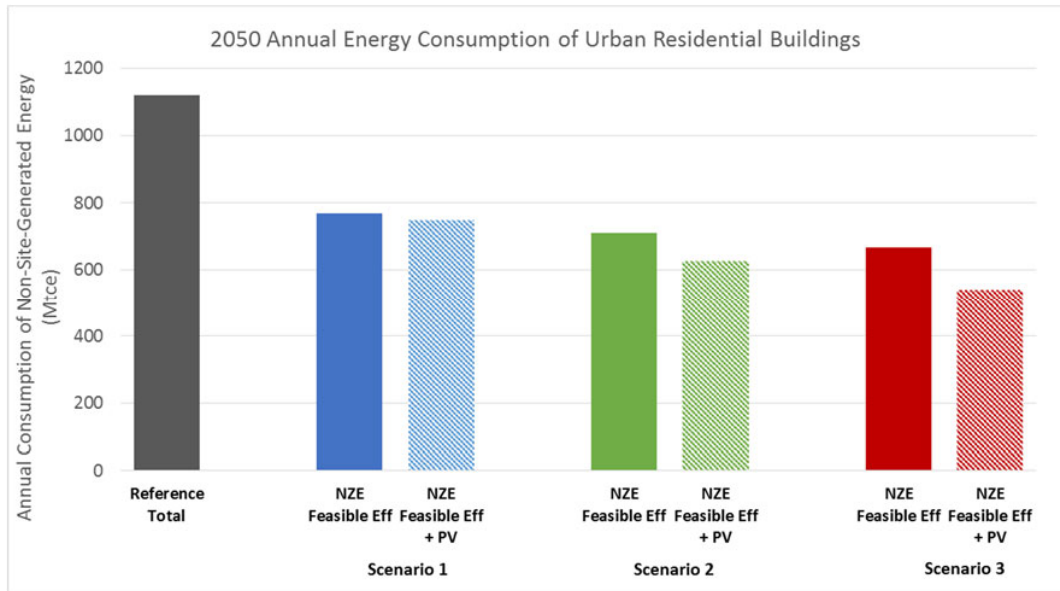


Figure 6. 2050 Annual Energy Consumption of Total and NZE Feasible Urban Residential Buildings under Different Scenarios

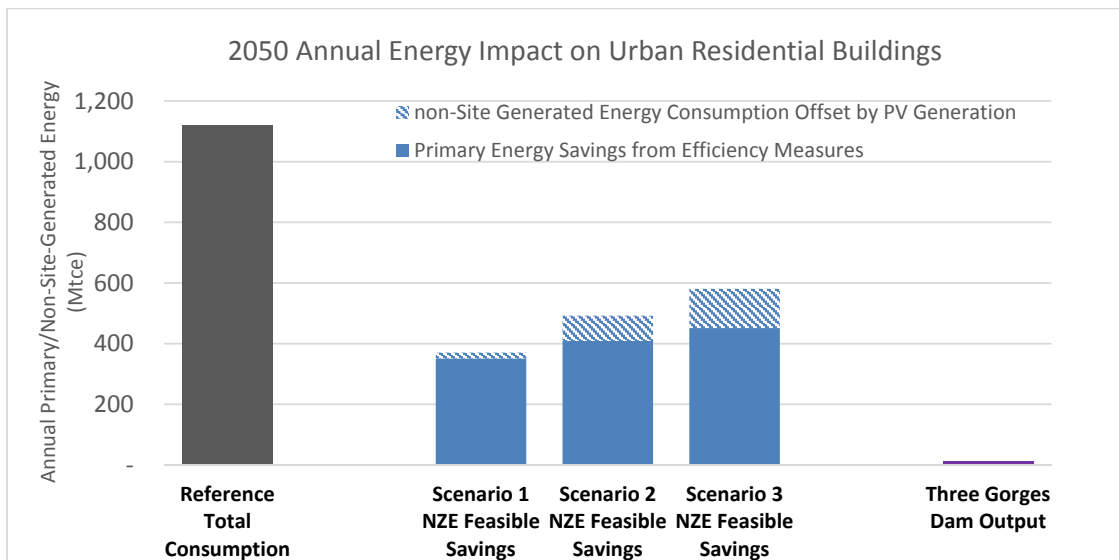


Figure 7. Comparison of Annual Energy Savings in 2050 of NZE Feasible Urban Residential Buildings

## All Buildings Energy Results

If we apply the same methodology used in calculating the urban residential energy and energy-related CO<sub>2</sub> savings to commercial, and rural residential stock, we can calculate the total savings potential of developing net zero energy building in China's entire buildings sector including commercial, residential and rural buildings. Results from previous study are used here to generate net zero energy building stock savings (Zhou et. al 2015). The annual energy impact of NZE feasible buildings on non-site-generated energy consumption of the entire building sector is shown in Figure 8. The solid black line represents the building sector's total consumption under the Reference scenario without any NZE buildings while the three dashed lines show all buildings' total consumption of non-site-generated energy after deducting savings from efficiency measures and solar PV generation in NZE feasible building stocks. The scale of annual primary energy savings increases significantly over time, with the primary energy savings growing to a range of 740 Mtce to 1060 Mtce under the three scenarios by 2050. Of the total savings, the majority comes from employing energy efficiency measures to reduce building energy demand.

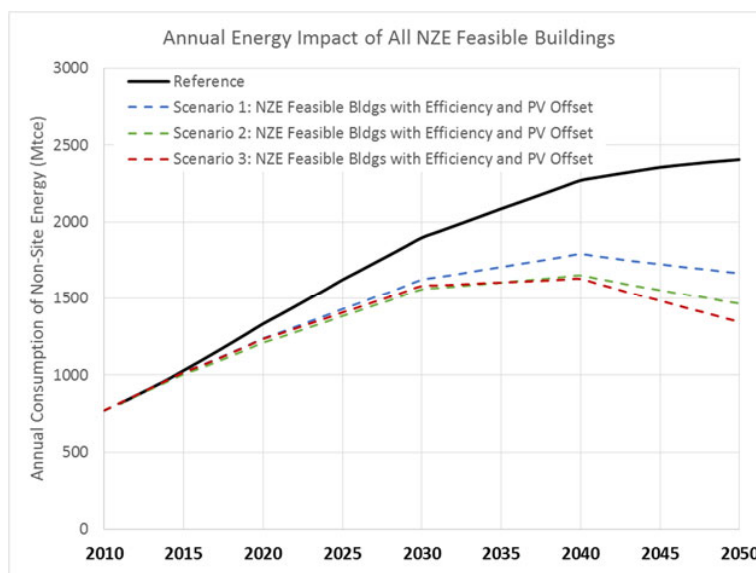


Figure 8. Annual Energy Impact of NZE Feasible Buildings on Entire Buildings Sector

## Discussion: Impact on CO<sub>2</sub> mitigation

The energy-related CO<sub>2</sub> emissions associated with building energy consumption can be calculated from the model. It takes into account the changing fuel mix for the building sector (e.g., switching from coal-based district heating to cleaner natural gas heating in Northern China) and for the power sector where non-fossil power (including solar PV), which is expected to contribute to a significantly larger share over time. As a result, the average CO<sub>2</sub> emissions factor per unit of primary energy and electricity consumed will decline over time.

Table shows the assumed CO<sub>2</sub> emissions factors used in this analysis.

Table 2. CO<sub>2</sub> Emissions for Electricity and Building Primary Energy Consumption

		2010	2020	2030	2040	2050
Buildings Primary Energy CO <sub>2</sub> Emissions Factor	Kg CO <sub>2</sub> /kgce primary energy <sup>6</sup>	2.4	2.3	2.2	2.1	1.9
Electricity CO <sub>2</sub> Emissions Factor	Kg CO <sub>2</sub> /kgce of electricity	6.1	4.5	3.7	2.2	0.4

Figure 9 shows the total CO<sub>2</sub> emissions for urban residential, rural and commercial buildings in China under the different NZE building analysis scenarios. Annual CO<sub>2</sub> emissions reductions could total 1310 to 1540 Mt CO<sub>2</sub> by 2050 if efficiency measures are adopted for all NZE feasible buildings, and total 1320 to 1630 Mt CO<sub>2</sub> by 2050 if the CO<sub>2</sub> emissions reduction from additional reduction in non-site-generated electricity by PV generation is also considered. Under the most aggressive Scenario 3, the annual CO<sub>2</sub> emissions of all buildings would be 36% lower than the total under the Reference scenario in 2050.

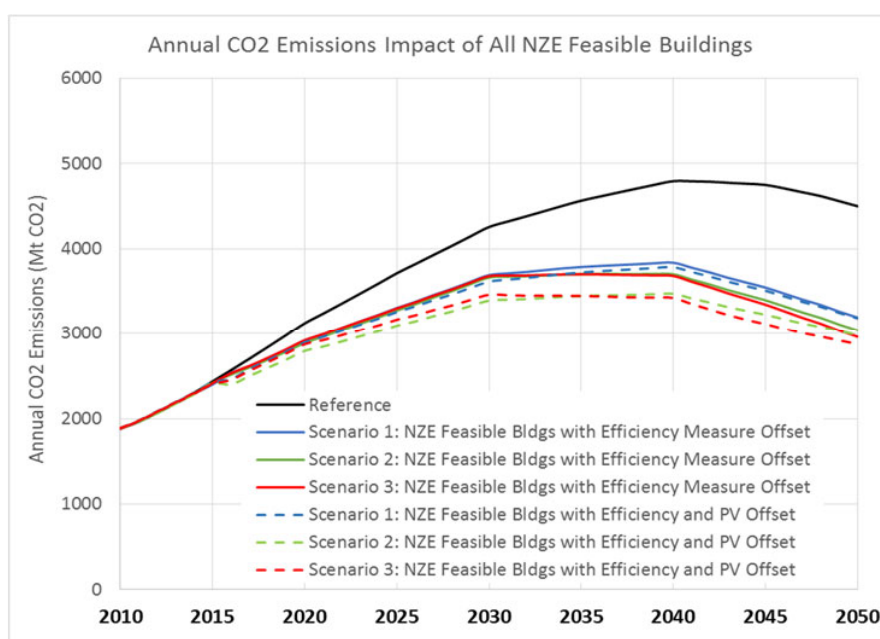


Figure 9. Annual CO<sub>2</sub> Emissions Impact of All NZE Feasible Buildings

In sum, the analysis and modeling results demonstrate that implementing policies to encourage net zero energy building development is essential to helping China reduce energy consumption in the building sector, and the energy saving potentials are significant. In 2050, NZE buildings can achieve slightly higher savings in the residential sector (scenario 2: 492 Mtce) than the commercial sector (scenario 2: 283 Mtce) even though the two sectors have similar baseline energy use in 2050. Priorities should be put on energy efficiency policies which produce the majority of savings in net zero energy buildings. Renewable energy utilization is also important and produce significant savings in buildings, but policies related to renewables use in buildings may take lower priority compared with energy efficiency. In order to promote net zero energy buildings, policies should be developed to improve energy efficiency in buildings as well as encourage renewable energy technologies installation in buildings. Incentive programs should be set up based on the potential energy saving impacts. Priorities should be

<sup>6</sup> kgce primary energy: kilogram coal equivalent. 1 kgce = 27.8 kBtu

paid to energy efficiency measures, and link energy performance and saving impacts with incentives buildings receive. Moreover, policies should be developed in a synergic way that energy efficiency and renewable energy utilization should be integrated together in order to lead towards net zero energy development in China<sup>7</sup>. Policies should focus on building performance based overall energy savings.

For future research, one important area is the techno-economic analysis of energy efficiency measures and renewable energy technologies in buildings. This will help understand how efficient technologies can be adopted in the Chinese market and provide better economic basis for developing net zero energy buildings.

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<sup>7</sup> In China, building energy efficiency policies are developed by MOHURD, and renewable energy policy is developed by National Energy Administration (NEA). A more synergic policy development framework is needed to coordinate the policies between MOHURD and NEA to support NZE buildings.

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