Deep decarbonization pathways in the building sector: China's NDC and the Paris agreement

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Abstract

China's economic growth has been largely relying on the consumption of coal. The country has realized that its economic development has to be free from dependence on fossil fuels. On 30 June 2015, China submitted its ‘Nationally Determined Contribution (NDC)’ in preparation for the Conference of Parties 21 (COP21). One of the important actions in China's NDC is to lower carbon dioxide (CO$_2$) emissions per unit of GDP by 60% to 65% from 2005 levels by 2030. This study examines the efforts from China's building sector (i.e. urban residential, rural residential and service) in achieving the CO$_2$ reduction target stated in China's NDC. Furthermore, this study also explores the post-NDC era and looks into the opportunities towards deep decarbonization in the building sector by mid-century for contributing to the Paris agreement. The study covers 31 provincial regions of mainland China and disparities of climate and socioeconomic indicators across regions are fully considered. We use a bottom-up cost optimization model called AIM/Enduse to evaluate the CO$_2$ reduction potential brought by efficient technologies in China's building sector. Five scenarios are designed to illustrate the emission pathways through 2050. The results show that, when energy constraint and emission target is introduced in mitigation scenarios, new generation biomass contribute a lot to emission reduction. Reduction potential in the nearly zero emission scenario is mainly from the urban residential sector, and to achieve deep decarbonization by 2050, it is important to bring a significant reduction of per-capita energy consumption in addition to city improvement both in urban and rural households. Co-benefit analysis suggests that air pollutants can also be significantly reduced by deep decarbonization policies.

1. Background

China's economy has drastically increased since the economic reform in 1978. As a result of its coal-dominant energy mix, energy-related greenhouse gas (GHG) emissions have caused serious environmental issues in the country. China has realized that its economic development has to be free from dependence on fossil fuels. On 30 June 2015, China submitted its ‘Nationally Determined Contribution (NDC)’ (NDRC 2015) to the United Nations Framework Convention on Climate Change in preparation for the Conference of Parties 21 (COP21) held in December. Several low carbon actions toward 2030 were stated in China’s NDC including a reduction of carbon dioxide (CO$_2$) emissions per unit of GDP at around 60% to 65% compared to the 2005 levels. However, it was pointed out that there are emission gaps more than ten GtCO$_2$ eq between the global GHG emissions based on the summation of NDCs in COP21 and the 2°C target pathways (UNEP 2017). Thus the Manila-Paris Declaration called for a more ambitious decarbonization target—the full decarbonization of the world economy, 100% renewable energy by 2050, and zero emissions by mid-century in order to keep the world on track for the target of achieving below 1.5 degrees of warming (IPCC 2018). Accroding to simulation results from multiple model, achieving
the 1.5 degrees target requires 50% to 90% CO₂ reduction in building sector, relative to 2015 emission level (Energy Foundation China 2020). More recently, China has announced to reach carbon neutrality by 2060 at the 2020 UN General Assembly.

Since the submission of NDCs, several studies have addressed the different mitigation targets in NDCs of China (Jiang et al 2019), Japan (Kuriyama et al 2019), Thailand (Chunark et al 2017), and global economies (Hof et al 2017, den Elzen et al 2019, Wang and Chen 2019). The majority of these existing publications have been concentrating on a national level while evaluating the NDCs. This study specifically aims to examine the role of the building sector in achieving NDC targets in China. The building sector is the largest energy-consuming sector in demand sectors, accounting for over one-third of final energy consumption globally and an equally important source of CO₂ emissions (IEA 2013). The building sector can be divided into residential and service sub-sectors, between which residential sub-sector shares the second or third largest of the final energy consumption globally (IEA 2013). In 2010, residential buildings consumed 23% of the total final energy consumption in China (IEA 2015). Compare to the residential sector, the service sector is still a minor sector in China in terms of energy consumption. However, IEA’s statistical data suggests that the energy use of the service sector is particularly influenced by urbanization level (Xing et al 2018). Over the past three decades, the total CO₂ emissions of China increased from 639 Mt in 1990 to 4896 Mt in 2018, while CO₂ emission from the building sector increased from 385 Mt to 542 Mt (note: CO₂ emissions by electricity and heat were not included, see appendix A) (IEA 2020). As China is going through a rapid economic growth and urbanization period, energy consumption and CO₂ emission from the building sector are expected to boom in the next few decades. When estimating future energy consumption and the corresponding emissions from the building sector, it is important to pay attention to climatic areas, because China has a diverse climate. For the built environment, China can be divided into five climatic areas: severe cold, cold, hot summer/cold winter, temperate, and hot summer/warm winter (MOHURD 1993). In severe cold and cold areas, coal-based central heating is commonly used during winter season. The rapid urbanization process has resulted in vast growth of property development. Building stock in China is relatively new and turnover rate is relatively high.

This study focuses on China’s building sector (i.e. the urban residential, rural residential and service sectors) and looks into decarbonization potentials. Several recent studies have examined building energy use in China. Eom et al (2012) projected the building energy demand in China on a national level by using the Global Change Assessment Model. Peng et al (2015) suggested that, in order to keep a stable economy and social development in China, it is necessary to limit building energy use in the entire country under 1 billion tce (tonne of coal equivalent). Zhang et al (2015) developed an estimation model of China’s building energy consumption and estimated that the building’s life-cycle energy approximately accounted for 43% of China’s total energy consumption from 2011 to 2013. Shi et al (2016) analyzed the impact of technological progress in China’s building sector and measured CO₂ emissions reduction potentials. They pointed out that with more non-carbon fuels (i.e. renewables) consumed, a low-carbon future in the building sector would be achievable in China. These previous studies provided important insights of improvements in energy efficiency in China’s building sector. However, they have been conducted analyses on a national level without considering regional disparities. Building energy demand is largely affected by both climate and socioeconomic conditions. Therefore the regional approach is crucial to analyze CO₂ mitigation potentials and barriers.

Xing et al analyzed China’s CO₂ emission pathways by considering regional disparities, and discussed residential and service sectors independently in the short- to mid-term perspectives. These studies suggested that energy consumption in China’s urban residential, rural residential and service sectors will increase to 220 Mtoe, 130 Mtoe and 50 Mtoe by 2030, respectively (Xing et al 2015a, 2015b, 2018). However, these studies focused on only short- to mid-term pathways under a single socio-economic scenario. Compared with these studies, this study focuses more on longer-term projections of energy consumption and energy-related CO₂ emission up to 2050 and analyzes effects of different socio-economic scenarios as well as energy efficiency improvement, in order to discuss decarbonization under the Paris agreement. This study considers diversities of socio-economic conditions at a sub-national (province) level and examines the provincial contributions for achieving the national mitigation goals in China’s NDC.

This study first evaluates the technological mitigation potentials and their implications in the building sector when achieving the CO₂ reduction targets stated in China’s NDC, and furthermore examines the possibility of applying deep decarbonization in the building sector. Energy-efficient technologies are assessed by using the AIM (Asia-Pacific Integrated Model)/Enduse model, which is a bottom-up technology optimization model to evaluate GHG emissions and reduction potentials in the future. Five scenarios including socio-economic differences are designed in order to evaluate the impacts of different emission and energy constraints. This study addresses the building sector (i.e. the urban residential, rural residential and service sectors) and offers suggestions for achieving China’s NDC by 2030 and zero emission by 2050. Thus the main objectives of this study...
are to explore (a) the maximum emissions reduction potentials in the building sector in detail (sector-wise and provincial-wise), (b) the key drivers of CO\(_2\) emission change in the building sector, (c) solutions and additional costs of narrowing the gap between China's NDC and the 2 degree emissions pathway, and (d) co-benefits and tradeoffs of deep decarbonization measures for reducing non-CO\(_2\) emissions.

2. Methods

2.1. Overview of model description and analyses framework

This study uses the AIM/Enduse model to estimate future CO\(_2\) emission pathways. The AIM/Enduse model is a bottom-up optimization model designed to analyze mitigation measures and multiple-gas mitigation potentials (Kainuma et al 2003, Hanaoka et al 2015). The AIM/Enduse model consists of three main databases: energy and emissions factors, technologies, and socio-economic scenarios. Detailed input data of China's building sector have been developed through our previous studies (Xing et al 2015a, 2015b, 2016). Before analyzing technological mitigation potentials by using the AIM/Enduse model, it is necessary to set future socio-economic scenarios and energy service demand projections. This study uses population (\(p\)) and per capita GDP projections based on Shared Socioeconomic Pathway (SSP) scenarios (van Vuuren et al 2012) as a reference (REF), and estimates energy service demands by using service demand models developed in previous studies (Xing et al 2015a, 2015b, 2016). For the residential sector, we use a macro-model (Xing and Ikaga 2013) to estimate future energy service demand. This presented model is a combination of engineering information and social-economic scenario settings. Figure 1(a) illustrates the general modeling process and main exogenous inputs for estimating energy service demand in the residential sector (Xing et al 2015a, 2015b). For the service sector, energy service demand of six sub-sectors are estimated from different influencing factors (Xing et al 2018). Major indicators and estimation methods are described in figure 1(b). The service sector refers to service businesses buildings in urban area (e.g. retail stores, hotels and motels, restaurants, hospital etc.). The future energy service demand estimated by service demand models are given as exogenous variables into the AIM/Enduse model, and technology options are selected in order to satisfy the given energy service demand while minimizing the total system costs by using the AIM/Enduse model. In this study, both existing and efficient technologies are considered in the technology database.

2.2. Overview of scenario settings

In this study, five future scenarios are designed to evaluate the CO\(_2\) emission growth and reduction potentials: the technology frozen (FIX), REF, biomass promotion (BIO), electrification promotion (ELE) and nearly zero emission target (NZE) scenarios. Each scenario has its own storyline (e.g. emission constraint, energy constraint) to describe mitigation efforts in the future world. Different socioeconomic projections based on SSPs (IIASA 2012) are used to estimate energy service demand in five scenarios. In the FIX scenario, the technologies can be regarded as FIX, i.e. the technology levels remain at the base year (2010) level and no efficient technologies are implemented in the future. Thus, FIX evaluates how CO\(_2\) emissions will increase without any efficient technology intervention. Here, the increase of energy service demand is the sole driver of CO\(_2\) emission growth in the future. Three major pathways in SSPs (SSP1, SSP2, and SSP3) are used to estimate service demand in FIX1, FIX2 and FIX3 scenarios in order to evaluate the sensitivity of socioeconomic impacts on energy service demand and CO\(_2\) emission projection. Emission factors and technology share are also set as same as base year levels in each FIX scenario. In the REF scenario, efficient technologies are allowed to penetrate the future market without any carbon tax or carbon policy. Traditional technologies compete with efficient technologies over cost-effectiveness, but no carbon pricing or emission reduction target is imposed. In general terms, REF considers an autonomous energy efficiency improvement process for efficient technologies. This study allows the choice of any efficient technology to achieve a minimum total system cost. However, cost optimization simulation sometimes shows results of introducing a large renewable energy share that is above its capacity, hence leads to an over-estimation of renewable energy installment. Therefore we set constraints to address the future share of renewable energy. In the REF scenario, the shares of these renewables never surpass the level described by the IEA's Current Policies Scenario (CPS) in China (IEA 2016). Furthermore, emission factors of electricity are expected to decrease in the future due to the efficiency improvement of electricity generation. Thus future emission factors of electricity in REF are set based on the composition of power sources described in the IEA's CPS in China (IEA 2016). From the socioeconomic aspect, SSP2 which is the scenario to describe 'Current Trends Continue' is selected to estimate energy service demand in REF.

Both FIX and REF scenarios set no emissions cap or emissions tax and REF only accounts for the effects of no-regret mitigation options. In contrast, this study analyzes the set of three mitigation scenarios (BIO, ELE, NZE) in the building sector. The BIO scenario examines the impact of positively implementing bioenergy (excluding traditional biomass) devices compared to the REF scenario level. In this study, bioenergy refers to a sustainable and coming generation energy source that is carbon neutral and produces less indoor air pollutants. Implementation
rates of bioenergy differentiate across countries and regions globally. According to IEA’s projection, Europe will have the highest bioenergy share by 2040 in the Sustainable Development Scenario (13% of total energy demand, appendix B) (IEA 2017). Hence this study sets the share of bioenergy to be greater than or equal to 20% by 2050 in China in the BIO scenario. On the other hand, the ELE scenario examines the impact of an aggressive electrification process in the building sector. Electrification offers an efficient way to decarbonize in the building sector. Through the electrification process, the building sector can also benefit from the technological improvement of the power supply sector. In IEA’s projection, Brazil will have the highest electricity share by 2040 (74% of total energy demand in the building sector, appendix B) (IEA 2017), and China’s electricity share is about 47%–48%. In a recent publication of European Commission (Keramidas et al 2020), the share of electricity in China’s building sector ranges from 61% (REF scenario) to 66% (2 degree scenario) in 2050. Based on the projections from European Commission, this study accelerates the China’s electricity share level more than the IEA level, and sets the share of electricity to be greater than or equal to 60% in the building sector of China by 2050. The NZE scenario is the most stringent scenario and has two emission constraints. The first constraint is placed in 2030 that sets per unit of GDP CO$_2$ emission to 40% of the 2005 level, which refers to one of the
Table 1. Overview of scenario assumptions.

| Scenario Code | Socio economics | Technology setting | Energy transition setting | Emission factor setting | Energy constraint | Carbon cap |
|---------------|-----------------|--------------------|---------------------------|-------------------------|------------------|-----------|
| FIX1          | SSP1            | Future technology efficiency and diffusion ratio fixed at the 2010 level | Energy share fixed at the 2010 level | Future emission factors of electricity fixed at the 2010 level | N.a.             | N.a.      |
| FIX2          | SSP2            | Efficient technologies autonomously penetrate in the future market without considering any carbon policy | Energy share not to surpass the maximum value determined by energy transition model (Xing et al. 2017) | Future emission factors of electricity taken from IEA’s CPS | N.a.             | N.a.      |
| FIX3          | SSP3            | REF                | Efficient technologies penetrate in the future market to achieve the biomass employment target by 2050 | Minimum share of (next generation) biomass above 20% of the total energy service demand | N.a.             | N.a.      |
| BIO           | SSP1            | Efficient technologies penetrate in the future market to achieve the biomass employment target by 2050 | Minimum share of electricity above 60% of the total energy service demand | N.a.             | N.a.      |
| ELE           | SSP1            | Efficient technologies penetrate in the future market to achieve the emission level that determined by China’s NDC (2030) and the least emission level (2050) | Future emission factors of electricity taken from IEA’s 450 Scenario | CO$_2$ emission is decreased to the lowest feasible emission level by 2050 |

N.a. refers to ‘Not applicable’.

low-carbon actions described in China’s NDC. The second constraint is placed in 2050 which pushes CO$_2$ emission to the least feasible level (i.e. 20% of the FIX level). Besides efficient technology in the building sector, the three mitigation scenarios (BIO, ELE and NZE) also expect the same level of the best effort from the power generation sector. Emission factors of electricity are assumed to be further improved compared with the REF level (appendix C). Therefore emission factors of electricity are set based on the composition of power sources described in the IEA’s 450 Scenario (IEA 2016). The socioeconomic foundation in mitigation scenarios is also expected to be sustainable in order to achieve low-carbon targets. Therefore we use the energy demand estimation based on SSP1 which is the socio-economic scenario to describe ‘Sustainability’.

The energy transition perspective is also considered while designing all five scenarios. Our previous study (Xing et al. 2017) suggested that households will switch from primitive fuels (e.g. traditional biomass) to advanced fuels (e.g. electricity) as their income increases. And the maximum share of each energy source in the household sector can be determined by various socio-economic indicators. For all five scenarios, the model will consider energy transition constraints and select a share of each energy source so as not to exceed the maximum value considered by socioeconomic constraints (Xing et al. 2017). Table 1 summarizes the definitions of the five scenarios.

2.3. Decomposition analysis

The quantitative decomposition analysis in this study is conducted based on Kaya identity (Yamaji et al. 1991), which states that total GHG emission can be affected by essential factors such as $p$, per capita GDP, energy intensity, carbon intensity (ci) and so on. Kaya identity has been widely applied in climate change studies (Kawase et al. 2006, Hanaoka et al. 2009, Kainuma et al. 2015). When several detailed factors are considered in the analysis, sometimes it brings a confounding factor and the decomposition analysis can be at risk of a spurious association. Therefore in this study, Kaya identity is adopted in a simplified style which looks into the impact on carbon emission from
three major factors: \( c_i \), per-capita energy consumption \( (p e) \) and \( p \) change. Here, the energy consumption refers to operational energy that is required during the service life of the building and embodied energy is not included. The decomposition analysis applied in the building sector is defined as below:

\[
\sum_{k=\text{all}} C_k = \sum_{k=\text{all}} C_k \times \sum_{k=\text{all}} \frac{\text{FE}_k}{\text{POP}} \times \text{POP} \\
= c_i \times p e \times p \tag{1}
\]

\[
\frac{\Delta C}{C} = \frac{\Delta c_i}{c_i} + \frac{\Delta p e}{p e} + \frac{\Delta p}{p} + \text{residual} \tag{2}
\]

Where

- \( C \) = CO\(_2\) emission
- \( \text{FE} \) = Final energy consumption
- \( \text{POP} \) = Population
- \( c_i \) = Carbon intensity
- \( p e \) = Per-capita energy consumption
- \( P \) = Population

Besides the three factors in equation (1), this study takes a step further and looks into the drivers of \( c_i \) from electricity and fuels perspectives. Carbon intensities of electricity \( (\text{cies}) \) and fossil fuels are calculated by equations (3) and (4), respectively.

\[
\text{cies} = \frac{C_k=\text{electricity}}{\text{FE}_k=\text{electricity}} \tag{3}
\]

\[
\text{cif} = \frac{\sum_{k=\text{all}} C_k - C_k=\text{electricity}}{\sum_{k=\text{all}} \text{FE}_k - \text{FE}_k=\text{electricity}} \tag{4}
\]

Where

- \( \text{cies} \) = Carbon intensity of electricity
- \( \text{cif} \) = Carbon intensity of fossil fuels
- \( k \) = Energy type (i.e. biomass, coal, electricity, natural gas, heat, oil products)

### 3. Results and discussion

#### 3.1. Impact on energy service demand projections by different socioeconomic settings

Figure 2 shows the energy service demand projections of three FIX scenarios: FIX1, FIX2 and FIX3, estimated in this study by using different socio-economic assumptions such as \( p \), GDP and urbanization level described in SSP1, SSP2 and SSP3. GDP per capita and urbanization are higher in SSP1 than SSP3. As a result, total energy service demand ranked from high to low by FIX1, FIX2 and FIX3. However, the differences in service demand caused by socioeconomic indicators are rather small. Therefore, hereinafter from section 3.2 to section 3.5, FIX2 is selected as the FIX scenario to compare with other mitigation scenarios.

#### 3.2. Energy consumption projections

Figure 3 indicates the projected energy consumption through 2050 in five scenarios. In FIX2, energy consumption will increase to about three-fold of the 2010 level (0.154 Gtoe) by 2050 (0.445 Gtoe). In REF, no-regret CO\(_2\) reduction options are selected compared to FIX2, thus energy compositions are different from those of FIX2. For example, in the urban residential sector, coal-based space heating will be replaced by central heating (northern area) or new generation biomass (southern area); in the rural residential sector, total energy consumptions are lower than the FIX2 levels because of efforts from autonomous energy efficiency improvement; in the service sector, the share of new generation biomass and other renewables (i.e. geothermal, solar water heater, PV panel, wind turbine) will increase for their applications in water heating and space heating. In the three mitigation scenarios (BIO, ELE and NZE), the share of new generation biomass reaches a significant level while the share other renewables still retains its rather low penetration rate. This implicates that new generation...
biomass has advantages in cost-effectiveness when competes with other renewables.

In the urban residential sector, heating application still largely relies on central heating in BIO, ELE and REF, which leads to a considerable heat share in final energy consumption. However, in China heat is mainly provided by coal which contributes to the bulk of CO$_2$ emission. Therefore in NZE, the share of central heat is sharply decreased to nearly zero by switching to electricity heating, in order to achieve the deep decarbonization target. In this study the existing coal based central heat is the only technology available. Other model results suggested that zero emission can be achieved by decarbonization of central heating as well (Energy Foundation China 2020).

In the rural residential sector, non-electricity has a dominant share, thus accelerating electrification will have a huge impact on energy compositions in ELE. However for the rural residential sector, the model does not have electric technologies for space heating or water heating. In order to satisfy the pre-set energy constraint, fluorescent lamps are replaced by a less efficient alternative—incandescent lamps, which caused the electricity increase in ELE. Nevertheless, in rural area, electricity devices are not competitive due to their expensive costs compared with low carbon energy sources. In NZE, a considerable amount of coal will be reduced due to the implementation of high-efficiency devices. However, traditional biomass still remains as a major energy carrier in rural area across all five scenarios. In the service sector, because of the minimum energy share settings, new generation biomass will increase in BIO and ELE, and electricity will increase in ELE, compared with REF. New generation biomass is a relatively cheap energy without any carbon emission, therefore it is largely adopted in ELE as well as balancing the extra cost brought by the installation of electric technologies. In NZE, energy share is similar to REF up to 2030 to achieve the NDC target, but the share of coal and natural gas will sharply decrease afterward because of emission regulations toward low carbon buildings.

One caveat is that, during a series of simulations, a share of 30% bioenergy is found to be infeasible due to bioenergy supply constraints. Thus, this study sets the minimum share of bioenergy at 20% of the total final energy consumption.

3.3. CO$_2$ emission projections
Figure 4 shows the projected CO$_2$ emission pathways of five scenarios in three sectors. Characteristics of CO$_2$ emission projections in BIO and ELE widely differentiate among the urban residential, rural residential and service sectors. Both in the urban residential sector and service sectors, CO$_2$ emission in BIO and ELE are similar and the pathways overlap with each other because energy amounts and these compositions are similar as shown in figure 3. However, CO$_2$ emission trends in BIO and ELE are different between the urban residential sector and the service sector; CO$_2$ emission will keep increasing in the urban residential sector but keep decreasing in the service sector. This is caused by different characteristics of energy compositions between urban residential and service sectors.
service sectors. In the rural residential sector, characteristics of energy compositions are largely different from those of urban residential and service sectors as shown in figure 3, as results both emission profiles and trajectories in BIO and ELE in rural residential entirely differ from those of urban residential and service sectors in figure 4.

In NZE, by achieving the Chinese NDC target by 2030, CO2 emissions levels in 2030 become lower than REF. Compared with REF, over 30% emission reduction can be observed in both urban and rural residential sectors. However, the emission level in 2030 is still two times higher than the 2010 level. It indicates that the NDC target is not enough for realizing the low-carbon society, thus this study set emission constraints toward NZEs by 2050. In the result, CO2 emissions in the urban and rural residential sectors peak out in 2030 and decrease to the similar levels of the base year by 2050. In the service sector, CO2 emission is reduced to 62% by achieving the NDC target in 2030, and to 11% by shifting from coal to renewables toward NZE target in 2050, compared with the base year level.

Furthermore, figure 5 shows the estimated CO2 emission by energy source. In urban area (i.e. the urban residential and service sectors), the remaining
commercial energy source by 2050 in NZE is electricity. While in rural area, coal consumed by water heaters is the dominant contributor to CO$_2$ emission in NZE. In this study, the exogenous emission factors of electricity are taken from IEA’s scenarios. However, in a more ambitious policy scenario, zero emission in urban area could be achieved by combinations of high-level electrification and green electricity by a cleaner power sector.

The national projections in figure 4 are derived from the aggregation of 31 provincial results. In figure 6, in order to analyze regional disparities, we select four characteristic provincial regions to analyze features of their emission pathways in five scenarios. Table 2 gives basic information of the four representative regions. Beijing and Hebei represent high and low-income regions in the cold area. Shanghai and Anhui are a pair of income comparison regions in the warm area. Figure 5 indicates that projected emission pathways are generally similar in the service sub-sector. However, different emission pathways are observed between cold and warm regions. Especially within the urban residential sub-sector of the high come group (Beijing and Shanghai) in NZE scenario, emission decreases in Beijing but increases in Shanghai by 2050. The reduction potential in Beijing’s urban households is largely contributed by efficient heating technologies. While in Shanghai where heating demand is not as high as that in a cold region, it is difficult to reduce CO$_2$ emission in the urban residential sub-sector. CO$_2$ emission levels in three sub-sectors across the 31 sub-national regions by 2050 are summarized in appendices D and E.
To achieve emission reductions, additional investment costs are required in mitigation scenarios. REF is used as a baseline scenario to calculate additional investment cost in mitigation scenarios (i.e. BIO, ELE and NZE). In all three mitigations scenarios, the urban residential sub-sector accounts for over 50% of the total investment cost. By 2050, the additional investment costs reach 0.21 and 0.24 bil. US$ in BIO and ELE, but drastically increase to 0.63 bil. US$ in NZE. Figure 7 indicates both the share of sector-wise total investment costs and the additional investment costs up to 2050.

3.4. Decomposition analysis of CO₂ emissions
Figure 8 indicates five component factors of CO₂ emission changes: ci, cie, ci of fossil fuel (cif), pe and p as described in equation (1). All factors are compared to relative values of the base year, i.e. the 2010 value is shown as 1. In BIO and ELE, trends of ci and cif resemble those trends in REF, where BIO has the lower ci value. In NZE, ci is reduced to about 40% of the base year level. Ci decrease in BIO is contributed by the implementation of new generation biomass, but in NZE ci decrease is mainly contributed by the implementation of renewable energy. Decomposition analysis of CO₂ emissions...
Figure 9. Sector-wise decomposition effects of CO$_2$ emission changes and pathways of cie and cif.

analysis of cie shows three pathways, which aligns with three IEA scenarios of electricity emission factor shown in table 1. ci decrease in most scenarios is contributed by cie, however in NZE ci decrease is contributed by both cie and cif. Pe will continue increasing in all scenarios except NZE. It is estimated that pe can reach three-fold of the 2010 level by 2050 in four mitigation scenarios. In NZE, pe increases at a similar pace as that of REF until 2030 and then decreases to about two-fold of the 2010 level by 2050. It implies that, although China’s NDC is considered in NZE by setting an emission constraint, the NDC emission target does not bring a significant reduction from the viewpoint of pe. As explained in section 2.2, the five scenarios use p projections from two SSPs (i.e. SSP1 and SSP2), therefore the decomposition analysis of p show two pathways, with the p peaking by 2030 in FIX and REF (aligns with SSP2) and by 2020 in three mitigations scenarios (aligns with SSP1).

Figure 9 shows the decomposition effects of three drivers of CO$_2$ emission changes and pathways of cie and cif from 2020 to 2050 in REF and NZE, in not only the total building sector but also the urban residential, rural residential and service sectors. The trends of ELE and BIO show similar decomposition results as REF, thus comparisons between REF and NZE are highlighted in figure 9. At a national level, in REF, the major driver of emission increase is pe, while the decrease of ci contributes to emission reduction up to 2030. The changes in ci can be further interpreted as changes in cie and cif, and pathways of both cie and cif show decreasing trends up to 2030 as well in
However, from 2030 no significant impact from ci can be observed because both cie and cif turn to a steady trend through 2050 in REF. P growth in China is expected to peak around 2030, and afterward, p decrease will lead to emission reductions.

On the other hand, emission reduction in NZE at a national level is achieved by a decrease of cie by 2040 and afterward by cif. Ci becomes a key driver of emission reduction as cif continually decreases throughout 2040. Up to 2030, pe keeps increasing and contributes to emission growth. However in order to achieve nearly zero-emission target by 2050, pe turns to a driver of emission reduction after 2030 due to energy efficiency improvement. In this study, the energy mix settings of electricity generation are taken from IEA’s 450 Scenario. As a result, compared with cif, cie does not show an equally sharp decreasing trend through 2050. If there is more cie improvement (i.e. low-carbon electricity generation), it will increase the possibility to achieve zero carbon emission in the building sector.

For the urban residential sector, the most influencing drivers are similar with those in the national total. As a result of urbanization, population change (Δp) contributes to CO₂ emission growth in the urban residential sector, but brings emission reduction in the rural residential sector due to population decreases in rural area. CO₂ emission in the service sub-sector is not largely affected by most drivers except ci, which is a major contributor of CO₂ emission reduction in this sub-sector.

3.5. Co-benefits of reducing non-CO₂ by deep decarbonization

Figure 10 shows emission pathways of four air pollutant gases (i.e. SO₂, NOx, BC and PM₉.₅) as a
result of low-carbon measures. A large source of air pollutant emissions in urban area is coal for central heating. In mitigation scenarios, without any carbon emission cap, coal is difficult to be replaced by new generation biomass or electricity from a cost optimization perspective. Therefore in the urban residential sector, two major trends of air pollutant emissions are observed, i.e. FIX2 and NZE. The trends of REF, BIO and ELE overlap with each other and NZE is lightly lower than those three scenarios. However, only for NO\_x emission, differentiation between NZE and ELE are observed due to the difference of nature gas share.

In the rural residential sector, air pollutant emissions are much higher than those of the urban residential sector, despite its lower per-capita energy service demand. Coal for cooking, hot water and space heating is used both in urban and rural areas, however its share is much higher in rural area. In urban area, coal for cooking, hot water and space heating is a minor energy carrier which is only used in the suburban area. Furthermore, traditional biomass (firewood and stalks) is wildly adopted by common rural households, which contributes to the bulk of all air pollutant emissions, especially for BC and PM\textsubscript{2.5}. Those are reasons for larger air pollutant emissions in rural area.

Service sector only has commercial energy sources (e.g. coal, gas and electricity) and traditional biomass is not used in the service sector. Thus in the service sector, impacts on SO\_2 and NO\_x emissions, which are contributed by commercial energy, are larger than BC and PM\textsubscript{2.5} emissions, which are contributed by traditional biomass. In all sectors, a certain co-benefit of reducing air pollutant emissions by low-carbon measures can be seen. Especially in NZE, air pollutants can be reduced significantly. However, even in NZE, there is still a certain amount of air pollutant emission left which is caused by traditional biomass in the rural residential sector. The traditional biomass is considered as carbon neutral energy source and therefore will not be affected by carbon emission cap in scenario settings. However traditional biomass is a major factor of indoor air pollutants. To efficiently improve indoor air quality in the rural residential sector, explicit policies regarding traditional biomass are required, in addition to low carbon measures for achieving a decarbonized society.

4. Conclusion

This study concentrated on the pathways toward deep decarbonization in China's building sector and examined CO\textsubscript{2} emission reduction potentials by paying attention to regional disparity. This study contributes to discussions on decarbonization further than previous studies from the following key aspects. First, it covered 31 provincial regions in China, and analyzed the total building emissions divided into the urban residential, rural residential and service sectors, while considering climate and socioeconomic disparities across regions. Second, it analyzed CO\textsubscript{2} emission reduction potentials in China's building sector towards deep decarbonization in 2050 and evaluated its co-benefit of reducing air pollutant emissions. Third, it evaluated required mitigation costs among different scenarios and examined major influencing drivers of energy consumption and emissions changes in China's building sector. Results indicate that in NZE emission reduction is mostly achieved by a decrease in cif. Analysis of air pollutant gas emission in NZE shows a positive co-benefit that air pollutants can be significantly reduced by deep decarbonization policies. In order to achieve the carbon-neutral target by 2060 stated at the 2020 UN General Assembly as well as improve indoor air quality in rural area, it is required to promote more electrification together with low-carbon or carbon-neutral electricity generation and enhance renewable energies in China's building sector.

Data availability statement

The data that support the findings of this study are available upon request from the authors.

All data that support the findings of this study are included within the article (and any supplementary files).

Acknowledgments

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Appendix A. China’s CO₂ emissions by sector (IEA 2020)

[Graph showing CO₂ emissions by sector for China from 1990 to 2018, with emissions by sector including Residential, Commercial and public services, Transport, Industry, Other energy industries, Electricity and heat producers, Agriculture, and Final consumption not elsewhere specified.]

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Appendix B. Electricity and biomass shares in IEA’s projection (% of total energy consumption in building sector, 2040, Biomass = ‘Bioenergy’ — ‘traditional biomass’)

| Regional       | Biomass Current policy | Sustainable development | Electricity Current policy | Sustainable development |
|----------------|------------------------|-------------------------|---------------------------|-------------------------|
| China          | 0                      | 1                       | 48                        | 47                      |
| World          | 3                      | 5                       | 42                        | 47                      |
| United States  | 3                      | 4                       | 57                        | 58                      |
| Brazil         | 0                      | 1                       | 75                        | 74                      |
| Europe         | 11                     | 13                      | 40                        | 38                      |
| Africa         | 4                      | 6                       | 17                        | 38                      |
| South Africa   | 3                      | 4                       | 59                        | 63                      |
| Middle East    | 1                      | 1                       | 42                        | 41                      |
| Eurasia        | 1                      | 2                       | 20                        | 21                      |
| Russia         | 1                      | 1                       | 20                        | 17                      |
| India          | 3                      | 4                       | 45                        | 55                      |
| Japan          | 0                      | 0                       | 60                        | 60                      |
| Southeast Asia | 0                      | 1                       | 56                        | 70                      |
| OECD           | 6                      | 8                       | 51                        | 50                      |
| Non-OECD       | 2                      | 2                       | 38                        | 45                      |

Appendix C. Emission factor settings of electricity (unit: tCO₂eq/ktoe)

| Scenario  | 2010    | 2020    | 2030    | 2040    | 2050    |
|-----------|---------|---------|---------|---------|---------|
| FIX       | 3107.599| 3107.599| 3107.599| 3107.599| 3107.599|
| REF; BIO; ELE | 3107.599| 2675.885| 2579.737| 2556.128| 2556.128|
| NZE       | 3107.599| 2479.239| 1483.437| 864.6668| 864.6668|
Appendix D. Provincial CO₂ emission levels

The emissions level of CO₂ in the FIX2 scenario in the base year (2010) is assigned a value of 1 and compared with the emission levels in the five scenarios in the target year (2050). Whiskers represent upper and lower emission levels of 31 Chinese provinces.

Appendix E. Provincial CO₂ emissions projections in three sub-sectors (Mt-CO₂)

| Region     | Year | FIX2 | REF  | BIO  | ELE  | NZE  |
|------------|------|------|------|------|------|------|
| Beijing    | 2010 | 11.75| 11.75| 11.75| 11.75| 11.75|
|            | 2020 | 20.39| 17.40| 17.55| 17.55| 17.55|
|            | 2030 | 27.08| 21.54| 21.91| 21.91| 20.39|
|            | 2040 | 32.44| 24.92| 25.53| 24.69| 16.48|
|            | 2050 | 36.90| 26.90| 27.40| 27.40| 11.28|
| Shanghai   | 2010 | 5.82 | 5.82 | 5.82 | 5.82 | 5.82 |
|            | 2020 | 11.80| 11.43| 11.60| 11.60| 7.39 |
|            | 2030 | 18.78| 16.58| 17.81| 17.20| 12.53|
|            | 2040 | 27.31| 23.77| 24.48| 24.48| 16.55|
|            | 2050 | 38.10| 33.54| 31.36| 31.36| 18.74|
| Heilongjiang| 2010| 17.12| 17.12| 17.12| 17.12| 17.12|
|            | 2020| 45.84| 41.30| 41.58| 41.58| 21.67|
|            | 2030| 64.05| 56.37| 57.40| 57.40| 43.98|
|            | 2040| 74.15| 65.00| 64.90| 64.90| 28.43|
|            | 2050| 77.59| 67.01| 68.75| 68.75| 8.37 |
| Inner-Mongolia | 2010| 11.17| 11.17| 11.17| 11.17| 11.17|
|             | 2020| 23.28| 19.37| 19.50| 19.50| 8.08 |
|             | 2030| 31.18| 25.78| 26.24| 26.24| 16.10|
|             | 2040| 36.15| 29.85| 28.75| 28.75| 5.82 |
|             | 2050| 38.63| 30.89| 31.81| 31.81| 4.96 |
| Region | Year | FIX2  | REF  | BIO  | ELE  | NZE  |
|--------|------|-------|------|------|------|------|
| Qinghai| 2010 | 1.61  | 1.61 | 1.61 | 1.61 | 1.61 |
|        | 2020 | 4.35  | 3.70 | 3.72 | 3.72 | 2.47 |
|        | 2030 | 5.95  | 4.58 | 4.67 | 4.67 | 3.62 |
|        | 2040 | 7.04  | 5.33 | 5.29 | 5.29 | 1.41 |
|        | 2050 | 7.81  | 5.81 | 5.99 | 5.99 | 0.90 |
| Tibet  | 2010 | 1.50  | 1.50 | 1.50 | 1.50 | 1.50 |
|        | 2020 | 4.93  | 4.37 | 4.40 | 4.40 | 3.77 |
|        | 2030 | 6.83  | 5.71 | 5.81 | 5.81 | 4.80 |
|        | 2040 | 8.12  | 6.68 | 6.84 | 6.84 | 3.40 |
|        | 2050 | 9.08  | 7.43 | 7.63 | 7.63 | 0.86 |
| Xinjiang| 2010 | 8.51  | 8.51 | 8.51 | 8.51 | 8.51 |
|        | 2020 | 24.28 | 22.93| 23.09| 23.09| 23.06|
|        | 2030 | 34.71 | 31.35| 31.96| 31.96| 28.93|
|        | 2040 | 42.66 | 37.93| 38.14| 38.14| 19.68|
|        | 2050 | 48.96 | 42.67| 44.00| 44.00| 7.10 |
| Jilin  | 2010 | 10.57 | 10.57| 10.57| 10.57| 10.57|
|        | 2020 | 25.08 | 22.80| 22.96| 22.96| 15.75|
|        | 2030 | 34.58 | 29.93| 30.57| 30.57| 26.01|
|        | 2040 | 39.98 | 33.17| 34.13| 34.15| 17.77|
|        | 2050 | 41.97 | 34.76| 35.99| 35.99| 6.35 |
| Liaoning| 2010 | 20.47 | 20.47| 20.47| 20.47| 20.47|
|        | 2020 | 43.98 | 39.88| 40.15| 40.15| 33.87|
|        | 2030 | 59.90 | 52.48| 53.45| 53.45| 44.44|
|        | 2040 | 68.91 | 59.39| 59.98| 61.27| 14.58|
|        | 2050 | 71.88 | 61.20| 62.44| 62.44| 11.98|
| Tianjin| 2010 | 6.54  | 6.54 | 6.54 | 6.54 | 6.54 |
|        | 2020 | 11.24 | 9.61 | 9.68 | 9.68 | 9.61 |
|        | 2030 | 14.50 | 11.12| 11.29| 11.29| 10.15|
|        | 2040 | 16.79 | 12.32| 12.15| 12.15| 7.77 |
|        | 2050 | 18.30 | 12.61| 12.79| 12.79| 3.99 |
| Hebei  | 2010 | 15.29 | 15.29| 15.29| 15.29| 15.29|
|        | 2020 | 37.34 | 29.84| 30.12| 30.12| 30.00|
|        | 2030 | 50.65 | 37.40| 38.27| 38.27| 35.69|
|        | 2040 | 59.09 | 42.69| 43.99| 43.99| 20.54|
|        | 2050 | 64.00 | 45.63| 45.93| 45.93| 9.88 |
| Shandong| 2010 | 20.65 | 20.65| 20.56| 20.56| 20.56|
|        | 2020 | 43.61 | 35.31| 35.67| 35.67| 35.45|
|        | 2030 | 58.90 | 44.23| 45.31| 45.31| 39.67|
|        | 2040 | 68.13 | 50.13| 51.72| 51.72| 16.89|
|        | 2050 | 72.52 | 51.39| 53.43| 53.43| 13.16|
| Ningxia| 2010 | 1.93  | 1.93 | 1.93 | 1.93 | 1.93 |
|        | 2020 | 4.40  | 3.90 | 3.93 | 3.93 | 3.93 |
|        | 2030 | 5.65  | 4.40 | 4.49 | 4.49 | 4.36 |
|        | 2040 | 6.45  | 4.82 | 4.96 | 4.96 | 4.38 |
|        | 2050 | 6.97  | 5.11 | 5.29 | 5.29 | 1.11 |
| Sichuan| 2010 | 4.31  | 4.31 | 4.31 | 4.31 | 4.31 |
|        | 2020 | 10.94 | 10.01| 10.21| 9.86 | 7.50 |
|        | 2030 | 14.29 | 13.14| 13.69| 13.69| 9.16 |
|        | 2040 | 15.86 | 14.80| 15.57| 15.57| 9.17 |
|        | 2050 | 16.15 | 14.95| 15.85| 15.85| 7.02 |
| Shaanxi| 2010 | 5.95  | 5.95 | 5.95 | 5.95 | 5.95 |
|        | 2020 | 14.20 | 11.95| 12.09| 12.09| 12.08|
|        | 2030 | 19.11 | 14.60| 15.04| 15.04| 13.96|
|        | 2040 | 22.27 | 16.55| 17.27| 17.27| 11.09|
|        | 2050 | 24.14 | 17.53| 18.44| 18.44| 6.69 |
| Region      | Year | FIX2   | REF   | BIO   | ELE   | NZE   |
|-------------|------|--------|-------|-------|-------|-------|
| Shanxi      | 2010 | 14.10  | 14.10 | 14.10 | 14.10 | 14.10 |
|             | 2020 | 42.32  | 35.43 | 35.67 | 35.67 | 21.64 |
|             | 2030 | 61.52  | 50.08 | 51.02 | 51.02 | 31.94 |
|             | 2040 | 74.46  | 60.25 | 61.71 | 61.71 | 23.40 |
|             | 2050 | 82.32  | 66.04 | 66.86 | 66.86 | 9.91  |
| Gansu       | 2010 | 3.86   | 3.86  | 3.86  | 3.86  | 3.86  |
|             | 2020 | 11.83  | 9.91  | 9.99  | 9.99  | 9.99  |
|             | 2030 | 15.55  | 12.14 | 12.41 | 12.41 | 11.32 |
|             | 2040 | 17.63  | 13.34 | 13.95 | 13.71 | 7.75  |
|             | 2050 | 18.70  | 14.28 | 14.62 | 14.62 | 2.45  |
| Anhui       | 2010 | 3.47   | 3.47  | 3.47  | 3.47  | 3.47  |
|             | 2020 | 8.73   | 8.26  | 8.41  | 8.34  | 7.39  |
|             | 2030 | 11.69  | 10.52 | 10.96 | 11.00 | 8.77  |
|             | 2040 | 13.72  | 12.34 | 13.05 | 13.05 | 8.37  |
|             | 2050 | 15.10  | 13.40 | 14.19 | 14.19 | 6.96  |
| Henan       | 2010 | 7.39   | 7.39  | 7.39  | 7.39  | 7.39  |
|             | 2020 | 17.03  | 16.48 | 16.71 | 16.71 | 15.13 |
|             | 2030 | 21.38  | 19.97 | 20.58 | 20.58 | 15.78 |
|             | 2040 | 23.17  | 21.53 | 22.37 | 22.37 | 12.16 |
|             | 2050 | 23.30  | 21.26 | 22.21 | 22.21 | 6.64  |
| Jiangsu     | 2010 | 13.37  | 13.37 | 13.37 | 13.37 | 13.37 |
|             | 2020 | 23.59  | 26.16 | 27.00 | 26.92 | 18.20 |
|             | 2030 | 30.75  | 35.40 | 36.34 | 36.34 | 24.38 |
|             | 2040 | 35.27  | 43.04 | 44.47 | 44.47 | 22.41 |
|             | 2050 | 37.42  | 44.52 | 46.25 | 46.25 | 15.71 |
| Chongqing   | 2010 | 2.18   | 2.18  | 2.18  | 2.18  | 2.18  |
|             | 2020 | 4.78   | 5.32  | 5.42  | 5.42  | 3.79  |
|             | 2030 | 6.34   | 7.61  | 7.64  | 7.64  | 5.01  |
|             | 2040 | 7.22   | 8.99  | 9.47  | 9.47  | 5.26  |
|             | 2050 | 7.55   | 9.49  | 10.06 | 10.06 | 4.07  |
| Hunan       | 2010 | 3.03   | 3.03  | 3.03  | 3.03  | 3.03  |
|             | 2020 | 7.50   | 6.72  | 6.85  | 6.85  | 5.57  |
|             | 2030 | 10.18  | 10.21 | 10.59 | 10.59 | 9.42  |
|             | 2040 | 11.95  | 10.15 | 10.66 | 10.66 | 9.26  |
|             | 2050 | 13.01  | 8.62  | 8.20  | 8.20  | 6.87  |
| Zhejiang    | 2010 | 7.46   | 7.46  | 7.46  | 7.46  | 7.46  |
|             | 2020 | 14.46  | 15.99 | 16.25 | 16.25 | 10.12 |
|             | 2030 | 20.85  | 24.17 | 25.15 | 25.15 | 15.28 |
|             | 2040 | 26.65  | 30.01 | 31.55 | 31.55 | 18.79 |
|             | 2050 | 31.64  | 33.99 | 36.17 | 36.17 | 17.81 |
| Hubei       | 2010 | 5.14   | 5.14  | 5.14  | 5.14  | 5.14  |
|             | 2020 | 11.66  | 11.39 | 11.58 | 11.58 | 8.54  |
|             | 2030 | 16.13  | 15.86 | 16.52 | 16.52 | 11.38 |
|             | 2040 | 19.17  | 19.53 | 20.59 | 20.59 | 11.80 |
|             | 2050 | 20.83  | 20.73 | 22.08 | 22.08 | 9.02  |
| Jiangxi     | 2010 | 2.39   | 2.39  | 2.39  | 2.39  | 2.39  |
|             | 2020 | 5.92   | 5.45  | 5.54  | 5.54  | 4.74  |
|             | 2030 | 7.93   | 6.66  | 6.94  | 6.94  | 5.40  |
|             | 2040 | 9.32   | 7.61  | 8.04  | 8.04  | 5.72  |
|             | 2050 | 10.21  | 7.80  | 8.35  | 8.35  | 4.39  |
| Yunan       | 2010 | 1.38   | 1.38  | 1.38  | 1.38  | 1.38  |
|             | 2020 | 4.49   | 3.73  | 3.82  | 3.82  | 3.06  |
|             | 2030 | 6.39   | 4.92  | 5.19  | 5.19  | 3.70  |
|             | 2040 | 7.84   | 5.97  | 6.41  | 6.41  | 5.14  |
|             | 2050 | 8.91   | 6.60  | 7.18  | 7.18  | 4.08  |
| Guizhou     | 2010 | 1.14   | 1.14  | 1.14  | 1.14  | 1.14  |
|             | 2020 | 3.64   | 3.14  | 3.21  | 3.21  | 2.40  |
|             | 2030 | 4.84   | 4.19  | 4.37  | 4.37  | 2.87  |
|             | 2040 | 5.54   | 5.00  | 5.28  | 5.28  | 3.09  |
|             | 2050 | 5.90   | 5.38  | 5.71  | 5.71  | 2.43  |
| Region   | Year | FIX2 | REF | BIO  | ELE  | NZE  |
|----------|------|------|-----|------|------|------|
| Guangxi  | 2010 | 2.17 | 2.17| 2.17 | 2.17 | 2.17 |
|          | 2020 | 5.55 | 4.98| 5.09 | 5.09 | 4.82 |
|          | 2030 | 7.62 | 5.47| 5.78 | 5.78 | 5.30 |
|          | 2040 | 9.11 | 6.23| 6.72 | 6.72 | 5.68 |
|          | 2050 | 10.10| 6.29| 6.90 | 6.90 | 5.11 |
| Guangdong| 2010 | 10.75| 10.75|10.75 |10.75 |10.75 |
|          | 2020 | 20.57| 17.97|17.82 |18.32 |16.75 |
|          | 2030 | 29.13| 21.67|22.36 |22.66 |19.96 |
|          | 2040 | 36.79| 25.37|27.04 |27.04 |21.17 |
|          | 2050 | 45.82| 28.45|30.99 |30.99 |23.77 |
| Fujian   | 2010 | 3.64 | 3.64| 3.64 | 3.64 | 3.64 |
|          | 2020 | 6.78 | 6.60| 6.71 | 6.71 | 5.27 |
|          | 2030 | 8.92 | 8.41| 8.42 | 8.73 | 6.37 |
|          | 2040 | 10.30| 9.68| 10.15|10.15 |6.44 |
|          | 2050 | 11.04| 9.81|10.37 |10.37 |4.83 |
| Hainan   | 2010 | 0.80 | 0.80| 0.80 | 0.80 | 0.80 |
|          | 2020 | 1.85 | 1.57| 1.59 | 1.59 | 1.59 |
|          | 2030 | 2.47 | 1.35| 1.41 | 1.41 | 1.41 |
|          | 2040 | 2.97 | 1.48| 1.58 | 1.58 | 1.54 |
|          | 2050 | 3.40 | 1.49| 1.60 | 1.60 | 1.32 |
| Beijing  | 2010 | 0.83 | 0.83| 0.83 | 0.83 | 0.83 |
|          | 2020 | 2.38 | 3.89| 3.86 | 4.18 | 3.12 |
|          | 2030 | 3.09 | 5.62| 5.54 | 6.03 | 4.31 |
|          | 2040 | 3.99 | 5.66| 5.56 | 6.13 | 4.12 |
|          | 2050 | 4.89 | 5.71| 5.56 | 6.22 | 3.31 |
| Shanghai | 2010 | 0.86 | 0.86| 0.86 | 0.86 | 0.86 |
|          | 2020 | 2.50 | 2.51| 2.33 | 2.69 | 2.30 |
|          | 2030 | 3.07 | 3.47| 3.33 | 3.86 | 3.05 |
|          | 2040 | 4.00 | 3.49| 3.34 | 3.96 | 2.71 |
|          | 2050 | 4.97 | 3.56| 3.35 | 4.04 | 2.41 |
| Heilongjiang| 2010| 2.81 | 2.81| 2.81 | 2.81 | 2.81 |
|          | 2020 | 8.00 | 2.45| 2.37 | 2.62 | 2.42 |
|          | 2030 | 9.60 | 2.92| 2.81 | 3.33 | 2.86 |
|          | 2040 | 9.17 | 2.87| 2.77 | 3.37 | 2.74 |
|          | 2050 | 8.04 | 2.81| 2.71 | 3.33 | 1.77 |
| Inner-Mongolia| 2010| 2.14 | 2.14| 2.14 | 2.14 | 2.14 |
|          | 2020 | 4.92 | 5.31| 5.17 | 5.43 | 5.14 |
|          | 2030 | 5.86 | 6.08| 5.98 | 6.48 | 5.37 |
|          | 2040 | 5.80 | 6.04| 5.97 | 6.54 | 4.09 |
|          | 2050 | 5.31 | 6.00| 5.94 | 6.55 | 2.53 |
| Qinghai  | 2010 | 0.38 | 0.38| 0.38 | 0.38 | 0.38 |
|          | 2020 | 1.06 | 1.61| 1.58 | 1.71 | 1.18 |
|          | 2030 | 1.37 | 1.85| 1.83 | 2.24 | 1.48 |
|          | 2040 | 1.42 | 1.85| 1.83 | 2.32 | 1.09 |
|          | 2050 | 1.34 | 1.84| 1.83 | 2.30 | 0.71 |
| Tibet    | 2010 | 0.24 | 0.24| 0.24 | 0.24 | 0.24 |
|          | 2020 | 0.74 | 0.87| 0.85 | 1.14 | 0.85 |
|          | 2030 | 1.05 | 1.03| 1.02 | 1.48 | 1.02 |
|          | 2040 | 1.21 | 1.03| 1.02 | 1.58 | 0.84 |
|          | 2050 | 1.27 | 1.03| 1.02 | 1.65 | 0.67 |
| Xinjiang | 2010 | 1.79 | 1.79| 1.79 | 1.79 | 1.79 |
|          | 2020 | 4.88 | 6.43| 6.41 | 6.67 | 5.09 |
|          | 2030 | 6.83 | 8.00| 7.92 | 8.45 | 6.57 |
|          | 2040 | 7.80 | 7.99| 7.92 | 8.60 | 4.59 |
|          | 2050 | 8.13 | 7.98| 7.92 | 8.67 | 3.85 |
| Jilin    | 2010 | 2.14 | 2.14| 2.14 | 2.14 | 2.14 |
|          | 2020 | 5.74 | 2.24| 2.04 | 2.31 | 2.04 |
|          | 2030 | 7.06 | 2.66| 2.50 | 3.00 | 2.55 |
|          | 2040 | 6.99 | 2.59| 2.47 | 3.06 | 2.45 |
|          | 2050 | 6.35 | 2.54| 2.44 | 3.06 | 2.03 |
| Region   | Year | FIX2  | REF  | BIO  | ELE  | NZE  |
|----------|------|-------|------|------|------|------|
| Liaoning | 2010 | 3.30  | 3.30 | 3.30 | 3.30 | 3.30 |
|          | 2020 | 7.54  | 3.59 | 3.55 | 3.83 | 3.53 |
|          | 2030 | 8.84  | 4.35 | 4.26 | 4.83 | 4.28 |
|          | 2040 | 8.75  | 4.33 | 4.23 | 4.90 | 3.98 |
|          | 2050 | 8.01  | 4.29 | 4.18 | 4.88 | 2.39 |
| Tianjin  | 2010 | 0.67  | 0.67 | 0.67 | 0.67 | 0.67 |
|          | 2020 | 1.63  | 0.96 | 0.94 | 1.25 | 0.94 |
|          | 2030 | 2.01  | 1.22 | 1.19 | 1.66 | 1.20 |
|          | 2040 | 2.34  | 1.24 | 1.19 | 1.76 | 1.23 |
|          | 2050 | 2.57  | 1.25 | 1.20 | 1.83 | 0.90 |
| Hebei    | 2010 | 4.93  | 4.93 | 4.93 | 4.93 | 4.93 |
|          | 2020 | 12.11 | 15.83| 15.38| 15.68| 12.39|
|          | 2030 | 15.27 | 18.82| 18.49| 19.46| 14.22|
|          | 2040 | 15.72 | 18.71| 18.46| 19.65| 9.42 |
|          | 2050 | 14.78 | 18.59| 18.38| 19.61| 5.82 |
| Shandong | 2010 | 7.50  | 7.50 | 7.50 | 7.50 | 7.50 |
|          | 2020 | 15.89 | 12.41| 12.34| 12.61| 12.28|
|          | 2030 | 19.37 | 14.40| 14.03| 15.20| 13.98|
|          | 2040 | 19.54 | 14.27| 13.95| 15.37| 10.59|
|          | 2050 | 18.07 | 14.13| 13.82| 15.25| 5.87 |
| Ningxia  | 2010 | 0.44  | 0.44 | 0.44 | 0.44 | 0.44 |
|          | 2020 | 1.10  | 1.71 | 1.70 | 1.80 | 1.31 |
|          | 2030 | 1.45  | 2.08 | 2.07 | 2.45 | 1.55 |
|          | 2040 | 1.57  | 2.08 | 2.07 | 2.57 | 1.07 |
|          | 2050 | 1.56  | 2.08 | 2.07 | 2.62 | 0.84 |
| Sichuan  | 2010 | 3.68  | 3.68 | 3.68 | 3.68 | 3.68 |
|          | 2020 | 8.97  | 4.98 | 4.43 | 4.84 | 4.43 |
|          | 2030 | 10.28 | 4.79 | 4.43 | 19.41| 4.48 |
|          | 2040 | 9.58  | 4.58 | 4.34 | 5.45 | 3.96 |
|          | 2050 | 8.15  | 4.40 | 4.23 | 5.30 | 2.52 |
| Shaanxi  | 2010 | 2.28  | 2.28 | 2.28 | 2.28 | 2.28 |
|          | 2020 | 5.43  | 2.03 | 2.01 | 2.25 | 2.00 |
|          | 2030 | 6.60  | 2.19 | 2.10 | 2.69 | 2.10 |
|          | 2040 | 6.55  | 2.17 | 2.08 | 2.78 | 1.99 |
|          | 2050 | 5.93  | 2.13 | 2.04 | 2.77 | 1.37 |
| Shanxi   | 2010 | 2.33  | 2.33 | 2.33 | 2.33 | 2.33 |
|          | 2020 | 6.04  | 7.57 | 7.54 | 7.91 | 6.28 |
|          | 2030 | 7.60  | 9.05 | 8.96 | 9.58 | 6.97 |
|          | 2040 | 7.82  | 9.04 | 8.95 | 9.66 | 4.61 |
|          | 2050 | 7.34  | 9.01 | 8.92 | 9.65 | 3.22 |
| Gansu    | 2010 | 1.23  | 1.23 | 1.23 | 1.23 | 1.23 |
|          | 2020 | 3.58  | 4.00 | 4.00 | 4.26 | 4.00 |
|          | 2030 | 4.40  | 4.57 | 4.52 | 5.02 | 4.14 |
|          | 2040 | 4.37  | 4.54 | 4.51 | 5.12 | 3.37 |
|          | 2050 | 3.95  | 4.52 | 4.48 | 5.13 | 2.14 |
| Anhui    | 2010 | 2.80  | 2.80 | 2.80 | 2.80 | 2.80 |
|          | 2020 | 7.16  | 4.17 | 4.17 | 4.46 | 4.17 |
|          | 2030 | 8.47  | 4.14 | 3.95 | 4.70 | 3.95 |
|          | 2040 | 8.13  | 4.06 | 3.89 | 4.75 | 3.13 |
|          | 2050 | 7.11  | 3.98 | 3.81 | 4.65 | 2.28 |
| Henan    | 2010 | 6.29  | 6.29 | 6.29 | 6.29 | 6.29 |
|          | 2020 | 14.80 | 15.92| 15.89| 16.33| 15.88|
|          | 2030 | 17.92 | 17.66| 17.55| 18.72| 16.09|
|          | 2040 | 17.61 | 17.60| 17.49| 18.85| 11.27|
|          | 2050 | 15.75 | 17.49| 17.37| 18.73| 7.48 |
| Jiangsu  | 2010 | 6.59  | 6.59 | 6.59 | 6.59 | 6.59 |
|          | 2020 | 13.89 | 2.80 | 2.78 | 3.31 | 2.77 |
|          | 2030 | 16.77 | 3.44 | 3.31 | 4.59 | 3.36 |
|          | 2040 | 17.18 | 3.42 | 3.25 | 4.76 | 3.52 |
|          | 2050 | 16.30 | 3.35 | 3.14 | 4.69 | 2.68 |

(Continued.)
| Region   | Year | FIX2  | REF  | BIO  | ELE  | NZE  |
|----------|------|-------|------|------|------|------|
| Chongqing | 2010 | 1.15  | 1.15 | 1.15 | 1.15 | 1.15 |
|          | 2020 | 2.91  | 1.62 | 1.60 | 1.89 | 1.60 |
|          | 2030 | 3.29  | 1.65 | 1.61 | 2.13 | 1.64 |
|          | 2040 | 3.01  | 1.63 | 1.58 | 2.16 | 1.58 |
|          | 2050 | 2.53  | 1.59 | 1.53 | 2.12 | 1.15 |
| Hunan    | 2010 | 3.29  | 3.29 | 3.29 | 3.29 | 3.29 |
|          | 2020 | 8.46  | 10.17| 9.81 | 10.17| 9.81 |
|          | 2030 | 9.90  | 11.12| 10.76| 11.73| 10.39|
|          | 2040 | 9.45  | 10.92| 10.71| 11.87| 7.08 |
|          | 2050 | 8.24  | 10.78| 10.65| 11.76| 1.96 |
| Zhejiang | 2010 | 4.83  | 4.83 | 4.83 | 4.83 | 4.83 |
|          | 2020 | 11.08 | 5.58 | 5.25 | 5.66 | 5.24 |
|          | 2030 | 14.22 | 7.48 | 7.01 | 8.21 | 7.09 |
|          | 2040 | 15.49 | 7.35 | 7.00 | 41.55| 7.24 |
|          | 2050 | 15.67 | 7.27 | 6.94 | 8.57 | 5.80 |
| Hubei    | 2010 | 3.30  | 3.30 | 3.30 | 3.30 | 3.30 |
|          | 2020 | 8.37  | 5.43 | 5.40 | 5.99 | 5.37 |
|          | 2030 | 9.83  | 5.99 | 5.89 | 6.85 | 5.95 |
|          | 2040 | 9.24  | 5.93 | 5.82 | 6.84 | 4.69 |
|          | 2050 | 7.95  | 5.84 | 5.73 | 6.71 | 2.99 |
| Jiangxi  | 2010 | 2.01  | 2.01 | 2.01 | 2.01 | 2.01 |
|          | 2020 | 5.66  | 3.59 | 3.59 | 4.03 | 3.58 |
|          | 2030 | 7.19  | 3.82 | 3.72 | 4.62 | 3.75 |
|          | 2040 | 7.41  | 3.77 | 3.70 | 4.78 | 3.04 |
|          | 2050 | 6.96  | 3.72 | 3.67 | 4.80 | 2.54 |
| Yunan    | 2010 | 1.41  | 1.41 | 1.41 | 1.41 | 1.41 |
|          | 2020 | 4.19  | 3.92 | 3.91 | 4.21 | 3.98 |
|          | 2030 | 5.51  | 4.38 | 4.24 | 4.95 | 4.28 |
|          | 2040 | 5.89  | 4.34 | 4.24 | 5.13 | 3.57 |
|          | 2050 | 5.74  | 4.31 | 4.22 | 5.18 | 2.25 |
| Guizhou  | 2010 | 1.15  | 1.15 | 1.15 | 1.15 | 1.15 |
|          | 2020 | 3.38  | 4.77 | 4.78 | 5.21 | 4.78 |
|          | 2030 | 4.02  | 5.02 | 4.78 | 5.44 | 5.02 |
|          | 2040 | 3.85  | 4.89 | 4.77 | 5.53 | 2.87 |
|          | 2050 | 3.36  | 4.81 | 4.74 | 54.88| 1.60 |
| Guangxi  | 2010 | 0.82  | 0.82 | 0.82 | 0.82 | 0.82 |
|          | 2020 | 1.74  | 1.47 | 1.45 | 1.82 | 1.45 |
|          | 2030 | 2.06  | 1.26 | 1.24 | 1.85 | 1.27 |
|          | 2040 | 1.98  | 1.23 | 1.22 | 1.93 | 1.05 |
|          | 2050 | 1.75  | 1.19 | 1.19 | 1.93 | 0.52 |
| Guangdong| 2010 | 1.68  | 1.68 | 1.68 | 1.68 | 1.68 |
|          | 2020 | 3.22  | 0.92 | 0.79 | 1.29 | 0.78 |
|          | 2030 | 4.40  | 1.26 | 0.71 | 1.92 | 0.89 |
|          | 2040 | 5.11  | 1.32 | 0.76 | 2.33 | 1.23 |
|          | 2050 | 5.54  | 1.42 | 0.77 | 2.56 | 0.55 |
| Fujian   | 2010 | 1.53  | 1.53 | 1.53 | 1.53 | 1.53 |
|          | 2020 | 3.50  | 2.58 | 2.57 | 3.08 | 2.58 |
|          | 2030 | 4.48  | 3.05 | 2.98 | 3.84 | 3.19 |
|          | 2040 | 4.73  | 3.06 | 2.97 | 3.97 | 2.82 |
|          | 2050 | 4.60  | 3.04 | 2.93 | 3.98 | 1.54 |
| Hainan   | 2010 | 0.08  | 0.08 | 0.08 | 0.08 | 0.08 |
|          | 2020 | 0.21  | 0.23 | 0.19 | 0.35 | 0.19 |
|          | 2030 | 0.28  | 0.26 | 0.16 | 0.59 | 0.25 |
|          | 2040 | 0.30  | 0.22 | 0.16 | 0.67 | 0.34 |
|          | 2050 | 0.30  | 0.19 | 0.16 | 0.70 | 0.34 |
| Region      | Year | FIX2 | REF | BIO | ELE | NZE |
|------------|------|------|-----|-----|-----|-----|
| Beijing    | 2010 | 6.77 | 6.77| 6.77| 6.77| 6.77|
|            | 2020 | 6.35 | 4.51| 4.11| 3.76| 4.30|
|            | 2030 | 7.52 | 4.31| 3.37| 3.50| 3.89|
|            | 2040 | 8.11 | 4.37| 3.30| 3.30| 2.20|
|            | 2050 | 8.41 | 3.85| 2.99| 2.80| 0.61|
| Shanghai   | 2010 | 2.41 | 2.41| 2.41| 2.41| 2.41|
|            | 2020 | 2.39 | 1.71| 1.77| 1.81| 1.74|
|            | 2030 | 2.85 | 1.69| 1.54| 1.50| 1.52|
|            | 2040 | 3.16 | 1.79| 1.38| 1.45| 0.98|
|            | 2050 | 3.40 | 1.89| 1.37| 1.51| 0.35|
| Heilongjiang| 2010 | 6.85 | 6.85| 6.85| 6.85| 6.85|
|            | 2020 | 6.31 | 4.46| 4.86| 4.71| 4.84|
|            | 2030 | 7.19 | 4.53| 3.63| 3.84| 3.75|
|            | 2040 | 7.68 | 4.37| 3.51| 3.10| 2.39|
|            | 2050 | 7.75 | 4.54| 3.12| 2.67| 0.60|
| Inner-Mongolia | 2010 | 4.46 | 4.46| 4.46| 4.46| 4.46|
|            | 2020 | 4.32 | 2.99| 3.03| 2.90| 2.96|
|            | 2030 | 5.01 | 3.03| 2.53| 2.52| 2.64|
|            | 2040 | 5.41 | 2.87| 2.27| 2.62| 1.38|
|            | 2050 | 5.51 | 3.11| 1.87| 2.18| 0.41|
| Qinghai    | 2010 | 0.81 | 0.81| 0.81| 0.81| 0.81|
|            | 2020 | 0.92 | 0.59| 0.63| 0.57| 0.58|
|            | 2030 | 1.10 | 0.57| 0.53| 0.59| 0.55|
|            | 2040 | 1.22 | 0.58| 0.49| 0.53| 0.35|
|            | 2050 | 1.28 | 0.64| 0.43| 0.44| 0.10|
| Tibet      | 2010 | 0.24 | 0.24| 0.24| 0.24| 0.24|
|            | 2020 | 0.32 | 0.19| 0.19| 0.18| 0.19|
|            | 2030 | 0.40 | 0.22| 0.22| 0.23| 0.18|
|            | 2040 | 0.46 | 0.27| 0.25| 0.25| 0.12|
|            | 2050 | 0.50 | 0.29| 0.20| 0.21| 0.04|
| Xinjiang   | 2010 | 3.00 | 3.00| 3.00| 3.00| 3.00|
|            | 2020 | 3.54 | 2.12| 2.40| 2.55| 2.13|
|            | 2030 | 4.37 | 2.40| 2.14| 2.00| 2.16|
|            | 2040 | 4.96 | 3.11| 1.94| 2.18| 1.48|
|            | 2050 | 5.31 | 3.40| 1.91| 1.87| 0.40|
| Jilin      | 2010 | 4.73 | 4.73| 4.73| 4.73| 4.73|
|            | 2020 | 4.35 | 3.36| 2.81| 3.40| 3.02|
|            | 2030 | 5.00 | 3.00| 2.67| 2.58| 2.35|
|            | 2040 | 5.40 | 3.17| 2.35| 2.42| 1.31|
|            | 2050 | 5.52 | 3.07| 2.15| 2.19| 0.42|
| Liaoning   | 2010 | 9.35 | 9.35| 9.35| 9.35| 9.35|
|            | 2020 | 8.97 | 6.94| 5.87| 6.29| 6.04|
|            | 2030 | 10.18 | 5.94| 5.62| 4.78| 6.11|
|            | 2040 | 10.66 | 6.86| 4.58| 3.78| 2.53|
|            | 2050 | 10.56 | 7.27| 3.83| 3.22| 0.75|
| Tianjin    | 2010 | 3.60 | 3.60| 3.60| 3.60| 3.60|
|            | 2020 | 3.42 | 2.33| 2.14| 2.33| 2.57|
|            | 2030 | 3.94 | 2.39| 1.92| 2.01| 1.90|
|            | 2040 | 4.14 | 2.20| 1.84| 1.78| 1.13|
|            | 2050 | 4.15 | 2.25| 1.49| 1.64| 0.29|
| Hebei      | 2010 | 10.57 | 10.57| 10.57| 10.57| 10.57|
|            | 2020 | 11.82 | 8.89| 6.95| 8.10| 7.39|
|            | 2030 | 14.09 | 8.09| 6.93| 6.81| 7.13|
|            | 2040 | 15.55 | 8.00| 6.95| 6.43| 4.04|
|            | 2050 | 16.24 | 7.91| 6.07| 6.19| 1.12|
| Region    | Year | FIX2 | REF | BIO | ELE | NZE |
|-----------|------|------|-----|-----|-----|-----|
| Shandong  | 2010 | 15.86| 15.86| 15.86| 15.86| 15.86|
|           | 2020 | 17.22| 11.11| 10.62| 11.20| 12.36|
|           | 2030 | 20.47| 12.03| 9.00 | 8.52 | 9.50 |
|           | 2040 | 22.37| 12.99| 8.45 | 8.45 | 6.40 |
|           | 2050 | 23.16| 13.01| 7.88 | 7.00 | 1.69 |
| Ningxia   | 2010 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
|           | 2020 | 1.11 | 0.70 | 0.76 | 0.68 | 0.76 |
|           | 2030 | 1.35 | 0.77 | 0.72 | 0.67 | 0.71 |
|           | 2040 | 1.50 | 0.82 | 0.63 | 0.64 | 0.37 |
|           | 2050 | 1.59 | 0.81 | 0.55 | 0.70 | 0.12 |
| Sichuan   | 2010 | 10.96| 10.96| 10.96| 10.96| 10.96|
|           | 2020 | 12.41| 8.25 | 8.01 | 7.58 | 7.79 |
|           | 2030 | 14.52| 8.47 | 6.28 | 6.12 | 7.18 |
|           | 2040 | 15.69| 9.42 | 6.42 | 6.17 | 4.31 |
|           | 2050 | 16.22| 8.62 | 6.04 | 5.45 | 1.11 |
| Shaanxi   | 2010 | 5.82 | 5.82 | 5.82 | 5.82 | 5.82 |
|           | 2020 | 6.50 | 6.17 | 4.41 | 3.61 | 3.96 |
|           | 2030 | 7.65 | 4.92 | 3.17 | 3.41 | 3.66 |
|           | 2040 | 8.34 | 4.83 | 3.56 | 3.71 | 2.28 |
|           | 2050 | 8.59 | 4.55 | 3.34 | 3.29 | 0.66 |
| Shanxi    | 2010 | 5.80 | 5.80 | 5.80 | 5.80 | 5.80 |
|           | 2020 | 6.41 | 4.12 | 4.20 | 4.70 | 4.56 |
|           | 2030 | 7.64 | 4.02 | 3.66 | 3.51 | 3.70 |
|           | 2040 | 8.42 | 4.88 | 3.43 | 3.16 | 2.34 |
|           | 2050 | 8.73 | 4.89 | 3.55 | 3.41 | 0.61 |
| Gansu     | 2010 | 3.22 | 3.22 | 3.22 | 3.22 | 3.22 |
|           | 2020 | 3.86 | 2.47 | 2.61 | 2.41 | 2.30 |
|           | 2030 | 4.60 | 2.46 | 2.26 | 2.78 | 2.08 |
|           | 2040 | 5.07 | 2.66 | 1.73 | 2.61 | 1.34 |
|           | 2050 | 5.30 | 2.82 | 1.93 | 2.08 | 0.36 |
| Anhui     | 2010 | 2.92 | 2.92 | 2.92 | 2.92 | 2.92 |
|           | 2020 | 3.03 | 2.24 | 2.19 | 2.20 | 2.14 |
|           | 2030 | 3.26 | 2.18 | 1.99 | 1.90 | 1.87 |
|           | 2040 | 3.34 | 2.30 | 1.82 | 1.73 | 1.04 |
|           | 2050 | 3.30 | 2.14 | 1.63 | 1.53 | 0.35 |
| Henan     | 2010 | 4.69 | 4.69 | 4.69 | 4.69 | 4.69 |
|           | 2020 | 5.09 | 4.01 | 3.82 | 3.76 | 3.67 |
|           | 2030 | 5.62 | 3.94 | 3.25 | 3.24 | 3.24 |
|           | 2040 | 5.87 | 4.23 | 2.92 | 3.14 | 1.93 |
|           | 2050 | 5.85 | 4.19 | 2.67 | 2.71 | 0.63 |
| Jiangsu   | 2010 | 5.18 | 5.18 | 5.18 | 5.18 | 5.18 |
|           | 2020 | 5.18 | 4.00 | 4.04 | 3.98 | 3.70 |
|           | 2030 | 5.67 | 3.66 | 3.41 | 3.24 | 2.82 |
|           | 2040 | 5.85 | 3.94 | 3.08 | 2.89 | 1.92 |
|           | 2050 | 5.78 | 4.05 | 2.73 | 2.46 | 0.62 |
| Chongqing | 2010 | 1.66 | 1.66 | 1.66 | 1.66 | 1.66 |
|           | 2020 | 1.56 | 1.41 | 1.23 | 1.23 | 1.15 |
|           | 2030 | 1.61 | 1.18 | 0.99 | 0.98 | 0.90 |
|           | 2040 | 1.58 | 1.27 | 0.80 | 0.88 | 0.55 |
|           | 2050 | 1.51 | 1.08 | 0.75 | 0.79 | 0.16 |
| Hunan     | 2010 | 3.24 | 3.24 | 3.24 | 3.24 | 3.24 |
|           | 2020 | 3.38 | 3.34 | 2.55 | 2.40 | 2.61 |
|           | 2030 | 3.69 | 2.80 | 2.17 | 2.33 | 2.10 |
|           | 2040 | 3.81 | 2.78 | 1.95 | 2.20 | 1.36 |
|           | 2050 | 3.78 | 3.15 | 1.88 | 1.94 | 0.43 |
| Region   | Year | FIX2  | REF  | BIO  | ELE  | NZE  |
|----------|------|-------|------|------|------|------|
| Zhejiang | 2010 | 3.79  | 3.79 | 3.79 | 3.79 | 3.79 |
|          | 2020 | 3.88  | 2.86 | 3.03 | 3.03 | 2.85 |
|          | 2030 | 4.36  | 2.93 | 2.31 | 2.49 | 2.39 |
|          | 2040 | 4.63  | 3.31 | 2.28 | 2.39 | 1.55 |
|          | 2050 | 4.68  | 3.51 | 2.16 | 2.24 | 0.51 |
| Hubei    | 2010 | 3.23  | 3.23 | 3.23 | 3.23 | 3.23 |
|          | 2020 | 3.09  | 2.63 | 2.48 | 2.40 | 2.34 |
|          | 2030 | 3.23  | 2.00 | 1.78 | 2.06 | 1.84 |
|          | 2040 | 3.27  | 2.34 | 1.66 | 2.12 | 1.05 |
|          | 2050 | 3.18  | 2.25 | 1.49 | 1.84 | 0.34 |
| Jiangxi  | 2010 | 2.33  | 2.33 | 2.33 | 2.33 | 2.33 |
|          | 2020 | 2.53  | 2.39 | 1.88 | 1.86 | 1.92 |
|          | 2030 | 2.83  | 2.02 | 1.57 | 1.67 | 1.54 |
|          | 2040 | 2.99  | 2.19 | 1.46 | 1.67 | 0.96 |
|          | 2050 | 3.01  | 2.23 | 1.43 | 1.51 | 0.33 |
| Yunan    | 2010 | 2.11  | 2.11 | 2.11 | 2.11 | 2.11 |
|          | 2020 | 2.44  | 2.08 | 1.80 | 1.74 | 1.73 |
|          | 2030 | 2.76  | 2.13 | 1.60 | 1.54 | 1.37 |
|          | 2040 | 2.94  | 2.23 | 1.40 | 1.60 | 0.82 |
|          | 2050 | 2.99  | 2.09 | 1.30 | 1.40 | 0.32 |
| Guizhou  | 2010 | 1.54  | 1.54 | 1.54 | 1.54 | 1.54 |
|          | 2020 | 1.69  | 1.24 | 1.28 | 1.37 | 1.17 |
|          | 2030 | 1.85  | 1.32 | 1.12 | 1.25 | 0.96 |
|          | 2040 | 1.87  | 1.43 | 0.99 | 1.08 | 0.60 |
|          | 2050 | 1.83  | 1.48 | 0.91 | 0.95 | 0.20 |
| Guangxi  | 2010 | 2.23  | 2.23 | 2.23 | 2.23 | 2.23 |
|          | 2020 | 2.41  | 1.76 | 1.91 | 1.84 | 1.74 |
|          | 2030 | 2.66  | 1.86 | 1.56 | 1.72 | 1.49 |
|          | 2040 | 2.77  | 2.07 | 1.55 | 1.57 | 0.83 |
|          | 2050 | 2.76  | 2.33 | 1.37 | 1.38 | 0.29 |
| Guangdong| 2010 | 8.21  | 8.21 | 8.21 | 8.21 | 8.21 |
|          | 2020 | 8.33  | 6.24 | 6.36 | 6.13 | 6.00 |
|          | 2030 | 9.80  | 6.44 | 5.30 | 5.85 | 4.86 |
|          | 2040 | 10.85 | 7.58 | 5.32 | 5.90 | 3.46 |
|          | 2050 | 11.48 | 7.23 | 4.85 | 5.34 | 1.17 |
| Fujian   | 2010 | 2.27  | 2.27 | 2.27 | 2.27 | 2.27 |
|          | 2020 | 2.31  | 1.74 | 1.73 | 1.71 | 1.67 |
|          | 2030 | 2.55  | 1.73 | 1.43 | 1.52 | 1.32 |
|          | 2040 | 2.68  | 1.95 | 1.27 | 1.56 | 0.97 |
|          | 2050 | 2.69  | 2.06 | 1.23 | 1.49 | 0.29 |
| Hainan   | 2010 | 0.49  | 0.49 | 0.49 | 0.49 | 0.49 |
|          | 2020 | 0.52  | 0.38 | 0.41 | 0.40 | 0.38 |
|          | 2030 | 0.58  | 0.38 | 0.35 | 0.34 | 0.29 |
|          | 2040 | 0.62  | 0.44 | 0.31 | 0.34 | 0.19 |
|          | 2050 | 0.63  | 0.45 | 0.30 | 0.32 | 0.07 |

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