Supporting Information:

Co-benefits of energy efficient air conditioners in the residential building sector of China

Xu Wang[§,†,‡,*], *Pallav Purohit* [‡,*], *Lena Höglund-Isaksson*[‡], *Shaohui Zhang*[†,‡], *Hong Fang*[†]

[§] College of Economics and Management, Beijing University of Technology, China
[†] School of Economics and Management, Beihang University, China
[‡] International Institute for Applied Systems Analysis (IIASA), Laxenburg, Austria
[*] Corresponding authors: wngxu@buaa.edu.cn, purohit@iiasa.ac.at

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S1 Residential air-conditioning in China

Energy and environmental impacts associated with the building sector in China are significant, representing nearly 16% of total global final energy consumption in buildings [1]. In 2016, Chinese building sector consumed 899 million ton of coal equivalent (Mtce), accounting for 20.6% of Chinese annual energy consumption around all sectors [2]. Energy demand for space cooling in Chinese building sector is rising rapidly, placing strains on the electricity system and contributing to local air pollution and carbon dioxide (CO_2) emissions. The energy consumption for space cooling increased by a factor of 5.4 from 2001 to 2011 [3]. In addition, in 2018, under the background of consumption upgrade and industrial structure upgrade in China, the retail volume of air conditioner (AC) market was 57 million units, an increase of 1.6% year-on-year. The total production number, export volume, domestic retail volume of Chinese room AC market from 2003 to 2017 is shown in Figure S1. The annual sales volume of ACs have grown steadily, from 20 million in 2003 to 88 million in 2017, an increase by more than four times.

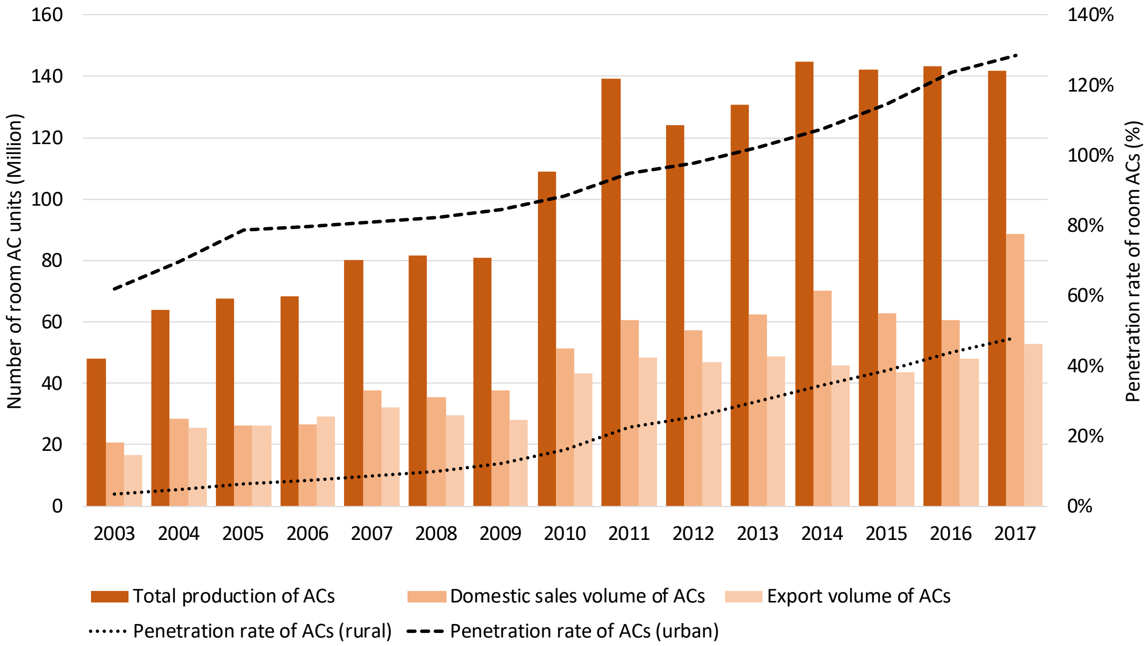

Figure S1. The volume and penetration rate of room air conditioners in China
Source: Compiled by authors with reference to the data of NBSC (2019) [4] and related news reports.

To eliminate the pressures of energy consumption, air pollution and greenhouse gas (GHG) emissions caused by increasing cooling demand, the National Quality and Technical Supervision Bureau of China released the first set of household energy efficiency standards as early as 1989 [5]. Since then, China has issued a series of relevant standards for the classification of air-conditioning energy efficiency, including GB12021.3-2004 [6] and GB12021.3-2010 [7] about the energy efficiency ratio (EER) level of fixed- speed room air-conditioning, as well as GB 21455-2008 [8] and GB21455-2013 [9] about the seasonal energy efficiency ratio (SEER) level of variable-speed room air-conditioning. The detailed energy efficiency grades level (I to V) are presented in Table S1. EER and SEER are used to measure different type of room ACs, and comparing the data specified in the same cooling capacity of fixed-speed AC and variable-speed AC, the SEER is usually 1.17 to 1.5 times of the EER [10]. EER is the ratio of output per hour to the energy consumed, which can be used to measure the efficiency of fixed speed air conditioners whereas SEER is the cooling output during a typical cooling-season divided by the total electrical energy input during the same period, which is used to describe the efficiency of variable speed air conditioners [11].

Table S1. Energy efficiency grades for room ACs in China

Standard	Cooling Capacity (CC)/(W)	Energy Efficiency Ratio (EER)				
		I	II	III	IV	V
GB12021.3-2004 [6]	CC ≤ 4500	3.40	3.20	3.00	2.80	2.60
	4500 < CC ≤ 7100	3.30	3.10	2.90	2.70	2.50
	7100 < CC ≤ 14000	3.20	3.00	2.80	2.60	2.40
GB12021.3-2010 [7]	CC ≤ 4500	3.60	3.40	3.20	--	--
	4500 < CC ≤ 7100	3.50	3.30	3.10	--	--
	7100 < CC ≤ 14000	3.40	3.20	3.00	--	--
	Cooling Capacity (CC)/(W)	Seasonal energy efficiency ratio (SEER)				
GB 21455-2008 [8]	CC ≤ 4500	5.20	4.50	3.90	3.40	3.00
	4500 < CC ≤ 7100	4.70	4.10	3.60	3.20	2.90
	7100 < CC ≤ 14000	4.20	3.70	3.30	3.00	2.80
GB21455-2013 [9]	CC ≤ 4500	5.40	5.00	4.30	--	--
	4500 < CC ≤ 7100	5.10	4.40	3.90	--	--
	7100 < CC ≤ 14000	4.70	4.00	3.50	--	--

Under the background of active promotion of energy efficient ACs and environmental protection of China, the energy efficiency level of room ACs in the market changed significantly. However, consumer preferences for AC energy efficiency levels vary widely, with only 47.6% focusing on high energy efficient ACs, which have significant impact on energy consumption together with GHG and air pollutant emissions. As shown in Figure S2, the sales share of different levels of EER in China (see Table S1 above) have great differences in 2017 and 2018. In the floor mounted column AC market, the retail sales of Grade-I energy-efficient ACs increased from 29.5% to 39.5%, whereas in the wall mounted split AC market, the retail sales of Grade-I energy-efficient ACs increased from 35% to 56.6%.

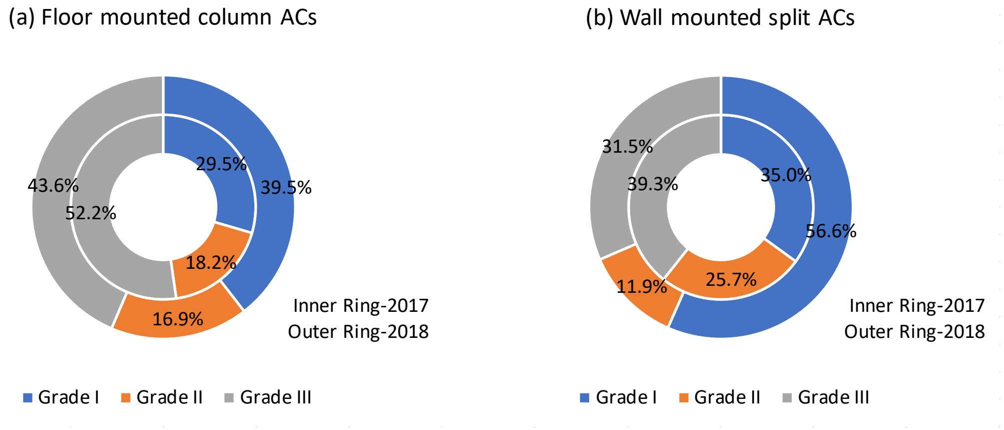

Figure S2. Sales share of different EER grades in China
Data Sources: Authors' compilation from publicly available documents.

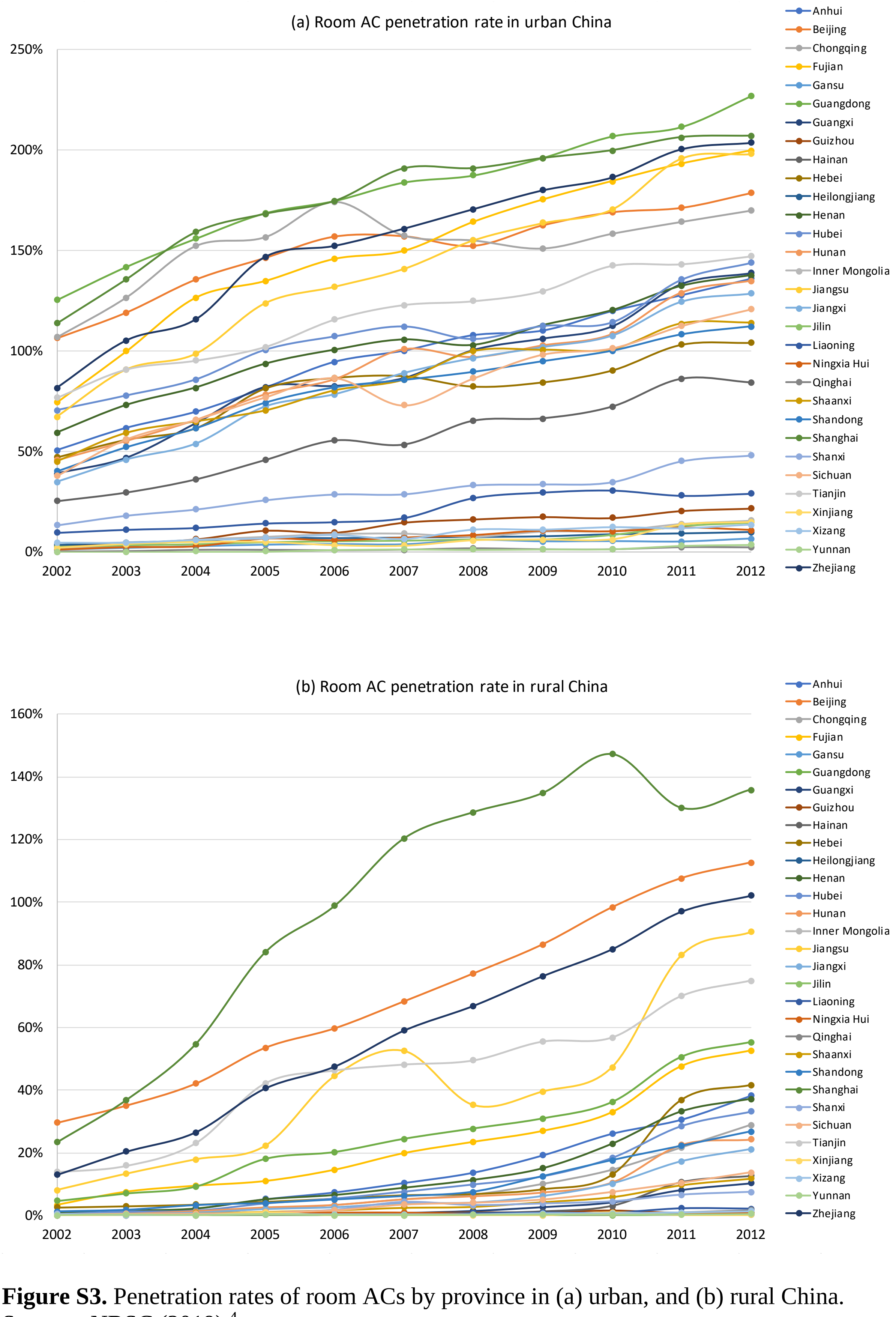

Figure S3. Penetration rates of room ACs by province in (a) urban, and (b) rural China. Sources: NBSC (2019) [4].

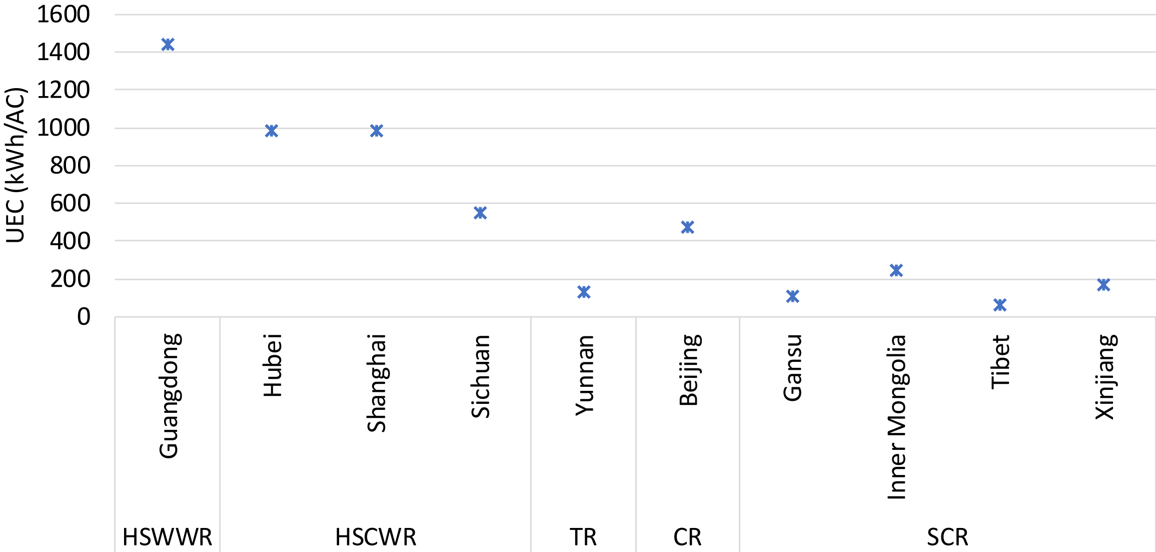

Figure S4. Unit energy consumption (UEC) of room ACs by province
Source: Mendes et al. (2014) [12] and Guo et al. (2017) [13].

S2. Key assumptions and data sources used in estimating room AC penetration

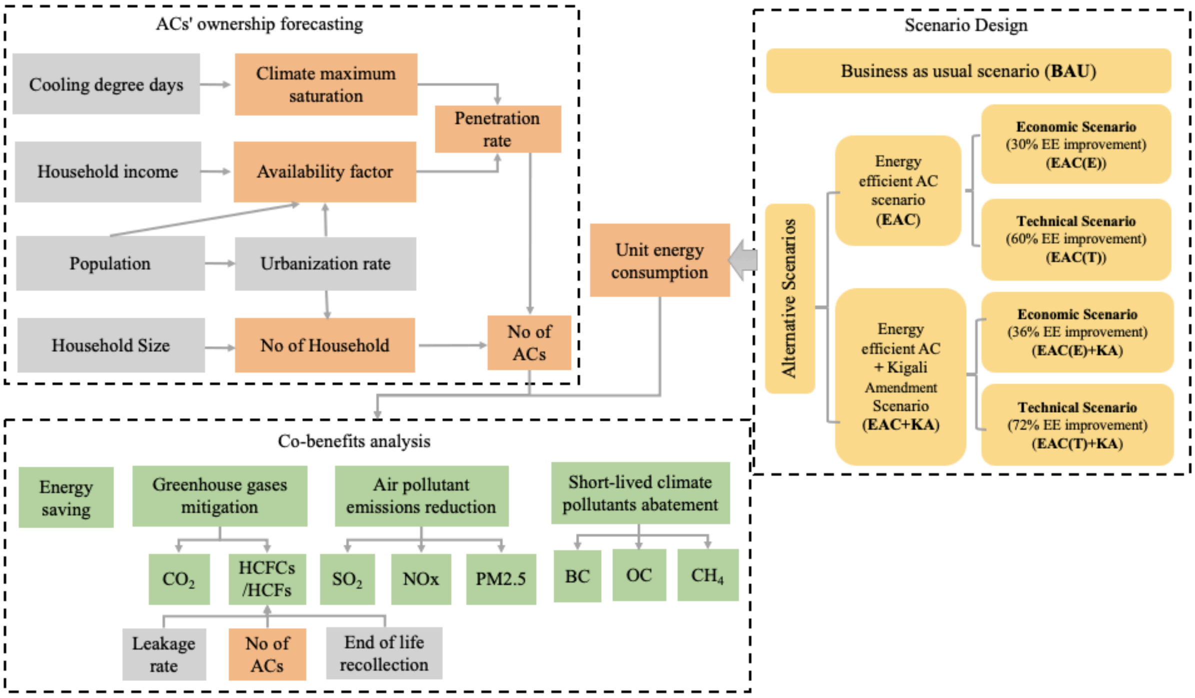

Figure S5. Conceptual framework of this study

The cooling degree day (CDD) is the most common climatic index for measuring the demand of space cooling services, which is gauged by calculating the deviation between the average temperature and a specific base temperature. The base temperature setting varies a lot in different studies [14-17], whereas, being consistent with Isaac and van Vuuren (2009) [18] and Jakubcionis and Carlsson (2017) [19], we set 18 Celsius as the base temperature in this study. Using the BizEE Degree Days Weather Data for Energy Professionals to calculate the average CDDs during the last five years of each province (see Table S2) and set this data as the historical CDD of 2015. The trend projection of CDDs for China until 2050 is obtained from IEA (2018) [20]. We assume that the CDDs of all provinces have the same trend as the average level of China.

In order to estimate the Eq. (3) about $AF_{i,t}$, we mainly follow these four steps: First of all, the historical penetration data in urban and rural China from 2002 to 2012 of each province is obtained from NBSC (2019) [4]. Using Eq. (3), the historical data of $AF_{i,t}$ can be calculated for urban and rural areas from 2002 to 2012 for each province. As a next step, the urban and rural population data from 2002 to 2012 of each province is obtained from NBSC (2019) [4] as shown in Table S2, and the population as well as urbanization rate projections for China are reaped from UN DESA (2018) [21]. Due to the lack of population projections at the provincial level we assume that the growth trends of population and urbanization rate in all provinces are the same as national level. In addition, the relationship between the urban/rural residential consumption expenditure and the provincial average residential consumption expenditure is estimated and assuming that the relationships between urban/rural GDP and provincial average GDP are the same as those between consumption expenditure level. The GDP projections at the provincial level are taken from the GAINS model using IEA/WEO (2018) new policies scenario (NPS). Using the relationship between urban/ rural GDP and provincial average GDP, we can estimate the urban/rural GDP for each province (Table S3). The historical data for household size of each province is obtained from CASS IPLE (2001) [22], CASS IPLE (2006) [23] and CASS IPLE (2011) [24], whereas the projection of household size is obtained from Zeng et al. (2008) [25].

Finally, using the historical data of $AF_{i,t}$ and projections of household income at the provincial level the regression coefficient used in Eq. (3) can be estimated for $AF_{i,t}$ by province (see Table S4).

Table S2. Macro-economic parameters in 2015 and cooling degree days at the provincial level

Province	GDP (billion Euro)	Population(million)		Household size		CDD
		Urban	Rural	Urban	Rural	
Anhui	318	31.03	30.41	3.26	3.50	1226
Beijing	333	18.77	2.93	2.54	2.20	1064
Chongqing	227	18.38	11.78	2.86	3.21	1370
Fujian	375	24.03	14.36	3.49	3.71	1634
Gansu	98	11.23	14.77	3.49	3.78	302
Guangdong	1052	74.54	33.95	3.71	4.13	2325
Guangxi	243	22.57	25.39	3.48	3.68	1556
Guizhou	152	14.83	20.47	3.63	3.82	776
Hainan	53	5.02	4.09	3.53	3.73	2305
Hebei	431	38.11	36.14	3.3	3.46	1197
Heilongjiang	218	22.41	15.7	2.76	3.01	518
Henan	535	44.41	50.39	3.54	3.77	1204
Hubei	427	33.27	25.25	3.06	3.29	1423
Hunan	418	34.52	33.31	3.19	3.43	1490
Inner Mongolia	203	15.23	12.3	2.79	2.89	495
Jiangsu	1013	53.06	26.7	3.09	3.50	1252
Jiangxi	242	23.57	22.09	3.29	3.50	1593
Jilin	414	29.52	14.31	2.88	3.12	547
Liaoning	258	15.14	9.97	2.86	3.15	730
Ningxia	42	3.69	2.99	3.14	3.54	728
Qinghai	35	2.96	2.92	3.4	3.65	211
Shaanxi	260	20.45	17.48	3.23	3.36	1048
Shandong	363	21.16	2.99	3.18	3.48	1407
Shanghai	910	56.14	42.33	2.72	2.40	1208
Shanxi	184	20.16	16.48	2.92	3.03	745
Sichuan	434	39.12	42.92	2.96	3.19	1247
Tianjin	239	12.78	2.69	2.86	3.18	1106
Tibet	15	0.9	2.34	4.01	4.57	151
Xinjiang	135	11.15	12.45	3.35	3.74	973
Yunnan	197	20.55	26.87	3.42	3.71	367
Zhejiang	620	36.45	18.94	2.95	3.15	1451
China	318	31.03	30.41	3.26	3.50	982

Data source: GDP, urban population and rural population are obtained from NBSC (2019) [4]; CDDs are compiled by authors from BizEE.

Table S3. GDP per capita in urban and rural areas of different provinces

Province	Urban areas (Euro)			Rural Areas (Euro)		
	2015	2030	2050	2015	2030	2050
Anhui	5957	10143	16568	2924	4979	8133
Beijing	13881	23640	38616	8284	14108	23045
Chongqing	6168	10503	17156	2671	4548	7429
Fujian	9461	16109	26314	5678	9668	15793
Gansu	5560	9468	15465	2387	4065	6640
Guangdong	10460	17809	29091	5058	8612	14068
Guangxi	5888	10025	16375	2667	4540	7416
Guizhou	4180	7117	11625	1943	3308	5403
Hainan	6521	11104	18138	3454	5882	9607
Hebei	8653	14732	24065	4396	7485	12227
Heilongjiang	8335	14191	23180	4535	7721	12611
Henan	6988	11899	19437	3354	5711	9328
Hubei	7571	12890	21056	3866	6582	10751
Hunan	6760	12165	19870	3430	6173	10083
Inner Mongolia	7676	13071	21351	4138	7046	11509
Jiangsu	10399	17706	28922	6574	11193	18284
Jiangxi	6070	10334	16880	3508	5972	9756
Jilin	10139	17261	28196	5431	9246	15103
Liaoning	8468	14417	23549	4383	7462	12188
Ningxia	5671	9646	15757	2733	4650	7595
Qinghai	6190	10540	17217	3272	5572	9101
Shaanxi	6042	10288	16806	2779	4732	7730
Shandong	19072	32472	53042	10405	17714	28936
Shanghai	8216	13990	22852	4764	8112	13251
Shanxi	6051	10304	16832	3337	5682	9281
Sichuan	5745	9781	15977	3260	5550	9066
Tianjin	13346	22724	37119	8325	14175	23154
Tibet	8091	13760	22476	3279	5576	9108
Xinjiang	7634	13000	21235	3585	6106	9973
Yunnan	5414	9219	15058	2535	4316	7051
Zhejiang	10636	18107	29578	6781	11545	18858

Source: NBSC (2019) [4], and authors' estimation; Projections for GDP of different provinces in China are taken from GAINS model.

Table S4. Regression coefficients for the availability factor by province

Availability factor	α	β	γ	R square
Anhui	2.5	-0.005	6	0.784
Beijing	3.0	-0.001	2	0.862
Chongqing	2.5	-0.007	7	0.829
Fujian	3.0	-0.003	6	0.941
Gansu	1.0	-0.004	7	0.838
Guangdong	3.0	-0.002	5	0.917
Guangxi	2.5	-0.007	9	0.881
Guizhou	1.0	-0.007	7	0.895
Hainan	3.0	-0.006	9	0.875
Hebei	3.0	-0.003	5	0.858
Heilongjiang	1.0	-0.004	8	0.864
Henan	3.0	-0.004	6	0.854
Hubei	3.0	-0.005	6	0.837
Hunan	2.5	-0.006	7	0.879
Inner Mongolia	1.0	-0.004	7	0.902
Jiangsu	3.0	-0.003	5	0.933
Jiangxi	2.5	-0.007	8	0.849
Jilin	1.0	-0.005	8	0.851
Liaoning	1.0	-0.004	7	0.932
Ningxia	1.0	-0.005	7	0.857
Qinghai	1.0	-0.003	7	0.688
Shaanxi	2.5	-0.006	7	0.892
Shandong	3.0	-0.002	6	0.891
Shanghai	2.5	-0.003	2	0.827
Shanxi	1.0	-0.006	6	0.923
Sichuan	2.5	-0.008	8	0.914
Tianjin	1.0	-0.002	3	0.874
Tibet	2.5	-0.003	7	0.907
Xinjiang	3.0	-0.004	8	0.837
Yunnan	1.0	-0.003	7	0.604
Zhejiang	3.0	-0.002	4	0.921

Source: Authors' estimation.

Table S5. Number of room ACs at the provincial level in China

Province	Urban China (million)			Rural China (million)		
	2015	2030	2050	2015	2030	2050
Anhui	19.5	32.3	37.2	2.7	9.2	10.8
Beijing	13.3	26.5	33.4	1.2	1.5	1.5
Chongqing	14.8	22.3	25.6	1.0	4.4	4.7
Fujian	18.5	29.4	33.6	3.6	7.8	6.1
Gansu	0.6	2.2	2.8	0.0	0.1	0.6
Guangdong	51.1	87.7	99.9	5.0	11.6	12.8
Guangxi	15.1	23.0	26.2	0.6	5.6	9.0
Guizhou	2.6	4.8	5.7	0.2	0.9	2.2
Hainan	3.9	6.2	7.1	0.2	1.6	1.8
Hebei	26.8	46.7	53.9	4.3	12.6	15.3
Heilongjiang	2.5	7.9	9.5	0.1	0.7	1.9
Henan	32.1	50.9	58.7	6.0	18.3	20.0
Hubei	29.8	45.6	52.2	4.0	13.4	12.0
Hunan	25.6	38.1	43.5	4.5	16.5	12.8
Inner Mongolia	1.5	5.1	6.2	0.1	0.4	1.1
Jiangsu	46.3	70.3	80.9	14.9	16.6	11.7
Jiangxi	17.1	25.4	29.0	3.6	11.3	8.3
Jilin	3.5	5.4	6.3	0.5	2.0	1.5
Liaoning	5.0	11.8	14.0	0.2	1.0	1.9
Ningxia	0.4	1.3	1.6	0.0	0.1	0.3
Qinghai	0.1	0.4	0.6	0.0	0.0	0.1
Shaanxi	13.1	20.7	24.0	0.8	4.2	6.2
Shandong	49.6	73.9	84.6	12.6	25.6	19.0
Shanghai	17.6	26.3	30.3	2.1	2.1	1.6
Shanxi	5.1	8.0	9.4	0.9	2.7	2.4
Sichuan	29.1	45.1	51.8	4.6	21.4	17.2
Tianjin	11.5	17.8	20.5	1.7	1.8	1.3
Tibet	0.0	0.1	0.1	0.0	0.0	0.1
Xinjiang	2.0	4.2	4.9	0.1	0.6	1.5
Yunnan	0.3	2.5	5.7	0.0	0.1	0.4
Zhejiang	27.6	51.1	59.5	6.6	10.8	9.3
Total China	486	793	919	82	205	195

Source: NBSC (2019) [4], and authors' estimation; Projections for GDP of different provinces in China are taken from GAINS model.

S3 Low-GWP refrigerants for room air-conditioning

The GHG emissions from space cooling are not only just from the energy consumption in room ACs units but also from the leakage of refrigerants in cooling machines. There are three major types of refrigerants used in room ACs: chlorofluorocarbons (CFCs), hydrochloro-fluorocarbons (HCFCs) and hydrofluorocarbons (HFCs), which are generally thousands of times more powerful than CO_2 as greenhouse gas (see Table S6). Clean and energy efficient cooling can advance three internationally agreed goals simultaneously: the Paris Climate Agreement; the UN Sustainable Development Goals (SDGs); and the Kigali Amendment (KA) of Montreal Protocol (MP). MP transitions result in the improvement of design and energy performance of equipment, and CFCs are replaced initially by HCFCs which have smaller ozone-depleting potentials (ODP) and/or by non-ozone-depleting substances and technologies. The ban on CFCs in developing countries following the MP was completed in 2010 [28], as well as China has already achieved it ahead of schedule in 2006 [29]. KA aims at the conversion from equipment using HFC refrigerants with high global warming potentials (GWPs) to refrigerants with lower GWPs through a differentiated phase-down of HFCs across countries over the next three decades (see Table S7), and provides an important opportunity to consider other possible technological improvements that can offer additional climate benefits (SDG7 and SDG13) [30]. As a signatory to KA, China is planning to phase-out HCFC-22 and phase-down HFC-410A as well as HFC-32 consumption with the new ozone and environment friendly refrigerant (e.g. HC-290 or propane) [31, 32].

Table S6. The detailed descriptions of different main refrigerants used in ACs

Refrigerant Name	Chemical Formula	Ozone Depletion Potential (ODP)	Global Warming Potential (GWP_{100})
CFCs			
CFC-11	CCl_3F	1	4660
CFC-12	CCl_2F_2	0.73-0.81	10200
HCFCs			
HCFC-22	$CHClF_2$	0.024-0.034	1760
HCFC-142b	CH_3CClF_2	0.023-0.057	1980
HFCs			
HFC-32	CH_2F_2	0	677
HFC-125	CHF_2CF_3	0	3170
HFC-134a	CH_2FCF_3	0	1300
HFC-143a	CH_3CF_3	0	4800
HFC-410A	CH_2F_2&CHF_2CF_3	0	1923.5
Others			
Propane, R-290	$CH_3CH_2CH_3$	0	<1
Isobutane, R-600a	$(CH_3)_2CHCH_3$	0	<<1
Carbon dioxide, R-744	CO_2	0	1
Ammonia, R-717	NH_3	0	<1

Notes: There may be minor differences between different versions of documents about ODP and GWP. The data in this paper is mainly from IPCC AR5 [33], Scientific Assessment of Ozone Depletion 2018 [34], and Goetzler et al., (2016) [35].

The Kigali Amendment to the Montreal Protocol sets targets for the phase-down of consumption of HFCs for four different Party groups. The first group includes 136 primarily developing countries that make up all Article 5 countries as specified under the MP with the exception of Bahrain, India, Iran, Iraq, Kuwait, Oman, Pakistan, Qatar, Saudi Arabia, and the United Arab Emirates (UAE). These ten countries are characterized by high ambient air temperatures and make up a second and separate group of Article 5 countries. Countries specified as non-Article 5 countries under the MP are primarily developed countries and under the KA divided into two separate groups with 45 countries in a first group and with the five countries (Belarus, the Russian Federation, Kazakhstan, Tajikistan and Uzbekistan) forming a separate second group. Table S2 presents the HFC phase-down schedule of Article-5 and non-Article-5 Parties. We will hereafter refer to these four Party groups as Article 5 Group I, Article 5 Group II, non-Article 5 Group I, and non-Article 5 Group II.

Table S7. Baseline and HFCs phasedown schedule of Art. 5 and non-Art. 5 Parties under KA

	Article 5 Parties: Group I		Article 5 Parties: Group II	
Baseline Years	2020, 2021 & 2022		2024, 2025 & 2026	
Baseline Calculation	Average production/consumption of HFCs in 2020, 2021, and 2022 *plus* 65% of HCFC baseline production/consumption		Average production/consumption of HFCs in 2024, 2025, and 2026 *plus* 65% of HCFC baseline production/consumption	
Reduction steps Freeze	2024		2028	
Step 1	2029	10%	2032	10%
Step 2	2035	30%	2037	20%
Step 3	2040	50%	2042	30%
Step 4	2045	80%	2047	85%
	Non-Article 5: Group I		Non-Article 5: Group II	
Baseline Years	2011, 2012 & 2013		2011, 2012 & 2013	
Baseline Calculation	Average production/consumption of HFCs in 2011, 2012 & 2013 *plus* 15% of HCFC baseline production/consumption.		Average production/consumption of HFCs in 2011, 2012 & 2013 *plus* 25% of HCFC baseline production/consumption.	
Reduction steps Step 1	2019	10%	2020	5%
Step 2	2024	40%	2025	35%
Step 3	2029	70%	2029	70%
Step 4	2034	80%	2034	80%
Step 5	2036	85%	2036	85%

Source: UNEP, (2016) [31].

S4 Co-benefits analysis

The annual energy consumption of room AC in year t, EC_t, can be estimated by using the following equation:

$$EC_t = \sum_{i=j=1}^{m,n} \frac{N_{i,t}^{j} \cdot PR_{i,t}^{j} \cdot UEC_{i,t}^{j}}{EER_{i,t}^{j}} \qquad \text{(s1)}$$

where $N_{i,t}^{j}$, represents the number of households, $PR_{i,t}^{j}$ the penetration rate of room ACs, $UEC_{i,t}^{j}$ the unit energy consumption and $EER_{i,t}^{j}$ the energy efficiency ratio of room ACs in the j^{th} area (urban/rural) of the i^{th} province in the t^{th} year.

Once the annual energy consumption in the BAU scenario is estimated using Eq. (s1) the annual electricity saving potential in the alternative scenarios is estimated by subtracting the annual electricity consumption in the BAU and alternative scenarios respectively. Using the implied emission factors for power plants from the GAINS model we have estimated annual reductions in carbon dioxide, air pollutants and SLCP emissions in the alternative scenarios due to electricity savings.

The implied emission factors are obtained from GAINS model (Purohit et al., 2020)[46] that reflect the expected year- specific fuel mixes used in power plants in the IEA-WEO (2018) Current Policy Scenario (CPS), New Policy Scenario (NPS) and Sustainable Development Scenario (SDS), respectively, in the timeframe to 2050. Among them, the CPS only considers the impact of those policies and measures that are firmly enshrined in legislation as of mid-2018. It provides a cautious assessment of where momentum from existing policies might lead the vingector in the absence of any other impetus from government. The NPS aims to provide a sense of where today's policy ambitions seem likely to take the energy sector. It incorporates not just the policies and measures that governments around the world have already put in place, but also the likely effects of announced policies, including the Nationally Determined Contributions (NDCs) made for the Paris Agreement. The SDS represents a low carbon scenario consistent with a $2^{o}C$ (i.e., 450 ppm) global warming target for this century, and with considerably lower air pollution. This scenario outlines an integrated approach to achieving internationally agreed objectives on climate change, air quality and universal access to modern energy.

The HFC emissions from room ACs are not only from the electricity savings due to energy efficiency improvement of the AC systems but also from transitioning away from the high-GWP refrigerants. To assess HFC emissions from room ACs it is important to estimate the number of ACs with different type of refrigerants. Since it is difficult to get the exact sales share of each type of AC units in different provinces, we assume that all the provinces have the same share of refrigerants use in room ACs. Using the method described in the methodology section, we can estimate the number of room ACs by province until 2050, and the number of new-added ACs can be estimated by calculating difference between the number of room ACs in each year and lifetime of room ACs. Once the number of ACs with different refrigerant types are estimated, we can calculate the refrigerant bank of room ACs.

The GAINS model has previously been used to produce detailed future scenarios for HFC emissions to 2050 [30, 36], which have fed into climate models to assess potential impacts on global warming [37-39]. In GAINS, HFC emissions are estimated separately for “banked” emissions, i.e., leakage from equipment in use, and for “scrapping” emissions, i.e., emissions released at the end-of-life of the equipment. In general, the life cycle of ACs contain five processes, namely production, installation, operation, servicing and end-of-life. Different processes have different leakage rates of refrigerants, and the total emissions of room ACs will be the sum of five processes. In this study, we follow the similar approach as used by Liu et al. (2019) [40] for estimating the HFC emissions from all the above-mentioned processes from room AC sector in China.

In addition, in order to simplify the calculations in this paper, we assume that all the ACs used in 2000 are bought in year 2000, which will not have a significant impact on GHG mitigation, as AC stock in year 2000 is much less than the later situation. The charge size of different type of refrigerants, emission factors at different stages of life-cycle, as well as the rates of servicing and end-of-life are shown in Table S8:

Table S8. Refrigerant charge size and emission factors of room ACs

Refrigerants	GWP[a] (100-yr)	Charge size (kg/unit)	Emission factor (%)				
			Production	Installation	Operation	Servicing	End of life
HCFC-22	1760[a]	1.2[b]	0.2%[c]	0.2%[c]	2.5%[b]	100%[c] (0.03%[c])	75%[b,e] (10%[d])
HFC-410A	1923.5[a]	0.96[b]					
HFC-32	677[a]	0.68[f]					
R290	1[a]	0.6[b]					

Notes: *Data in bracket presents the rate of servicing and end of life); a. Data source: IPCC, (2014) [33]; b. Data source: Wang et al., (2016) [41]; c. Data source: Liu et al., (2019) [40]; d. Data source: Li et al., (2016) [42]; e. Data source: Wan et al., (2009) [43]; f. The charge size of HFC-32 is calculated from the charge sizes of HFC-410A. According to Mei et al. (2011) [44], the charge size of HFC-32 is 0.71 times that of HFC-410A.

Finally, to assess the total GHG mitigation, we have added the CO_2 emissions reduction due to energy efficiency improvement of air conditioners using low-GWP refrigerants and HFC mitigation (CO_2 equivalent) due to transitioning towards low-GWP refrigerants.

Table S9. Annual electricity saving and associated CO_2 mitigation, and air pollutants abatement potential in EAC(T)+KA scenario using implied emission factors from NPS

Climatic zones	Province	Electricity saving (TWh)		CO_2 mitigation (Mt)		Air pollutants abatement (kt)		
						SO_2	NO_x	$PM_{2.5}$
		2030	2050	2030	2050	2050	2050	2050
HSCWR	Anhui	10.84	29.79	3.30	8.15	3.25	5.21	0.93
CR	Beijing	10.83	34.46	3.30	9.42	3.76	6.03	1.08
HSCWR	Chongqing	7.10	18.89	2.16	5.17	2.06	3.31	0.59
HSWWR	Fujian	15.67	41.24	4.77	11.28	4.50	7.22	1.29
SCR	Gansu	0.18	0.88	0.05	0.24	0.10	0.16	0.03
HSWWR	Guangdong	53.31	145.90	16.22	39.90	15.90	25.54	4.55
HSWWR	Guangxi	8.68	24.41	2.64	6.68	2.66	4.27	0.76
HSCWR	Guizhou	0.97	3.17	0.29	0.87	0.35	0.56	0.10
HSWWR	Hainan	3.01	7.80	0.92	2.13	0.85	1.36	0.24
CR	Hebei	19.57	56.04	5.95	15.33	6.11	9.81	1.75
SCR	Heilongjiang	1.52	5.43	0.46	1.49	0.59	0.95	0.17
CR	Henan	20.39	56.40	6.20	15.42	6.15	9.87	1.76
HSCWR	Hubei	18.45	48.38	5.61	13.23	5.27	8.47	1.51
HSCWR	Hunan	16.84	42.06	5.12	11.50	4.58	7.36	1.31
SCR	Inner Mongolia	3.04	9.67	0.93	2.65	1.05	1.69	0.30
HSCWR	Jiangsu	32.84	88.10	9.99	24.09	9.60	15.42	2.75
HSCWR	Jiangxi	11.00	26.59	3.35	7.27	2.90	4.65	0.83
SCR	Jilin	0.87	3.18	0.26	0.87	0.35	0.56	0.10
SCR	Liaoning	1.56	4.78	0.47	1.31	0.52	0.84	0.15
SCR	Ningxia	0.27	0.88	0.08	0.24	0.10	0.15	0.03
SCR	Qinghai	0.01	0.14	0.00	0.04	0.02	0.03	0.00
CR	Shaanxi	6.05	17.53	1.84	4.80	1.91	3.07	0.55
CR	Shandong	8.41	23.11	2.56	6.32	2.52	4.05	0.72
HSCWR	Shanghai	60.61	165.50	18.44	45.26	18.04	28.97	5.16
CR	Shanxi	1.90	5.47	0.58	1.50	0.60	0.96	0.17
HSCWR	Sichuan	16.02	39.80	4.87	10.88	4.34	6.97	1.24
CR	Tianjin	8.15	23.29	2.48	6.37	2.54	4.08	0.73
SCR	Tibet	0.01	0.05	0.00	0.01	0.01	0.01	0.00
SCR	Xinjiang	1.38	4.40	0.42	1.20	0.48	0.77	0.14
TR	Yunnan	0.25	1.93	0.08	0.53	0.21	0.34	0.06
HSCWR	Zhejiang	24.42	66.95	7.43	18.31	7.30	11.72	2.09
	China (Total)	364.15	996.21	110.77	272.45	108.57	174.37	31.08

Notes: There are five climatic zones in China in total, including hot summer and warm winter region (HSWWR), hot summer and cold winter region (HSCWR), temperate region (TR), cold region (CR), as well as severe cold region (SCR) [45].

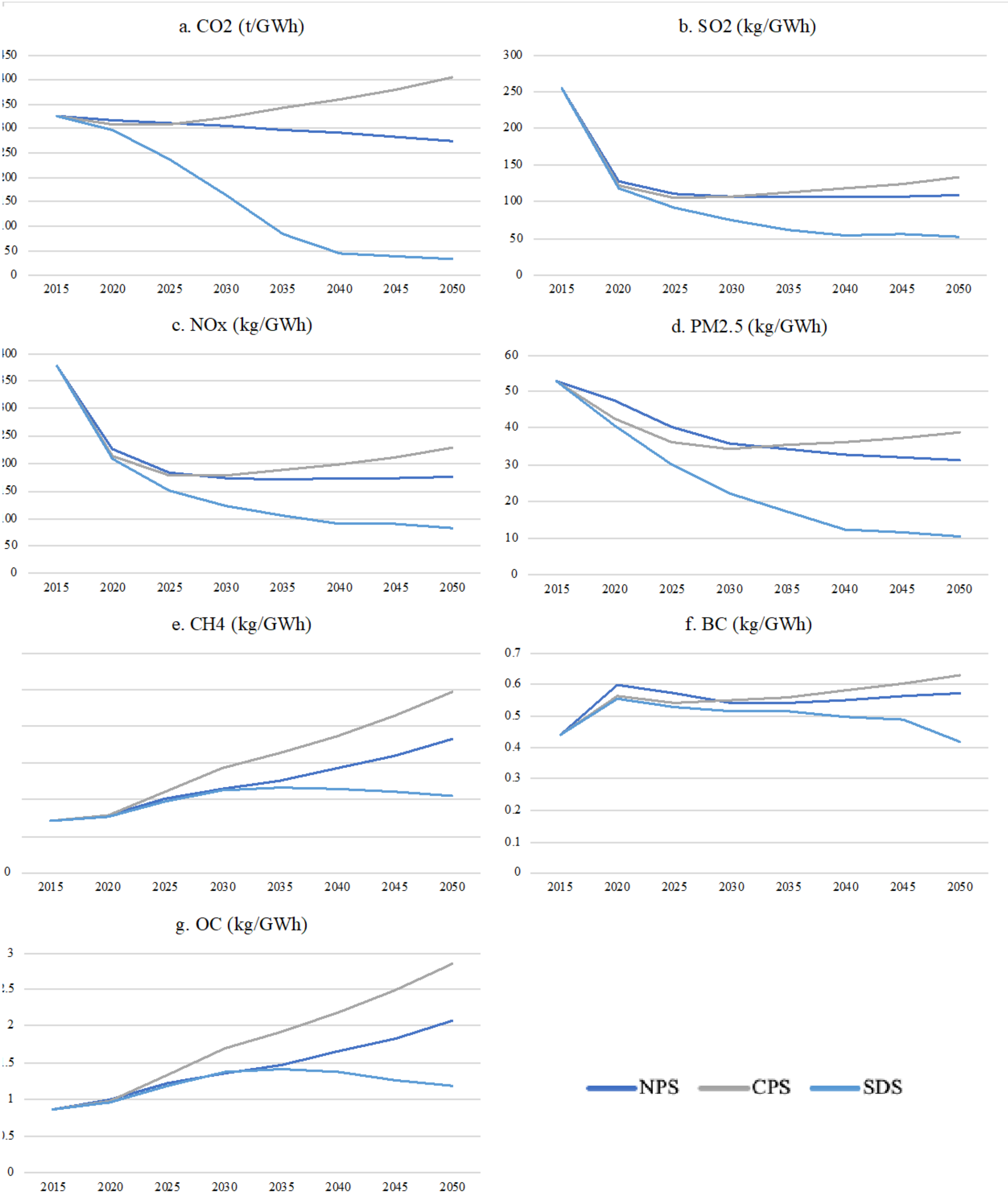

Figure S6. The implied emission factors for CO_2, air pollutants, and SLCPs

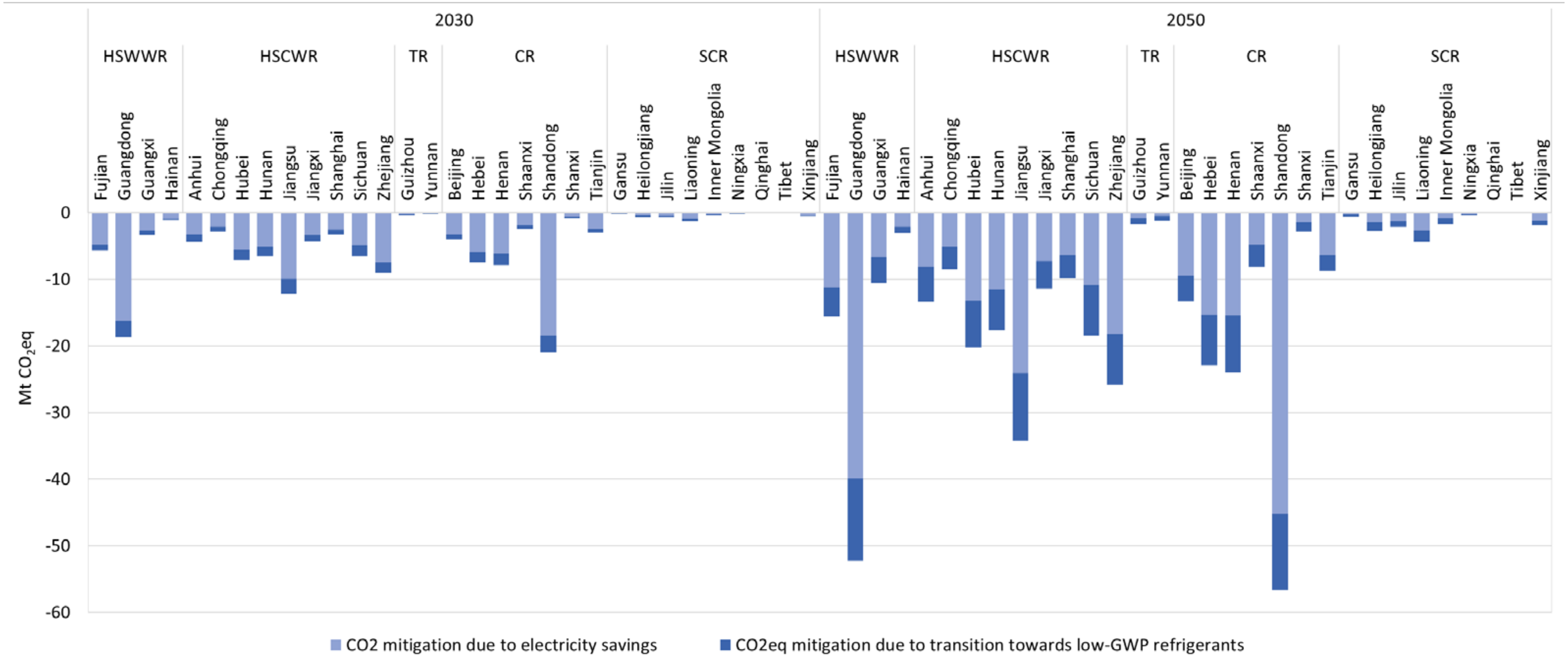

Figure S7. GHG mitigation at the provincial level due to enhanced ACs system efficiency and the substitution of high-GWP refrigerants

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