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Supplementary appendix

This appendix formed part of the original submission and has been peer reviewed. We post it as supplied by the authors.

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The 2022 Chinese Report of The Lancet Countdown on Health and Climate Change: leveraging climate actions for healthy ageing

Appendix

Section 1: Climate change impacts, exposures, and vulnerability

Indicator 1.1: Health and heat

Indicator 1.1.1: Heatwave-related mortality

Methods

The heatwave event was defined as a period of three or more days where the daily maximum temperature was higher than the reference (92.5th percentile of daily maximum temperature between 1986 and 2005) at a given location, which was chosen among different heatwave definitions to best capture the health effects of heat events in China[1,2]. The days of heatwave were defined as the number of days within the heatwave event. The deaths attributable to heatwave (AN) are calculated. The method is as follows:

$$\boldsymbol{AN_{y,p} = Pop_{y,p} \times Mort_{y,p} \times HW_{y,p} \times AF_{y,p}}$$

Where $Pop_{y,\,p}$ refers to the grid cell-level population size in a specific year. $Mort_{y,\,p}$ is the baseline daily non-accidental mortality rate; Since the mortality rate from China Statistical Yearbook is an annual statistic and mortality has seasonal patterns with a marked excess of deaths in winter[3], the mortality rate is multiplied by monthly mortality proportion and then divided by days per month as a pre-process. $HW_{y,\,p}$ is the grid cell-level heatwave days in a specific year. $AF_{y,\,p}$ is the attributable fraction (AF), which is calculated as:

$$\boldsymbol{AF = (RR - 1)/RR}$$

Where relative risks (RR) represent the increase in the risk of mortality resulting from heatwave compared with non-heatwave, and RR here refers to the gridded RR by matching climate division-specific RR with the grid. The exposure-response relationship between heatwave and mortality in different provinces (autonomous regions) is represented by the related capital cities in mainland China[2], and the relationship is assumed to be consistent during the study period. Then gridded annual deaths number of heatwave from 2000 to 2021 could be calculated by the above formulas, and summed to gain provincial and national AN. We limit our research on the warm season since a previous study has shown that approximately 90% of deaths attributable to heatwave occurred during May-September[4].

Besides, we calculated the mortality for different age groups. The method is similar to AN for the total population above, except for the age-specific RR and population of a specific age group are used to replace the whole-age RR and whole population for calculation.

The method for subgroup analysis is as follows:

$$\boldsymbol{AN_{y,\,p} = Pop_{y,\,p} \times Mort_{y,p} \times AgeP_{y,p,a} \times HW_{y,p} \times AF_{y,p,a}} \qquad \textbf{(a=65+ or 0-64)}$$

And the $AF_{y,\,p,a}$ is the age-specific AF. $AgeP_{y,\,p,a}$ is the proportion of age-specific population.

Data

1. Original RR values are derived from Yang et al[2]. Based on the general trend that risks are homogeneous in the same climate region and higher in the north of China than that in the south[5], this study combines risks through meta-analysis according to the climate zones based on the basic risk distribution pattern.
2. Non-accidental mortality rates and monthly mortality proportion ($\boldsymbol{Mort_{y,p}}$), as well as population structure data at province levels are derived from China Statistical Yearbook.
3. Gridded climate data was from the European Centre for Medium-Range Weather Forecasts (ECMWF), ERA5 project.[6]
4. Population data was from the Chambers (2020) hybrid gridded demographic data for the world.[7]
5. We choose 1986-2005 as temperature reference period for heatwave threshold to keep consistent with the Global report, which resulted in about 5000 attributable deaths per year since the temperature is lower in 1986-2005 than 2007-2013, which is the former reference period we took to keep consistent with the exposure-response functions derived from this period.

Caveats

The main caveats of this indicator are the limited number of exposure-response functions for such a big country like China and that the effects of heatwave on mortality were assumed to be constant without considering population adaptation.

The selection of the most appropriate heatwave definition remains controversial[8]. We chose heatwave definitions among different definitions to best capture the health effects of heat events in China[1,2]. The detailed chosen progress could be found in Lancet Countdown 2020[9].

Future Form of Indicator

One possible improvement of this indicator would be to use more localized city-level exposure-response function parameters within each province. And try to take the population adaptation over time into consideration. Another improvement could be to calculate the mortality for different diseases or gender.

Additional Information

In 2021, the death attributable to heatwave for elderly people older than 65 years old is 18,761, which is three and four times for the people younger than 15 years old and working people between 15 and 64 years old, respectively.

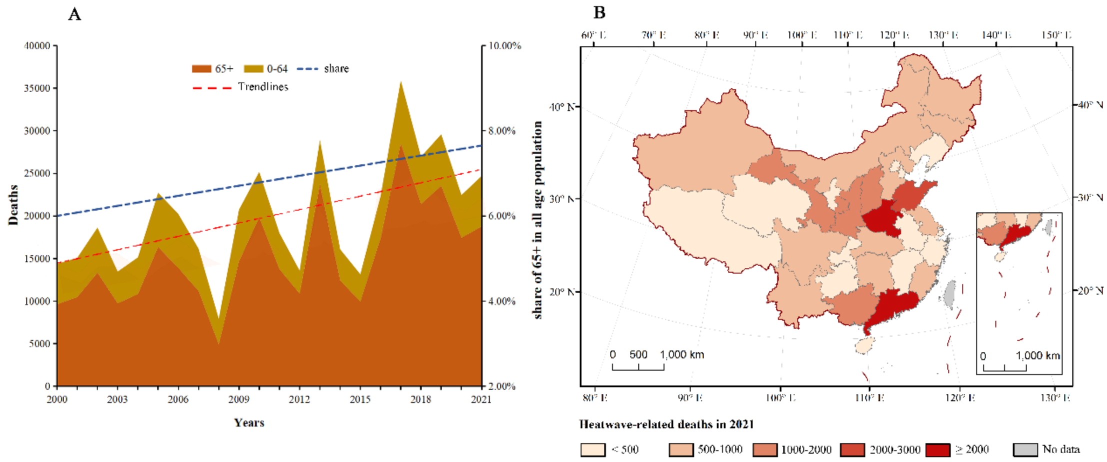


Figure 1: **Heatwave-related mortality in China. (A) Trend of heatwave-related mortality in 2000–2021. (B) Heatwave-related mortality by province in 2021.**

The red dashed line shows the linear trend with the equation: heatwave-related deaths = 397*year – 785447, P<0.05. The blue dashed line shows the share of people elder than 65 years in the total population.

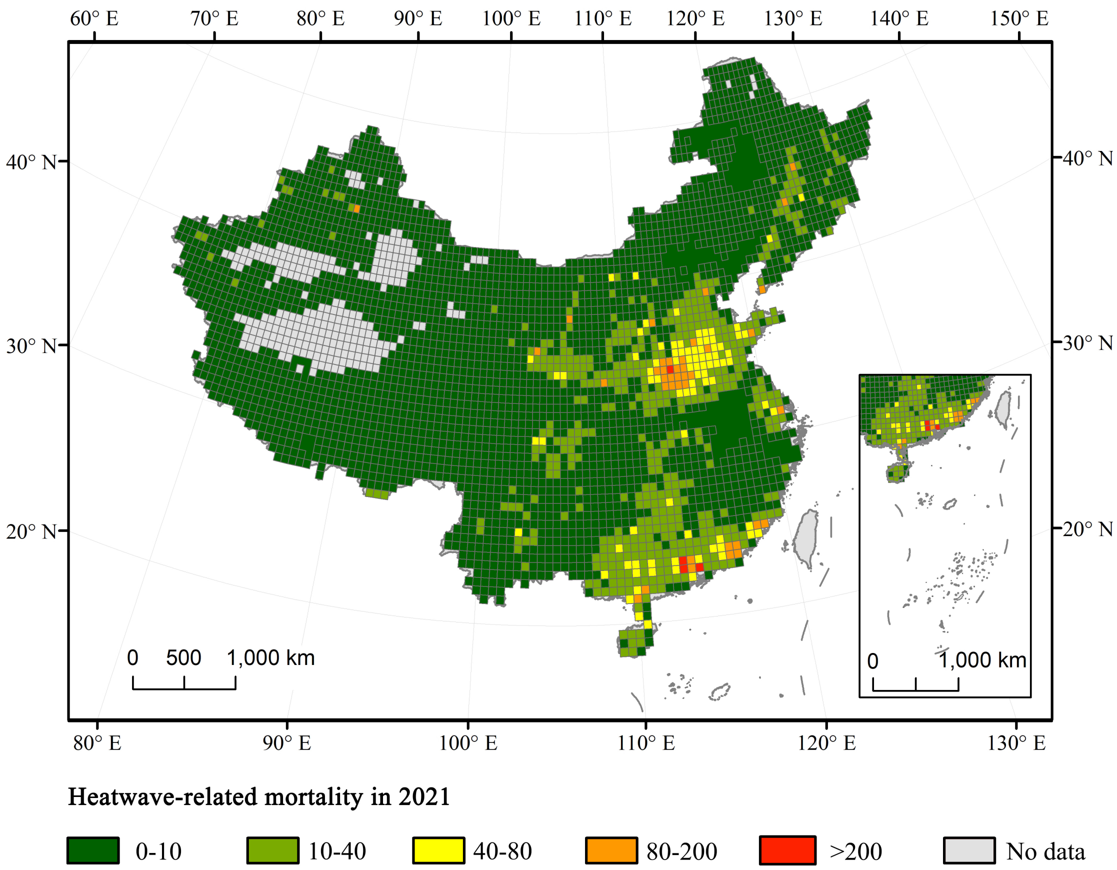


Figure 2: **Heatwave-related mortality in China on grid level.**

Indicator 1.1.2 Change in labour capacity

Methods

This indicator has been improved from the 2021 China Lancet Countdown report to show changes of work hours lost (WHL) in different industries compared with the baseline period (1986-2005).

Firstly, wet bulb globe temperature was estimated based on gridded (0.5° * 0.5°) climate data. We calculated the hourly WBGT in the shade (WBGT_shade) using temperature and dew point temperature, and calculated the hourly WBGT in the sun (WBGT_sun) using temperature, dew point temperature, solar radiation and wind speed. The detailed iteration calculation method is described in Kjellstrom et al.[10]

Secondly, we estimated the grid employment population by collecting employment rates for different sectors in each province from the national and provincial yearbooks. Then we multiplied the gridded population by the provincial employment rates to estimate the gridded working population in each sector during 1986-2021.

Thirdly, the fraction of work hours lost (WHL) in each industry was estimated based on the loss function between WBGT and WHL.[11] The loss function was shown as:

$$loss\ fraction = \frac{1}{2}\left(1 + \mathrm{ERF}\left(\frac{\mathrm{WBGT_{hour}} - \mathrm{Prod_{mean}}}{\mathrm{Prod_{sd}} * \sqrt{2}}\right)\right)$$

$\mathrm{WBGT_{hour}}$ is the hourly WBGT_shade or WBGT_sun estimated in the first step. $\mathrm{Prod_{mean}}$ and $\mathrm{Prod_{sd}}$ are the fixed parameters for laborers working with different activity levels (**Table 1**). In this study, labour was divided into engaging in agriculture, construction, manufacturing and service. We assumed labor in agriculture and construction working at a metabolic rate of 400W, manufacturing at 300W and service at 200W. As the agriculture and construction sectors require mainly outdoor work, while service and manufacturing require mainly indoor work. Therefore, we used the WBGT_sun to calculate the hourly work time loss in agriculture and construction, and WBGT_shade in manufacturing and service.

Finally, we assumed a laborer works 8 hours a day (typically from 8am to 5pm with an hour break from 12am to 1pm for Chinese workers), and 8 hours is the legal working time stipulated by the Labor Law of China. We counted the girded number of annual losses by summing the hourly work time loss in the second step, and then multiply by the girded annual number of workers to obtain the WHL in different sectors. The total WHL was estimated by summing WHL in all four industries.

Table 1: Input values for labor loss fraction

Metabolic rate	$\mathrm{Prod_{mean}}$	$\mathrm{Prod_{sd}}$
200W	35.53	3.94
300W	33.49	3.94
400W	32.47	4.16

W: watts

Data

Gridded climate data was from the European Centre for Medium-Range Weather Forecasts (ECMWF), ERA5 project.[6] Population data was from the hybrid gridded demographic data for the world. [7] Data on the percentage of people working in each industry was from national and provincial Statistical Yearbook of China.

Caveats

Due to lacking official employment rates of the elderly, we did not quantitatively assess the productivity losses among the elderly.

Future form of indicator

This indicator will be updated to project WHL in the future periods, for instance in 2060, the time point of achieving the carbon neutrality goal in China. In addition, considering workers usually work overtime to get more pay in China, we plan to add more analysis on the assumptions of different daily working hours (e.g., 9 or 10 hours a day).

Additional Information

Table 2: The total WHL and average WHL for each person in four industries from 2000 to 2021 in China (Unit in total loss: billion hours; Unit in each person's loss: hours)

Year	agriculture		construction		manufacturing		Service	
	Total	Each person	Total	Each person	Total	Each person	Total	Each person
2000	29.5	84.7	1.8	89.2	1.4	11.6	0.1	0.4
2001	27.8	79.5	1.6	81.7	1.5	11.9	0.1	0.7
2002	29.8	85.3	1.9	89.1	1.6	12.5	0.2	1.3
2003	29.2	84.8	2.1	93.4	2.3	18.4	0.4	2.3
2004	26.1	77.4	2.1	86.4	1.7	12.3	0.1	0.5
2005	27.8	84.4	2.4	93.4	1.8	12.6	0.1	0.4
2006	29.0	89.7	2.8	103.3	2.1	14.4	0.1	0.6
2007	25.9	81.4	2.8	98.5	2.2	13.8	0.1	0.6
2008	23.5	75.5	2.9	92.7	1.6	9.4	0.0	0.2
2009	24.6	80.1	3.1	92.7	2.0	11.7	0.1	0.3
2010	27.4	90.2	4.0	108.3	3.0	17	0.4	1.4
2011	22.1	74.7	3.7	90.3	1.7	9.8	0.1	0.3
2012	22.2	75.7	3.5	90.1	2.1	11	0.1	0.2
2013	27.4	95.4	5.2	122.5	3.7	19.7	0.3	1
2014	21.6	76.6	4.0	88.2	2.4	12.6	0.2	0.6
2015	19.4	70.2	3.8	83.6	2.2	11.3	0.1	0.3
2016	27.3	100.4	6.5	128.9	4.5	23.8	0.8	2.6
2017	27.1	101.4	6.8	135	4.6	25.2	0.7	2.3
2018	27.5	105.9	7.5	138.5	4.1	23	0.3	1.1
2019	23.7	93.2	6.4	118.1	3.6	20.3	0.6	1.7
2020	21.7	87.2	6.3	117.3	3.2	18.2	0.3	0.9
2021	23.2	93.2	6.4	119.6	3.1	18.1	0.2	0.7

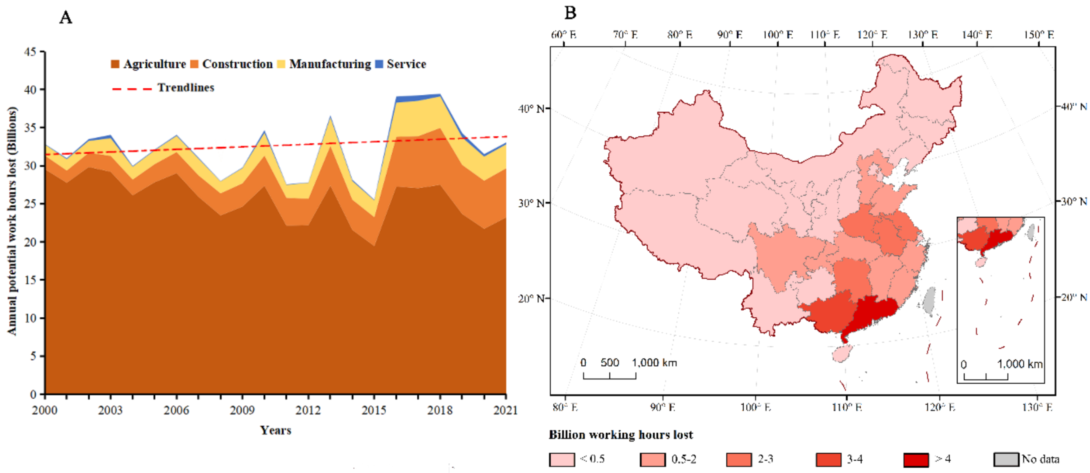


Figure 3: Heat-related work hours lost in China. **(A) Annual potential work hours lost due to heat in each industry from 2000 to 2021. (B) Total work hours lost in different provinces in 2021.**

Indicator 1.1.3: Heat and physical activities

Methods

This indicator was newly added in the 2022 report with similar method to global report 2022.Firstly, China's gridded hourly temperature and relative humidity were used to calculate Heat Index (HI) according to the equation derived from Steadman's temperature-humidity scale.[12] For each raster the number of hours in which the HI was above 33 ºC were cumulatively calculated in very single year from 1986 to 2021.

Secondly, Heat Index is a world-widely used indicator for the assessment of environment heat stress which can be also considered as apparent temperature or the temperature the body "feels" according to Steadman. An HI value of 33ºC is the threshold cited by Heat Stroke Expert Group of the Whole Army, Expert Consensus Group on Diagnosis and Treatment of Heat Stroke in China[13] and Sports Medicine Australia(SMA),[14] above which the risk of heat illness increases and extreme caution during the outdoor physical activity should be taken into account. Besides, like another heat stress indicator WBGT, the HI indicator was originally used in military training to prevent extreme heat illness like sunstroke and heat stroke, but now it has been applicable to general populations, not just to the elite athletes or the soldiers, which indicates how the ambient heat affects on our body. Moreover, HI is also widely used in Chinese weather forecasting, making it easily to be understood and acknowledged by public.

Thirdly, the calculation of total potential population weighted hours lost in each raster was performed by multiplying the numbers of hours lost to the corresponding population. The population weighted hours lost in each raster were summed up to province or region scale in China, and then divided by the corresponding total population and then divided by 365 to obtain the number of physical activity hours lost per person per day in each year.

Data

1. Hersbach, H., Bell, B., Berrisford, P., Biavati, G., Horányi, A., Muñoz Sabater, J., Nicolas, J., Peubey, C., Radu, R., Rozum, I., Schepers, D., Simmons, A., Soci, C., Dee, D., Thépaut, J-N. (2018): ERA5 hourly data on single levels from 1979 to present. Copernicus Climate Change Service (C3S) Climate Data Store (CDS). (Accessed 2022.03.25), 10.24381/cds.adbb2d47.
2. Hybrid gridded demographic data for China, 1979-2100. An overview of this dataset can be found at https://zenodo.org/record/4554571#.YlQf0JFBxyw. (Accessed 2022.03.25), 10.5281/zenodo.4554571.

Caveats

The Heat Index was widely used by sport associations and authorities, however, whether the threshold is appropriate for different age population groups and different sport activities in China is still need to be further tested. In addition, it's acknowledged physical activity and exercise ability are affected by factors such as age, clothing, wind and physiology, not just by ambient temperature and humidity, and these inter-individual factors needs a more robust index.

Future forms of the indicator

The exploration to different heat stress index and its thresholds will allow better reflection to true outdoor physical activity hours lost on several target population groups. And the report in next year will be updated when the 2021 gridded population data are available. Considering the effects of COVID-19 pandemic, outdoor physical activities can be encouraged to increase, therefore the indicator should be considered not only in the shade but also in the sun. We plan to conduct a national willingness-to-pay (WTP) survey to derive the value of a statistical life (VSL) on the topic of physical activity habits and preferences, in order to calculate the economic loss related to AHL.

Additional information

Since the physical activity hours lost per person per day in the main report is calculated in Heat Index(the trend is as followed in ***Figure 4***), it is can be also obtained by the indicator WBGT(***Figure 5***, ***Figure 6***), the function and threshold 26ºC used here is as same as the 2022 global report of the Lancet Countdown,[10] but weighted with different gridded population database. There is also an increasing trend of WBGT and thus potential safe activity hours lost has occurred across China, the annual average WBGT in 2021 increased by 16.9% compared to the baseline years (1986-2005), resulting in a 48.5% increase in physical activity hours lost (AHL) per person. In 2021, the national average physical activity hours lost was estimated to be 2.46 hours, and people in South Central China also has been affected the most, with estimated 4.76 hours lost per day on average and a highest average growth rate during 2000-2021(2.02% per year).

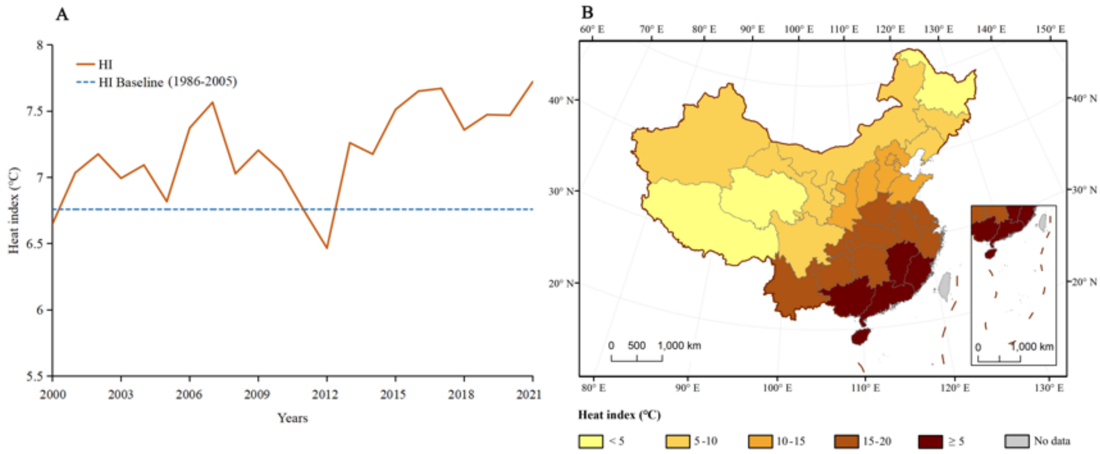


Figure 4 The trend of indicator Heat Index in China.

(A) The trend of annual average Heat Index in China from 2000 to 2021, with the horizontal dashed line shows the mean of the 1986–2005 baseline period.

(B) Annual average Heat Index in different provinces in 2021. Undefined-No Data.

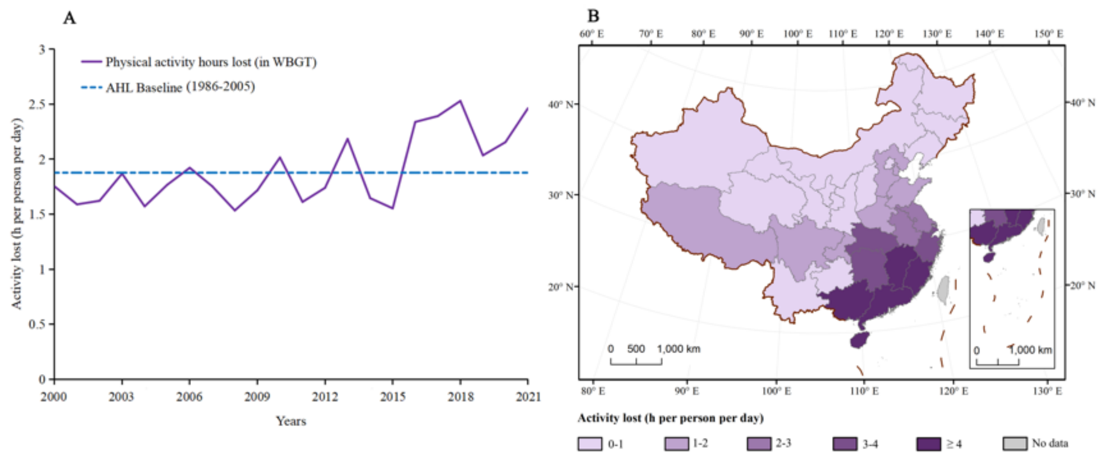


Figure 5 Heat-related Physical activity hours lost in China (in WBGT).

(A) The trend of annual potential AHL per person per day in China from 2000 to 2021, with the horizontal dashed line shows the mean of the 1986–2005 baseline period.

(B) Potential AHL per person per day in different provinces in 2021. AHL(WBGT)- physical activity hours lost in WBGT, Undefined-No Data.

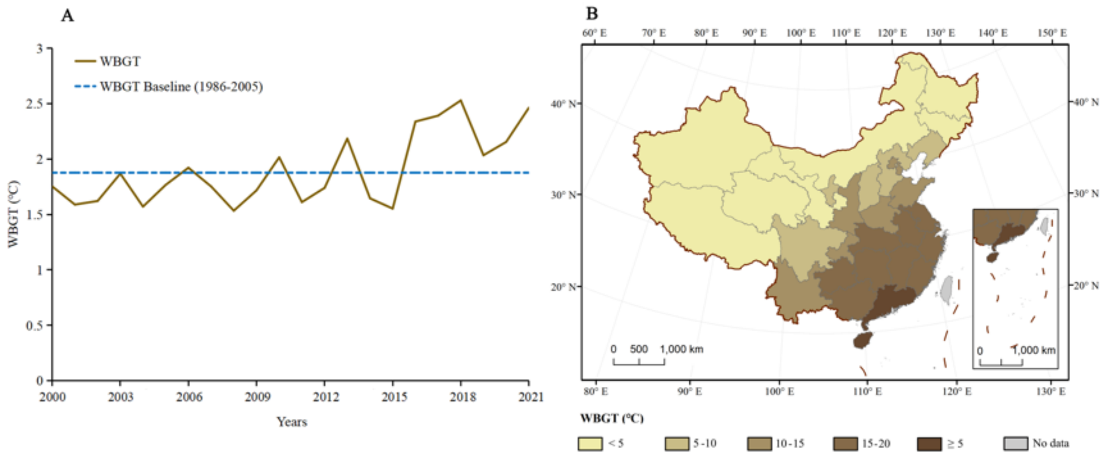


Figure 6 The trend of indicator WBGT in China.

(A) The trend of annual average WBGT in China from 2000 to 2021, with the horizontal dashed line shows the mean of the 1986–2005 baseline period.

(B) Annual average WBGT in different provinces in 2021. Undefined-No Data.

Indicator 1.1.4: Health and exposure to warming

Methods

This indicator remains the same to the methodology described in the 2021 global Lancet Countdown report and 2021 China Lancet Countdown report. Monthly averaged summer temperature (June, July and August) was obtained from the ERA5 reanalysis data set and population count data from a hybrid gridded demographic data. Both are gridded data with horizontal grid of 0.5°. Population-weighted temperature and area-weighted temperature were calculated every year from 1986 to 2021 for every province and the entire country. Changes in population-weighted and area-weighted temperatures were calculated every year from 2000 to 2021 with 1986-2005 as the baseline. Area-weighted temperature was calculated by averaging temperature records at every grid inside a province/for the entire country. Population-weighted temperature was calculated in a similar method with weights proportional to population count.

Data

1. Climate data was taken from European Centre for Medium-Range Weather Forecasts (ECMWF), ERA5 project.[6]

2. Population data is from a hybrid gridded demographic data for the world, created by Chambers (2020).[7]

3. Age structure data for China is from Chen et al's paper (2020) [15].

Caveats

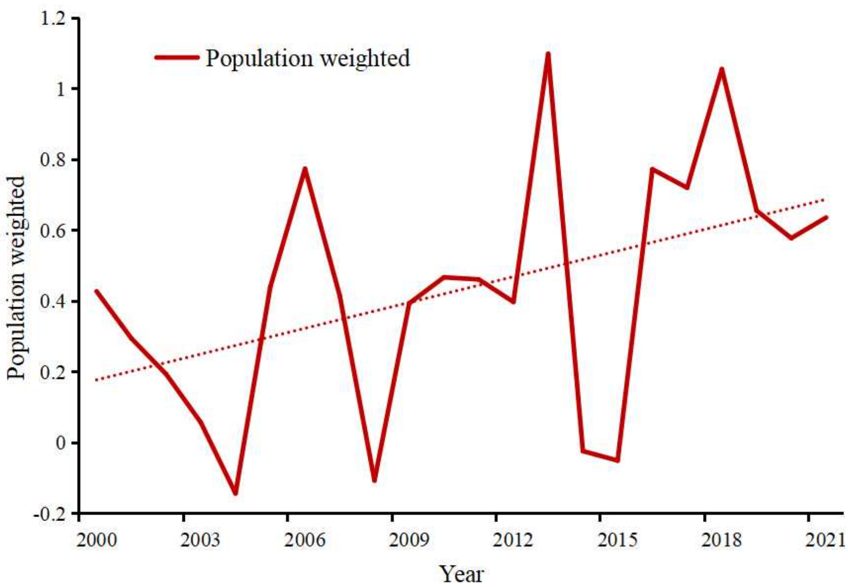
The horizontal resolution of temperature data is too coarse to reflect warming trend at local level. The population figures for 2021 are not based on the real situation, but are calculated based on the spatial distribution and the pattern of change of the population in previous years, and cannot reflect the real population situation.

Future Form of Indicator

Future version may consider using localized reanalysis data set, instead of the global reanalysis data set.

Additional Information

The country-wide population-weighted temperature rose by 0.64°C in 2021 compared with the 1986-2005 baseline, with a slight increase compared to 2020, but still lower than 2016-2019 (***Figure 7 up***). The increase of population weighted temperature in aged group is lower than that in the 0-64 age group. Actually, the population weighted temperature in aged group was higher in the baseline period, but as the proportion of older people increases, the gap between the two groups is getting smaller (***Figure 7 bottom***). Province-level changes in annual average population-weighted temperature in 2021 relative to the 1986-2005 average are presented in ***Figure 8***. Similar with the spatial distribution in 2020, regions with profound warming were in South of the Yangtze River and the Middle Regions, such as Jiangxi, Hunan, Fujian, Guizhou, Ningxia, Xinjiang Gansu and Qinghai Provinces.



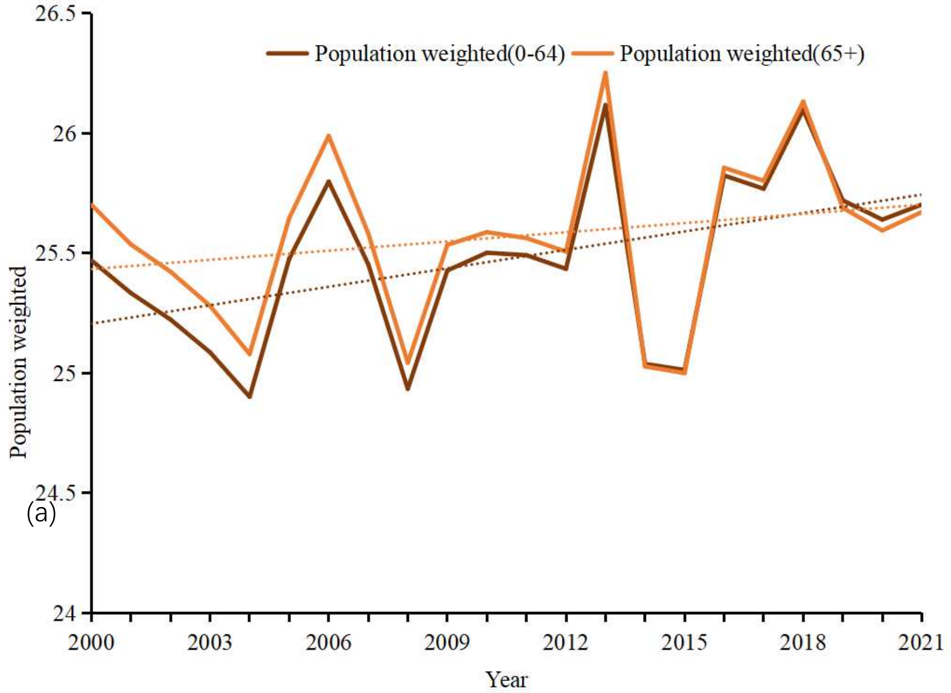


Figure 7 Mean summer warming relative to the 1986–2005 average in China (up); (b)Mean summer population-weighted exposure for different age groups in China (bottom).

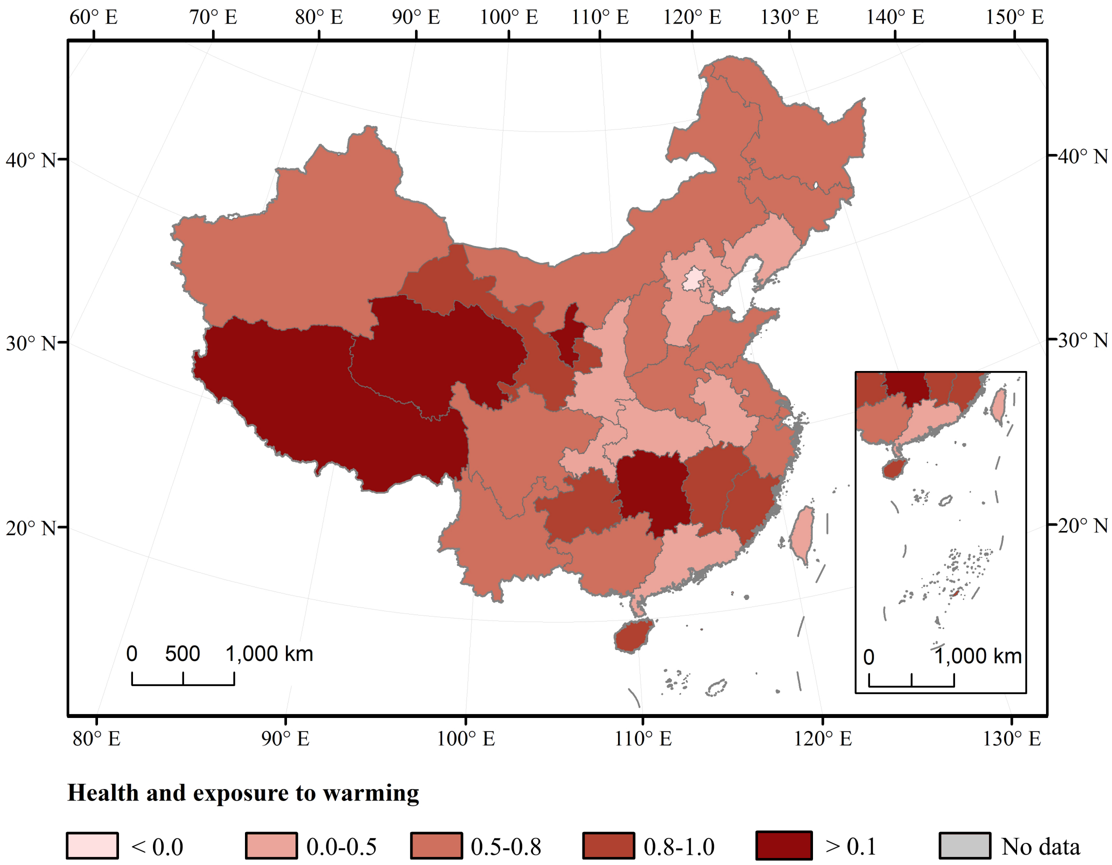


Figure 8 Change in population-weighted summer temperature in 2020, relative to the 1986-2005

average

Indicator 1.2: Health and extreme weather events

Indicator 1.2.1: Wildfires

Methods

This indicator has been improved from the 2021 China Lancet Countdown report to assess the impacts of wildfires on health by adding the analysis for people older than 65 years. Besides, a sensitivity analysis on spatial resolution was also included.

China's population[11] with a spatial resolution of 0.25° for each year from 2001 to 2020 was used in the study, which includes people older than 65 years. The Global Artificial Impervious Areas (GAIA) data[16], which track the development of impervious areas from 1985-2018 using the full archive of 30-m resolution Landsat images, are reclassified to generate a mask of wildfire surface (impervious area excluded) for population. Additionally, since only the artificial impervious areas are used as the land cover mask for urban areas, the estimated results include crop fires.

The change in model-based risks is represented as the change in the average annual number of days that people are exposed to high fire danger. The detailed method is identical to the 2021 global Lancet Countdown report[11]. Provided by ECMWF ERA5 atmospheric reanalysis, the model-based risks identify meteorological conditions that would cause flames to spread out of control, which is classified into 6 classes based on the numerical value: very low, low, medium, high, very high and extreme. The indicator was calculated by:

$$RPD_y = Pop_y \times \sum FR_{d,pixel}$$

where RPD_y refers to yearly person-days exposed to high fire risk (FDI≥5) in a specified year y, and Pop_y refers to the population from gridded population data in year y. $FR_{d,pixel}$ refers to a high fire risk count located within a population data *pixel* on a unique day *d* of year *y.* Fire risk pixels were aggregated yearly from 2001 to 2020 and spatially joined with global population data on 0.25° grids.

Satellite-observed exposure is represented in terms of the average annual number of days people were exposed to active fire. The combustion NASA Near Real-Time MODIS Active Fire Detections Products (MCD14DL)[17] were used as fire point data. The indicator was calculated by:

$$CPD_y = Pop_y \times \sum FP_{d,pixel}$$

where CPD_y refers to person-days exposed to wildfire in a specified year *y*, and Pop_y refers to the population from gridded population data in a specified year y. $FP_{d,pixel}$ refers to a fire point count located within a population data pixel on a unique day d of year y. Active fire pixels were aggregated yearly from 2001 to 2020 and spatially joined with global population data on 0.25° grids.

Data

1. Fire danger indices (FDI) data from Copernicus Emergency Management Service for the European Forest Fire Information System (EFFIS).[18]
2. NASA Near Real-Time MODIS Active Fire Detections Products (MCD14DL) from 2001 to 2019 were used as fire point data, which contain both Terra (from November 2000) and Aqua (from July 2002) pixels in the same annual file.[17]
3. Population data from Hybrid gridded demographic data for China, 1979-2100[11].
4. Annual maps of global artificial impervious area (GAIA) between 1985 and 2018 as an urban-area population mask.[16]
5. China boundary data, in the CGCS_2000 geographic coordinate system, from the National Geomatics Center of China (http://www.ngcc.cn/ngcc/).

Caveats

To capture the wildfire influences on people older than 65 years, the population used for this year report has a 0.25° spatial resolution that is coarser than that used in the 2021 report. This change results in an increase in the wildfire exposure assessment as the assumed area of influence of the active fire changes from a 0.5' x 0.5' grid population to a 0.25° x 0.25° grid population. Additionally, the population and artificial impervious areas in 2021 are the same as those in 2020, which leads to bias in the results.
Due to limited observational capabilities, this indicator does not explicitly quantify and model human exposure to wildfire smoke, which is associated with respiratory morbidity and with growing evidence supporting an association with all-cause mortality.[18]

Additionally, FDI data cannot capture all the changes in the summer monsoon and fire season temperature in China under the context of climate change.

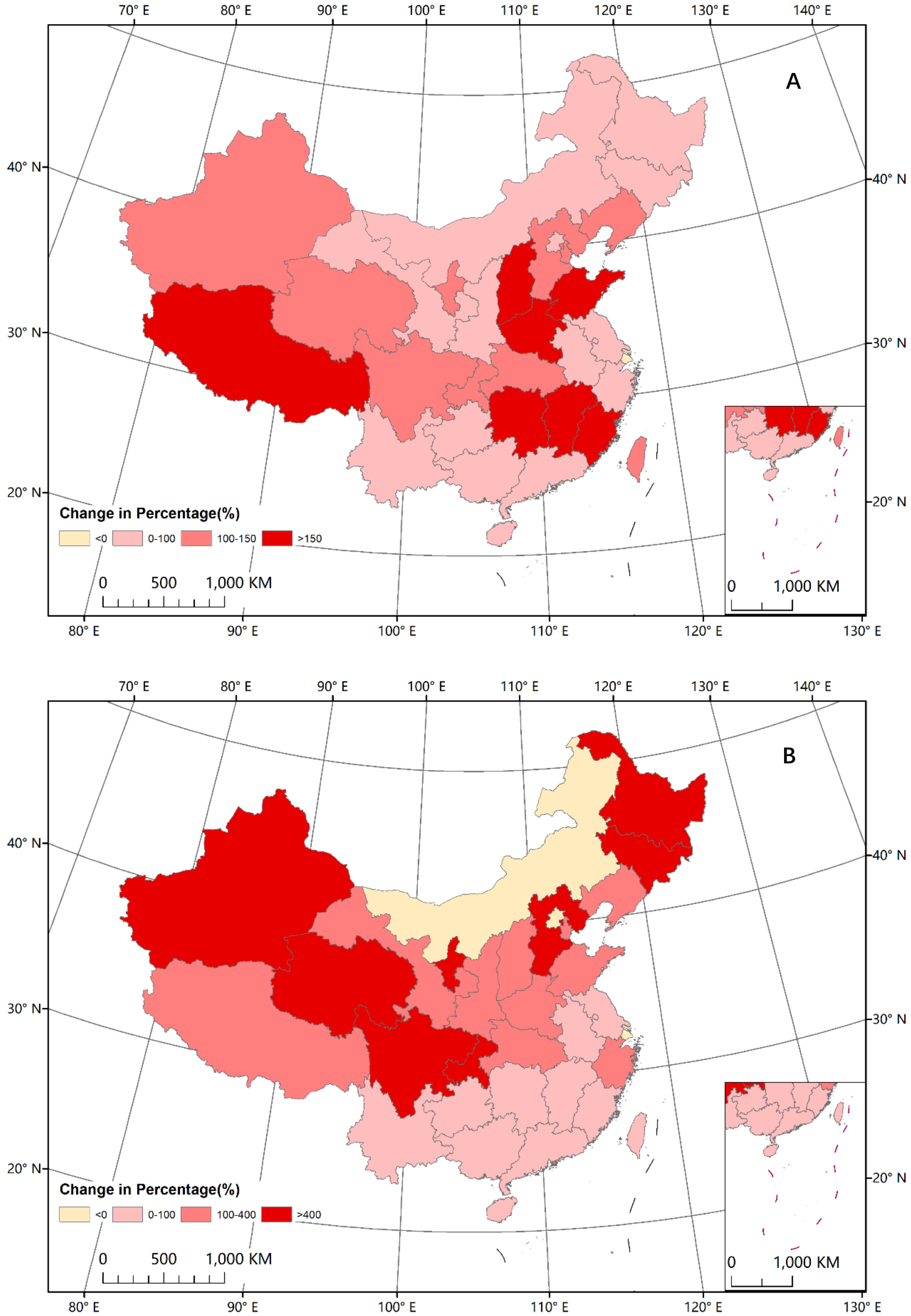


Figure 9: Change in model-based risks (A) and satellite-observed (B) exposure for people older than 65 years to wildfires across China from 2001-2005 to 2016-2020.

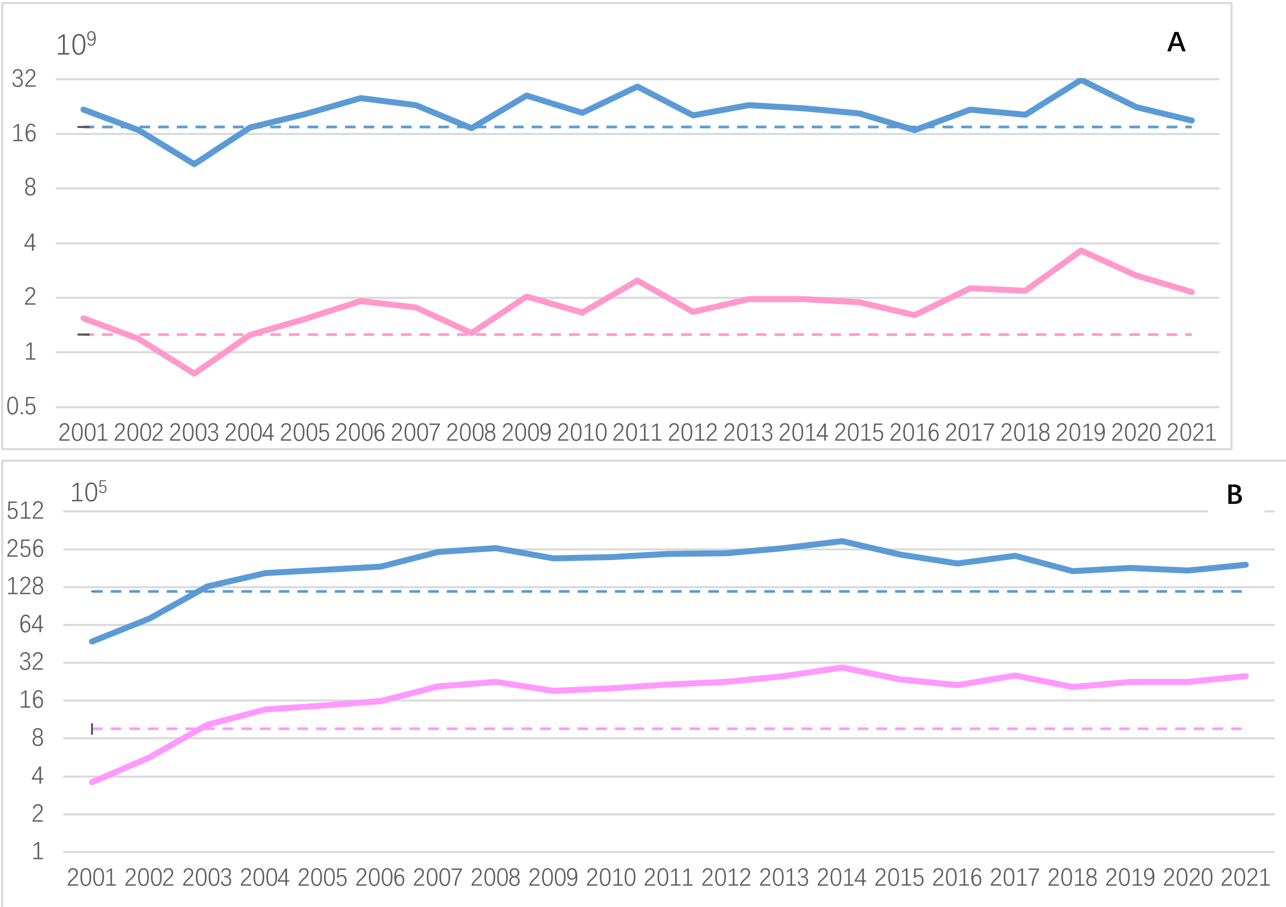


Figure 10: Model-based risks (A), satellite-observed exposure (B) for all age groups (blue) and people older than 65 years (red) national trend from 2001-20. The solid line represents the person-days in each year, and the horizontal dashed line represents the mean of the 2001–2005 reference period.

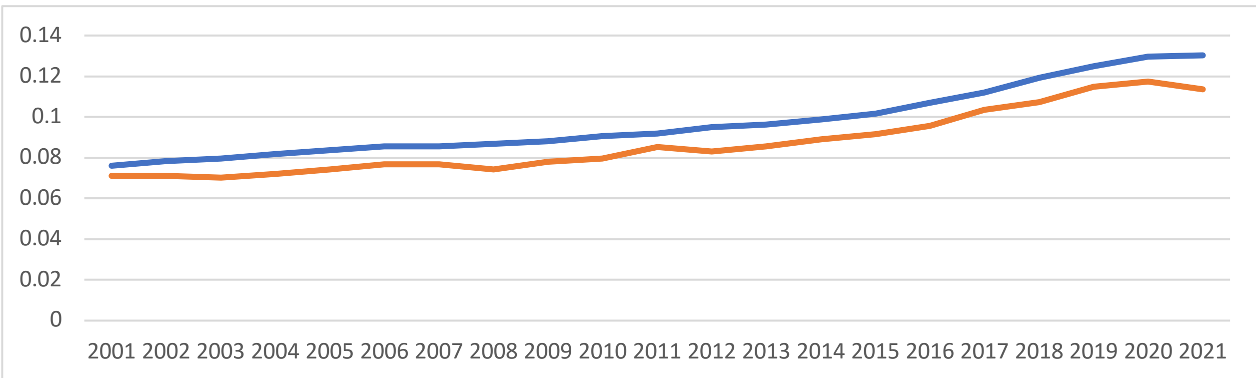


Figure 11: The proportion of model-based risks (orange) and satellite-observed exposure (blue) for people older than 65 years to the total population national trend from 2001-20.

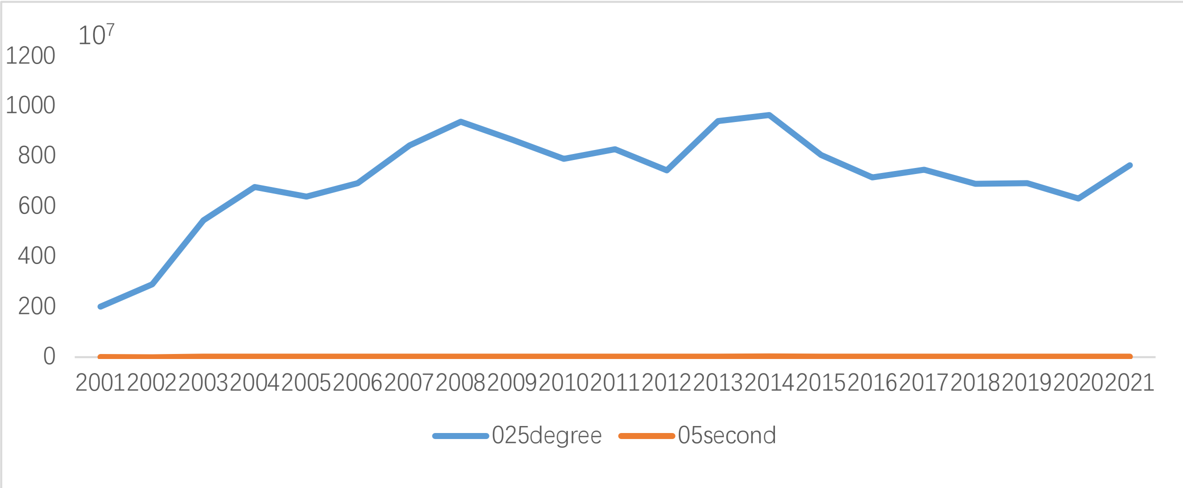


Figure 12: The difference between results in wildfire exposure with 0.5‘ and these with 0.25° of population

Table 3: Population exposure to extreme rainfall and drought in 1986–2020.

Spatial Resolution	2011-2005 average （10^7）	2017-2021 average(10^7)
0.25degree	470.703307	705.526691
0.5second	1.18252826	1.89170638

Table 4: Wildfire Exposure grid spatial resolution in other articles.

Spatial Resolution	Range	Citation
0.5ationR	China, 2001-2020	2020, 2021 China Lancet Countdown Report[9,19]
10 km x 10km	Global, 2001-2020	2020, 2021 Global Lancet Countdown Report[11,20]
1 km x 1 km	European, 1981 -2100	Increasing risk over time of weather-related hazards to the European population: a data-driven prognostic study, TL Planet Health,2017

Indicator 1.2.2: Extreme rainfall and drought

Methods

The calculation of this indicator follows the methodology described in the Global Lancet Countdown Reports in 2018 and 2019. [21,22]

We used extreme rainfall events as an indicator of flood risk. The occurrence and duration of an extreme rainfall event was defined to start when the five-day total precipitations exceeding the ten-year return level and end when it dropped below this value. The ten-year return level of rainfall was calculated following previous research.[23] Briefly, the time series of daily precipitations was firstly descended. Then, the probability of exceedance (p) for a given rank was calculated according to the Gringorten formula:

$$p = \frac{r - 0.44}{N + 0.12} \times 100$$

where N means the total days, r means the rank number of daily precipitations sorted in descending order. We calculated the grids with at least one occurrence of extreme rainfall, which was then summed to the national level. The population size exposed to extreme rainfall events was calculated by multiplying the counts of extreme rainfall events at each location by the local population (in person-events), compared with reference period (1986–2005) average. We also calculated per person exposure of people elder than 65 years and all-age group, by dividing the annual exposure person-events or person-months by the total annual population.

The standardised precipitation index (SPI) is a recommended indicator of drought, representing the drought severity on multiple time scales.[24] Here, a given month was defined as being in a drought when the SPI-6, i.e., the six-month rolling sum of monthly precipitation, was less than –1.5. The national exposure to drought per year was calculated by summing the grids with at least one drought event this year. Exposure frequency of drought was measured as the number of person-months in drought. The national total exposure in drought was calculated as the sum of months in drought over each grid times the gridded population (in person-months).

In addition, the exposure of the elderly (over 65 years) was calculated. The trend of exposure population was analyzed by Mann Kendall trend test, a two-tailed $p < 0.05$ was considered statistically significant. The average growth rate was calculated to analyze the change of population exposure in extreme rainfall and drought, from 1986 to 2020.

Data

1. Climate data was collected from the CN05.1 dataset (0·25°×0·25°) of the China Meteorological Administration.[25,26]
2. Population data for China (0·5°×0·5°) was collected from a dataset developed by combining the NASA SEDAC Gridded Population of the World version 4 (GPWv4, UN WPP-Adjusted Population Count) with gridded population from the Inter-Sectoral Impact Model Intercomparison Project (ISIMIP, Histsoc gridded population data). It gave as 21 five-year age groups of population.[15]

Caveats

This indicator focused on the meteorological flood and drought risk, which was only a necessary precursor. However not sufficient conditions for the occurrence of agricultural and hydrological floods and drought.

In addition, we used extreme rainfall events as a proxy indicator for flood in this report. That hindered the comparison with our previous reports, which concentrated on the recorded flood disasters.

Due to the limited availability of precipitation data, we cannot analyse the precipitation pattern in 2021.

Future form of indicator

Future versions of the indicator are expected to migrate to updated population data source with finer spatial resolution (0·25°×0·25°).

Additional information

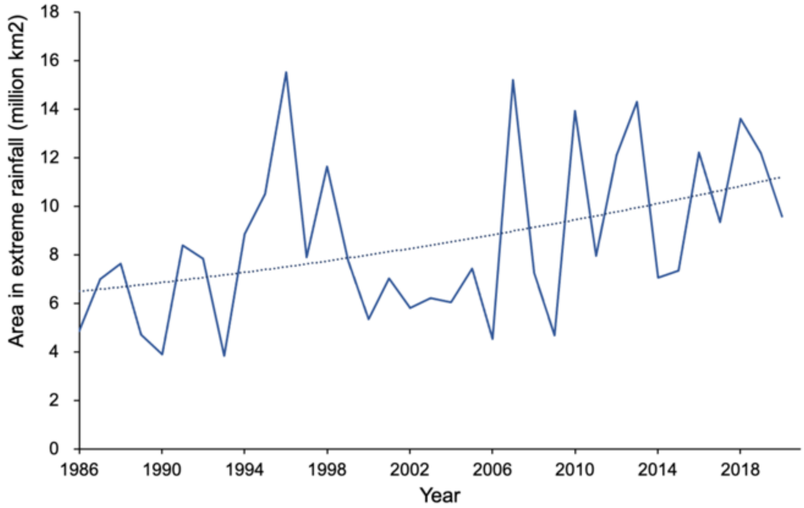


Figure 13: **Trend of national area in extreme rainfall in 1986–2020.**

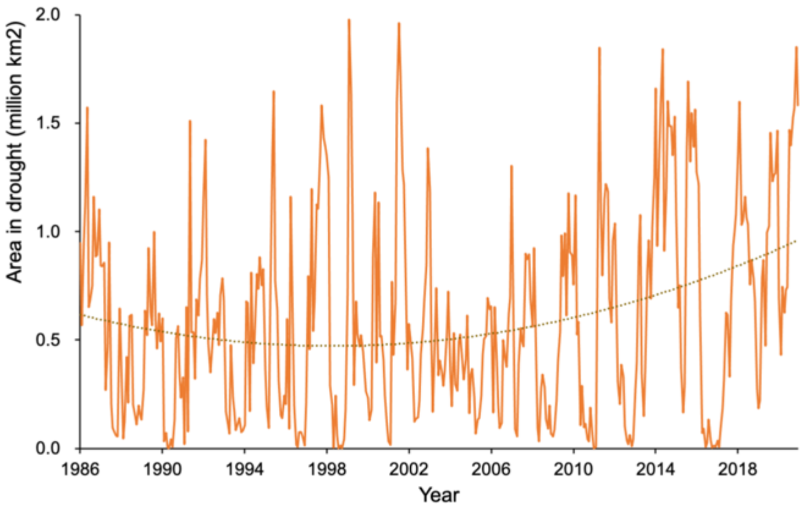


Figure 14: **Trend of national area in drought in 1986–2020.**

Table 5: Population exposure to extreme rainfall and drought in 1986–2020.

Year	Population exposure to extreme rainfall (million person-events)	Elderly population exposure to extreme rainfall (million person-events)	Population exposure to drought (million person-months)	Elderly population exposure to drought (million person-months)
1986–2005 average	98.915	10.326	995.569	106.887

1986	35.554	1.884	1086.054	60.942
1987	26.180	1.481	387.781	19.689
1988	52.009	2.680	681.131	39.338
1989	89.620	4.953	1102.423	62.583
1990	44.312	2.385	457.449	25.666
1991	176.824	12.938	847.906	56.404
1992	39.830	2.591	1193.160	86.329
1993	58.667	4.133	460.131	31.935
1994	199.188	14.382	675.692	52.040
1995	96.732	6.526	695.325	46.225
1996	134.977	9.277	817.474	61.580
1997	105.418	7.817	2088.679	150.549
1998	153.077	10.453	385.810	25.924
1999	150.969	11.505	2228.762	158.064
2000	120.239	16.970	1299.862	186.613
2001	62.778	12.120	1558.657	318.614
2002	94.185	17.701	1263.419	247.912
2003	155.867	31.904	1166.550	227.575
2004	62.678	11.847	887.496	170.045
2005	119.206	22.978	627.629	109.716
2006	87.409	16.442	997.725	208.756
2007	144.889	29.026	801.725	156.243
2008	122.406	20.342	376.865	74.041
2009	52.670	10.837	748.146	137.478
2010	138.436	27.451	546.002	101.585
2011	47.445	8.947	3137.922	607.099
2012	171.047	34.731	472.770	91.083
2013	242.548	48.035	477.226	90.247
2014	121.028	21.106	343.219	63.649
2015	113.957	21.248	328.082	56.894
2016	244.508	48.600	38.601	7.008
2017	123.571	23.169	172.123	32.951
2018	221.393	40.387	226.400	40.242
2019	159.484	32.182	597.142	113.353
2020	218.258	43.407	299.103	48.902

Table 6: National area affected by extreme rainfall in 1986–2020.

Year	Area in extreme rainfall (million km^2)	Area in drought (million km^2)
1986–2005	7.404	6.318

average		
1986	4.856	11.298
1987	7.006	5.363
1988	7.625	3.266
1989	4.700	6.852
1990	3.894	2.541
1991	8.381	6.938
1992	7.831	8.275
1993	3.838	2.431
1994	8.838	7.371
1995	10.494	6.594
1996	15.513	3.074
1997	7.906	11.884
1998	11.650	3.633
1999	7.750	8.956
2000	5.338	5.924
2001	7.013	10.979
2002	5.794	5.995
2003	6.200	6.103
2004	6.025	4.561
2005	7.431	4.325
2006	4.531	4.894
2007	15.194	7.224
2008	7.256	3.417
2009	4.669	7.666
2010	13.925	3.959
2011	7.956	10.316
2012	12.100	3.208
2013	14.319	8.281
2014	7.044	16.952
2015	7.356	12.191
2016	12.225	3.498
2017	9.331	5.894
2018	13.606	11.676
2019	12.188	11.249
2020	9.581	13.368

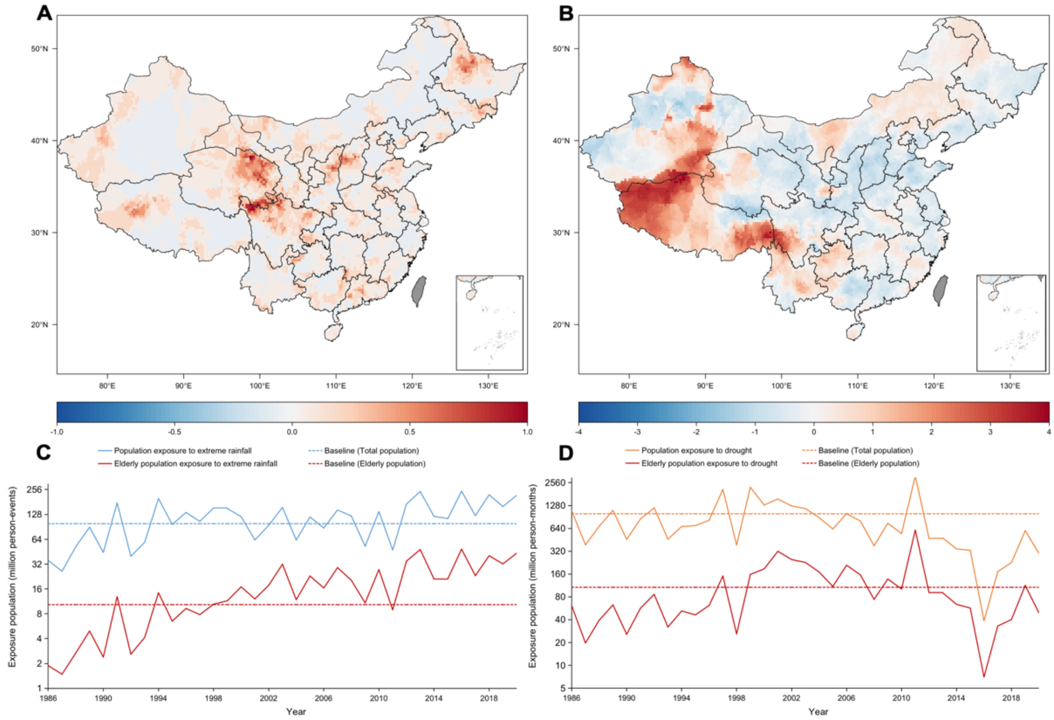


Figure 15: **Change in number and exposure of extreme rainfall and drought during 1986–2020**

(A) Mean change in number of extreme rainfall events per year over 2000–20 compared with the 1986–2005 average. (B) Mean change in number of droughts per year over 2000–20 compared with 1986–2005 average. (C) Exposure to extreme rainfall events in 1986–2020. The horizontal dashed line shows the mean of the 1986–2005 reference period. (D) Drought exposure in 1986–2020. The horizontal dashed line shows the mean of the 1986–2005 reference period.

Indicator 1.3: Climate-sensitive infectious diseases

Methods

There are three sub-indicators – the climate suitability for *Aedes aegypti and Ae. albopictus,* the vulnerability index to dengue, and the disease burden for dengue in China. The methodology for these indicators were the same as the 2020 China Lancet Countdown report. And the report was divided into the provincial level results.

The climate suitability *Ae. aegypti and Ae. albopictus* is represented by vectorial capacity (VC), which expresses the average daily number of subsequent cases in a susceptible population resulting from one infected case. It is affected by climatic and environmental factors such as land-use type, temperature and rainfall. The VC was calculated according to the method provided by Rocklöv et al.(2019) [27] and Liu-Helmersson et al. (2014)[28]. It takes into account interaction among host, vector and virus. VC is expressed as:

$$VC = xyma^2 b_m p^n / - \ln p$$

Where x is the ratio referring to the number of *Aedes* vector distribution counties in each year after 2016 divided by the number of *Aedes* vector distribution counties in 2016, y is the ratio referring to urban population proportion in each year after 2004 divided by urban population proportion in 2004, a is the average vector biting rate, b_m is the probability of vector infection and transmission of virus to its saliva, p is the daily survival probability, n is the duration of the extrinsic incubation period (EIP) , and m is set to 1 assuming female vector and human population as in Watts et al.(2019).[22] Detailed model description and explanation, as well as the relationship between daily temperature with these parameters can be found in Rocklöv et al. (2019).[27] In this study, the time unit is 1 day, and each vector parameter depends on the temperature. The parameter value comes from the literature, usually from experimental data, as described in Liu-Helmersson et al. (2014).[28] The trend of VC time series was analyzed by Mann Kendall trend test. The time unit is 1 year. A two-tailed $p < 0.05$ was considered statistically significant.

The dengue vulnerability index was calculated by dividing VC with average International Health Regulation (IHR) core capacity. The average of IHR core capacity scores is the percentage of attributes of 13 core capacities that have been attained at a specific point in time (presented on an annual basis). It measures the ability to detect, assess, report, inform and deal with public health emergencies.

The 13 core capacities of IHR are: (1) National legislation, policy and financing; (2) Coordination and National Focal Point communications; (3) Surveillance; (4) Response; (5) Preparedness; (6) Risk communication; (7) Human resources; (8) Laboratory; (9) Points of entry; (10) Zoonotic events; (11) Food safety; (12) Chemical events; (13) Radionuclear emergencies.

$$\text{Vulnerability} = \frac{\text{VC}}{\text{Average IHR core capacity score}}$$

Considering the limitation of the availability of provincial-level IHR score in China, we replace the average IHR core capacity score with average provincial comprehensive health emergencies management index reported in indicator 2.2.1 in this report. The index developed in indicator 2.2.1 in this report considers 20 indicators covering three aspects (risk exposure and preparedness, detection and response, and resource support and social participation), which is similar to the assessment framework of IHR. This index was then calibrated with correction coefficient of the provincial health emergency management index which was set according to literature with the eastern provinces as the baseline, the central and western provinces multiplied by 0.951 and 1.0024 respectively.

Then, the estimated vulnerability of provincial-level from 2010-2020 is calculated by the following formula:

$$\text{Estimated vulnerability} = \frac{\text{VC}}{\begin{array}{c}\text{Average provincial comprehensive health emergencies}\\ \text{management index}\end{array}}$$

And, the average provincial comprehensive health emergencies management index, 2010-2020 is calculated by the following formula:

$$\text{Average provincial comprehensive health emergencies management index, } 2010-2020$$
$$= \left(\frac{\text{average comprehensive health emergencies management ability score in China in 2019}}{\text{average IHR score in China in 2019}}\right)$$
$$\times (\text{average IHR score in China, } 2010-2020) \times \text{Correction efficient}$$

The national Disability-Adjusted Life Years (DALYs) for dengue fever between 2005 and 2020 are calculated based on the method provided by Xu et al. (2020) which is updated based on the technical basis for DALYs of the World Health Organization (Murray, 1994). The national trends are presented as all-age DALY rates per 1,000,000 individuals over the period.

$$\text{DALY} = \int_{a}^{a+l} D\left[KCxe^{-\beta x} + (1-K)\right]e^{-r(x-a)}\,dx$$

Time lived at different ages has been valued using an exponential function of the form $Cxe^{-\beta x}$. A continuous discounting function of the form $e^{-r(x-a)}$ has been used where *r* is the discount rate and *a* is the age of onset. *D* is the disability weight (or 1 for premature mortality). K is an age-weighting modifier. The solution of the definite integral from the age of onset *a* to *a*+*L* where *L* is the duration of disability or time lost due to premature mortality gives us the DALY formula for an individual：

$$\text{DALY} = \frac{KDCe^{-\beta a}}{(\beta+r)^2}\left[e^{-(\beta+r)(l)}\left(1+(\beta+r)(l+a)\right) - (1+(\beta+r)a)\right] + \frac{D(1-K)}{r}(1-e^{-rl})$$

Where *D* is the disability weight (or 1 for premature mortality), *r* is the discount rate, *C* is the age-weighting correction constant, β is the parameter from the age-weighting function, *a* is the age of onset, and *L* is the duration of disability or time lost due to premature mortality. In the specific form used for calculating DALYs, *r* equals 0.03, β equals 0.04, and *C* equals 0.1658 (Murray, 1994)[29]. K equals 1. *L* is set as 14 days and *D* equals 0.81 for dengue based on Endy et al. (2007)[30], Shepard et al. (2013)[31], and Guidelines for clinical diagnosis and treatment of dengue fever in China (2018)[32].

Data

1. Monthly average daily temperature data with the resolution 0.25° from 2004-2020 were from Library for Climate Studies of Chinese Meteorological Administration.[33]
2. The spatio-temporal distributions of *Ae. aegypti* and *Ae. albopictus* in China were from the China CDC.[34]
3. The data of Urbanization rates in China were from the 2021 Statistical Yearbook
4. The IHR core capacity scores from 2010 to 2020 in China were downloaded from WHO website.[35]
5. The provincial comprehensive health emergencies management index in 2019 is from Indicator 2.2.1

of this report.

6. The correction coefficients of provincial health emergency management index were set according to a reference. [36]
7. The incidence and mortality data of dengue fever come from the infectious disease information monitoring system of the China CDC.

Additional Information

Total VC in most of the provinces in China has increased since 2004. *Ae. albopictus* only existed in 25 provincial-level administration divisions (PLADs) of China, and *Ae.aegypti* only existed in Guangdong, Hainan and Yunnan, according to spatio-temporal distributions of *Ae. aegypti* and *Ae. albopictus* in China provided by China CDC. Means of total VC in Guangdong and Hainan were the highest, and means of total VC in provinces in southwestern border and southeastern coastal areas were relatively higher (***Figure 16***). The VC from 19 PLADs in China shows statistically significant increasing trend between 2004-2020(***Figure 17***).

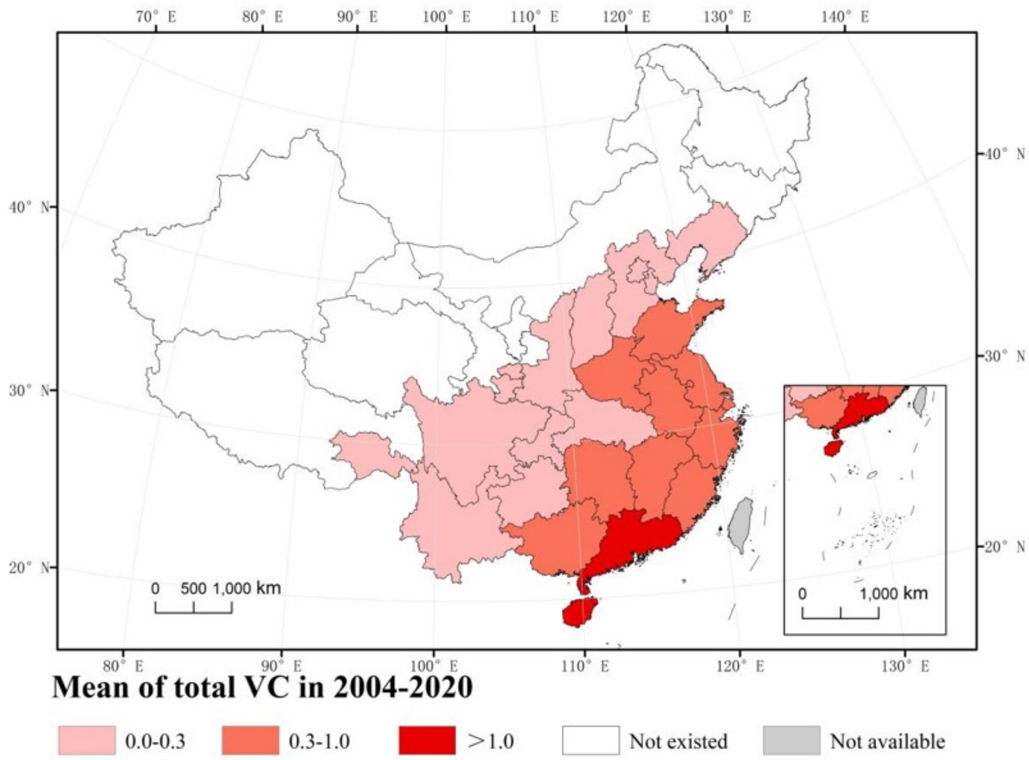


Figure 16:Mean of total VC in China in 2004-2020.

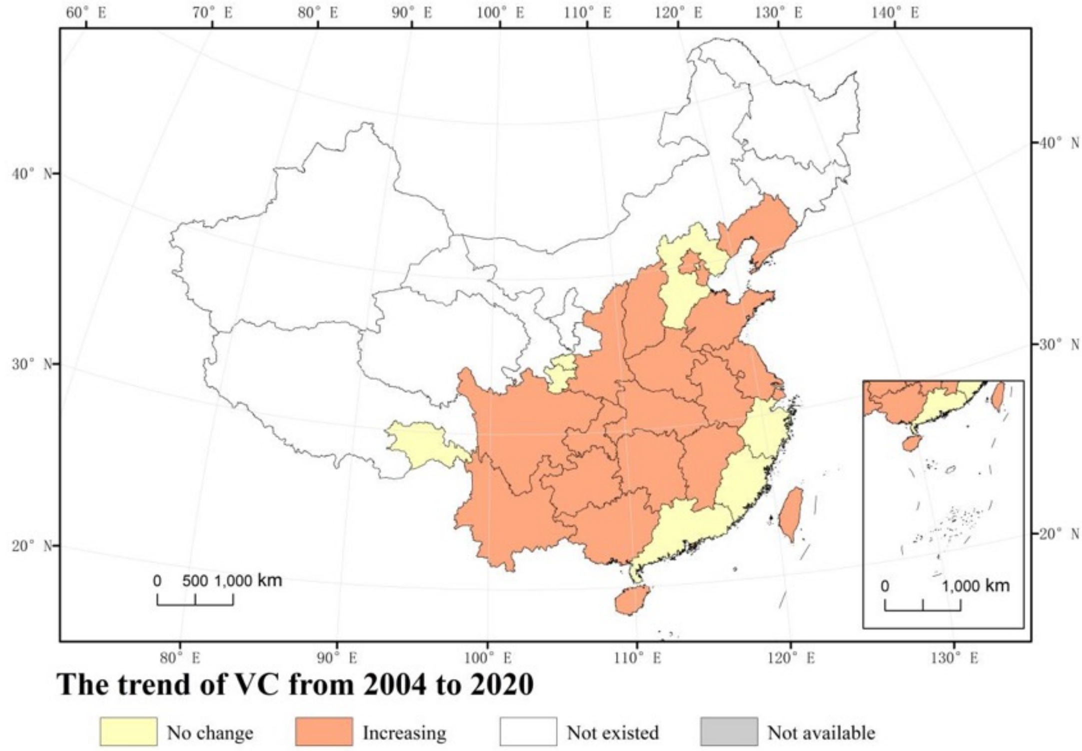


***Figure 17*:** The result of Mann—Kenddall test of the trend of VC, China, 2004-2020.

Dengue vulnerability index in 20 single *Ae. albopictus* distribution PLAD**s** show an increasing trend from 2010-2020. These PLADs include Gansu, Beijing, Shanxi, Liaoning, Jiangsu, Zhejiang, Anhui, Fujian, Jiangxi, Shandong, Tianjin, Henan, Hubei, Hunan, Guangxi, Sichuan, Guizhou, Shaanxi, Shanghai, Chongqing, respectively. In contrast, dengue vulnerability index in 2 single *Ae. albopictus* distribution PLADs, including Tibet and Hebei, show no obvious change.

For dengue vulnerability index in 3 PLADs with both *Ae. aegypti* and *Ae. albopictus* distribution, it shows an increasing trend of Guangdong, Hainan and Yunnan from 2011-2020. Specifically, compared with the average DF vulnerability from 2011-2015, that increased slightly in 3 PLADs with both *Ae. aegypti* and *Ae. albopictus* distribution, including Guangdong (12.19%), Hainan (9.29%), and Yunnan (1.37%), respectively, from 2016-2020. Change for the mean DF vulnerability from 2011-2015 compared with that from 2016-2020 is shown in ***Figure 18***. The average DF vulnerability show no change of that in Tibet and Gansu, and an increasing trend of that in other 23 PLADs.

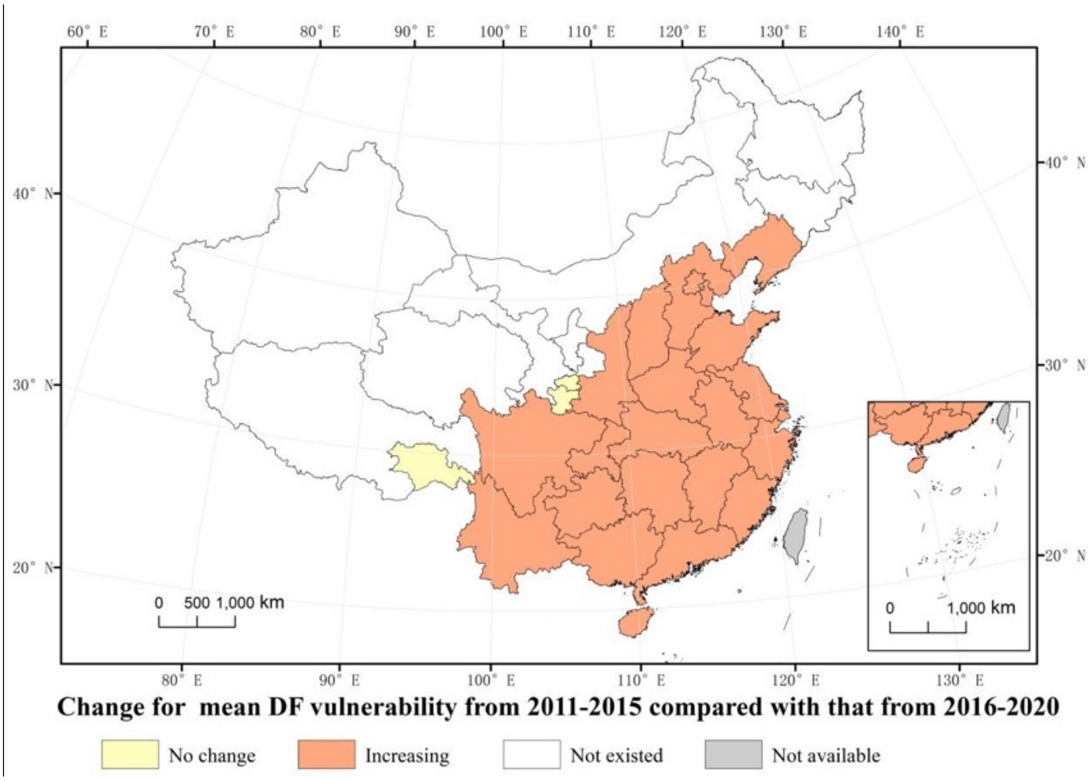


Figure 18**:** Change for mean DF vulnerability from 2011-2015 compared with that from 2016-2020

Compared with the DF vulnerability index in 2010, it increased in 3 PLADs with both *Ae. aegypti* and *Ae. albopictus* distribution in 2020, including Guangdong (28.2%), Hainan (34.18%), and Yunnan (33.01%), respectively (***Figure 19***) (***Table** 7*).

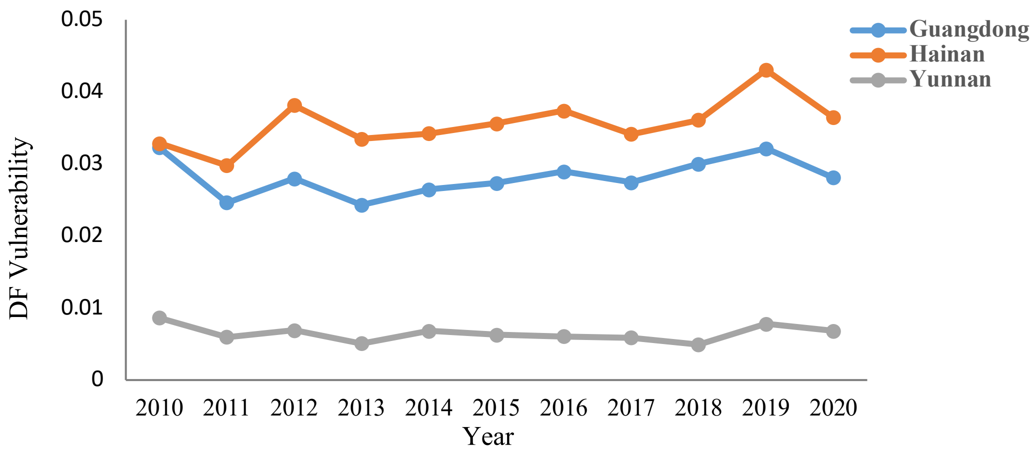


Figure 19**:** Dengue vulnerability index in 3 PLADs with both *Ae. aegypti* and *Ae. albopictus* distribution, China, 2010-2020.

Table 7: Provincial-vulnerability index of dengue fever between 2010 and 2020 in China

No	PLADs	District	Vulnerability index										
			2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
1	Beijing	Eastern	0.002243	0.002272	0.002118	0.002121	0.00232	0.001921	0.002478	0.002419	0.003483	0.002871	0.002441
2	Tianjin	Eastern	0.005448	0.005337	0.005287	0.005108	0.005243	0.005014	0.00541	0.006157	0.006847	0.006727	0.005417
3	Hebei	Eastern	0.004704	0.003536	0.00328	0.003544	0.003233	0.003017	0.003322	0.003849	0.004817	0.004009	0.003206
4	Shanxi	Central	0.002512	0.001721	0.001757	0.002667	0.000944	0.001593	0.001975	0.002507	0.004017	0.003809	0.00241
5	Liaoning	Eastern	0.002279	0.002294	0.002227	0.003352	0.003166	0.002467	0.003425	0.003824	0.004677	0.003742	0.003843
6	Shanghai	Eastern	0.005893	0.00644	0.006844	0.005843	0.005218	0.00549	0.006849	0.006405	0.008481	0.006873	0.007085
7	Jiangsu	Eastern	0.005263	0.004144	0.005309	0.004663	0.003783	0.003804	0.004844	0.005005	0.005917	0.005141	0.00488
8	Zhejiang	Eastern	0.008477	0.004841	0.004856	0.005671	0.004171	0.003572	0.005224	0.005535	0.006161	0.005066	0.005667
9	Anhui	Central	0.007768	0.006197	0.007396	0.007124	0.00541	0.005516	0.006544	0.006815	0.008283	0.008021	0.006934
10	Fujian	Eastern	0.007221	0.005952	0.005917	0.00593	0.005985	0.004774	0.006247	0.006055	0.006107	0.005853	0.006238
11	Jiangxi	Central	0.009442	0.009082	0.009326	0.009787	0.009061	0.008305	0.009746	0.009729	0.011343	0.010726	0.010506
12	Shandong	Eastern	0.003614	0.005597	0.006879	0.007399	0.005659	0.006163	0.007079	0.008023	0.008741	0.008984	0.006581
13	Henan	Central	0.005663	0.005522	0.007148	0.008661	0.005662	0.00545	0.007494	0.008048	0.009211	0.009855	0.007768
14	Hubei	Central	0.005677	0.004804	0.006205	0.007028	0.004483	0.004596	0.006602	0.006257	0.007787	0.007582	0.005661
15	Hunan	Central	0.008494	0.008874	0.009951	0.011099	0.007822	0.008329	0.010289	0.010897	0.012709	0.012011	0.011916
16	Guangdong	Eastern	0.032251	0.02463	0.027971	0.024304	0.026428	0.027317	0.028938	0.027448	0.030001	0.032119	0.028074
17	Guangxi	Eastern	0.010701	0.010706	0.012494	0.010386	0.012467	0.012299	0.014026	0.012168	0.013029	0.014614	0.014035

18	Hainan	Eastern	0.032842	0.029763	0.038109	0.033462	0.03424	0.035594	0.037356	0.034136	0.03607	0.043044	0.03646
19	Chongqing	Western	0.004516	0.004378	0.003845	0.005276	0.003382	0.002675	0.004972	0.004991	0.005331	0.004649	0.004063
20	Sichuan	Western	0.001748	0.00221	0.001628	0.002557	0.001329	0.001654	0.002534	0.002048	0.002466	0.002078	0.002017
21	Guizhou	Western	0.002273	0.003166	0.002216	0.003734	0.003001	0.002211	0.003484	0.003223	0.003645	0.003493	0.003778
22	Yunnan	Western	0.008614	0.005969	0.006902	0.005063	0.006836	0.006286	0.006047	0.005889	0.004924	0.007812	0.006808
23	Tibet	Western	0	0	0	0	0	0	0	0	0	0	0
24	Shaanxi	Western	0.001195	0.000606	0.001962	0.002434	0.001152	0.001307	0.002855	0.002397	0.002503	0.001623	0.001243
25	Gansu	Western	0	0	0	0	0	0	0.00062	0.000702	0	0	0

Table 8: National all-age DALY rate between 2005 and 2019 for dengue in China

Year	All-age DALY rate (per 1 000 000)
2005	0.03
2006	0.03
2007	0.02
2008	0.01
2009	0.01
2010	0.01
2011	0.02
2012	0.02
2013	0.14
2014	1.35
2015	0.11
2016	0.06
2017	0.19
2018	0.17
2019	0.66
2020	0.02

Caveats

Overall, VC should be improved by a more sophisticated model in the future. In addition, lacking data concerning IHR core capacities score in each province of China is another major caveat.

Future Form of Indicator

In future reports, VC can be calculated considering more climatic, environmental and social factors according to different mosquito virus serotypes. New information about data, method and spatial-temporal scale, etc. can be investigated further.

In addition, the DF vulnerability index of the provinces with *Ae. aegypti* and *Ae. albopictus* distribution can be calculated if we can obtain more index to estimate the precise comprehensive health emergencies management index at the provincial level.

Indicator 1.4: Population exposure to regional sea level rise

Methods

This is the first year the indicator has been included in the Lancet Countdown China report. We adopted this indicator from the Lancet Countdown global report with a modification according to China coastal areas. This indicator represents a measure of population exposure to future projected regional sea level (RSL) rise under various greenhouse gas emissions based on current population distribution and coastal elevation.

Firstly, regional sea level rise projections from the Chapter 9 of IPCC AR6 are extracted alone the coastal areas of China from 2020 to 2150 in multiple greenhouse gas emission scenarios: low emission (SSP1-1.9), moderate emission (SSP2-4.5), and high emission (SSP5-8.5). Secondly, the potential inundation areas are determined by overlays future regional sea level under different emission scenarios and years with grid-cells coastal elevation value (CoastalDEM90TMv2.1). Thirdly, using the population grid data (GPWv4) in the coastal areas of China in 2020, the population exposure to sea level rise is calculated from the population number on the grid cells that are submerged. Finally, the province-level population exposure is obtained by aggregating the grid-cell population exposure to the province areas, to reveal the risk at administrative level. The population over 65 years old is obtained from multiplying total population exposure by the proportion of the elderly population in each province based on 2020 population census of China.

Data

1. Regional sea level data projections in 3 GHG emission scenarios from 2020 to 2150 are from Chapter 9 of IPCC AR6[37,38].
2. The coastal elevation data in 2021 is extracted from the Coastal Digital Elevation Model (CoastalDEM90TMv2.1)[39].

3. The 1km-resolution population data in 2020 is obtained from the Gridded Population of the World, Version 4 (GPWv4)[40].
4. 2020 population census of China[41].

Caveats

The major uncertainties of this indicator come from projected sea level rise, which varies according to the projected timeframes, emission scenarios, and the methods involving contributions from multiple factors, e.g. dynamic sea level, glacier and ice sheet melting etc.

There are large uncertainties of future projections on population distribution and age structure due to uncertainties of socioeconomic development, policy adjustment or unpredicted catastrophes, etc. As the first version of this indicator, we implement current population data in 2020 instead of future population changes. Therefore, this indicator highlights the current population exposure to the changes and uncertainties of projected regional sea level rise along the China coastal areas. The impact of uncertainties and changes of population projections are not included in the current version of this indicator.

Unlike the indicator in the Lancet Countdown global report, this indicator did not include migration and displacement due to regional sea level rise or climate changes, because no national-level policies report related to migration and displacement due to climate change is found in China at current stage.

Future Form of Indicator

In future forms of this indicator projected future population data under various socioeconomic pathways could be used to reveal effects from both population evolution and RSL changes on population exposure. In addition, the economic activity could be also included to consider the vulnerability and adaptability of the population who are exposed to the RSL rise. If the accuracy and spatial resolution of the data are updated, the calculation methods will be further optimized, thus improving the reliability of population exposure.

Additional Information

1. The median estimation and likely range of regional sea level (RSL) rises averaged along the China coast are shown in **Table 9**.
2. The median estimation and likely range of population exposure to regional sea level (RSL) rise can be found in **Table 10**.
3. The population exposure in each coastal province in 2100 is shown in **Figure 21.** Median estimation of population exposure to regional sea level rise in each province along Chinese coast in 2100 under 3 different scenarios: SSP1-1.9, SSP2-4.5, SSP5-8.5.

Table 9: Averaged of regional sea level rise of China at 17th, 50th, 83th percentile in 2060, 2100, and 2150 and three emission scenarios (SSP1-1.9, SSP2-4.5, SSP5-8.5).

Year	Percentile	SSP1-1.9	SSP2-4.5	SSP5-8.5
	17	0.051	0.092	0.141

2060	50	0.219	0.261	0.313
	83	0.403	0.447	0.503
2100	17	0.067	0.245	0.469
	50	0.382	0.566	0.806
	83	0.723	0.932	1.206
2150	17	0.072	0.395	0.776
	50	0.576	0.946	1.400
	83	1.124	1.584	2.166

Table 10: Population exposure of China at 17th, 50th, 83th percentile in 2060, 2100, and 2150 and three emission scenarios (SSP1-1.9, SSP2-4.5, SSP5-8.5).

Year	Percentile	SSP1-1.9	SSP2-4.5	SSP5-8.5
2060	17	19716	36722	59810
	50	90315	99826	156183
	83	226972	266367	339140
2100	17	25810	114762	287619
	50	207063	439513	855383
	83	712431	1115618	1873287
2150	17	27462	215282	796560
	50	458814	1138690	2566208
	83	1608825	3309120	7265057

Table 11: Population exposure of people over 65 years-old in China at 17th, 50th, 83th percentile in 2060, 2100, and 2150 and three emission scenarios (SSP1-1.9, SSP2-4.5, SSP5-8.5).

Year	Percentile	SSP1-1.9	SSP2-4.5	SSP5-8.5
2060	17	2348	4449	7370
	50	12235	11120	19304
	83	27814	32562	41431
2100	17	3074	13871	35385
	50	25213	51979	102537
	83	83989	133172	229720
2150	17	3203	25823	95242
	50	54055	135208	319098
	83	193392	410361	924760

Table 12: Population exposure of each province at 17th, 50th, 83th percentile in 2060 and 2100 and three emission scenarios (SSP1-1.9, SSP2-4.5, SSP5-8.5).

	2060			2100		
	SSP1-1.9	SSP2-4.5	SSP5-8.5	SSP1-1.9	SSP2-4.5	SSP5-8.5
Fujian	1029	1333	1915	2434	3953	7563
Guangdong	41645	46282	69096	95388	209064	383643
Guangxi	1403	1859	4075	6935	27076	60331
Hainan	898	1105	2420	4437	20218	35728
Hebei	1497	1570	3269	4103	9517	24464
Jiangsu	29854	32414	51192	64065	111890	215648
Liaoning	1973	2129	3509	4206	8379	17439
Shandong	3157	3295	5872	7059	13393	25827
Shanghai	1356	1442	2003	2611	4456	11035
Taiwan	1723	1841	3008	3956	6396	11133
Tianjin	3150	3296	4953	5935	14187	40793
Hong Kong	730	1204	1663	1936	4251	6904
Zhejiang	1900	2056	3208	3998	6733	14875
Total	90315	99826	156183	207063	439513	855383

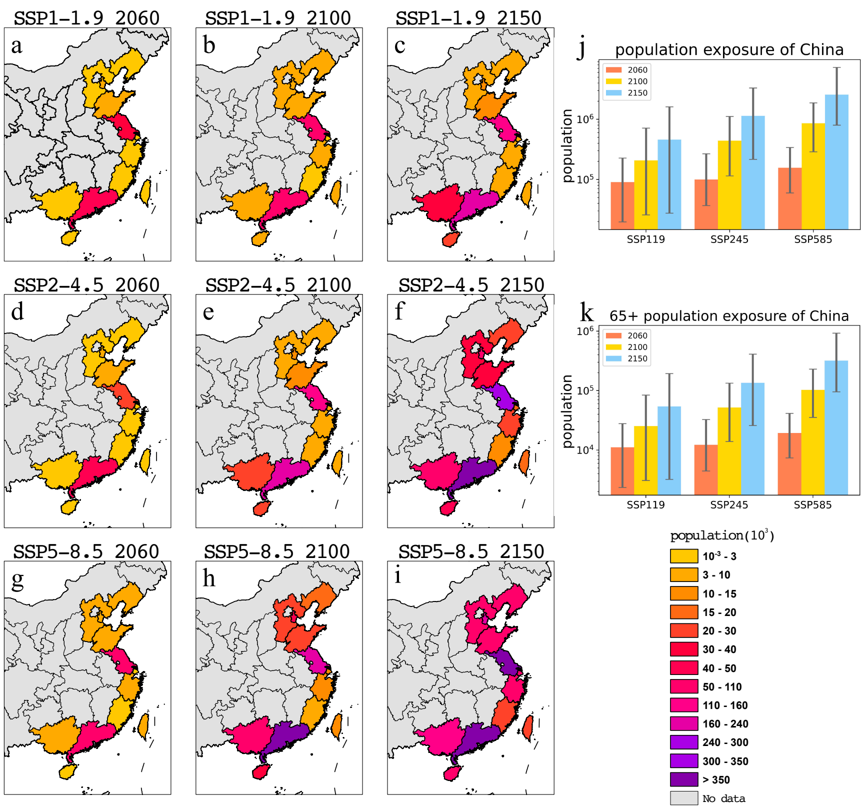


Figure 20. Median estimation of population living in coastal areas below future RSL in provinces of

China

(a-i), the sum of population in these coastal areas for all-age groups (j) and age group over 65 years old (k) in 2060, 2100, and 2150 and 3 greenhouse-gas emissions: SSP1-1.9, SSP2-4.5, and SSP5-8.5. Error bars in j and k indicate the likely range (17th-83th percentile) of estimation.

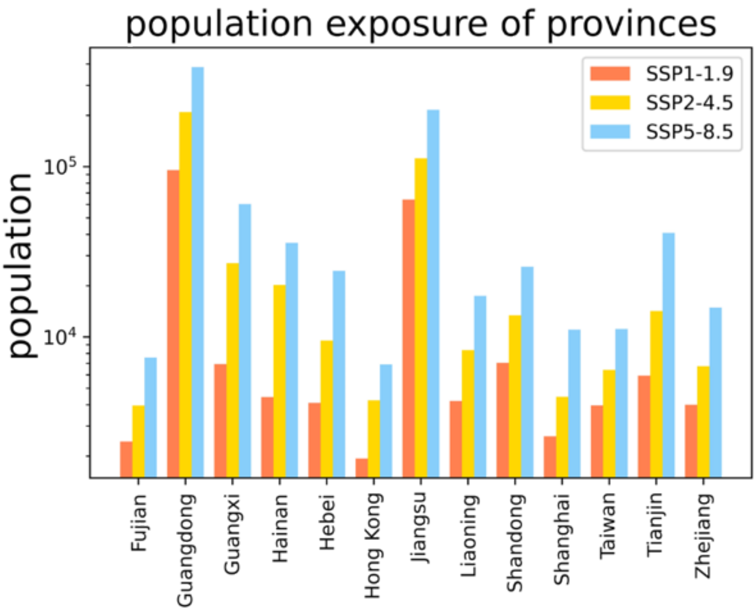


Figure 21. Median estimation of population exposure to regional sea level rise in each province along Chinese coast in 2100 under 3 different scenarios: SSP1-1.9, SSP2-4.5, SSP5-8.5

Section 2: Adaptation, planning, and resilience for health

Indicator 2.1: Adaptation planning and assessment

Indicator 2.1.1: National level adaptation planning and assessment

The methodology for this indicator has been improved from the 2021 China Lancet Countdown report appendix. A mixed approach, including qualitative analysis of national government documents and national assessment reports related to climate change response and a nation-wide China Health and Climate Change Survey for quantitative analysis, was applied for this indicator this year. Both document review and quantitative survey will continue to be conducted annually.

Government documents were searched on the websites of the State Council of PRC, the National Development and Reform Commission, the National Health Commission of PRC *etc.*, and search covered keywords related to climate change, health, adaptation, vulnerabilities, and response *etc*. In addition, we searched government documents relevant to climate change and the health of older populations. All the documents were read through and relevant contents/sections related to climate change and health adaptations were mainly reviewed to qualitatively summarize the national planning findings. The following national government documents were identified as highly relevant:

- The State Council of the People's Republic of China, China's policies and actions to respond to climate change (white paper) (in Chinese). 2021[42].
- Ministry of Ecology and Environment of the People's Republic of China, National Climate Change Adaptation Strategy 2035 (in Chinese). 2022 [43].
- National Health Commission of the People's Republic of China and fourteen other ministries, The 14th Five-Year Plan on Healthy Ageing (in Chinese), 2022 [44].

National reports and documents on assessments of climate change impacts, vulnerability, and adaptation for health released since the year 2020 were also systematically searched. The series of reports, "Climate and Environmental Evolution in China", "The National Assessment Report on Climate Change", and "Green Book of Climate Change-Annual Report on Actions to Address Climate Change" were mainly reviewed to qualitatively summarize the national assessment findings.

The quantitative data for this indicator included a voluntary national online survey, the China Health and Climate Change Survey, which was designed by referring to the 2021 WHO Health and Climate Change Country Survey [49]. The survey items related to adaptation assessment mainly include assessment of health impacts, vulnerability, and adaptation, impacts of assessment results on health services policy etc. In the WHO survey, impacts, vulnerability and adaptation assessments for health is a single assessment. However, in our survey we differentiated it as three stages of assessments to get more detailed information on progress in each province. Otherwise, some of the respondents might report no assessments completed even if they actually finished one or two of the assessments.

Focus group discussions and key informant consultations were operated to ensure the validation of the questionnaire. The survey was sent to the provincial centers for Disease Control and prevention in all 31 provinces / districts / cities in Chinese Mainland at the end of June 2022, of which 20 completed the survey.

The English version of the questionnaire is shown below.

2022 China health and climate change survey

Dear Sir/Madam: Hello!

I am an investigator of the project "China Climate Change and Health ". We sincerely invite you to participate in this survey. The purpose of this survey is to track and understand the adaptation policies, measures and assessment of climate change health risks in China, and summarize the progress, problems and challenges for climate change and health at China's national and provincial level, so as to provide reference for future policy formulation, implementation and climate change health adaptation.

Your truthful answers are very important to our research. The information you provide will be completely confidential. The completion and submission of this questionnaire indicates that you have informed consent to this survey.

Thank you again for your cooperation.

Basic information of participants：

Your name: ________________________________

Your work sector: ________________________________

Your workplace: ________________________________

Your tel: ________________________________

Your email: ________________________________

Part One: Institutional arrangement and management

1. **Which ministry is responsible for climate change-related work in your province? [Multiple choice] ***

   A. Development and Reform Commission

   B. Environmental Agency

   C. Meteorological Bureau

   D. Health Commission

   E. Other________________*

2. **Which ministry is responsible for climate change and health-related work in your province? [Multiple choice] ***

   A. Development and Reform Commission

   B. Environmental Agency

   C. Meteorological Bureau

   D. Health Commission

   E. Other ________________*

3. **Does the CDC have a section in charge of climate change and health? [Multiple choice] ***

   A. Yes (section name) ________________ *

   B. No

   C. Unclear

   If you answer "Yes", please answer 3.1

3.1 How many full-time staff (or equivalent) are dedicated to health and climate change in the Ministry of Health _____________ [Fill in the blank] *

4. Is there a memorandum of understanding or other agreement between the health department in your province and the following relevant departments in which a specific division of work and responsibility for climate change and health is identified?

Health-determining sectors/ministries	Yes	No	Unclear
Development and Reform Commission	○	○	○
Agriculture	○	○	○
Education	○	○	○
Energy	○	○	○
Environment	○	○	○
Urban development/Housing	○	○	○
National meteorological and hydrological services	○	○	○
Transportation	○	○	○
Other_________ *	○	○	○

Part Two: Impact, Vulnerability and Adaptation Assessment

5. Has your province organized any assessment of the impact of climate change on population health? *

A. Province-wide

B. A few cities (list the names of the cities in which they are carried out) ______________ *

C. Under development

D. Not at all

E. Unclear

If you answer "Province-wide" or "Individual cities", please answer 5.1

5.1 In a recent evaluation, which health impacts were primarily assessed? [Multiple choice] *

A. Vector-borne diseases

B. Water-borne or food-borne diseases

C. Respiratory or cardiovascular morbidity or mortality
D. Heatwave related morbidity or mortality
E. Extreme events (flooding, typhoon, etc.) related injury or deaths
F. Malnutrition and food security
G. Women and children health
H. Mental health
I. Occupational health and labor capacity
J. Other health effects _________________*

6. Has your province organized any vulnerability assessment of climate change and population health risks? *

A. Province-wide
B. A few cities (list the names of the cities in which they are carried out) ____________ *
C. Under development
D. Not at all
E. Unclear

7. Has your province organized any adaptation assessment of climate change and population health risks? *

A. Province-wide
B. A few cities (list the names of the cities in which they are carried out) _____________ *
C. Under development
D. Not at all
E. Unclear

If you have organized any of the above assessments 5-7, answer "Province-wide" or "A few cities", please answer the following questions for each assessment.

Assessment 1

7.1 Name of the assessment report [Fill in the blank] *_______________

7.2 Year in which the assessment was conducted [Fill in the blank] *_______________

7.3 Scope covered by the assessment [Multiple choice] *
A. Climate change impact assessment on population health
B. Vulnerability assessment of climate change and health risks
C. Adaptation assessment of climate change and health risks

7.4 Specific populations considered in the assessment [Multiple choice] *
A. Children

B. Women
C. Elderly (65 years old and above)
D. local population
E. Migrant workers
F. Poor people
G. Rural population
H. Urban/suburban population
I. Don't know
J. Other ________________*

7.5 How have the results of the assessment influenced the government's development of climate change and health plans/strategies? *
A. Greater impact
B. There are some effects
C. Minimal impact
D. No effect
E. Unclear

7.6 How have the results of the assessment impacted health resource allocation (e.g., increased staffing, financial support, etc.)? *
A. Greater impact
B. There are some effects
C. Minimal impact
D. No effect
E. Unclear

7.7 Please upload the assessments reports [Upload File] *

7.8 Are there any other assessments to report? [Single-choice] *
A. Yes
B. No

Part Three: Adaptation plans and actions

8. Has your province developed or implemented policies or action plans to address the health risks of climate change? [Multiple choice]*

A. Province-wide

B. A few cities (list the names of the cities in which they are carried out) ________________ *

C. Under development

D. Not at all

E. Unclear

If you answer "Province-wide" or "A few cities", please answer the following questions for each assessment.

Policy 1

8.1 Name of the policy measure/action plan implemented or the name of the document issued [Fill in the blank] *_____________________

8.2 Year covered by policy measures/action plans [Fill in the blank] *__________________

8.3 Is there a budget and staffing required for the policies/action plans? *

A. Yes

B. No

C. I don't know

8.4 Has the policies/action plan received government funding support? *

A. Yes

B. No

C. Unclear

8.5 Is the progress of the policies/action plans monitored? *

A. With monitoring

B. No monitoring

C. Unclear

8.6 Please upload the policies/action plans [Upload file] *

8.7 Are there any other policies/measures that need to be reported? *

A. Yes

B. No

9. Are there other work plans in your province that address climate change and health risk response*

A. Yes, (please list the specific program name) _________________ *

B. No

C. I don't know

10. What do you think are the main challenges in your province in addressing the health risks of climate change? [Multiple choice] *

A. Poor awareness of government

B. Insufficient scientific understanding of the health risks of climate change

C. Unclear responsible department or leading sector

D. Lack of a mechanism for multi-sectoral cooperation

E. Government funding deficiency

F. Short of health workforce resources

G. Inadequate primary healthcare capacities

H. Incomplete national surveillance system

I. Insufficient risk monitoring and assessment technologies

J. Lack of comprehensive response plan/strategy

K. Other _________________*

11. Has the outbreak of the global novel coronavirus pneumonia (COVID-19) epidemic contributed to your province's consideration of the impact of climate change in health-related efforts? *

A. Yes

B. No

C. Unclear

If you answer "Yes", please answer 11.1.

11.1 Specifically, in which work are the health effects of climate change primarily considered [Fill in the blank]__________

12. Has the development of a dual carbon (carbon peaking, carbon neutral) strategy contributed to your province's consideration of climate change impacts in health-related efforts? *

A. Yes

B. No

C. Unclear

If you answer "Yes", please answer 12.1

12.1 Specifically, in which work are the health effects of climate change primarily considered [Fill in the blank] _______________

Part Four: Risk monitoring/early warning

13. For the following climate-sensitive health outcomes, please indicate: whether there is a relevant disease surveillance system; whether the surveillance system includes meteorological information

	Is there a relevant disease surveillance system?	Does the monitoring system include meteorological information?
Morbidity or mortality from respiratory or cardiovascular disease		
Illness or death due to high temperature heat waves		
Injuries or deaths caused by extreme weather events such as floods and typhoons		
Malnutrition and food security		

Maternal and Child Health		
Spiritual and Mental Health		
Arboviral diseases		
Waterborne or foodborne diseases		
Zoonotic diseases		

14. Has the meteorological department in your province provided meteorological information services to health care departments or agencies? *

A. Yes

B. No

C. Unclear

If you answer "Yes", please answer 14.1-14.2

14.1 Please check which meteorological information related to population health has been provided. [Multiple choice] *

A. Temperature

B. Precipitation

C. Humidity

D. Wind

E. Disaster meteorological events (typhoons, dust storms, etc.)

F. Air quality

G. Ultraviolet light

H. Other ________________*

14.2 Does your province use these meteorological information services to guide decision making in health care? *

A. Yes, (please give a brief example) ________________ *

B. No

C. Unclear

15. **For the following extreme weather and climate events, please indicate: whether your province has an early warning for extreme weather and climate events; and whether the health sector has a response plan/program.**

Heat Wave *

	Yes	No	No idea
Is there early warning in your province?	○	○	○
Does the health department have a response plan/program?	○	○	○

If you answer "Yes", please upload a health sector response plan for the heat wave [Upload file] *

Cold spell *

	Yes	No	No idea
Is there early warning in your province?	○	○	○
Does the health department have a response plan/program?	○	○	○

If you answer "Yes", please upload the health department response plan for the cold snap [Upload file] *

Extreme precipitation/Flooding *

	Yes	No	No idea
Is there early warning in your province?	○	○	○

Does the health department have a response plan/program?	○	○	○

If you answer "Yes", please upload a health sector response plan for extreme precipitation/flooding [Upload file] *

Drought *

	Yes	No	No idea
Is there early warning in your province?	○	○	○
Does the health department have a response plan/program?	○	○	○

If you answer "Yes", please upload a health sector response plan for the drought [Upload file] *

Hurricane/Typhoon *

	Yes	No	No idea
Is there early warning in your province?	○	○	○
Does the health department have a response plan/program?	○	○	○

If you answer "Yes", please upload health sector response plans for hurricanes/typhoons, etc. [Upload file] *

16. Has the health sector conducted a province-wide awareness or science campaign on climate change and health to enhance public understanding of the issue? *

A. Yes

B. No

C. I don't know

17. **What are the main ways your answers come from? [Multiple choice] ***

A. Responsible for related work by yourself

B. Heard from a colleague

C. Learned in lectures/conferences

D. Read related documents

E. Other _________________*

Data

1. National reports and documents on adaptation planning and assessment of climate change impacts, vulnerability, and adaptation to health were retrieved from government websites or databases as described above.
2. Data on provincial adaptation planning and assessment for health were obtained from the nationwide online voluntary survey targeted on both provincial CDCs and Health Commission conducted by Sun Yat-sen University at the end of June 2022.

Caveats

The national online survey related to climate change and health adaptations was conducted in China for the third time in 2022. A total of 20 provinces and municipalities (including Anhui, Gansu, Guangdong, Guangxi, Hainan, Heilongjiang, Henan, Hubei, Hunan, Inner Mongolia, Jiangsu, Jiangxi, Ningxia, Qinghai, Shandong, Sichuan, Tianjin, Xinjiang, Yunnan, and Zhejiang) have participated in this survey. It was completed by the provincial Centers for Diseases Control and Prevention in the provinces/regions/municipalities in mainland China, which might only reflect the adaptation plans from local governments' perspectives.

Future Form of Indicator

National reports and documents on climate change and adaptation plans for health will continue to be searched and reviewed annually. The China Health and Climate Change Survey will also be conducted annually and will continue to be the primary source of data to track this indicator 2.1.1. The survey tool could be improved in the future, in terms of the stricter validation of the detailed response.

Additional Information

The State Council Information Office published white paper entitled China′s Policies and Actions on Climate Change in October 2021 [42]. The document proposed establishment of regional heat-health early warning systems for improving public's ability to adapt to climate change. National Climate Change Adaptation Strategy 2035 [43] lunched in 2022 includes a subsection on health, and emphasized action related to climate-health issues. Meanwhile, for the first time, the Healthy China Action Promotion Committee explicitly mentioned "promoting actions to address health impacts of climate change" in its annual work priorities in 2022, reflecting the increased awareness of the links between climate change and health in the healthcare sector.

In recent years, the national reports on climate change had involved health as a part of the assessment. For example, health had been included as a single chapter in the report of "Climate and Environmental Evolution in China: 2021" [45].

In terms of an adaptation assessment of the health risks of climate change, Guangdong province reported that a comprehensive, province-wide assessment of the health effects, vulnerability, and adaptation to climate change has been conducted. In other provinces, they stated the assessment was conducted in a few cities, such as Nanjing city in Jiangsu province, Jinan city and Qingdao city in Shandong province, Urumqi city in Xinjiang province, and Ningbo city in Zhejiang province (***Figure 21***).

Of the 20 provinces surveyed, Guangdong province reported that health and climate change adaptation plans or measures had been developed at the provincial level. In 2022, Guangdong province issued the "14th Five Year Plan of Guangdong Province to Address Climate Change". Three provinces (Henan, Inner Mongolia, and Sichuan) reported that they were developing related adaptation plans (***Figure 22***). In this survey, although eleven provinces (Anhui, Gansu, Guangdong, Guangxi, Henan, Hunan, Inner Mongolia, Jiangsu, Shandong, Xinjiang, and Yunnan) stated that provincial health departments and meteorological departments are working closely together in health and climate change adaptation plans and strategies, meteorological information was also provided to the health departments by the meteorological departments. However, only seven provinces (Gansu, Guangdong, Henan, Jiangsu, Shandong, Xinjiang, and Yunnan) stated they used meteorological information to guide health decision making (***Figure 23***). The survey found that the lack of government funding support (70%), the lack of a mechanism for multi-sectoral cooperation (65%), and the lack of risk monitoring and assessment technologies (65%) were major challenges in addressing the health risks of climate change (***Figure 24***).

Most provinces (except for Qinghai province) stated they have climate-sensitive disease surveillance systems in place. Water-borne or food-borne diseases (80%), respiratory or cardiovascular morbidity or mortality (75%), and vector-borne diseases (75%) are the most monitored diseases. However, few systems incorporate meteorological information (***Figure 25***). Except for Gansu, Hainan, Heilongjiang, Qinghai, and Sichuan, other provinces have established early warning systems for at least one extreme weather event, such as extreme precipitation or flooding (65%), cold spell (55%), and heat wave (55%), but they still lack response plans or programs to address extreme weather related health risks (***Figure 26***).

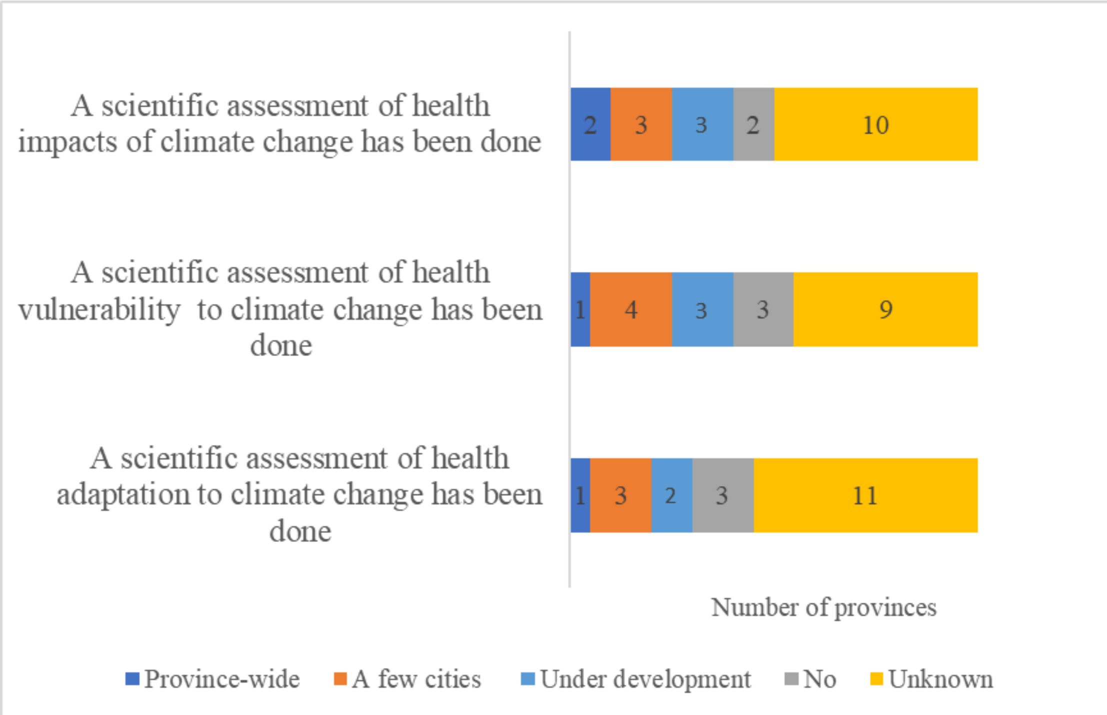


Figure 22: **Number of provinces with a scientific assessment of climate change impacts, vulnerability, and adaptation for health**

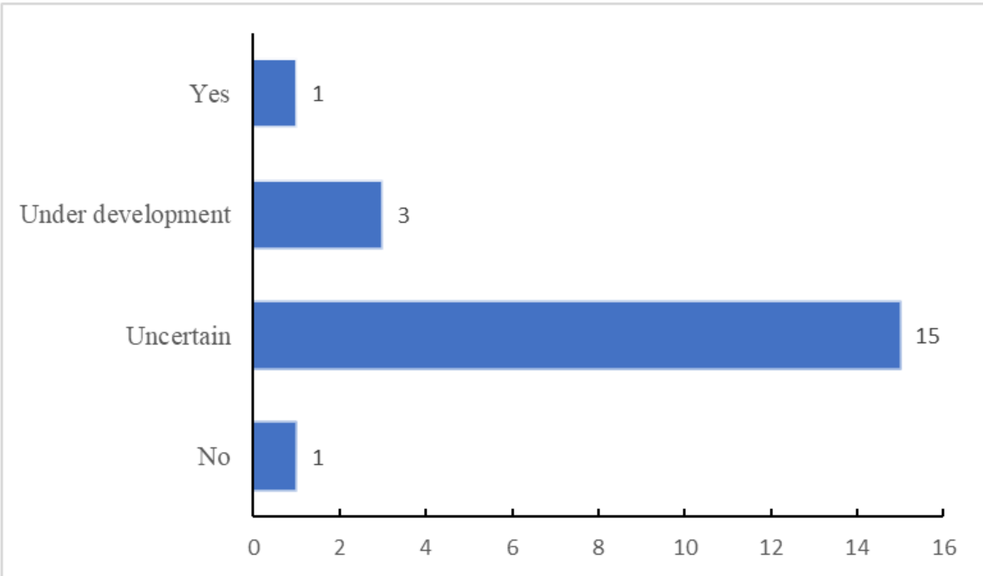


Figure 23: **Number of provinces declared policies implementation to deal with the health risks of climate change**

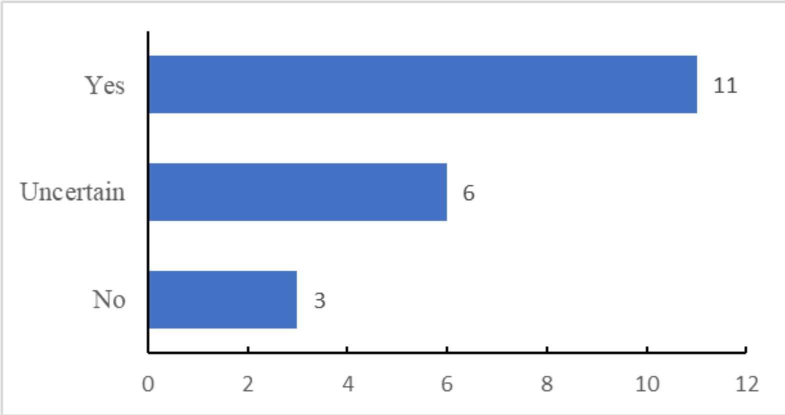


Figure 24: **Number of provinces declared health department collaborating with the meteorological department to tackle the health risks of climate change**

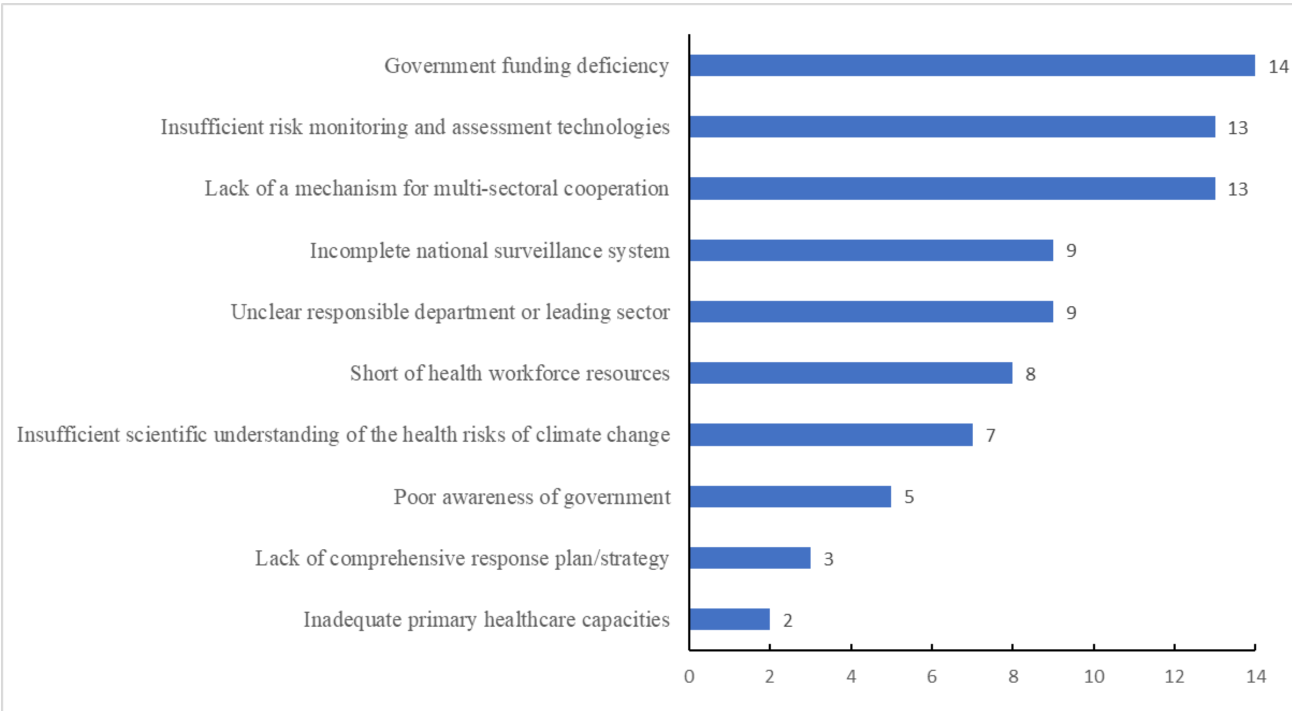


Figure 25: **The main challenges in addressing the health risks of climate change**

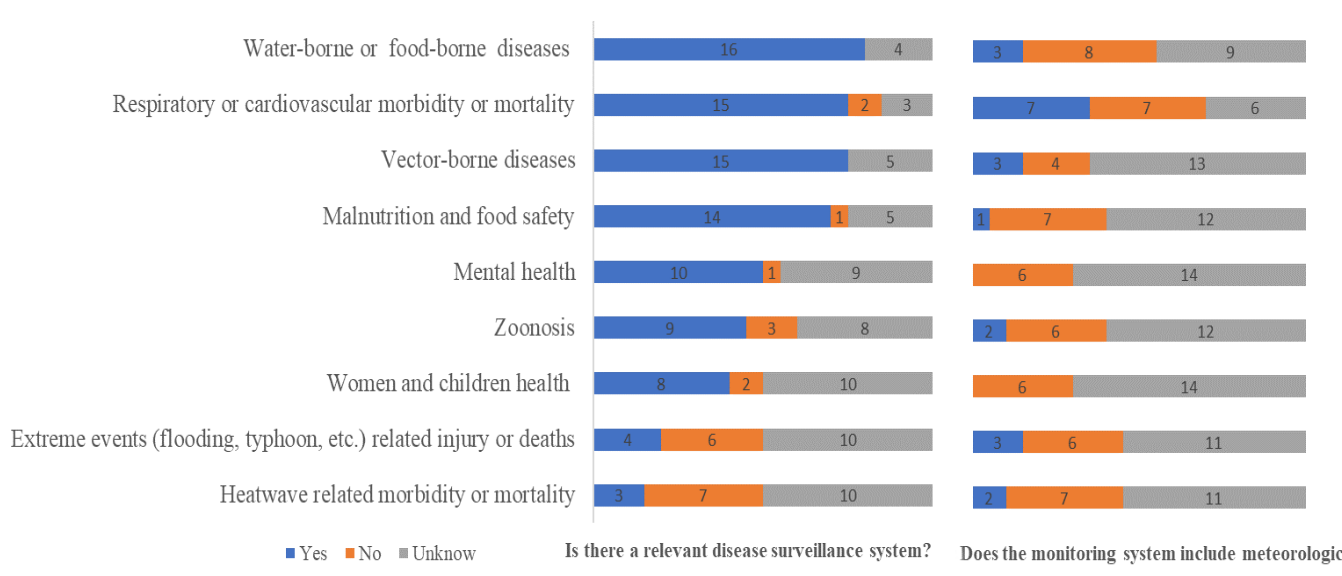


Figure 26: **The number of provinces with climate sensitive disease surveillance systems**

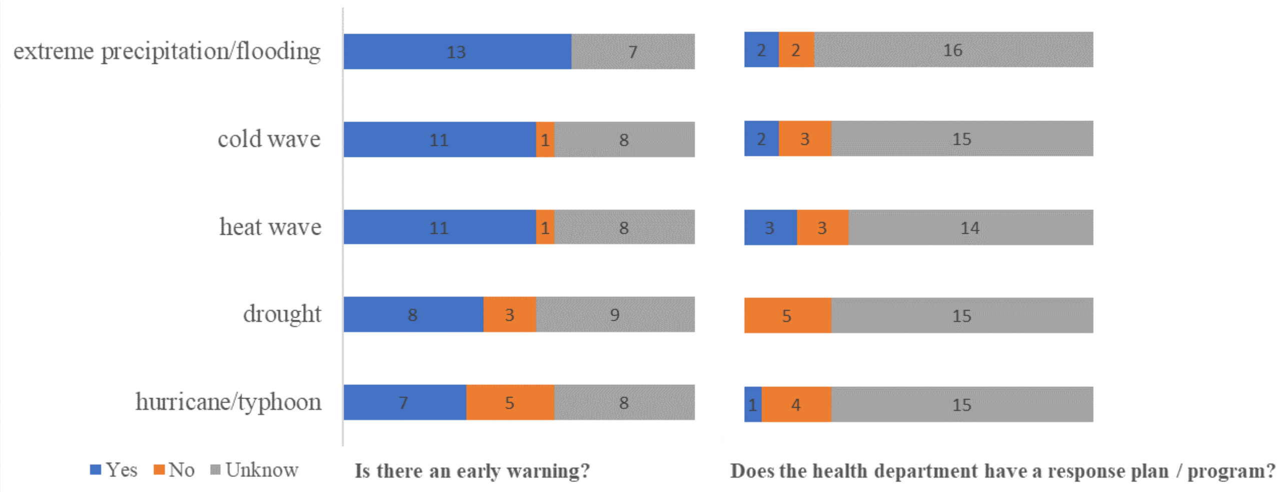


Figure 27: **The number of provinces with early warning systems for extreme weather events**

Indicator 2.1.2 City-level climate change risk assessments

Methods

An indicator was developed to measure the proportion of provinces with at least one city that has conducted or are conducting climate change risk or vulnerability assessments. The data were derived from the CDP Annual Cities Survey and the Annual Provincial Survey on Climate Change Assessment and Information Services. The latter was carried out by the authors who are responsible for this indicator.

In 2021, 19 cities responded to questions on climate change risk or vulnerability assessments in the

CDP Annual Cities Survey, including 9 from 7 provinces in mainland China, 9 cities from Taiwan Province, and Hong Kong.

The annual survey targeting provincial meteorological departments started for the 2021 report. In 2022, provincial meteorological departments in all 31 provinces in mainland China were invited to participate in this year's survey, and 29 responded. Hainan and Sichuan did not participate in the survey. The questions on city-level climate change risk or vulnerability assessments are consistent with the related questions in the CDP Annual Cities Survey.

The information of Macao is based on The People's Republic of China Third National Communication on Climate Change. The part of basic information of Macao SAR on addressing climate change shows the information of climate change impact assessment undertaken by the Macao SAR Government.

All these data sources were combined to reach the final results. As not all the respondents in the annual survey for provincial meteorological departments were responsible for the related work, for provinces with available results from the CDP survey, the CDP survey results prevailed. The results for some provinces from the 2022 survey for provincial meteorological departments were not consistent with those from the 2021 survey.

Data

1. CDP Annual Cities Survey[46]
2. Annual Provincial Survey on Climate Change Assessment and Information Services
3. The People's Republic of China Third National Communication on Climate Change[47]

Caveats

Only a small portion of Chinese cities participated in the CDP Annual Cities Survey. It made the first sub-indicator lack representativeness, though more cities in mainland China participated in 2020 than in 2019.

The annual survey targeting provincial meteorological departments is established on the collaborative relationships between the authors and the provincial meteorological departments rather than an official top-down mode.

Although for most provinces, the provincial meteorological bureaus were surveyed, for several provinces, the meteorological bureaus of the capital or major cities were surveyed instead due to the lack of contact with the corresponding provincial meteorological bureaus.

The authors tried best to look for people in charge of climate change assessment and adaptation in the meteorological departments to answer the questions, but it is unlikely to ensure that the actual respondents completely grasp the progress of city-level climate change risk assessments in their provinces.

Future Form of Indicator

The author team of the China report of the Lancet Countdown on health and climate change will seek for chances of official surveys led by the central government at the provincial level and even at the city level in the future and enrich the questionnaire content to investigate more details.

The author team will also organize a workshop for the annual survey next year. Provincial meteorological bureaus from all provinces will be invited to join the workshop, in which they will be informed of the objectives of the report and the scope of the survey. All the bureaus will be given more time to finish the questionnaire.

Findings

Headline finding: In 21 out of 34 provinces, there was at least one city with a climate change risk or vulnerability assessment undertaken or being undertaken in 2021.

There have been two rounds of official climate change assessments for regions in China with provinces involved, but city-level assessments are being developed in cities' own ways. Cities play a main role in taking measures for climate adaptation. According to the Cities Annual Survey by the Carbon Disclosure Project and the annual survey for provincial meteorological bureaus, 21 provinces had completed or ongoing city-level climate change risk or vulnerability assessments in 2021 with three more relative to 2020. Provinces in Northern China are still behind.

Additional information

In 2022, the 21 provinces with city-level climate change risk assessments included Anhui, Beijing, Chongqing, Fujian, Gansu, Guangdong, Guangxi, Guizhou, Henan, Hubei, Hunan, Jiangsu, Shandong, Shanghai, Sichuan, Tianjin, Xinjiang, Zhejiang, Hong Kong, Taiwan, and Macao. Compared with 2021, the three more provinces were Hunan, Shanghai, and Tianjin.

There have been two rounds of regional climate change assessment reports in China[48,49]. The eight regions are Northeast China, North China, Northwest China, East China, Central China, South China, Southwest China, and Xinjiang. The two rounds were completed in 2014 and 2020, respectively.

Indicator 2.2: Adaptation delivery and implementation

Indicator 2.2.1: Detection, preparedness, and response to health emergencies

Methods

This indicator reflects the situation of public health emergency management in 2020 in this report. The methodology for this indicator has been succeeded and improved from the 2020 China Lancet Countdown report. A comprehensive index system was built, using Entropy Weigh Method (EWM), to track the ability of provinces to detect and rapidly respond to public health emergencies, covering disease outbreaks, mass illness of unknown origin, serious food and occupational poisoning and other emergencies that jeopardise public health, including the climate-sensitive diseases and medical rescue caused by climate-related extreme events.

The index system includes three dimensions: risk exposure and preparedness, detection and response, resource support and social participation. The three dimensions are divided into six second-level indicators and 20 third-level indicators, among which two were replaced. First, according to the data from Chinese Center for Disease Control and Prevention, the construction rate of Infectious Disease Surveillance Reporting System has been reaching 100% in every province. The indicator D&R 1.1, therefore, was replaced by 'number of CDCs per 1,000 population'. Second, the indicator RS&SP 2.2 was changed into 'percentage of social expenditures in the medical and health sector out of local GDP' instead of 'number of private non-enterprises in the health sector', due to the update of statistic scale of China Civil Affairs' Statistics Yearbook, which has been compiled by the Ministry of Civil Affairs of the PRC since 1990.

In order to focus on the performance of every province dealing with COVID-19 pandemic, an extensional module with four more dynamic third-level indicators was added to the fundamental index system, which include 'D&R COVID 1.1: Information release level on public health emergencies', 'D&R COVID 2.1: System robustness of personal health code', 'D&R COVID 2.2: Average period of dynamic clearing of COVID-19 cases', and 'RS&SP COVID 1.1: Number of nucleic acid detection sites per 1,000 population'. The EWM is also applied to these indicators to calculate the relative weights. All indicators of the index system are listed as follows and the weights of fundamental indicators sum up to 100%.

Table 13: The indicators of the provincial comprehensive health emergencies management ability index system

First-level Indicators	Second-level Indicators	Third-level Indicators	Index weights / %
Risk Exposure and Preparedness(RE&P): the degree of risk faced by the provinces in the health environment and the work done about emergency preparedness.	RE&P 1: Health emergency environmental risks: the health risks due to population mobility and risk management of the provinces.	RE&P 1.1: Proportion of cities identifies as National Health Cities	7.190
		RE&P 1.2: Urban population density	3.831
		RE&P 1.3: Percentage of migrant population	1.970
		RE&P 1.4: Passenger traffic volume	2.767
		RE&P 1.5: Number of port entry personnel	0.908
	RE&P 2: Health emergency preparedness: the health emergency preparedness of the provinces, in terms of emergency planning, emergency space, and fiscal investment.	RE&P 2.1: Completeness of normative documents for public health emergencies	5.501
		RE&P 2.2: Construction space for emergency facilities per capita	6.307
		RE&P 2.3: Percentage of medical and health expenditure out of total government public expenditure	4.858
Detection and Response(D&R): the ability for infectious	D&R 1: Health emergency detection and early warning: the ability for infectious diseases	D&R 1.1: Number of CDCs per 1,000 population	11.993
		D&R 1.2: Availability rate of 4G mobile	4.674

diseases detection and early warming of the provinces, and the health emergency response ability from the perspective of results.	detection and early warming of the provinces from the perspective of information construction.	phone	
		D&R COVID 1.1: Information release level on public health emergencies	5.924
	D&R 2: Health emergency response: the management and response to infectious diseases of the provinces.	D&R 2.1: Incidence of category A and B infectious diseases	10.726
		D&R 2.2: Death rate of category A and B infectious diseases	5.941
		D&R COVID 2.1: System robustness of personal health code	9.097
		D&R COVID 2.2: Average period of dynamic clearing of COVID-19 cases	8.790
Resource Support and Social Participation(RS&SP): the ability to guarantee medical services and the degree of participation of social forces in health care of the provinces.	RS&SP 1: Medical service and resource support: the condition of medical resources and material supplies of the provinces.	RS&SP 1.1: Number of hospitals per 1,000 population	1.083
		RS&SP 1.2: Number of primary health care institutions per 1,000 population	2.191
		RS&SP 1.3: Number of beds in medical and health institutions per 1,000 population	0.248
		RS&SP 1.4: Number of practicing and assistant doctors per 1,000 population	0.335
		RS&SP 1.5: Number of registered nurses per 1,000 population	0.342
		RS&SP 1.6: Production capacity of pharmaceutical manufacturing industry	12.467
		RS&SP COVID 1.1: Number of nucleic acid detection sites per 1,000 population	5.787
	RS&SP 2: Health emergency social participation: the participation of stakeholders in health emergencies.	RS&SP 2.1: Percentage of registered volunteers	7.316
		RS&SP 2.2: Percentage of social expenditures in the medical and health sector out of local GDP	9.351

The contents and calculation methods of the indicators are described as follows.

Fundamental Capability Indicators:

- *RE&P 1.1: Proportion of cities identified as National Health Cities*: This indicator is measured by the ratio of the number of National Health Cities in one province to the total number of cities in the province. The National Health City is a national selection carried out every year by Bureau of Disease Control and Prevention, National Health Commission of the PRC.
- *RE&P 1.2: Urban population density*: Urban population density is relevant to the risk of disease spread. It was obtained from China Urban and Rural Construction Statistical Yearbook.
- *RE&P 1.3: Percentage of migrant population*: The percentage of migrant population reflects the risk level of imported infectious diseases and affect community resilience to emergencies. It was obtained from Migrant Population Data Platform, which is an online database provided by Migrant Population Service Center, National Health Commission of the PRC.

- *RE&P 1.4: Passenger traffic volume*: This indicator is measured by the domestic passenger traffic volume per year via one province, including railway, highway and waterway. It's also an indicator reflects the risk level of imported infectious diseases. The data were obtained from China Statistical Yearbook.
- *RE&P 1.5: Number of port entry personnel*: This indicator is measured including entry passengers via land ports, waterway ports and air ports in one province. It also reflects the risk level of imported infectious diseases. The data was obtained from China Port Statistical Yearbook.

- *RE&P 2.1: Completeness of normative documents for public health emergencies*: This indicator is measured by text analysis to provincial emergency planning, disease control regulations and local standards for public health emergencies. The results are graded into 0-12 points. The criteria of text analysis include general prevention and control standards, mechanisms of emergency response, crucial point regulations, medical product standards, epidemiological investigation and medical treatment measures, medical facilities construction standards, and medical informatization standards. The text of normative documents was obtained from website of general office of provincial government.
- *RE&P 2.2: Construction space for emergency facilities per capita*: The redundancy of construction space for emergency facilities is important when severe epidemic outbreaks. The data of area of urban construction land for municipal utilities was obtained from China Urban and Rural Construction Statistical Yearbook.
- *RE&P 2.3: Percentage of medical and health expenditure out of total government public expenditure*: Fiscal investment is a fundamental work in health emergency preparedness. The data were obtained from China Statistical Yearbook.

- *D&R 1.1: Number of CDCs per 1,000 population*: The CDC systems at all levels are the major access of health emergency early warning and response. The data were obtained from China Health Statistics Yearbook.
- *D&R 1.2: Availability rate of 4G mobile phone*: This indicator is measured by the percentage of population who own a 4G mobile phone. It is a key indicator that reflects the accessibility of warming information. The data were obtained from China Information Almanac.

- *D&R 2.1: Incidence of category A and B infectious diseases*: This indicator is one of the most common used indicators in health emergency response assessment. The infectious diseases are divided into Category A, B and C based on the Law of the People's Republic of China on the Prevention and Treatment of Infectious Diseases[50]. Category A and B infectious diseases are the diseases prevalent and cause casualties easily. The data were obtained from China Health Statistics Yearbook.
- *D&R 2.2: Death rate of category A and B infectious diseases*: This indicator is another one of the most common used indicators in health emergency response assessment.

- *RS&SP 1.1: Number of hospitals per 1,000 population*: Hospitals are the major place for health emergency medical treatment. The data were obtained from China Health Statistics Yearbook.

- *RS&SP 1.2: Number of primary health care institutions per 1,000 population*: Primary health care institutions are the major place for early medical treatment and disease prevention. The data were obtained from China Health Statistics Yearbook.
- *RS&SP 1.3: Number of beds in medical and health institutions per 1,000 population*: The number of beds in medical and health institutions reflects the admission capacity for health emergency. The data were obtained from China Health Statistics Yearbook.
- *RS&SP 1.4: Number of practicing and assistant doctors per 1,000 population*: The number of doctors reflects the ability of treatment for health emergency. The data were obtained from China Health Statistics Yearbook.
- *RS&SP 1.5: Number of registered nurses per 1,000 population*: The number of nurses reflects the ability of nursing for health emergency. The data were obtained from China Health Statistics Yearbook.
- *RS&SP 1.6: Production capacity of pharmaceutical manufacturing industry*: The production capacity of pharmaceutical manufacturing industry is important for medical material supplies when severe epidemic outbreaks. This indicator is measured by the annual gross domestic product of pharmaceutical manufacturing industry per 10,000 population. The data were obtained from China Industry Statistics Yearbook.

- *RS&SP 2.1: Percentage of registered volunteers*: Volunteer participation assists the response to health emergency, and it also reflects residents' resilience to health emergency. The data were obtained from the Website of China Volunteer Service, an online platform provided by Ministry of Civil Affairs of the PRC.
- *RS&SP 2.2: Percentage of social expenditures in the medical and health sector out of local GDP*: Social investments act as important additions to public affairs in the process of heath emergency response. The data of social expenditures were obtained from China Health Statistics Yearbook.

COVID-19 Extensional Module:

- *D&R COVID 1.1: Information release level on public health emergencies*: This indicator reflects the completeness, timeliness, accessibility, readability, and data curation of the officially released information at the early stage of COVID-19 pandemic. The original data were obtained from the research report on data release of Chinese provincial government on COVID-19 from Fudan University[50].
- *D&R COVID 2.1: System robustness of personal health code*: The indicator is measured by the frequency of failures (in natural logarithm) of personal health code system, divided by the availability rate of 4G mobile phone of each province. The original data were obtained from public text collected on social media platform(Weibo).
- *D&R COVID 2.2: Average period of dynamic clearing of COVID-19 cases*: The indicator is measured by the average timespan of an emergence of COVID-19 cases. The open data on COVID-19 cases were used.
- *RS&SP COVID 1.1: Number of nucleic acid detection sites per 1,000 population*: The data were obtained from the network site of National Government Service Platform.

To integrate the above indictors into an index, we determine weights for all the indicators. It is assumed that the six second-level indicators(without extensional modules) take equal weights to be one-sixth, and the relative weights of the third-level indicators, including the extensional ones, are determined by Entropy Weigh Method(EWM) under each one of the second-level indicators.

The calculation steps of EWM:

a) Min-Max Normalization.

$$\varphi_{ij}^{'} = \begin{cases} \dfrac{\varphi_{ij} - min\left\{\varphi_{1j}, \varphi_{2j}, \dots, \varphi_{nj}\right\}}{max\left\{\varphi_{1j}, \varphi_{2j}, \dots, \varphi_{nj}\right\} - min\left\{\varphi_{1j}, \varphi_{2j}, \dots, \varphi_{nj}\right\}} \ (for\ positive\ indicators) \\ \dfrac{max\left\{\varphi_{1j}, \varphi_{2j}, \dots, \varphi_{nj}\right\} - \varphi_{ij}}{max\left\{\varphi_{1j}, \varphi_{2j}, \dots, \varphi_{nj}\right\} - min\left\{\varphi_{1j}, \varphi_{2j}, \dots, \varphi_{nj}\right\}} \ (for\ negative\ indicators) \end{cases}$$

φ_{ij} is the original data of the jth third-level indicator of the ith province, n is the amount of provinces. A positive indicator is an indicator that larger value means better result, while a negative indicator is an indicator that larger value means worse result.

b) Calculate the proportion of normalised sample value.

$$p_{ij} = \frac{\varphi_{ij}^{'}}{\sum_{i=1}^{n} \varphi_{ij}^{'}} \ (j = 1, 2, \dots m)$$

m is the amount of the third-level indicators under the same second-level indicator.

c) Calculate the entropy of indicators.

$$e_j = -\frac{1}{\ln n} \sum_{i=1}^{n} p_{ij} \ln\left(p_{ij}\right) \ (j = 1, 2, \dots m)$$

e_j is the entropy of the jth third-level indicator.

d) Calculate the entropy redundancy of indicators.

$$d_j = 1 - e_j$$

d_j is the entropy redundancy of the jth third-level indicator.

e) Determine the relative weights of indicators.

$$w_j = \frac{d_j}{\sum_{j=1}^{m} d_j} \ (j = 1, 2, \dots m)$$

The weight value of third-level indicators are shown above in **Table 13**.

Considering the renewing of the index, data source and weights, it would be invalid to compare directly the scores regarding health emergencies management in 2020 with those in previous years. A linear revising process was applied to modify the results into the same criteria in accordance with the 2018 index system. And if there are further updates of the index system in the future(which will be quite slight to ensure the stability of index system), such revision process will ensure the comparability of results between different years, so that time-series analyses are possible.

The revising procedure is described as follows:

a) Let the original index scores in the present year be s_{20}, the revised score results in the present year be s_{21}, and the revised index scores in the previous year be s_{11}. Make the linear transformation function as:

$$s_{21} = a\, s_{20} + b$$

b) Calculate the average score of the present year in both original and revised standards.

$s_{20,avg}$. is the average of original index scores among provinces in the present year. $s_{21,avg}$ is the corresponding score of $s_{20,avg}$ putting into the old criterion, which could have been obtained in the previous year with the average level of indicators in the present year. For the third-level indicators that were not included in this year's index system, use data from last year as an alternative.

c) Compare and fit the score results s_{11} and s_{20}.

It is assumed that the ranking distributions of provincial indexes are similar in two successive years, so that s_{11} and s_{20} have linear relationship as

$$s_{11} = a' s_{20} + b'$$

$$a \approx a'$$

Fit the results of two years and get the estimated value of a as 0.7839.

d) Calculate the constant b.

$$b = s_{21,avg} - a\, s_{20,avg}$$

e) Finally calculate the revised results s_{21}.

Data

Unless otherwise specified, the most recent version of data available is used in this study.

1. The list of *2021 National Health Cities* is obtained from the website of National Health Commission of the PRC (http://www.nhc.gov.cn/).
2. For data of total cities, population, GDPs, passenger traffic volume, and percentage of medical and health expenditure in government public expenditure, the most recent available version is China Statistical Yearbook 2021[51], which contains the data of every province in 2020.
3. The data on urban population density and area of urban construction land for municipal utilities are based on China Urban and Rural Construction Statistical Yearbook. The most recent available version is China Urban and Rural Construction Statistical Yearbook 2020[52], which contains the data of every province in 2020.
4. The data on the percentage of migrant population are based on the website of Migrant Population Data Platform (http://www.chinaldrk.org.cn/wjw/#/home). The most recent available data are based on the Seventh National Census of China in 2020.
5. The data on the number of port entry personnel are from China's Ports of Entry 2020 Yearbook[52], which contains the data of every province in 2019.
6. The text of provincial normative documents for public health emergencies is taken from the websites of the general office of every provincial government.
7. The data on the percentage of population available to a 4G mobile phone are based on China Information Almanac 2021[53], which contains the data of every province in 2019.

8. The data on the incidence and death rate of category A and B infectious diseases, the number of CDCs, social expenditures, and the other indicators about medical supporting resources are based on China Health Statistics Yearbook 2021[54]. The most recent available version contains the data of every province in 2020, except for social expenditures in 2019.
9. The data on annual gross domestic product of pharmaceutical manufacturing industry are based on 2021 China Industry Statistical Yearbook[55], which contains the data of every province in 2020.
10. The data of percentage of registered volunteers are based on the Website of China Volunteer Service (https://npo.chinavolunteer.cn). The data we use in this study were obtained on 2022-03-09.
11. The data on information release level are based on *Research Report on Data Release of Chinese Provincial Government on COVID-19*[50], which contains the data of every province in the first half of 2020.
12. The data on personal health code failures in 2020 are based on text collected from Weibo(https://weibo.com).
13. The data on COVID-19 cases are collected from the website of DX Doctor COVID-19 Global Pandemic Real-time Report (https://ncov.dxy.cn/ncovh5/view/pneumonia).
14. The data on nucleic acid detection sites were obtained from the network site of National Government Service Platform (https://gjzwfw.www.gov.cn). The data we use in this study were obtained on 2022-03-16.

Caveats

Firstly, in this study, the data of most third-level indicators are based on 2020. But limited by the availability of data, the data of some third-level indicators are based on 2019. The sharp decline of port entry in 2020 has not been shown in the index score.

Secondly, the provincial performance of COVID-19 response is dominated by many complex and dynamic factors. An occasional oversight could result in a significant fluctuation on medical cases. Thus, a higher score can not be equated with lower incidence or death rate. The index reflects the capability of public health system in year scale facing emergencies, and the increasing score implies the performance in adapting and learning from the pandemic.

Future Form of Indicator

An extensional module of dynamic indicators has been made around COVID-19 this year. This attempt provides an extensible pattern for a more consummate index system, in which more dynamic modules could be created and join to the fundamental indicators. Each module expounds a special aspect of concern.

In addition, the time-series analysis has been developed. All the data adopted this year are collected by official government and could be updated in the next years.

Additional Information

This assessment covers all the other 31 provinces of China except Hong Kong, Macau, Taiwan. The index results and rank of provincial comprehensive health emergencies management ability are listed below. The basic index results present regional differences and take the order of North China, East China,

Northeast China, Southwest China, Northwest China, South Central China, from higher to lower. Among all the provinces, Tibet, Zhejiang, Henan, Shanxi and Jiangsu made the largest rise in rankings.
To clarify the major driving force of score improvement, we quantified the increment (or decrement) of average index score caused by third-level indicators (***Figure 28***). The aspects with largest contributions include public health standards, medical informatization, medical hygiene expenditures, selection of National Health Cities, environmental risk of disease control, and public facilities and resources. However, the COVID-19 pandemic also caused an evident strike in the incidence and death rate of infectious diseases. Apart from the improvement in absolute value of indicators, weight change and distribution of indicator values, like the narrowing gap between provinces in some low-score indicators, also contributed to the improvement of the overall scores.

Table 14: Index results and rank of provincial comprehensive health emergencies management ability in 2019 and 2020

Region	Province	Index result (basic in 2020)	Rank (basic in 2020)	Index result (extensional in 2020)	Rank (extensional in 2020)	Index result (2019)	Rank (2019)
North China	Beijing	95.19	1	107.26	1	75.23	1
	Tianjin	74.86	8	85.88	9	61.06	6
	Hebei	72.24	13	78.38	21	57.18	12
	Shanxi	71.44	17	84.34	11	52.86	23
	Inner Mongolia	71.25	18	81.08	16	55.93	16
Northeast China	Liaoning	70.07	20	73.44	29	55.25	19
	Jilin	77.21	6	90.36	5	59.35	9
	Heilongjiang	73.37	11	81.28	15	57.30	11
East China	Shanghai	86.37	2	95.48	3	66.27	2
	Jiangsu	81.94	3	86.04	7	59.51	8
	Zhejiang	79.12	5	85.37	10	55.61	17
	Anhui	70.52	19	78.20	22	56.35	15
	Fujian	67.74	28	76.12	25	49.93	26
	Jiangxi	68.81	24	78.47	20	53.97	21
	Shandong	79.47	4	83.19	12	61.79	5
	Taiwan	——	——	——	——	——	——
South Central China	Henan	72.18	14	79.40	19	53.72	22
	Hubei	68.18	25	75.54	27	55.60	18
	Hunan	65.87	29	71.04	31	48.07	28
	Guangdong	65.35	30	73.28	30	49.84	27
	Guangxi	64.53	31	75.15	28	52.68	24
	Hainan	69.83	21	80.45	18	62.78	4
	Hong Kong	——	——	——	——	——	——
	Macau	——	——	——	——	——	——
Southwest	Chongqing	73	12	87.19	6	56.59	14

China	Sichuan	71.84	15	76.07	26	59.63	7
	Guizhou	69.76	22	82.60	13	54.47	20
	Yunnan	69.69	23	76.89	24	51.47	25
	Tibet	74.59	10	95.61	2	47.49	30
Northwest China	Shaanxi	71.53	16	80.78	17	56.83	13
	Gansu	74.62	9	92.14	4	58.88	10
	Qinghai	68.16	26	81.91	14	47.90	29
	Ningxia	76.17	7	85.94	8	65.06	3
	Xinjiang	67.89	27	78.02	23	42.54	31

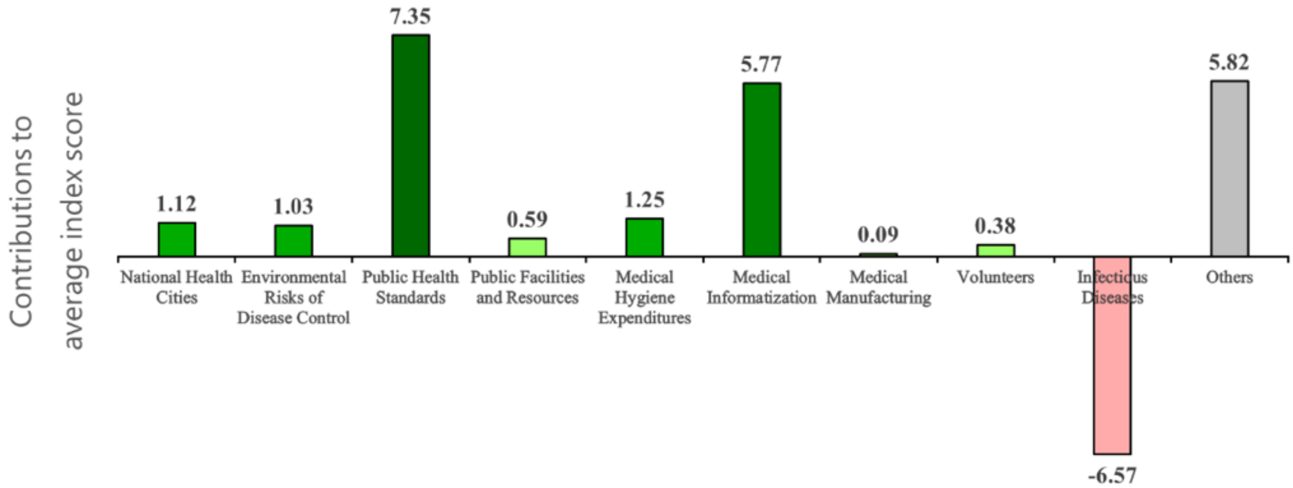


***Figure 28*: The increment (or decrement) of average index score for health emergencies management caused by third-level indicators**

Indicator 2.2.2: Air conditioning - benefits and harms

Methods

The 2020 and 2021 China report of Lancet Countdown calculated the prevented fraction of heatwave-related mortality due to the use of air conditioning. However, the prevented fraction did not provide information on the absolute number of heat-related deaths averted by air conditioning.

The 2022 report overcomes the limitation of the prevented fraction by adopting results from Indicator 1.1.1, and further presents the estimated heat-related deaths prevented by air conditioning in people aged 65 years and older.

The method is kept the same as that in the global Lancet Countdown 2021 report[11]. Firstly, the estimated heat-related deaths in persons aged 65 years and older was taken from Indicator 1.1.1 (Do). Secondly, the number of heat-related deaths in the 65-and-older population in the complete absence of household air conditioning (De) was calculated as:

De=Do/(1-PF)

where PF is the prevented fraction. The formula for PF is consistent with that in the 2020 and 2021 China report of Lancet Countdown, which is shown as:

PF=Pac*(1 – RRac) = Pac*(1 – 0.24) = Pac*(0.76)

where Pac is the proportion of the population having household air conditioning, compared with a scenario of complete absence of household air conditioning; RRac is the relative risk of death during a heatwave or hot weather among persons who have household air conditioning compared with persons who do not have household air conditioning.

Finally, the heat-related deaths prevented by air conditioning in people aged 65 years and older (Da) was estimated as:

Da=De-Do

Data

The International Energy Agency (IEA) provided the proportion of the Chinese population having household air conditioning (Pac), and carbon dioxide emissions by air conditioning in China.

The research group of Indicator 1.1.1 kindly provided the estimated heat-related deaths in persons aged 65 years and older in China (Do).

Caveats

1. The PF calculation was based on the RRac, whose value may vary among different countries. However, the specific estimate of RRac in China is absent. In this study, we assumed RRac to be 0.24 from a meta-analysis in five countries (the United States, France, Italy, Greece and Australia).

2. This indicator focused on the target population ⩾ 65 years. In the De calculation, the PF should be the prevented fraction in the 65-and-older population. However, the Pac and RRac used for the PF calculation were from the general population. It is possible that Pac and RRac differ between persons ⩾ 65 years of age and younger persons.

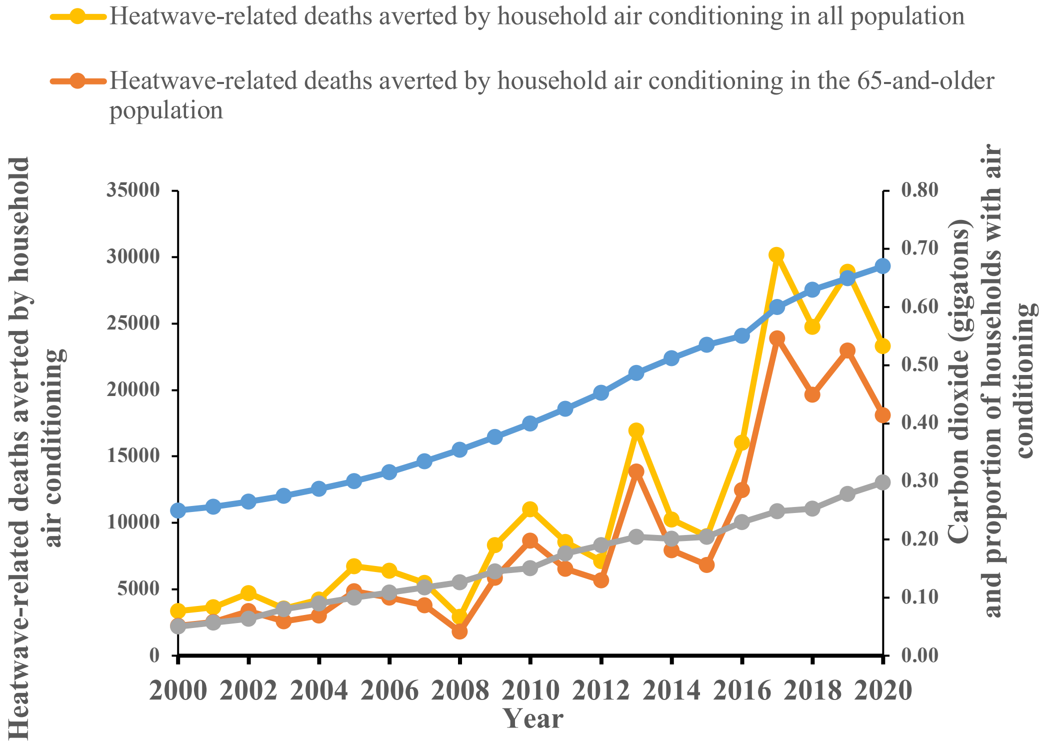


Figure 29: Heatwave-related deaths averted by air conditioning and carbon dioxide emissions from air conditioning in China

Indicator 2.2.3: Urban green space

Methods

The urban green space indicator considers green space changes measured through remote sensing satellite images, taking into account urban boundaries and population density. Normalized Difference Vegetation Index (NDVI), the most commonly used metrics to monitor vegetation, is calculated as the ratio between the difference in the surface reflectance intensities of the red (around 0.66 μm) and infrared radiation (around 0.86 μm) divided by the sum of their intensities. NDVI is associated with the fraction of solar radiation absorbed by plants during photosynthesis. NDVI value is between -1 and 1, a large positive NDVI value is typically associated with a high density of green vegetation and thus indicates a higher greenness level. We used NDVI images from the Moderate Resolution Imaging Spectroradiometer (MODIS) sensor at a 250-meter resolution to estimate the urban green space level. MOD13Q1 data is processed in 16-day periods by compiling the best available pixel value over the 16 days. We used cloud masks to remove cloud pixels to retain the best-quality information about vegetation. All MOD13Q1 images from the year 2011 to 2021 were acquired. For each year, one NDVI median layer was computed from the MODIS NDVI time series stack to represent the average greenness condition by finding the median value of the time series profile on a pixel basis. Using median value instead of the mean is to remove the potential outliers. To estimate the effects of greenness on communities, population-weighted NDVI for each province was calculated as

$$\frac{\sum_{i=1}^{n}(NDVI_i \times Pop_i)}{\sum_{i=1}^{n} Pop_i} \qquad (1)$$

where n is the number of pixels in urban area with valid NDVI data in a province. We used population-weighted NDVI to measure urban greenness and its trend in the past decade. We used linear regression to calculate the annual population-weighted NDVI from 2011 to 2021 for each province. If the coefficient of the slope was positive or negative and its p value was less than 0.05, the green space in the province was defined as having a significant increase or decrease trend. If the p value was larger than 0.05, the green space was defined as having no significant change.

For a more effective indication of provinces' greenness levels, we categorized NDVI values using the following table:

Table 15: Categorization of greenness level by NDVI value[20]:

Greenness level	Categorization	NDVI range
Exceptionally low	1	<0.19
Very low	2	0.2-0.29
Low	3	0.3-0.39
Moderate	4	0.4-0.49
High	5	0.5-0.59
Very high	6	0.6-0.69
Exceptionally high	7	0.7-0.79

Mortality attributable to NDVI change M is expressed as

$$M = y_0 \times Pop \times AF \qquad (2)$$

where y_0 is the province-level annual non-injury mortality rate, Pop is the population size and AF is the attributable fraction of NDVI difference between 2011 and 2021.

AF is calculated via the relative risk (RR), which represents the decrease of risk of mortality resulting from the NDVI difference. AF is calculated as

$$AF = \frac{RR-1}{RR} \qquad (3)$$

According to a limited literature review [56], a 0,1-unit increase of NDVI could reduce mortality risk by 4%, i.e. $RR_{0.1-unit-increase} = 0.96$ [95% CI $0.94 - 0.97$]. Therefore, RR of NDVI difference between 2011 and 2021 is calculated as

$$RR_{diff} = {RR_{0.1-unit-increase}}^{diff/0.1} \qquad (4)$$

Where $diff$ is NDVI in 2021 subtracted by NDVI in 2011. This method was applied to the NDVI and population layers, and mortality attributable to NDVI change was summed up by province.

Data

1. MODIS NDVI products were obtained from MOD13Q1 V6 Terra VI 16-day global 250m. [57]

2. City boundaries were collected from the Global Rural-Urban Mapping Project (GRUMP) urban extent polygons.[58,59]

3. Population data in 2011-2020 was acquired from Population data from the NASA Socioeconomic Data and Applications Center (SEDAC) Gridded Population of the World (GPWv4) and The Inter-Sectoral Impact Model Intercomparison Project (ISIMIP) Histsoc dataset. Population in Taiwan and Macao were unavailable. Since the latest data is by 2020, results in 2021 was calculated using population data in 2020. [60-62]

4. Province-level mortality rate was obtained from national or provincial annual statistics. In Tianjin, Liaoning, Sichuan, Anhui, Hainan, Ningxia, and Xizang, the latest data available was in 2019; in Jilin and Hongkong, the latest mortality rate data was in 2020; for other areas, the mortality rate in 2011 was used.

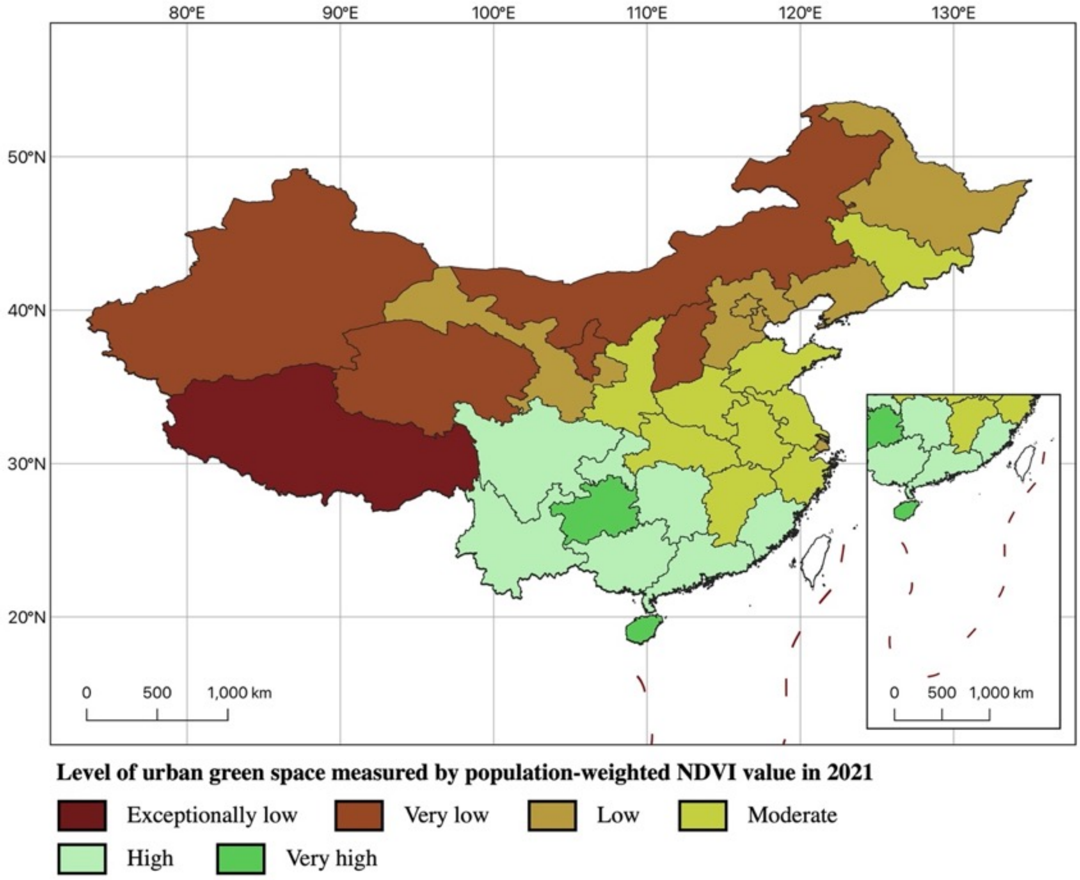
Caveats

NDVI is a continuous indicator varying from -1 to 1, and provides information for each pixel on the landscape, including non-vegetated lands (e.g., impervious surfaces, water, and snow). We did not exclude the non-vegetated areas for calculating province-level NDVI considering several reasons given by previous research. [19] It was suggested that taking the median value of annual NDVI data and its trend over decade can reflect the changes in vegetation. The quantity of green space, as measured by NDVI, does not reflect the quality of green space.

The future form of the indicator

1. Future forms of green space will include indicators on quality of green space, by utilizing existing databases on street view, and other remote sensing techniques.
2. Considering city expansion, rapid urbanization and peri-urbanization, there may be opposite trends of green space on the outskirts versus inner city. We need to take green space inequality into account.
3. We aim to use higher resolution of population data and green space data in future indicators, so that we can generate more precise estimates of green space changes.

Additional information


80°E
90°E
100°E
110°E
120°E
130°E
50°N
40°N
30°N
20°N
0 500 1,000 km
0 500 1,000 km
Level of urban green space measured by population-weighted NDVI value in 2021
Exceptionally low
Very low
Low
Moderate
High
Very high

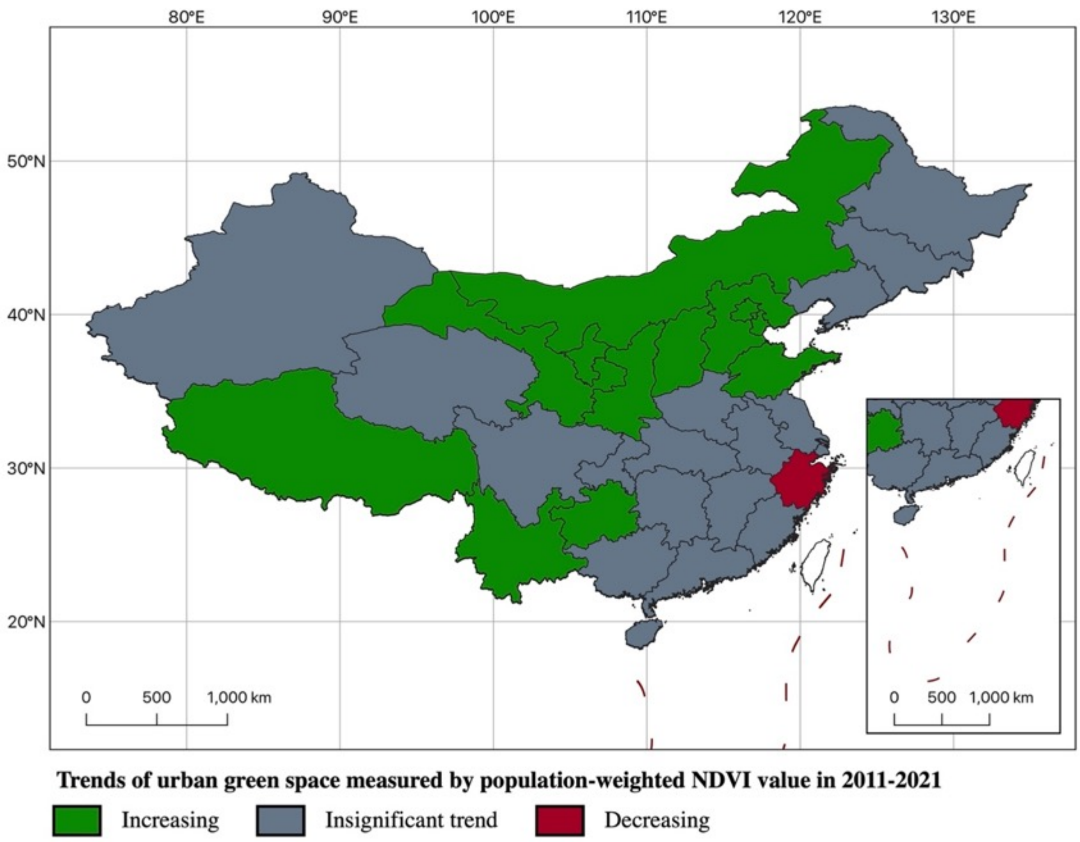

80°E
90°E
100°E
110°E
120°E
130°E
50°N
40°N
30°N
20°N
0 500 1,000 km
0 500 1,000 km
Trends of urban green space measured by population-weighted NDVI value in 2011-2021
Increasing
Insignificant trend
Decreasing

Figure 30: Level of urban green space measured by population-weighted NDVI in 2021 (up) and change between 2011 and 2021 (down)

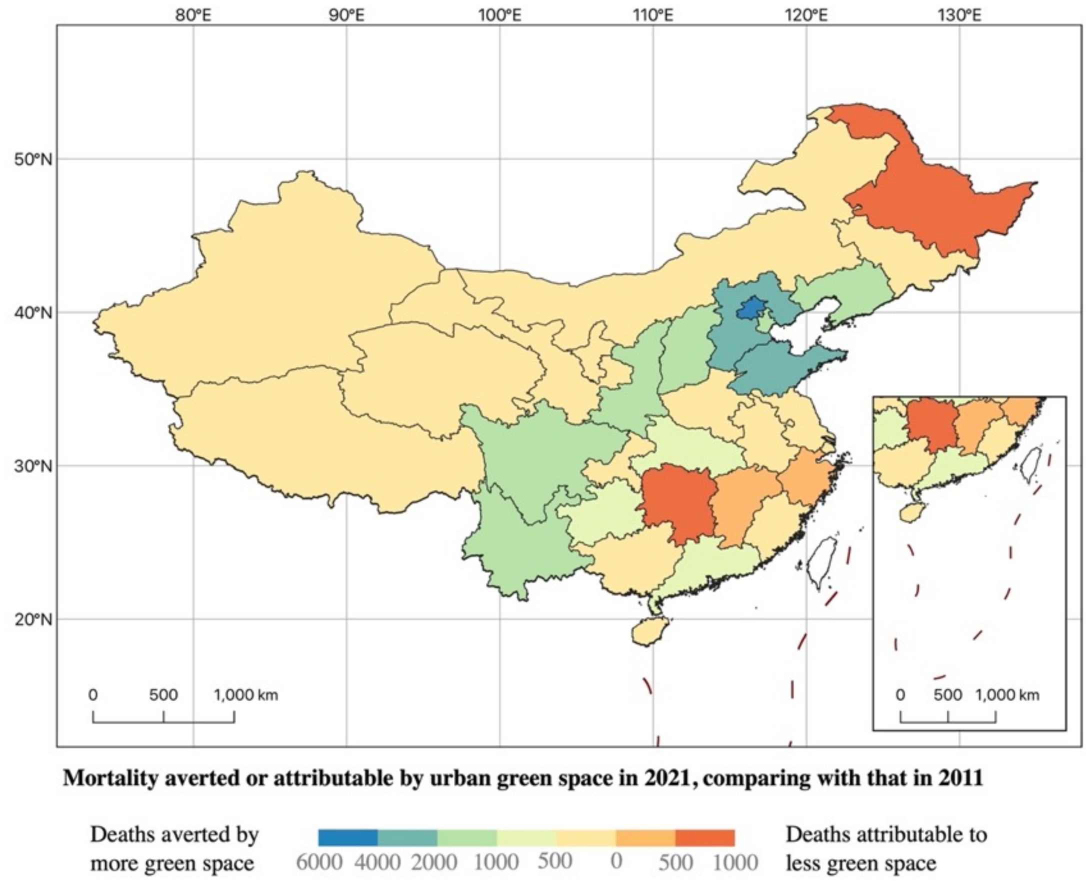


Figure 31: Mortality change related to urban green space between 2011 and 2021.

Indicator 2.3: Climate information services for health

Methods

This indicator includes two sub-indicators. The first tracks in which provinces provincial meteorological departments provide climate and weather information or products to the public health sector, and the second tracks in which provinces meteorological departments and public health departments have signed collaboration agreements.

The annual survey targeting provincial meteorological departments, mentioned in indicator 2.1.2, covers questions for the two sub-indicators. Detailed information on the response rate can be found in indicator 2.1.2. The question for the first sub-indicator was included in the 2021 survey. The responses to the question in the 2022 survey track the progress of the sub-indicator. The question for the second sub-indicator was new in the 2022 survey.

Meanwhile, governmental news releases on collaboration between local meteorological departments and public health departments or organizations were searched for in the Baidu search engine. The author team selected a set of keywords and created search queries to cover meteorological bureaus and health-related departments or organizations in China, define the scope to collaboration, and limit the source to governmental websites. Health-related departments or organizations include health commissions, centers for disease control and prevention, medical colleges, hospitals, etc. Only collaborations involving meteorological information were included. Hence, collaborations for releasing COVID-19 warnings via the emergency early warning release system operated by meteorological bureaus were not included. Queries and keywords used are shown in Table 16. There were two rounds of searching. The first round was conducted by using the queries. The second round was specifically for provinces without explicit findings in the first round searching.

Table 16 Queries and keywords used for searching for official news posted online on collaboration between meteorological bureaus and public health-related governmental departments

Query	Source	Meteorology	Health	Collaboration
1	site:(gov.cn)	"气象"	(卫生 ｜ 健康 ｜ 卫健 ｜ 疾病 ｜ 疾控)	(合作 ｜ 协议)
2	inurl:cdc	"气象"	(卫生 ｜ 健康 ｜ 卫健 ｜ 疾病 ｜ 疾控)	(合作 ｜ 协议)

Data

1. Annual Provincial Survey on Climate Change Assessment and Information Services
2. Baidu

Caveats

Please see the caveats of the annual survey mentioned in indicator 2.1.2.

Searching results on Baidu only include related information posted on official websites of governmental departments in China. News on non-governmental websites and information not posted online were not covered, which could make the results biased.

Future Form of Indicator

Information on improvement in the annual survey can be found in indicator 2.1.2.

Headline finding: In 2021, in most provinces, meteorological data were provided to the public health sector, and in over one third of provinces, meteorological bureaus *collaborated with local health departments or organizations for climate information services for health.*

Meteorological information supports decision-making for climate change health adaptation. The results of the annual surveys of provinces' meteorological departments show that out of 31 provinces, there have been 27 provinces providing meteorological data to the public health sector. More important than data sharing, inter-agency collaborations drive climate information services for health open to the public. According to the news releases, in 21 provinces, province-, city-, or county-level meteorological bureaus have collaborated or signed collaboration agreements with local health-related departments or organizations for providing climate information services for health.

Additional information

Based on the survey results, the 27 provinces whose meteorological departments provided meteorological data to the public health sector included Anhui, Beijing, Chongqing, Fujian, Gansu, Guangdong, Guangxi, Guizhou, Hainan, Hebei, Heilongjiang, Henan, Hebei, Hunan, Inner Mongolia, Jiangxi, Liaoning, Ningxia, Qinghai, Shandong, Shanghai, Shanxi, Tianjin, Tibet, Xinjiang, Yunnan, and Zhejiang.

The 21 provinces with meteorology-health collaborations included Anhui, Beijing, Guangdong, Guangxi, Hainan, Hebei, Heilongjiang, Henan, Hubei, Hunan, Jiangsu, Jiangxi, Liaoning, Inner Mongolia, Shaanxi, Shanghai, Sichuan, Tianjin, Xinjiang, Yunnan, and Zhejiang.

Section 3: Mitigation actions and health co-benefits

Indicator 3.1: Energy system and health

Indicator 3.1.1: Carbon intensity of the energy system

Carbon intensity of China and six regions in China, supplemented with additional statistics for China CO_2 emissions from energy combustion.

Methods

This indicator contains two components:

1. Carbon intensity (CI) of the energy system, at national (2000-2021) scales, in kgCO_2/US$.
2. China national CO_2 emissions from energy combustion by fuel and industrial process (mainly cement), in MtCO_2 (2000-2021).

The technical definition of CI is the kilogram (kg) of CO_2 emitted for each unit (US$) of Gross Domestic Product (GDP). The rationale for the indicator choice is that carbon intensity of the economic system will provide information on the level of fossil fuel use, which has associated air pollution impacts. Higher intensity values indicate a more fossil dominated economic system, and one that is likely to have a higher coal share. As countries pursue climate mitigation goals, the carbon intensity is likely to reduce with benefits for air pollution. The indicator is calculated based on total CO_2 emissions from fossil fuel divided by GDP. GDP reflects the economic development status in an area/country.

The national CO_2 from 2000-2019 is from the World Bank[9,63-67]. The national CO_2 emissions from 2020 to 2021 is from the Carbon Monitor (https://carbonmonitor.org/). The calculation of CI is represented as below:

$$CI_t = CO2_t / GDP_t$$

Where *t* represents year; $CO2_t$ denotes CO_2 emission in *t*; GDP_t represents the GDP in *t* which is adjusted by the constant price in 2020 and the present GDP value and GDP index in t, which are collected from China Statistical Yearbook[67].

The sectoral approach is applied to calculate carbon emissions in this study and compared to the reference approach, carbon emissions calculated by the sectoral approach are 1% to 7% lower and these results are more accurate[64]. The sectoral approach can be generally formulated as:

$$CE_i = AD_i \times EF_i$$

Where CE_i refers to CO_2 emissions from type i included in types of fossil fuels and cement, AD_i refers to the activity data of the type i, and EF_i refers to the emission factor of the type i.

Data

1. Energy balance tables are taken from China Energy Statistical Yearbook 2001-2020[67];
2. The national CO_2 from 2000-2019 is from the World Bank;
3. The daily CO_2 emissions of China in 2020 and 2021 is taken from the Carbon Monitor (https://carbonmonitor.org/).

Caveats

Due to a lack of latest data from Chinese Energy statistical data for 2020 and 2021, in our paper, national carbon emissions of 2020 and 2021 is from the Carbon Monitor (https://carbonmonitor.org/), which is based on assumption of changes of social and economic activities, which can create bias from the real emissions.

Future Form of Indicator

This indicator for the national level and provinces will need to be updated to provide the data for the most recent years.

Additional Information

Indicator 3.1.2: Energy system and health - Coal phase-out

Methods

Two indicators are used here: (1) Total primary energy supply from coal in China and by province (in EJ units); and (2) share of coal in total primary energy supply.

The indicator on primary energy coal supply is an aggregation of all coal types used across all sectors from annual editions of Energy Statistical Yearbook of China. The data is available for the period 2000-2021 at the national level, and for the period 2000-2019 for each province. [68]

Data

The data for this indicator is taken from annual edition of Energy Statistical Yearbook of China. [68]

Caveats

These indicators provide a proxy for air quality emissions associated with the combustion of coal. Further work is required to convert coal use by sector and type into emissions of different air quality pollutants.

Future Form of Indicator

In the future, this indicator set could be developed to also estimate the actual air pollutant emissions associated with coal use. This will require sectoral use, coal type (both of which are available) and appropriate emission factors.

Additional Information

Table 17:Coal consumption by province, 2010-2019

Unit: PJ

Province	2015	2016	2017	2018	2019
Beijing	243.9	177.4	102.7	57.8	38.3
Tianjin	950.1	885.5	811.3	802.3	788.4
Hebei	6058.7	5883.4	5739.3	6194.9	6015.9
Shanxi	7769.4	7456.6	8989.2	10244.8	10745.4
Inner Mongolia	7640.6	7677.3	8079.3	9239.6	10264.8
Liaoning	3629.1	3546.9	3681.6	3748.0	3916.8
Jilin	2052.6	1971.3	1958.2	1790.5	1827.6
Heilongjiang	2811.9	2937.9	3028.8	2799.0	2960.5
Shanghai	989.8	968.3	958.3	925.4	887.2
Jiangsu	5695.8	5871.4	5572.4	5318.6	5212.8
Zhejiang	2894.2	2919.9	2985.5	2968.4	2863.0
Anhui	3280.5	3292.5	3367	3490.2	3495.8
Fujian	1603.5	1429	1579	1791.6	1825.0
Jiangxi	1611.5	1594.6	1624.7	1649.1	1673.8
Shandong	8567.3	8569.9	7989.1	8858.9	9029.1
Henan	4965.4	4862.1	4745.4	4675.0	4196.2
Hubei	2463	2446.2	2465.3	2323.6	2463.5
Hunan	2332.4	2395.5	2596.7	2286.4	2232.3
Guangdong	3472.3	3377.6	3594.7	3572.8	3523.9
Guangxi	1265.8	1364.4	1384.4	1536.5	1679.2
Hainan	224.4	212.5	230.1	243.4	236.6
Chongqing	1265.9	1187.8	1182	1073.8	1051.5
Sichuan	1944.5	1856.7	1644.5	1569.1	1614.7

Guizhou	2686.5	2855.9	2807.1	2513.7	2554.7
Yunnan	1614.6	1561.9	1509.6	1549.6	1576.8
Shaanxi	3846.2	4117.7	4201.2	4060.2	4510.9
Gansu	1372.6	1335	1331.5	1427.4	1425.6
Qinghai	315.7	410.8	365.7	343.2	322.8
Ningxia	1864.6	1813.9	2314.8	2660.9	2872.9
Xinjiang	3633.9	3974.2	4264.1	4561.4	4961.6

Note: (1) data for Tibet is not available. (2) Due to statistical difference, provincial sum does not equal to national total.

Although overall coal share in China's energy mix continued to decline, national coal use increased by 4.6% from 2020 to 2021[69], a highest annual growth rate since 2011, setting a historical record. From a regional perspective, Jing-Jin-Ji area and Eastern coastal provinces cut their coal use substantially in recent years partially due to strict air quality regulations, while a continuous increase was observed in Shanxi and Inner Mongolia, two provinces with abundant coal resources, and Northwestern provinces, i.e. Shaanxi, Ningxia and Xinjiang.

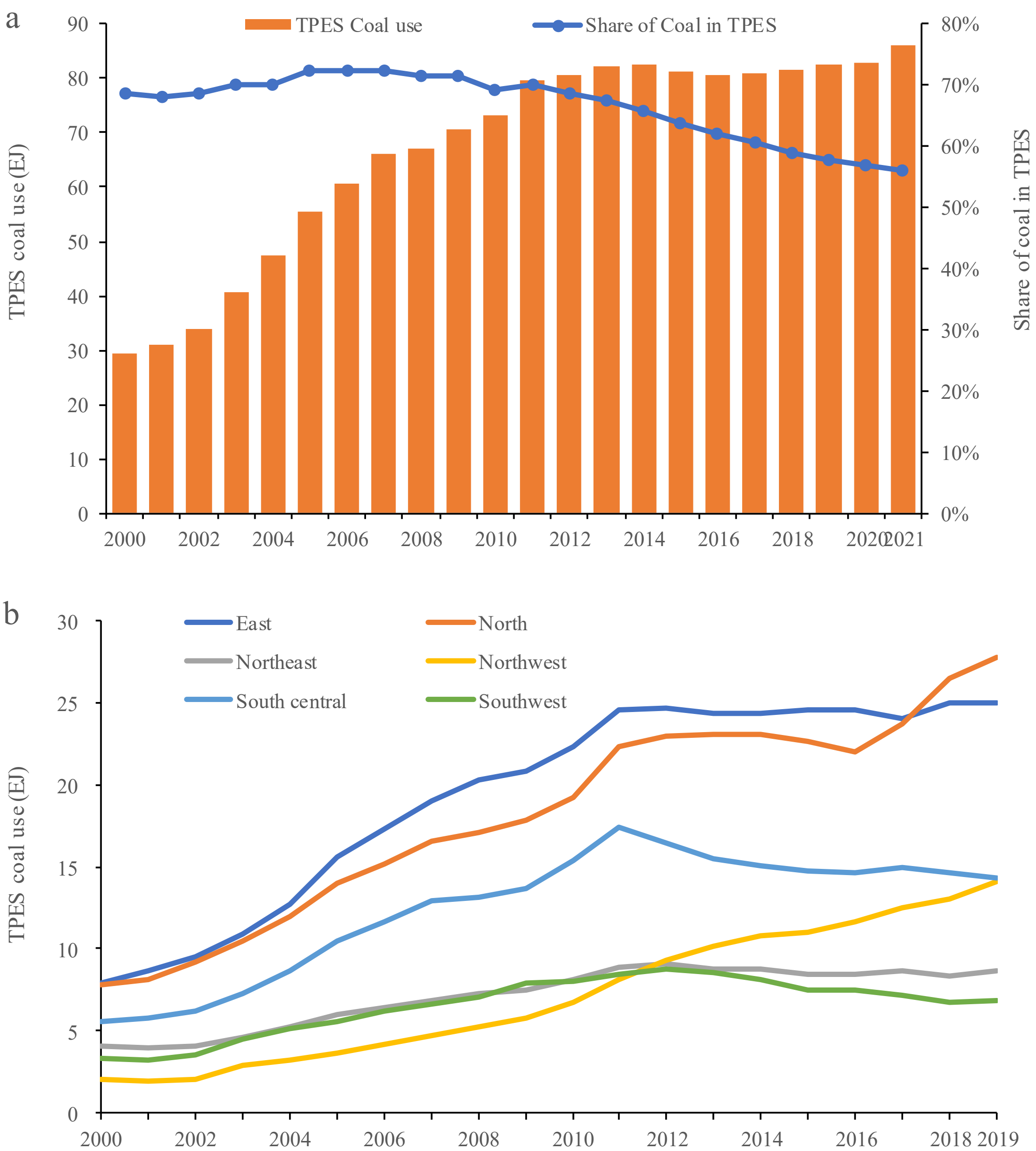


***Figure* 32: National and regional Total Primary Energy Supply (TPES) from coal. (A) TPES from coal and the proportion in TPES in China (2000-2021); (B) TPES from coal in six regions (2000-2019).**

Indicator 3.1.3: Low-carbon emission electricity

1. Total low carbon electricity generation(solar, hydro, wind and nuclear), in absolute terms (TWh) and as a percentage share of total electricity generated;

2. Total renewable generation (solar, hydro and wind), in TWh, and as a percentage share of total electricity generated.

Methods

Two indicators are used here, and presented in two ways:

1. Total low carbon electricity generation, in absolute terms (TWh) and as a percentage share of total electricity generated (to include solar, wind and nuclear and hydropower); and

2. Total renewable generation (include solar, wind and hydropower), in TWh, and as a percentage share of total electricity generated.

The increase in the use of low carbon and renewable energy for electricity generation will push other fossil fuels, such as coal, out of the mix over time, resulting in an improvement in air quality, with benefits to health. The indicator of renewable electricity has been used to allow for the racking of rapidly emergent renewable technologies. For both indicators, electricity generation, rather than capacity, has been chosen as a metric as the electricity generated from these technologies is what actually displaces fossil-based generation.

The absolute level indicators are total gross generated electricity aggregated from the relevant technologies. The share indicators are estimated as the low carbon or renewable generation as a percentage of total generation.

Data

The annual data of electricity by technology from 2010 to 2019 was from the China Energy Statistical Yearbook (2011-2020)[70]. Data of electricity by technology in 2020 and 2021 was from China electricity Council[71] and China Energy Statistical Yearbook (2021)[68]

Caveats

1. Solar, wind and nuclear generation were only recorded since 2015 by the National Bureau Statistics of China.

2. This indicator set does not provide information on the air pollutant emissions displaced due to the increasing share of renewable generation.

Future Form of Indicator

Detailed data of provinces should be updated to get the accurate regional results.

Additional Information

The hydropower accounted for a large share of low-carbon and renewable electricity from 2010 to 2014, the only low-carbon electricity in China is hydropowerr. From 2015 to 2021, the share of hydropower in low-carbon electricity was ranging from 74.1% to 49.1% in a descending trend, showing other sourced power are on the rising trend, especially the share of solar power in the low-carbon electricity increasing over 4 times, from 2.5% in 2015 to 12% in 2021. And the share of wind power in the low-carbon electricity had increased nearly 2 times, from 12.2 % in 2015 to 24% in 2021. The share of nuclear power was on the rise trend, increasing from 2.9% in 2015 to 4.9% in 2021 of the total power generation.

In 2021, renewable energy increased by 11.5 % while hydropower decreased by 1.1% compared to 2020. But, in 2021, the hydropower in Northeast, East, and Southwest region increased by 8.4%, 2% and 2%, respectively in 2021 and in North, South central, and Northwest region decreased by 8.4%, 6% and 9.8%, respectively. The Southern region (i.e. Southwest and South central) generated more hydropower than Northern provinces. The percentage of hydropower in South central and Southwest was around 24.4%

and 65.7% on average during 2010 and 2021. It is mainly because there are more rivers, better favorable and preferable terrain and a more humid climate in the Southern area of China than the Northern area. However, it should be noted that in Northwest China, its hydropower is also abundant, 16.2% on average of the total power generation from 2010 to 2021, comparing to 0.9%, 6.7% and 4.5% in North, Northeast and East region

The share of renewable energy in the Southwest region was higher than the national average level due to its dominant share of hydropower. There were 68.1%, 4.5% and 2.1% from hydropower, wind and solar generation, respectively in 2021 in the Southwest region. Since 2019, the share of renewable energy in the South-central region was below the national average due to the descending share of hydropower, but since 2017, the share of renewable energy in the Northwest region had started to be beyond the national average due to the rapid increase of wind and solar power although the decreasing share of hydropower. From 2017 to 2021, the wind and solar power had increasing by 1.2 and 1.9 times, respectively.

In 2021, the wind power increased predominately by 40.5% and South central increased 72% of wind power. Northeast China provided the largest output of wind power in 2021, taking up 23.5% and Inner Mongolia ranked the largest among provinces. Solar power continued to increase in 2021, it increased by 25.5%, 22.9%, 19%, 31%, 42.8% and 24.4% in North, Northeast, East, South central, Southwest, and Northwest region. Northwest China is the area that provides the most solar power in China, accounting for 36.1% of the total solar energy in China in 2021, due to the proper and suitable natural environment for solar generation. Among 31 provinces of China, Qinghai Province produced the most solar power, 3 TWh in 2021. Generally, The Northwest China generate the most wind and solar power in China in 2021 among six regions.

The detailed data of different sources of electricity generation in China and the other six regions see Table 18 to Table 24.

Table 18 : Different sources of electricity generation in China (TWh)

Year	Hydropower	Nuclear	Wind	Solar	Thermal power	Low carbon generation	Renewable generation	Total generation
2010	7221.7	0	0	0	33319.3	7221.7	7221.7	40541
2011	6989.5	0	0	0	3833	6989.5	6989.5	45326.5
2012	8721.1	0	0	0	38928.1	8721.1	8721.1	47649.2
2013	9202.9	0	0	0	42470.1	9202.9	9202.9	51673
2014	10728.9	0	0	0	44001.1	10728.9	10728.9	54730
2015	11302.7	1707.9	1857.7	387.8	42841.9	15256.1	13548.2	58098
2016	11840.5	2132.9	2370.7	615.9	44370.7	16959.9	14827	61330.6
2017	11978.6	2480.7	2972.3	1063.4	47546	18495	16014.3	66041
2018	12317.9	2943.6	3659.7	1775.2	50963.2	20696.4	17752.8	71659.6
2019	13044.4	3483.5	4060.3	2244.3	52201.5	22832.5	19314	75034
2020	13550.1	3662	4667.1	2612	51742	24491.2	20829	76261
2021	13401	4075	6556	3270	56463	27302	23227	83765

Table 19 : Different sources of electricity generation in North China (TWh)

Year	Hydropo	Nuclea	Wind	Solar	Therma	Low	Renewa	Total

	wer	r			l power	carbon generation	ble generation	generation
2010	46.6	0	0	0	4851.7	46.6	46.6	4898.3
2011	46.4	0	0	0	5391.4	46.4	46.4	5437.8
2012	52.9	0	0	0	557.3	52.9	52.9	5625.9
2013	54.7	0	0	0	5832.3	54.7	54.7	5887
2014	51.1	0	0	0	5924.1	51.1	51.1	5975.1
2015	46	0	280.8	13.3	56485	340.1	340.1	5988.6
2016	72.1	0	338.7	42.2	5764.6	453	453	6217.6
2017	69.3	0	423.3	127.5	6259	620	620	6879.1
2018	63.8	0	506.3	231.7	6806	801.8	801.8	7607.8
2019	75.8	0	556.2	324	6900.4	956	956	7856.4
2020	62.2	0	637.5	362	6671.6	1061.7	1061.7	7733.3
2021	57	0	960	454.4	6845.6	1471.4	1471.4	8317

Table 20 : Different sources of electricity generation in Northeast China (TWh)

Year	Hydropower	Nuclear	Wind	Solar	Thermal power	Low carbon generation	Renewable generation	Total generation
2010	188.3	0	0	0	4614.2	188.3	188.3	4802.5
2011	123.8	0	0	0	5262.9	123.8	123.8	5386.8
2012	138	0	0	0	5493.1	138	138	5631.2
2013	229.9	0	0	0	5840.1	229.9	229.9	6069.9
2014	171.9	0	0	0	6336.1	171.9	171.9	658
2015	144	144.7	657.1	59.2	6172.7	1004.9	860.2	7177.6
2016	173.8	199.8	757.4	8	6170.2	1219	1019.2	7389.2
2017	134.9	236	871	130.7	6598.9	1372.6	1136.6	7971.5
2018	159.7	301.6	1025.5	205.6	7171.4	1692.4	1390.8	8863.8
2019	196.1	327.3	1103.5	277.2	7722.1	1904.1	1576.8	9626.2
2020	201.2	322	1203.8	348.2	7689.8	2075.2	1753.2	9765
2021	218.2	405.9	1538	428	7828.6	2590.1	2184.2	10418.8

Table 21 : Different sources of electricity generation in East China (TWh)

Year	Hydropower	Nuclear	Wind	Solar	Thermal power	Low carbon generation	Renewable generation	Total generation
2010	826.4	0	0	0	11966.2	826.4	826.4	12792.5
2011	548.7	0	0	0	13491.1	548.7	548.7	14039.7
2012	806.9	0	0	0	13539.8	806.9	806.9	14346.7

2013	753.6	0	0	0	14864.4	753.6	753.6	15618
2014	826.1	0	0	0	15787.6	826.1	826.1	16613.7
2015	941.6	952.4	260.2	59.2	15563.3	2213.4	1261	17776.7
2016	1211.8	1066.5	370	129	16611.9	2777.2	1710.7	19389.1
2017	913.5	1243.4	462.7	248.9	17881	2868.4	1625	20749.4
2018	743.2	1511.5	598	531.8	18527.8	3384.4	1872.9	21912.1
2019	953.8	1785.8	643.9	644.2	18236.3	4027.7	2241.9	22264
2020	556.9	1924.6	722.2	508.6	17943.7	3712.4	1787.8	21656.1
2021	567.9	2203.2	1161	605.1	19533.4	4537.3	2334.1	24070.7

Table 22 : Different sources of electricity generation in South Central China (TWh)

Year	**Hydropower**	**Nuclear**	**Wind**	**Solar**	**Thermal power**	**Low carbon generation**	**Renewable generation**	**Total generation**
2010	2695.5	0	0	0	6737.5	2695.5	2695.5	9433
2011	2485.4	0	0	0	8059.9	2485.4	2485.4	10545.3
2012	3079	0	0	0	7784.3	3079	3079	10863.2
2013	2726.5	0	0	0	8553.1	2726.5	2726.5	11279.6
2014	3121	0	0	0	8279	3121	3121	11400
2015	3208.6	610.9	126.5	6.8	7920.2	3952.7	3341.9	11873
2016	3244.6	866.6	165.7	32.5	8012	4309.4	3442.9	12321.4
2017	3232.7	1001.3	217	88	8565.6	4538.9	3537.6	13104.5
2018	3125.8	1130.5	291.9	206.3	9436.1	4754.5	3624	14190.7
2019	3047.7	1370.5	373.9	265.3	9590.9	5057.3	3686.9	14648.2
2020	3164.8	1415.3	481.8	264.4	9345	5326.4	3911	14671.3
2021	2974.9	1465.9	828.5	346.5	10883.8	5615.9	4150	16499.7

Table 23 : Different sources of electricity generation in Southwest China (TWh)

Year	Hydropower	Nuclear	Wind	Solar	Thermal power	Low carbon generation	Renewable generation	Total generation
2010	2629.2	0	0	0	2423.1	2629.2	2629.2	5052.3
2011	2931.3	0	0	0	2567.6	2931.3	2931.3	5498.9
2012	3646.5	0	0	0	2451.5	3646.5	3646.5	6098
2013	4333.2	0	0	0	2750.5	4333.2	4333.2	7083.7
2014	5513.1	0	0	0	2477.6	5513.1	5513.1	7990.7
2015	5903.4	0	143.6	9.4	2164.4	6056.4	6056.4	8220.7
2016	6159.9	0	233	30.9	2201.3	6423.8	6423.8	8625.1
2017	6549.8	0	302.3	56.7	2220.3	6908.9	6908.9	9129.2
2018	6888	0	351.5	83.7	2513.7	7323.2	7323.2	9836.9
2019	7252	0	405.8	112	2723.1	7769.8	7769.8	10492.9
2020	8054.2	0	458.7	177.9	2725	8690.7	8690.7	11415.8

2021	8217.3	0	545.9	254	3051.2	9017.2	9017.2	12068.4

Table 24 : Different sources of electricity generation in Northwest China (TWh)

Year	Hydropower	Nuclear	Wind	Solar	Thermal power	Low carbon generation	Renewable generation	Total generation
2010	835.8	0	0	0	2726.6	835.8	835.8	3562.4
2011	853.8	0	0	0	3564.2	853.8	853.8	4418
2012	997.8	0	0	0	4086.5	997.8	997.8	5084.3
2013	1105.1	0	0	0	4629.7	1105.1	1105.1	5734.7
2014	1045.7	0	0	0	5196.9	1045.7	1045.7	6242.6
2015	1059.2	0	389.5	240	5372.8	1688.7	1688.7	7061.4
2016	978.3	0	505.9	293.3	5610.8	1777.5	1777.5	7388.2
2017	1078.4	0	696.1	411.7	6021.1	2186.2	2186.2	8207.3
2018	1337.5	0	886.5	516.2	6508.2	2740.1	2740.1	9248.3
2019	1519	0	977.1	621.5	7028.7	3117.6	3117.6	10107.7
2020	1513.8	0	1522.6	949.8	7394.9	3624.5	3624.5	11019.4
2021	1365.6	0	1522.6	1181.9	8320.3	4070.2	4070.2	12390.5

The total power generation increased by a larger rate in 2021 (9.8%) relative to 2020 (4.1%), primarily due to the rapid increase of thermal power in 2021 (9.1%), over 10 times than 2020 (0.8%)[71-73].

The trend of low-carbon electricity in China and six regions are generally on the rise, from 2015 to 2020, with an average annual increase rate of 9.9% nationally (**Error! Reference source not found.**A)[71-73]. In 2021, the increase rate of low-carbon electricity was 11.5%, compared to 7.4% in 2020 and 10.2% in 2019, making its share as 32.6% in 2021, increased 0.5 percent compared to 2020 and 1.5 percent compared to 2019[72-74]. In 2021, renewable electricity also increased by 11.5%, which was 1.5 times than the increase rate of 2020 (7.8%), making its share in the total power generation as 27.7% in 2021[71-73].

In 2021, the increase of wind power generation made a large stride, soaring by 40.5%, compared to 15.1% in 2020. The solar (3.9% of the total generation) and nuclear power (4.9%) generation continued to increase ; solar power still kept an unprecedented rate with 25.2% and nuclear power increased by 11.3% in 2021[71-73]. However, hydropower decreased by 1.1% than 2020. The renewable electricity in the North, Northeast, East, South central, Southwest, and Northwest region in 2021 increased by 38.6% (due to the rapid increase (50.6%) of wind power in 2021), 24.6%, 30.6%, 6.1%, 3.8% and 12.3%, respectively than 2020 (Figure 33). The Southwest region had the largest share of low-carbon electricity (68.1%) owing to the predominant share of hydropower (66.8%) but it had the least share of renewable electricity yet the growth rate of solar power (42.8% in 2021) ranked the top among six regions.

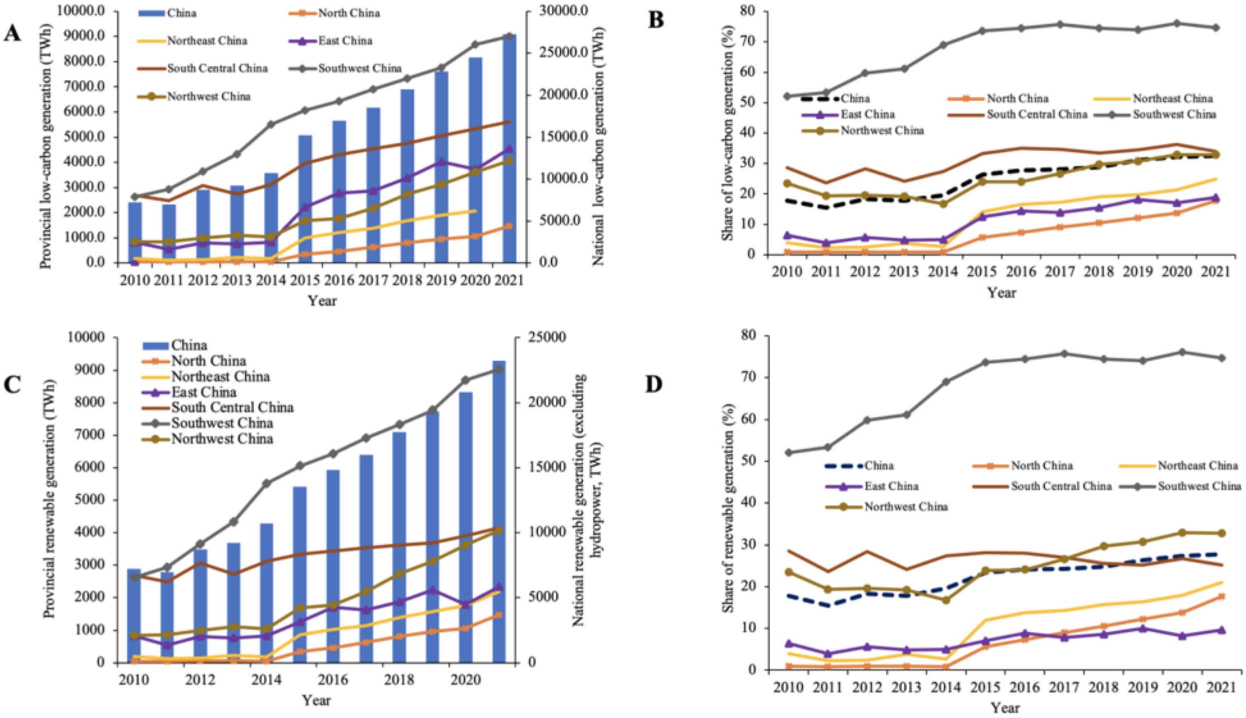


Figure 33: **Renewable and low-carbon emission electricity generation**

(A) Electricity generated from low-carbon sources. (B) Share of electricity generated from low-carbon sources. (C) Electricity generated from renewable sources (excluding hydropower). (D) Share of electricity generated from renewable sources (excluding hydropower). TWh=terawatt hour

Indicator 3.2: Clean household energy

Methods

This indicator is modelled with household investigation data compiled by National Bureau of Statistics and Institute for Health Metrics and Evaluation[75]. The statistical analysis was used as the major method.

Compared to the methods used in the 2021 Report, the new report mainly focused on the difference among age and gender.

Data

1. The per capital household energy consumption and population data are from the China Statistical Yearbook 2001-2021.

2. The health impact data of household air pollution from solid fuels are from the Global Burden of Disease Study (GBD) (2019).

3. The age-related data are from the China Health and Retirement Longitudinal Study (CHARLS) (2018).

Caveats

The caveats of this indicator would mainly be in two aspects. First, the regional difference should not be neglected considering the difference in climate and economics. Second, the health impact data from literature were collected before the COVID-2019 outbreak. More recent and adequate data should be further collected.

Additional Information

This indicator reports household energy consumption using the National Bureau of Statistics data. Per capita household energy consumption has increased significantly, by 235% from 3.9GJ in 2000 to 13.0 GJ in 2019. The year-on-year growth rate of per capita household energy was 1.8% in 2019, down three percentage points from 2018. While the urban per capita household energy was 2.4 times that in rural areas in the 2000s, the latter increased rapidly and reached the same level in 2016. The per capital coal consumption, reported as the preferred energy source as the substitution of biomass for rural residents[76], maintained a rapid downward trend with a decline of 14.5% in 2019 while liquefied petroleum gas consumption had reduced 10.2%.

The household air pollution from solid fuels is estimated to cause 36.3 thousand deaths in China in 2019, equating to 258 deaths per million people. The household air pollution from solid fuels related mortality rate increases with age. For middle-aged and older people, the mortality rate increases sharply. The mortality rate for people over 65 (1464 per million) is 5.7 times the average, while people over 80 (3450 per million) is even 13.4 times. Compared to non-solid fuels, solid fuel use significantly increases the possibility of chronic lung diseases (30%), exacerbation of chronic lung diseases (95%), seizure of heart disease (1.80 times), decreases self-evaluated health status of the elderly (1.38 times) and decreases cognitive function equivalent to differences between individuals who were 3.3 years apart[77,78].

Solid fuels were more widely used for cooking in rural areas (40.2% of 13860 samples) than in urban areas (5.6% of 3936 samples). In urban areas, thanks to the popularity of non-solid energy, there was no significant difference in the proportion of the elderly using solid fuel compared with the middle-aged. In rural areas, 47.5% of the elderly chose solid fuels as their energy sources for cooking, which was 11.4% higher than people under 65 and 20.6% than people under 50. Families with no child but at least an elderly member have a 10.3% lower probability of choosing clean fuels as their primary cooking fuel in rural areas[79]. The related field survey was conducted by stratified random sampling in July and August 2016. Six villages in Qihe County (Dezhou City, Shandong Province) and four in Wuqiang County (Hengshui City, Hebei Province) were selected.

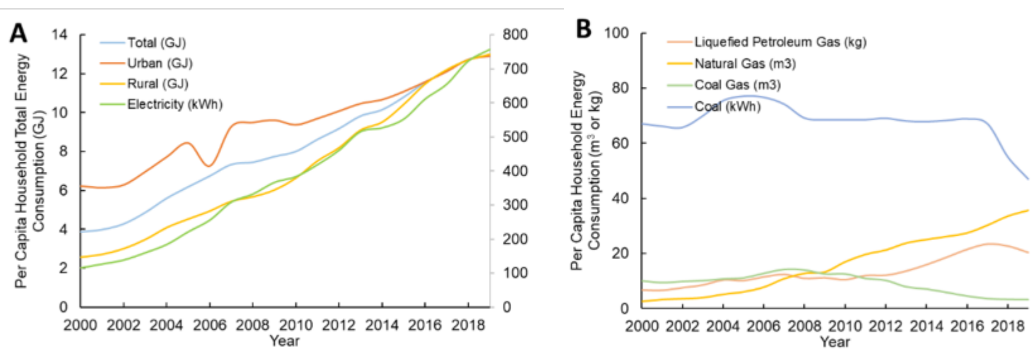


***Figure* 34: Development of Household Energy Consumption in China**

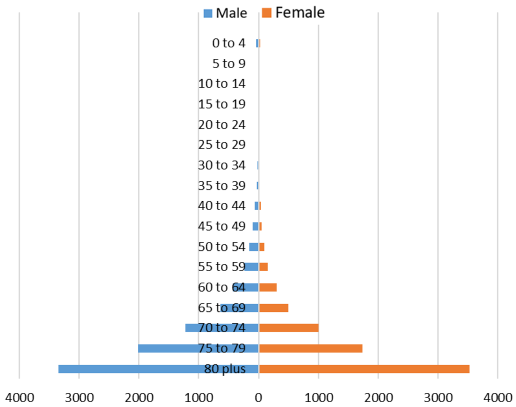


***Figure* 35: Household air pollution from solid fuels related deaths per million people from all ages**

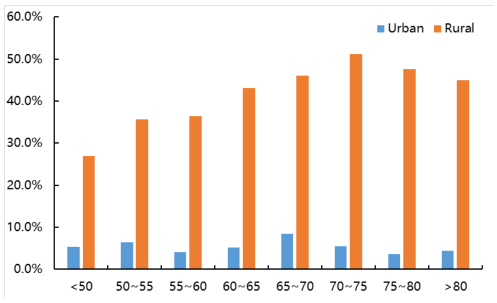


***Figure* 36: Proportion of solid fuels usage for cooking of people from all ages in urban and rural areas**

Indicator 3.3: Air pollution, energy, and transport

Indicator 3.3.1: Exposure to air pollution in cities

Methods

This indicator reports the trends of annual air pollutant concentrations in China's cities based on monitoring data. The distribution of city-specific annual average PM2.5 and annual daily maximum 8-hour average (ADMA8) ozone concentrations is illustrated based on the ground-monitoring data during 2015-2021 in China.

Data

Daily ground-monitoring PM2.5 and ozone data during 2015-2020 is from the Data Center of Ministry of Ecology and Environment of China[80] and the data in 2021 was from National Urban Air Quality Real-time Release Platform of China National Environmental Monitoring Centre (https://air.cnemc.cn:18007/). Referring to 'Technical Regulation for Ambient Air Quality Assessment' (HJ 633-2013) and Ambient air quality standard (GB 3095-2012), the city-specific annual average PM2.5 concentration is calculated by arithmetic mean of daily 24-hour average PM2.5 concentrations, and the value of the 90th percentile of daily maximum 8-hour average ozone concentrations DMA8 is set to be AMDA8.17,18

The 2015 city-level population data are collected from the National Economic and Social Development Bulletin. The 2015 population structure data at province levels are from the China Population and Employment Statistics Yearbook. The 2020 city-level population data and province-level population structure data are derived from the 7th national population census of China.19

Caveats

333 prefecture-level administrative cities and four municipalities of mainland China are considered. Due to the lack of monitoring data, the annual average PM2.5 concentrations and AMDA8 ozone concentrations of Danzhou, Bayingolin and Sansha between 2015-2020 are set to be none. In 2021, the annual average PM2.5 concentrations of Sansha, the AMDA8 ozone concentrations of Changzhou and Sansha are set to be none.

Additional Information

Table 25: Statistics for annual average PM2.5 concentrations for China's cities.

Year	Minimum ($\mu g/m^3$)	Median ($\mu g/m^3$)	Maximum ($\mu g/m^3$)	Number of cities with annual average $PM_{2.5}$ concentration >$35 \mu g/m^3$
2015	10	49	118	260
2016	11	44	157	240
2017	10	42	100	232
2018	8	38	116	195
2019	7	35	110	168
2020	6	32	113	136
2021	7	30	94	118

Table 26: Statistics for ADMA8 ozone concentrations for China's cities.

Year	Minimum ($\mu g/m^3$)	Median ($\mu g/m^3$)	Maximum ($\mu g/m^3$)	Number of cities with ADMA8 ozone concentration >$100 \mu g/m^3$
2015	62	135	202	307
2016	74	138	200	311
2017	78	146	219	326
2018	74	147	215	328
2019	82	146	208	326
2020	94	136	194	324
2021	94	134	197	328

Table 27: Elderly population (aged 65+) exposed to PM2.5 and ozone pollution.

		Elderly population (million person)		Change	Change rate
		Year 2015	Year 2020		
$PM_{2.5}$	>5 $\mu g/m^3$	141.8	188.8	47.1	+33.2%
	>35 $\mu g/m^3$	124.2	96.8	-27.3	-22.0%

Ozone	>100 μg/m^3	135.3	186.7	51.4	+38.0%
	>160 μg/m^3	41.2	53.7	12.5	+30.4%

Indicator 3.3.2: Premature mortality from ambient air pollution by sector

Methods

This indicator quantifies the number of premature deaths attributable to long-term ambient fine particulate matter (PM2·5) exposure by sectorial sources for each province in China. The greenhouse gas-air pollution interactions and synergies (GAINS) model[81] is used to quantify the sectorial contribution to ambient PM2·5. Data from the International Energy Agency (IEA) World Energy Outlook 2021[82] and the data of Chinese statistical yearbook in 2021 and China energy statistical yearbook 2020 are integrated into GAINS to develop the provincial air pollution emission inventory by fuels and sectors. National total energy consumption matches the IEA statistics (merged World Energy Model/statistics for 2020), while the provincial pattern relies on the Chinese statistical yearbook data. Activity data is combined with GAINS internal information on application of emission control technologies in each region and their emission factors to calculate emissions of $PM_{2.5}$ and its precursor gases SO_2, NOx, NH_3, and non-methane VOC.

Ambient $PM_{2.5}$ concentrations are calculated from the region and sector specific emissions by applying atmospheric transfer coefficients, which are a linear approximation of full chemistry-transport models. Atmospheric transfer coefficients in GAINS are based on full year perturbation simulations with the EMEP Chemistry Transport Model[83] at 0.1°×0.1° resolution (for low-level sources) / 0.5°×0.5° resolution (for all other sources) using meteorology of 2015.

We also made a validation between ambient annual PM2·5 concentration of the GAINS and the official data released by the Chinese government.

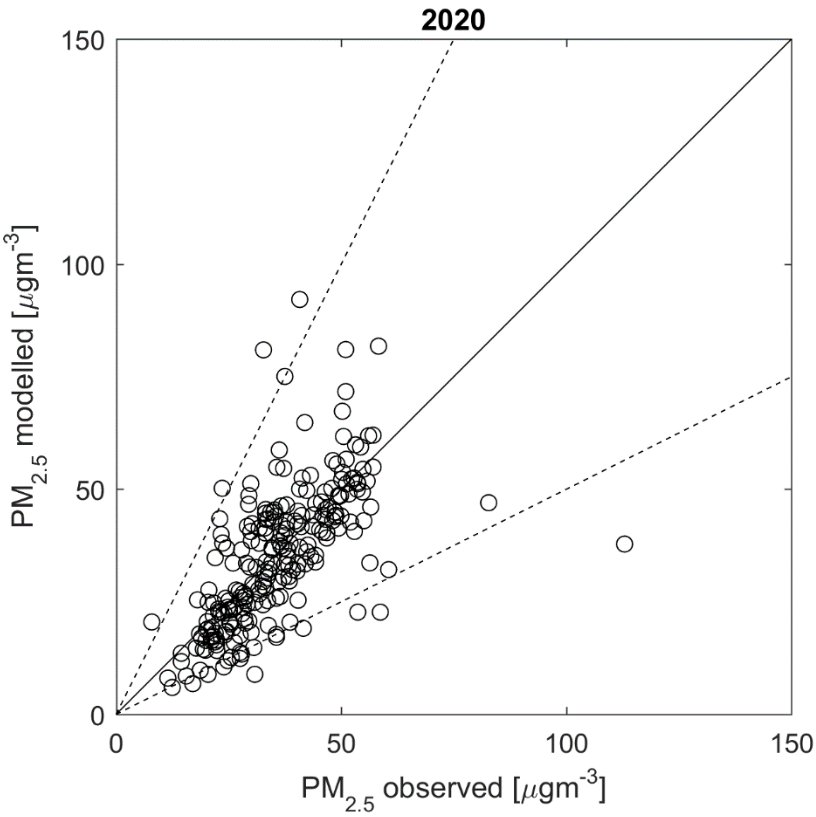


Figure 37. Validation between ambient annual PM2·5 concentration of the GAINS model

Premature deaths from total ambient PM2·5 by provinces and sectors in China are calculated using the methodology of the Global Burden of Disease 2019, which relies on cause-specific concentration-response functions to calculate relative risk (RR) for mortality for six causes of death.

The MR-BRT curves were obtained from the public release site[84] and relative risks for six diseases IHD, COPD, stroke, lung cancer, ALRI, and type 2 diabetes calculated from them. We used 1000 draws of the MRBRT curve for each disease and age group (where age specific) and scaled them to have RR=1 at the theoretical minimum-risk exposure level (taken from 1000 corresponding draws, average 4.15μgm^{-3}). Exposure levels below the TMREL level are assigned RR=1.

The concentration-response (C-R) functions and relative risks [Eq. (1)] were based on the MR-BRT functions from the GBD 2019 across the full range of PM2·5 concentrations. RR_{IER}(Z represents the relative risks in the PM2·5 exposure concentration of C (in micrograms per meter cubed); C_0 represents the counterfactual concentration below which it is assumed there is no additional risk. For very large C, RR_{IER}(Z) approximates 1+α. A power of PM2·5, δ, was included here to predict risk over a very large range of concentrations.

$$RR_{IER}(Z)=\begin{cases} 1, \text{ for } C < C_0 \\ 1+\alpha\{1-\exp[-\gamma(C-C_0)^{\delta}]\}, \text{ for } C \geq C_0 \end{cases} \quad (1)$$

We adopted a calculation approach [Eq. (2)] developed for the GBD 2019 to estimate PM2.5-related premature mortality in each province of China, and the following five endpoints are included in our estimation: ischemic heart disease (IHD), chronic obstructive pulmonary disease (COPD), lung cancer

(LC), and stroke in adults, and acute lower respiratory infections (ALRI) in children less than 5 years old. For IHD and stroke, the RR is different between age strata, and for COPD and LC, the RR in the same exposure concentration is the same for the entire group of adults (aged 25 or more). We estimated the premature mortality $M_{i,j}$ of each province (and of each age stratum for IHD and stroke) and disease endpoint j attributable to ambient PM2·5 for Province i.

$$M_{i,j}=P_i\times\hat{I}_j\times(RR_j(C_i)-1), \text{ where } \hat{I}_j=\frac{I_j}{RR_j} \quad (2)$$

$\hat{I}_j$ represents the hypothetical "underlying incidence" (i.e., cause-specific mortality rate) that would remain if PM2·5 concentrations were reduced to the theoretical minimum risk concentration. Here, P_i is the population of province i, I_j is the reported regional average annual disease incidence (mortality) rate for endpoint j, Ci represents the annual-average PM2·5 concentration in county i, $RR_j(C_i)$ is the relative risk for end point j at concentration C_i, and RR_j represents the average population-weighted relative risk for end point j.

Data

1. Emissions data was developed using the IEA World Energy Outlook 2021, the Chinese statistical yearbook in 2021, and the China energy statistical yearbook 2020.
2. Provincial air pollution emission inventory by fuels and sectors was from GAINS model;
3. Provincial demographic and mortality data was from Chinese statistical yearbook in 2015 and 2021;
4. Baseline mortality data was obtained from the results of GBD 2019 studies;
5. The RR value and estimated parameters were from GBD 2019.

Caveats

There are three key caveats of this indicator. Firstly, the annual mean PM2·5 concentration for each province was calculated from GAINS model, the health effects related to air pollution are calculated based on provincial concentration rather than grid data. Finally, PM2·5 from various sources used the same C-R function and RR, so the estimated results may deviate from the actual situation to some extent.

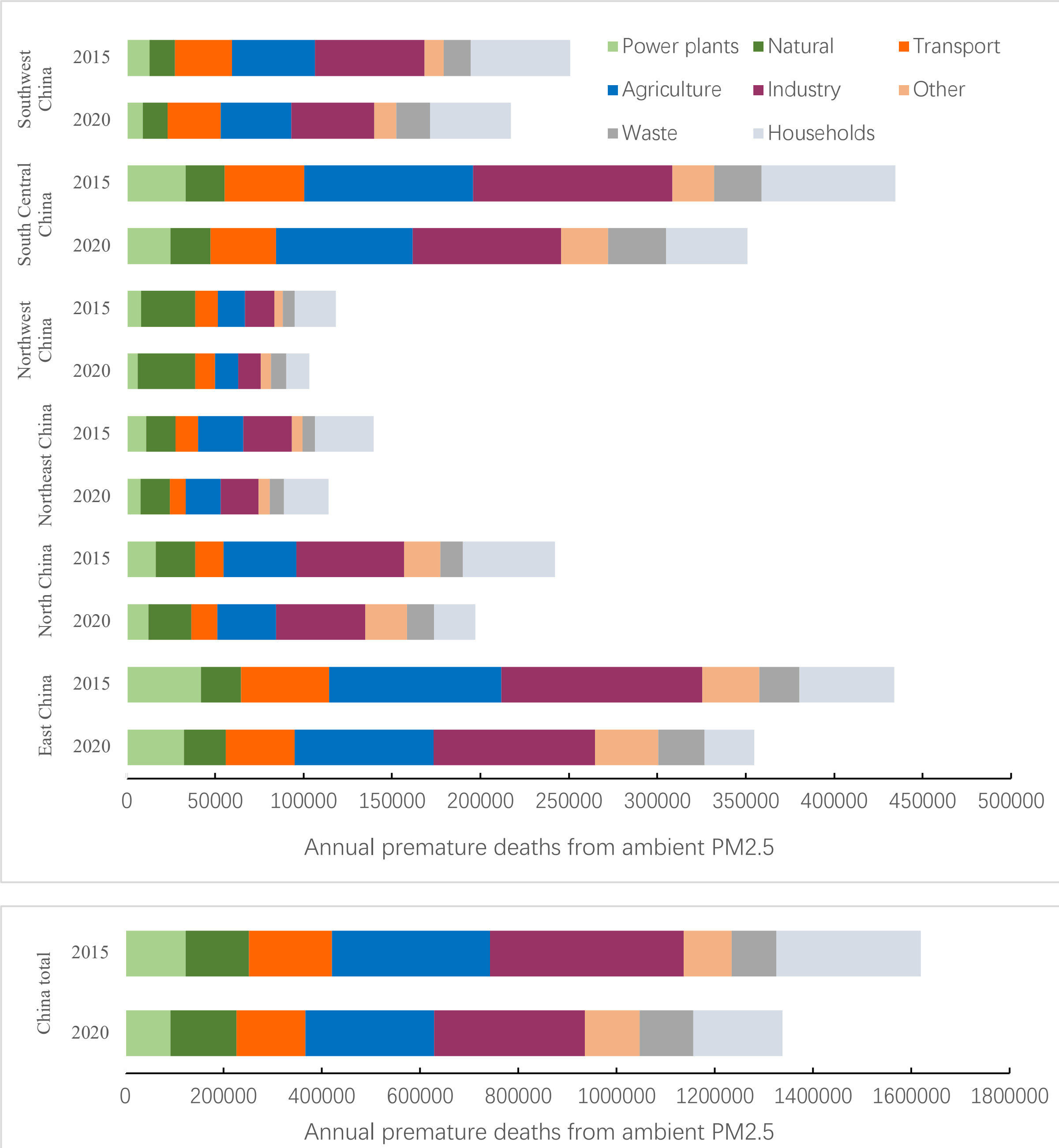


Figure 38: Premature deaths attributable to $PM_{2.5}$ by regions and sectors between 2015 and 2020

Indicator 3.3.3: Sustainable and healthy transportation

Methods

This indicator contains three components:

1. Emission intensity of freight transportation, indicating the road-freight induced emission per freight tonne-kilometer of major pollutants (CO, HC, NOx, and PM) from 2010 to 2021 for China;

2. Emission intensity of passenger transportation, indicating the road-passenger induced emission per passenger-kilometer;

3. Emission intensity of private car, indicating the average emission per private car.

The emission of each sector s including freight transportation, passenger transportation and private car is calculated as below:

$$E_{s,i,y} = P_{s,y} * EF_{s,i,y} * VKT_s$$

where i represents the pollutants including CO, HC, NOx, and PM, y represents the year, P represents the vehicle ownership, EF represents the emission factor, and VKT represents the vehicle kilometers of travel.

Data

1. Vehicle ownership data is from National Bureau of Statistics of China[85].

2. The vehicle kilometers of travel are from Guide for Emission Inventory of Air Pollutants from On-Road Vehicles [86].

3. The emission factor data is from Guide for Emission Inventory of Air Pollutants from On-Road Vehicles [86], Grigoratos' study [87] and Zhang's study [88].

Additional Information

From the perspective of freight transportation, benefiting from the implementation of several air pollution control strategies by the Chinese government, the road freight emissions were effectively controlled and decreased year by year (***Figure*** 39), while the freight tonne-kilometer rose by 59.2% from 2010 to 2021. Therefore, the emission intensities of carbon monoxide (CO), hydrocarbon (HC), nitrogen oxide (NO_x), and particulate matter (PM) all showed a downward trend during this period, dropping by 64.5%, 77.9%, 69.0%, 90.0%, respectively. The emission intensity for passenger transportation also declined sharply before 2020 due to the stricter emission standards. Affected by the COVID-19, the limitation on travel greatly reduced the value of passenger-kilometer, however, passenger vehicles were still be arranged on most necessary routes, with a high empty load rate. Thus, the reduction in emission from passenger vehicles was not matched by the reduction in road passenger-kilometer in 2020 and 2021. For private cars, the emission intensities for four pollutants were effectively controlled and decreased by about 80.0%, the control on emission of PM from private cars still needed to be strengthen since it will bring adverse effects on human health [89]. In addition, new energy vehicles (NEVs) have been adopted and promoted by governments in China in recent years [90-92], which is reported to alleviate urban air quality problem such as NO_2 [92]. By 2020, the population of NEVs in China reached 4.92 million, accounting for 1.75% of the total vehicle population [93]. In the future, China should continue to promote and increase the use of NEVs in cities. This can not only address the air pollution problems, but also reduce fossil energy consumption to ensure China's energy security.

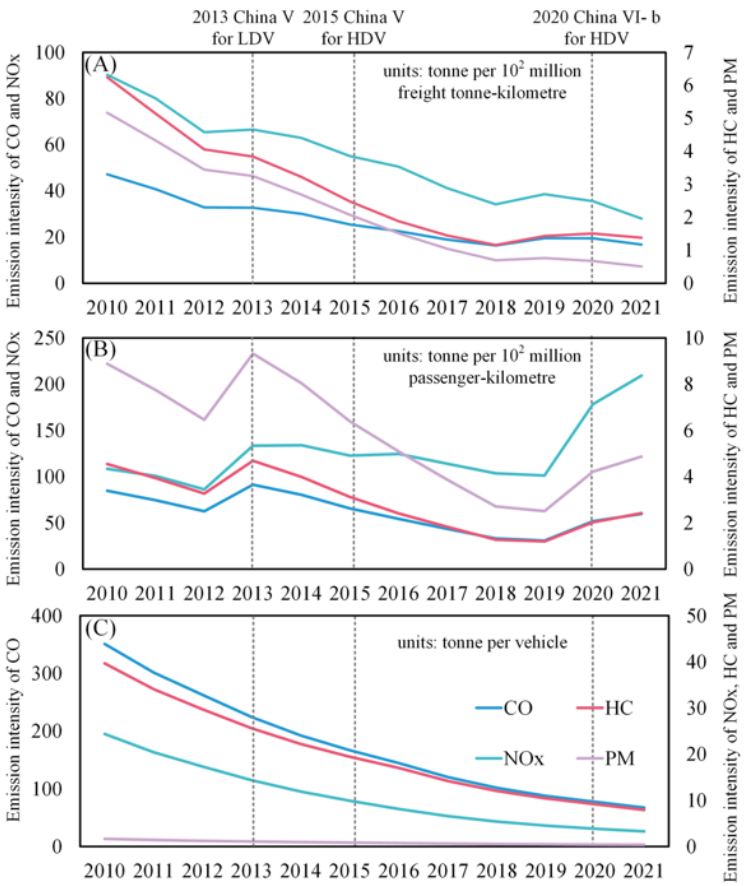


***Figure* 39: The air pollution emission intensity of (A) road freight transportation, (B) road passenger transportation and (C) private cars in China from 2010 to 2021 for CO, HC, NOx, and PM.**

Table 28: The freight tonne-kilometer and passenger-kilometer in China from 2010 to 2021

Year	Freight tonne-kilometer (billionfreight tonne-kilometre)	Passenger-kilometer (billion passenger-kilometre)
2010	4338.967	1502.081
2011	5137.474	1676.025
2012	5953.486	1846.755
2013	5573.808	1125.094
2014	5684.69	1099.675
2015	5795.572	1074.266
2016	6108.01	1022.871
2017	6677.152	976.518
2018	7124.921	927.968
2019	5963.639	885.708
2020	6017.185	464.101
2021	6908.77	362.75

Section 4: Economics and Finance

Indicator 4.1.1: Economic costs of heatwave-related mortality

Methods

Different from the 2021 report which just estimated the economic costs of heatwave-related mortality of working-age people, this year's indicator was updated to reflect the trend of ageing. We monetized value of heatwave-related all-aged mortality through value of a statistical life to reflect the trend of ageing. Using the heatwave-related working age mortality data provided by WG1 as the input, we used the Chinese IO tables available for eight years (2002, 2005, 2007, 2010, 2012, 2015, 2017, 2018) for national economic costs analysis. Assuming a fixed input-output relationship in 2018, 2019, 2020, and 2021 the evaluation on national level was extended to 2021. We used a multi-regional IO table in 2017 for provincial analysis. Using the heatwave-related all-aged mortality data provided by WG1 and value of a statistical life, we monetized each death in China across time.

For direct losses for each sector, we assumed the heatwave-related working age mortality rate equals to the direct loss rate of workers' compensation. The direct loss was then put in assessing model to estimate the overall economic cost for each year. Comparing the overall and direct losses gives the estimated indirect losses resulting from inter-dependence relationship among sectors and regions.

Data

1. Heatwave-related mortality data is provided by WG1;
2. The Chinese IO tables for eight years came from the website of the National Bureau of Statistics of China[94];
3. The Chinese multi-regional IO table for 2017 is obtained from the CEADs dataset[95].

Caveats

The caveats of this indicator would mainly be in three aspects.

First, the input-output analysis framework has assumed no market-based price adjustment and substitution of inputs, which implies the costs may be overestimated. Second, due to data available, the analysis is only performed at specific years with accessible IO tables. Third, the impact of COVID-19 on heatwave-related mortality as well as the impact of COVID-19 on the economic costs of heatwave-related mortality are not studied due to lack of data.

Additional information

Table 29: National direct and indirect economic losses from heatwave-related labor-aged mortality (US$ million, $2020)

	Primary		Secondary		Tertiary	
Years	**Direct losses**	**Indirect losses**	**Direct losses**	**Indirect losses**	**Direct losses**	**Indirect losses**
2002	1.15	1.7	1.96	7.7	2.05	3.9
2005	2.15	3.1	2.98	14.7	2.86	6.1
2007	1.84	2.6	3.22	16.4	2.63	5.3

2010	3.01	4.3	5.98	32.0	5.92	11.1
2012	1.68	2.4	3.32	16.9	3.63	7.1
2015	2.37	3.4	4.37	25.7	6.49	12.5
2017	5.02	7.1	11.04	54.2	17.73	33.5
2018	3.87	5.3	8.87	42.9	15.24	28.9
2019	4.33	6.0	9.94	48.1	17.08	32.4
2020	3.51	4.9	8.06	39.0	13.84	26.3
2021	4.02	5.6	9.23	44.6	15.85	30.1

Table 30: Provincial economic loss in 2017 (US$ million, $2020)

Provinces	Economic loss	Provinces	Economic loss	Provinces	Economic loss
Beijing	2.10	Tianjin	3.21	Hebei	5.45
Shanxi	3.00	Inner Mongolia	6.68	Liaoning	5.09
Jilin	3.75	Heilongjiang	3.55	Shanghai	1.08
Jiangsu	3.78	Zhejiang	3.02	Anhui	1.59
Fujian	1.48	Jiangxi	2.29	Shandong	4.71
Henan	7.57	Hubei	1.29	Hunan	3.23
Guangdong	3.09	Guangxi	1.01	Hainan	0.45
Chongqing	4.63	Sichuan	0.84	Guizhou	2.83
Yunnan	2.87	Tibet	0.07	Shaanxi	4.87
Gansu	8.01	Qinghai	0.13	Ningxia	3.68
Xinjiang	5.23				

Table 31: National economic losses from heatwave-related all-aged mortality (US$ billion, $2020)

Years	Economic loss	Years	Economic loss
2002	7.0	2012	5.1
2003	5.1	2013	10.9
2004	5.7	2014	6.0
2005	8.5	2015	4.9
2006	7.6	2016	8.4
2007	6.1	2017	13.5
2008	3	2018	10.1
2009	7.8	2019	11.1
2010	9.5	2020	8.4
2011	6.7	2021	9.3

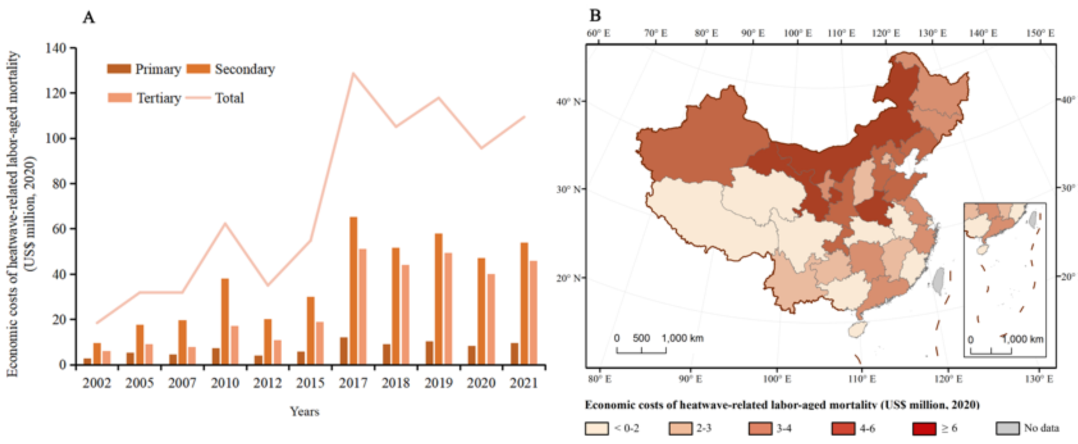


Figure 40: **Economic costs of heatwave-related labor-aged mortality (US$ million, 2020). (A)National economic losses; (B) Provincial economic loss in 2017**

Figure 41: **Economic costs of heatwave-related all-aged mortality (US$ billion, 2020).**

Indicator 4.1.2: Economic costs of heat-related labour productivity loss

Methods

In the 2022 report we use the same method, which is under the Adaptive Regional Input-Output (ARIO) framework[96], to evaluate the economic costs or losses of heat-related labour productivity loss, air pollution-related premature deaths and climate-related extreme events. This is consistent with indicator 4.1.4 and a full description of the model is provided in the appendix of the 2021 report.

Without capital damage caused by heat stress or air pollution, we mainly consider the reduction in labour input and its rippling effect through the production supply chain. Therefore, unlike indicator 4.1.4, the direct costs in indicators 4.1.2 and 4.1.3 are defined by the first-order losses of value added due to labour capacity loss and the indirect costs are the higher-order losses of value added resulting from the rippling effect along the inter-sectoral and inter-regional trade linkages.

First for the production module, we use γ_{ir}^{L} to indicate the proportion of labour productivity loss due to heat stress in sector i of region r. This input is obtained from WG1 responsible for indicator 1.1.2. Then the remaining productive capacity of labour in each sector at time t is:

$$x_{ir}^{L}(t) = \alpha_{ir}(t) \times \left(1 - \gamma_{ir}^{L}(t)\right) \times \bar{x}_{ir}. \quad (1)$$

Here $\overline{x}_{ir}$ is the output of sector i in region r at the pre-disaster level, which can be obtained from the Input-Output (IO) tables used. $\alpha_{ir}(t)$ represents the level of overproduction capacity of the sector due to the input shortage at time t. It is expressed as a percentage of the pre-disaster output level and usually greater than 100% during the input shortage. The dynamic adjustment of the overproduction capacity follows the principles in Hallegatte [97].

Assuming the Leontief production function, the maximum production capacity $x_{ir}^{\max}(t)$ can be expressed as:

$$x_{ir}^{\max}(t) = \min\left\{x_{ir}^{L}(t);\ \text{for all}\, j,\ x_{ir}^{j}(t)\right\}. \tag{2}$$

Here we do not consider the capital productivity constraint as there is basically no capital damage during the heat stress. $x_{ir}^{j}(t)$ is the production level of sector i in region r that the inventory of the intermediate input from sector j can support at time t, which is expressed as below:

$$x_{ir}^{j}(t) = \frac{S_{ir}^{j}(t-1)}{a_{j,ir}}. \tag{3}$$

Here $S_{ir}^{j}(t-1)$ refers to the amount of intermediate product j held by sector i in region r at the end of the time $t-1$. $a_{j,ir}$ is the technical coefficient indicating the amount of intermediate input j required to produce one unit of product i in region r, which can be obtained from the IO tables used.

The actual production of sector i in region r at each time step depends on both the maximum production capacity and the total orders expected to receive from the clients:

$$x_{ir}^{a}(t) = \min\left\{x_{ir}^{\max}(t),\ TD_{ir}(t-1)\right\}. \tag{4}$$

Here $TD_{ir}(t-1)$ is the total orders received by sector i in region r from its clients during the previous period, which is calculated in the demand module.

Therefore, the inventory of product j held by the sector i in region r will be consumed during the production process. We use $S_{ir}^{j,used}(t)$ to denote the amount of intermediate product j used in the production of sector i in region r at time t, as below:

$$S_{ir}^{j,used}(t) = a_{j,ir} \times x_{ir}^{a}(t). \tag{5}$$

Second, the **allocation module** is similar with the 2021 report, except that there is no reconstruction demand for capital recovery. This module mainly describes how suppliers allocate products to their clients. In the aftermath of an extreme event, the supply of a sector, including domestic products and imports, will not be able to fulfil all the orders of its clients due to production constraints. In this analysis we use a prioritized-proportional rationing scheme to model the resource allocation process during the disequilibrium period. We assume that the firm first allocates its products to address the intermediate demand and then proportionally allocates the remaining products to other categories of demands.

To fulfil the intermediate demand, products of sector i in region r is allocated to sector j in region s in quantities, $FRC_{js}^{ir}(t)$, as below:

$$FRC_{js}^{ir}(t) = \begin{cases} \dfrac{FOD_{js}^{ir}(t-1)}{\sum_s \sum_j FOD_{js}^{ir}(t-1)} \times \left(x_{ir}^a(t) + \overline{im}_{ir} \right), & if\ x_{ir}^a(t) + \overline{im}_{ir} < \sum_s \sum_j FOD_{js}^{ir}(t-1) \\ FOD_{js}^{ir}(t-1), & if\ x_{ir}^a(t) + \overline{im}_{ir} \geq \sum_s \sum_j FOD_{js}^{ir}(t-1) \end{cases}. \quad (6)$$

Here $FOD_{js}^{ir}(t-1)$ refers to the orders issued by firms of sector j in region s to its suppliers of sector i in region r at time $t-1$. If the total supply, that is, the actual output plus imports, of sector i in region r is small than its expected total orders from downstream sectors, $\sum_s \sum_j FOD_{js}^{ir}(t-1)$, it will allocate all its products to the business clients in proportion to the orders. Otherwise, it will allocate just enough products to satisfy the expected intermediate demand. We assume that the imports of a sector are not significantly affected by the extreme event and remain stable at the pre-disaster level, $\overline{im}_{ir}$, which can be obtained from the IO tables used.

The remaining products of sector i in region r, after satisfying the intermediate demand, at time step t, is equal to:

$$x_{ir}^{rem}(t) = x_{ir}^a(t) + \overline{im}_{ir} - \sum_s \sum_j FRC_{js}^{ir}(t). \quad (7)$$

Then, the remaining products will be proportionally allocated to the final demand. The final demand mainly consists of four types, that is, household consumption, government expenditure, fixed capital formation and exports. The quantities of products of sector i in region r allocated to the kth type of final demand in region h, $HRC_{kh}^{ir}(t)$, are expressed as follows:

$$HRC_{kh}^{ir}(t) = \frac{HOD_{kh}^{ir}(t-1)}{\sum_k \sum_h HOD_{kh}^{ir}(t-1)} \times x_{ir}^{rem}(t). \quad (8)$$

Here $HOD_{kh}^{ir}(t-1)$ refers to the orders issued by the kth type of final users in region h to its suppliers of sector i in region r at time $t-1$.

Then, sector j in region s receives intermediates from all regions to restore its inventories of product i at time step t, as below:

$$S_{js}^{i,restored}(t) = \sum_r FRC_{js}^{ir}(t). \quad (9)$$

Therefore, the quantities of intermediates i held by sector j in region s at the end of period t are as below:

$$S_{js}^{i}(t)=S_{js}^{i}(t-1)-S_{js}^{i,used}(t)+S_{js}^{i,restored}(t). \tag{10}$$

Third, the **demand module** is also similar with the 2021 report considering the possibility of demand readdressing according to the cross-regional substitutability. At the end of each period downstream clients issue orders to their suppliers according to their production and consumption plans for the next period. When a product comes from multiple suppliers, the orders are redistributed among suppliers from different regions according to their production capacities.

A firm issues orders to its suppliers because of the need to restore its intermediate product inventory. We assume that the firm of sector j in region s has a specific targeted inventory level of product i, $S_{js}^{i,G}(t)$, equal to a given number of days, n_{js}^{i}, of intermediate consumption of product i, based on its maximum production capacity at time step t, which is calculated as below:

$$S_{js}^{i,G}(t)=n_{js}^{i}\times a_{i,js}\times x_{js}^{\max}(t). \tag{11}$$

To fill the gap between the targeted and the actual inventory levels of intermediate product i, the firm of sector j in region s will allocate its orders among the suppliers of product i in different regions based on their production capacities. Then the order issued by the firm of sector j in region s to its supplier of sector i in region r is equal to:

$$FOD_{js}^{ir}(t)=\begin{cases}\left(S_{js}^{i,G}(t)-S_{js}^{i}(t)\right)\times\dfrac{\overline{FOD}_{js}^{ir}\times x_{ir}^{a}(t)}{\sum_{r}\overline{FOD}_{js}^{ir}\times x_{ir}^{a}(t)}, & if\ S_{js}^{i,G}(t)>S_{js}^{i}(t)\\ 0, & if\ S_{js}^{i,G}(t)\le S_{js}^{i}(t)\end{cases}. \tag{12}$$

Here $\overline{FOD}_{js}^{ir}$ is the intermediate demand of sector j in region s for inputs of sector i in region r at the pre-disaster level, which can be obtained from the IO tables used.

Similarly, final users (i.e., domestic households, governments, investors, and foreign consumers) allocate orders among their suppliers from different regions based on their demand and the production capacities of their suppliers. The targeted amount of the kth type of final demand in region h for product i at time t is obtained by adding up the demand from different regions at the pre-disaster levels, as below:

$$HOD_{kh}^{i,*}(t)=\sum_{r}\overline{HOD}_{kh}^{ir}. \tag{13}$$

Here $\overline{HOD}_{kh}^{ir}$ is the kth type of final demand in region h for product i in region r at the pre-disaster equilibrium, which can be obtained from the IO tables used. We assume that various types of final demand do not shift significantly in the short run after the extreme event.

Then, the orders issued by the kth type of final users of region h to the suppliers of product i in region r is as below:

$$HOD_{kh}^{ir}(t) = HOD_{kh}^{i,*}(t) \times \frac{\overline{HOD}_{kh}^{ir} \times x_{ir}^{a}(t)}{\sum_{r} \overline{HOD}_{kh}^{ir} \times x_{ir}^{a}(t)}. \tag{14}$$

Therefore, the total orders received by sector i in region r are:

$$TD_{ir}(t) = \sum_{s}\sum_{j} FOD_{js}^{ir}(t) + \sum_{k}\sum_{h} HOD_{kh}^{ir}(t). \tag{15}$$

At each time step the economic agents on the supply and demand sides go through the above production, allocation, inventory recovery, and demand adjustment procedures, through which the value added of each sector is:

$$va_{ir}(t) = x_{ir}^{a}(t) - \sum_{j}\sum_{s} a_{js,ir} \times x_{ir}^{a}(t). \tag{16}$$

Here $a_{js,ir}$, which is drawn from the IO tables, is the technical coefficient that indicates the amount of input from sector j in region s required to produce one unit of output of sector i in region r.

Finally, the heat-related total economic costs TC_{ir}, direct costs DC_{ir}, and indirect costs IC_{ir} of each sector and region are calculated as below:

$$TC_{ir} = \sum_{t}\left(\overline{va}_{ir} - va_{ir}(t)\right), \tag{17}$$

$$DC_{ir} = \sum_{t}\left(1 - \gamma_{ir}^{L}(t)\right) \times \overline{va}_{ir}, \tag{18}$$

and

$$IC_{ir} = TC_{ir} - DC_{ir}. \tag{19}$$

Here $\overline{va}_{ir}$ is the value added of sector i in region r at the initial level, which can be obtained from the IO tables used.

Data

1. The IO tables used for this indicator are from the same sources and processed in the same way as the 2021 report. The Chinese national IO tables are obtained from the website of the National Bureau of Statistics of China.[98] The national IO tables are only available for the years of 2012, 2015, 2017, and 2018, so we use the tables of the closest year to approximate the years without IO tables after scaling the tables used to the GDPs of the relevant years. The Chinese multi-regional IO table in 2017 is obtained from the CEADs dataset[99] and scaled to the year 2021 according to the ratio of GDPs between 2017 and 2021. All the IO tables used in this analysis are converted from current LCU prices into constant US$ in 2020. The economy is divided into 20 production sectors in each IO table, as listed in the right column of Table 32. Variables including the constant technical coefficients and sectoral value added, outputs, imports, intermediate demands, and final demands at the initial or pre-disaster levels are obtained from the IO tables used through basic calculations.

Table 32: Sector concordance.

Agriculture	Agriculture

Manufacture	Mining
	Foods and Tobacco
	Textiles
	Timbers and Furniture
	Paper and Printing
	Petroleum, Coking, Nuclear Fuel
	Chemicals
	Non-metallic Mineral Products
	Metal Products
	Ordinary Machinery
	Transport Equipment
	Electrical Equipment
	Electronic Equipment
	Other Manufacturing Industry
	Electricity, Gas, Water
Construction	Construction
Services	Transport
	Wholesale, Retail, Catering
	Other Services

2. Data on heat-related labour productivity loss is provided by WG1 responsible for indicator 1.1.2. It is calculated as percentage losses of annual working hours in four major sectors, including agricultural, construction, manufacturing, and services sectors, on both the national and provincial scales. We categorize the 20 sectors in the IO tables into the four major sectors (Table 32) and assume that sectors within the same categories share the same levels of heat-related labour productivity loss.

3. China's GDPs and currency exchange rates of the relevant years are obtained from China Statistical Yearbook 2021[85] and China's 2021 Statistical Bulletin on National Economics and Social Development[100].

Caveats

See indicator 1.1.2 for caveats related to the calculation of heat-related labour productivity loss.

The adoption of the ARIO model incorporates the possibilities of inventory adjustment and substitution between sectors, which increases the flexibility and resilience of the economy, but it assumes that the imports and final demand remain unchanged during the heat stress and mainly focuses on the supply chain propagation effects initiated by labour productivity loss.

Future Form of Indicator

This indicator will be updated annually with well-established China's IO tables on both the national and provincial scales.

Additional Information

Table 33: China's economic costs from heat-related labour productivity loss by sector and year. The direct and indirect costs are given in billions of US$ at 2020 prices, and the relative costs are given as percentages of China's GDP.

Year	Direct costs				Indirect costs				% GDP
	Agriculture	Manufacture	Construction	Services	Agriculture	Manufacture	Construction	Services	
2012	24.0	7.5	35.8	0.4	2.3	20.6	0.2	32.0	1.27%
2013	33.4	14.9	53.7	2.2	3.9	30.8	0.3	49.8	1.77%
2014	27.4	13.7	25.6	1.3	3.6	33.8	0.2	46.8	1.33%
2015	26.2	12.8	25.3	0.7	3.5	33.3	0.2	46.2	1.23%
2016	37.8	27.2	39.3	6.1	6.3	51.6	0.4	72.8	2.00%
2017	35.9	37.8	40.4	5.2	4.3	66.1	0.2	66.3	1.97%
2018	38.4	36.6	47.8	2.8	4.5	75.1	0.3	76.8	1.97%
2019	34.2	32.6	41.3	4.6	3.9	65.0	0.2	65.4	1.71%
2020	32.5	29.7	41.6	2.5	3.9	65.3	0.2	65.7	1.64%
2021	40.2	34.2	49.1	2.2	4.5	77.3	0.3	78.0	1.68%

Table 34: China's economic costs at the provincial level, in percent of regional GDP, from heat-related labour productivity loss in 2021.

Provinces	Direct costs	Indirect costs	Total costs
Beijing	0.04%	0.52%	0.56%
Tianjin	0.14%	0.54%	0.67%
Hebei	0.37%	0.47%	0.85%
Shanxi	0.06%	0.57%	0.64%
Inner Mongolia	0.05%	0.50%	0.55%
Liaoning	0.20%	0.33%	0.53%
Jilin	0.13%	0.39%	0.52%
Heilongjiang	0.21%	0.37%	0.58%
Shanghai	0.57%	0.83%	1.40%
Jiangsu	0.75%	0.63%	1.38%
Zhejiang	0.95%	0.73%	1.69%
Anhui	0.95%	0.94%	1.89%
Fujian	1.06%	1.01%	2.07%
Jiangxi	1.83%	1.51%	3.33%
Shandong	0.40%	0.49%	0.90%
Henan	0.65%	0.79%	1.45%
Hubei	1.20%	1.10%	2.30%
Hunan	1.36%	1.22%	2.58%
Guangdong	1.41%	1.14%	2.55%
Guangxi	2.29%	1.58%	3.86%
Hainan	3.09%	1.66%	4.75%

Chongqing	0.83%	0.66%	1.49%
Sichuan	0.47%	0.39%	0.86%
Guizhou	0.34%	0.53%	0.87%
Yunnan	0.14%	0.15%	0.29%
Tibet	0.57%	0.31%	0.88%
Shaanxi	0.20%	0.51%	0.70%
Gansu	0.02%	0.22%	0.24%
Qinghai	0.00%	-0.10%	-0.10%
Ningxia	0.04%	0.23%	0.27%
Xinjiang	0.07%	0.30%	0.37%
Macao	Null	Null	Null
Hong Kong	Null	Null	Null
Taiwan	Null	Null	Null
Total	0.74%	0.74%	1.48%

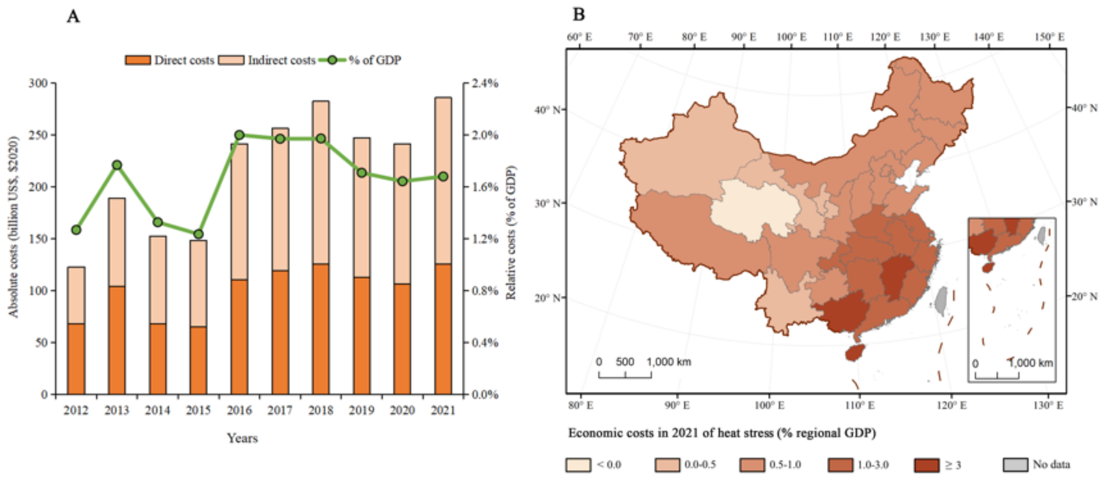


Figure 42: **Economic costs of heat-related labour productivity loss.**
(A) National-level results, by year, in billions of 2020 US$; (B) Provincial-level results in 2021, relative to provincial GDPs.
Note: Negative values indicate economic gains from inter-provincial trade.

Indicator 4.1.3: Economic costs of air pollution-related premature deaths

Methods

This indicator measures the direct and indirect economic costs of PM2.5-related premature deaths, using the same method as indicator 4.1.2. Compared with the previous year, the results are updated to year 2020.

The main calculation procedures are as follows:

1. The calculations are first performed on the national scale for two years 2015 and 2020 using the national IO tables, and then on the provincial scale for year 2020 using the multi-regional IO table. The national table of 2018 and the multi-provincial table of 2017 are scaled up to 2020 according to

the ratios of GDP between 2018 and 2020 and between 2017 and 2020 respectively. This is because the national and multi-provincial IO tables of 2020 are not available at the time of writing. All the IO tables used in this indicator are converted from current LCU prices into constant US$ in 2020. The economy is divided into 20 production sectors in each IO table, as listed in the right column of Table 32.

2. The percentage losses of labour productivity in the three industries (i.e., primary, secondary, and tertiary) are derived from the sectoral results of $PM_{2.5}$-related premature deaths in Indicator 3.3, using the same method as the 2021 report. The relative labour losses in the three industries are then disaggregated into the 20 production sectors according to the sector concordance in Table 32 (the construction sector belongs to the secondary industry), assuming that sectors within the same industry have the same level of $PM_{2.5}$-related labour productivity loss.

3. Finally, the relative labour losses are fed into the assessing model same as Indicator 4.1.2 to calculate the direct and indirect economic costs of $PM_{2.5}$-related premature deaths.

Data

1. The IO tables used for this indicator are from the same sources as the 2021 report. The Chinese national IO tables are obtained from the website of the National Bureau of Statistics of China.[98] The Chinese multi-regional IO table is obtained from the CEADs dataset.[99] Variables including the constant technical coefficients and sectoral value added, outputs, imports, intermediate demands, and final demands at the initial or pre-disaster levels are obtained from the IO tables used through basic calculations.

2. Data on PM2.5-related premature deaths is provided by WG3 responsible for indicator 3.3.2. It is processed in the same way as the 2021 report to calculate the percentage losses of labourers in the three industries (i.e., primary, secondary, and tertiary).

3. The numbers of national and provincial labourers by industry are collected from China Statistical Yearbook 2021[85].

4. The all-cause mortalities by province and age group are collected from the sixth national population census of China[101].

5. China's GDPs and currency exchange rates of the relevant years are obtained from China Statistical Yearbook 2021[85].

Caveats

See indicator 3.3.2, for caveats related to the calculation of premature mortality due to ambient $PM_{2.5}$ pollution.

The national economic costs due to $PM_{2.5}$-related premature deaths in 2015 are estimated at $9.00 billion in the 2022 report, among which the direct and indirect costs are $7.69 and $1.31 billion respectively. These results are higher than those of the same year in the 2021 report ($6.24, $5.84 and $0.40 billion respectively). This may be related to three reasons: 1) the costs are given in billions of US$ at 2020 prices in the 2022 report but at 2015 prices in the 2021 report; 2) compared to the number in China Statistical Yearbook 2020, the labour size of each year after 2010 was lowered in China Statistical Yearbook 2021, which increased the intensity of the direct labour shocks derived from $PM_{2.5}$-related premature deaths; 3) updates from indicator 3.3.2 make the $PM_{2.5}$-related premature deaths in 2015 more concentrated in the secondary industry and the adoption of the ARIO model highlights the potential effects of supply chain disruption, both of which increases the indirect costs caused by the same units of direct costs.

Finally, this indicator considers the economic costs of mortality related to people's ability to work, however it does not consider the monetary value people place on life (i.e., VSL).

Future Form of Indicator

An ideal form of this indicator would reflect economic costs resulting from both mortality and morbidity rates of $PM_{2.5}$ pollution. This can be developed in future iterations of this indicator.

Additional Information

Table 35: China's economic costs from $PM_{2.5}$-related premature deaths by sector and year. The direct and indirect costs are given in billions of US$ at 2020 prices, and the relative costs are given as percentages of China's GDP.

Year	Direct costs			Indirect costs			% GDP
	Primary industry	Secondary industry	Tertiary industry	Primary industry	Secondary industry	Tertiary industry	
2015	0.72	3.70	3.28	0.16	0.51	0.64	0.07%
2020	0.66	4.31	3.11	0.09	0.60	0.46	0.06%

Table 36: China's economic costs at the provincial level, in percent of regional GDP, from $PM_{2.5}$-related premature deaths in 2020.

Provinces	Direct costs	Indirect costs	Total costs
Beijing	0.032%	0.018%	0.050%
Tianjin	0.082%	0.002%	0.084%
Hebei	0.107%	0.010%	0.116%
Shanxi	0.073%	-0.001%	0.072%
Inner Mongolia	0.049%	-0.001%	0.048%
Liaoning	0.087%	0.007%	0.094%
Jilin	0.064%	0.010%	0.074%
Heilongjiang	0.058%	0.198%	0.256%
Shanghai	0.022%	0.001%	0.023%
Jiangsu	0.036%	0.001%	0.038%
Zhejiang	0.018%	0.001%	0.018%
Anhui	0.062%	0.050%	0.112%
Fujian	0.017%	-0.002%	0.015%
Jiangxi	0.038%	-0.001%	0.037%
Shandong	0.062%	0.004%	0.065%
Henan	0.093%	0.007%	0.101%
Hubei	0.073%	0.004%	0.077%
Hunan	0.068%	0.003%	0.071%
Guangdong	0.017%	0.005%	0.022%
Guangxi	0.036%	-0.001%	0.035%
Hainan	0.014%	-0.005%	0.009%
Chongqing	0.102%	0.009%	0.111%

Sichuan	0.096%	0.009%	0.106%
Guizhou	0.041%	-0.002%	0.038%
Yunnan	0.021%	-0.002%	0.019%
Tibet	0.000%	0.005%	0.006%
Shaanxi	0.076%	-0.002%	0.074%
Gansu	0.046%	0.013%	0.059%
Qinghai	0.058%	-0.282%	-0.223%
Ningxia	0.046%	0.005%	0.051%
Xinjiang	0.095%	0.172%	0.267%
Macao	Null	Null	Null
Hong Kong	Null	Null	Null
Taiwan	Null	Null	Null
Total	0.054%	0.011%	0.064%

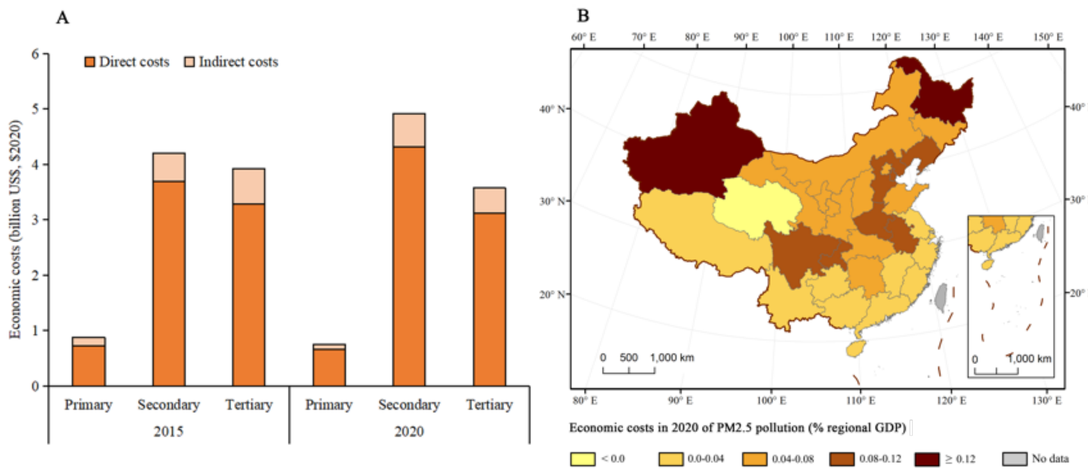


Figure 43: **Economic costs of $PM_{2.5}$-related premature deaths.**
(A) National-level results, by year and industry, in billions of 2020 US$; (B) Provincial-level results in 2020, relative to provincial GDPs.
Note: Negative values indicate economic gains from inter-provincial dependencies.

Indicator 4.1.4: Economic losses due to climate-related extreme events

Methods

This indicator measures both the direct and indirect economic losses of climate-related extreme events, including droughts, floods, hailstorms, thunderstorms, cyclones, blizzards and extreme low temperatures. Direct losses are the physical or tangible damage due to these events, while indirect losses or footprint refer to the subsequent losses, including business interruption losses of affected economic sectors, and the spread of losses towards other initially non-affected economic sectors, and the costs of recovery processes. The methodology for this indicator is the same with that in the 2021 report.

This year we add a box to discuss the economic losses of a famous compound event in 2021 of extreme flooding and coronavirus control in the Zhengzhou city of Henan Province. A full description of the methodology of evaluating such a compound event is given by Hu, Yang [102].

For the evaluation of such a compound event, we included the impact of COVID control on both transportation capacity and labour availability in the midst of flood responses. We describe the disease control as different combinations of strictness and duration of lockdown measures, as in Guan, Wang [103]. We use $\gamma_r^C(t)$ to indicate the strictness of the lockdown in the epidemic region r at time t, which represents the level of reduction in transportation capacity and labour availability relative to the pre-epidemic levels. The control measures have different effects on labour supply in different sectors. We set a specific multiplier η_i for sector i on the basis of three factors, that is, the exposure level of the sector's work, whether it is the lifeline and whether it is possible to work at home. Therefore, the epidemic-related labour productivity constraint is given by:

$$x_{ir}^{L,C}(t)=\alpha_{ir}(t)\times\left(1-\eta_i\times\gamma_r^C(t)\right)\times\bar{x}_{ir}. \quad (20)$$

Here $\bar{x}_{ir}$ is the output of sector i in region r at the pre-disaster level. $\alpha_{ir}(t)$ represents the level of overproduction capacity of the sector due to the input shortage at time t. It is expressed as a percentage of the pre-disaster output level and usually greater than 100% during the input shortage. The dynamic adjustment of the overproduction capacity follows the principles in Hallegatte [97].

On the other hand, the extreme weather events like the 2021 Zhengzhou flood can cause direct damage to physical assets, including both industrial and residential capital. Industrial capital is productive capital that is invested in production. Residential capital is not involved in production processes, but its restoration after a disaster would compete resources with that of industrial capital, and therefore affect the recovery of production. The damaged capital is recovered by the post-flood reconstruction activities. The capital held by firms of sector i or households in region r at time t is expressed as:

$$K_{ir}(t)=K_{ir}(t-1)-K_{ir}^{D}(t)+K_{ir}^{REC}(t-1), \quad (21)$$

and

$$K_{res,r}(t)=K_{res,r}(t-1)-K_{res,r}^{D}(t)+K_{res,r}^{REC}(t-1). \quad (22)$$

Here $K_{ir}(t)$ and $K_{res,r}(t)$ are the surviving capital stock held by industrial sector i and the residential sector in region r at time t, respectively. $K_{ir}^{D}(t)$ and $K_{res,r}^{D}(t)$ refer to the amount of capital damaged/destroyed by the flood. $K_{ir}^{REC}(t-1)$ and $K_{res,r}^{REC}(t-1)$ represent the recovered capital at the end of period $t-1$, which are calculated in the allocation and recovery module.

We use $\gamma_{ir}^{K,F}(t)$ to denote the percentage reduction in productive capital of sector i in region r at time t, relative to the pre-disaster level, in the aftermaths of the flood. It is calculated as:

$$\gamma_{ir}^{K,F}(t)=\frac{\bar{K}_{ir}-K_{ir}(t)}{\bar{K}_{ir}}. \quad (23)$$

Here $\bar{K}_{ir}$ is the capital stock of sector i in region r in the pre-disaster equilibrium.

Then the remaining productivity capacity of capital in each sector at time t is:

$$x_{ir}^{K,F}(t)=\alpha_{ir}(t)\times\left(1-\gamma_{ir}^{K,F}(t)\right)\times\bar{x}_{ir}. \quad (24)$$

The production module considers production constraints resulting from both the epidemic control and flood damage, which derives the maximum production capacity of each sector at time t as:

$$x_{ir}^{\max}(t)=\min\left\{x_{ir}^{K,F}(t);\ x_{ir}^{L,C}(t);\ \text{for all}\ j,\ x_{ir}^{j}(t)\right\}. \tag{25}$$

Here $x_{ir}^{j}(t)$ is the production level of sector i in region r that the inventory of the intermediate input from sector j can support at time t, expressed by Equation (3) in Indicator 4.1.2. The remaining part of the production module, regarding the actual production $x_{ir}^{a}(t)$ and the corresponding inventory used $S_{ir}^{j,used}(t)$, is also the same as Indicator 4.1.2 (see Equations (4) and (5)).

Then in the **allocation and recovery module**, a new type of demand, i.e., the reconstruction demand, arises from the needs to repair or rebuild the damaged capital assets owned by sectors and households. After satisfying the intermediate demand (following the same prioritized-proportional rationing scheme described by Equations (6) and (7) in Indicator 4.1.2), the remaining output $x_{ir}^{rem}(t)$ will be proportionally allocated to the final demand and reconstruction demand, as below:

$$HRC_{kh}^{ir}(t)=\frac{HOD_{kh}^{ir}(t-1)}{\sum_{k}\sum_{h}HOD_{kh}^{ir}(t-1)+\sum_{j}\sum_{s}ROD_{js}^{ir}(t-1)+\sum_{h}ROD_{res,h}^{ir}(t-1)}\times x_{ir}^{rem}(t), \tag{26}$$

$$RRC_{js}^{ir}(t)=\frac{ROD_{js}^{ir}(t-1)}{\sum_{k}\sum_{h}HOD_{kh}^{ir}(t-1)+\sum_{j}\sum_{s}ROD_{js}^{ir}(t-1)+\sum_{h}ROD_{res,h}^{ir}(t-1)}\times x_{ir}^{rem}(t), \tag{27}$$

and

$$RRC_{res,h}^{ir}(t)=\frac{ROD_{res,h}^{ir}(t-1)}{\sum_{k}\sum_{h}HOD_{kh}^{ir}(t-1)+\sum_{j}\sum_{s}ROD_{js}^{ir}(t-1)+\sum_{h}ROD_{res,h}^{ir}(t-1)}\times x_{ir}^{rem}(t). \tag{28}$$

Here $HRC_{kh}^{ir}(t)$ is the amount of output of sector i in region r allocated to the kth of the four types of final demands (i.e., household consumption, governmental expenditure, fixed capital formation, and exports) in region h. $RRC_{js}^{ir}(t)$ and $RRC_{res,h}^{ir}(t)$ refer to the amount of output of sector i in region r allocated to reconstruct the damaged capital of sector j in region s and of the residential sector in region h respectively. $HOD_{kh}^{ir}(t-1)$ refers to the orders issued by the kth type of final users in region h to its suppliers of sector i in region r at time $t-1$. $ROD_{js}^{ir}(t-1)$ and $ROD_{res,h}^{ir}(t-1)$ are the orders issued to support the reconstruction of damaged capital of sector j in region s and of the residential sector in region h, respectively. These demands are calculated in the demand module.

Therefore, the recovered capital of sector j in region s and the residential sector in region h at the end of period t are equal to:

$$K_{js}^{REC}(t)=\sum_i\sum_r RRC_{js}^{ir}(t), \tag{29}$$

and

$$K_{res,h}^{REC}(t)=\sum_i\sum_r RRC_{res,h}^{ir}(t). \tag{30}$$

And the restoration of inventories $S_{js}^{i,restored}(t)$ and the dynamics of inventories $S_{js}^{i}(t)$ at the end of each time step are calculated by Equations (17) and (18).

In the **demand module**, downstream clients issue orders to their suppliers according to their production, consumption, and reconstruction plans for the next period at the end of each time step. Unlike Indicator 4.1.2 where the demand redistribution is only based on the production capacity of suppliers, here the transportation capacity restricted by the COVID control (i.e., reduced by a percentage of $\gamma_r^C(t)$ in the epidemic region r) is also included. In other words, we assume that the economic agents redistribute their orders for a specific product among suppliers from different regions based on both the transportation and production capacities. Then the orders for the product of sector i in region r issued by a specific type of clients p (e.g., downstream production sectors, various final users, and reconstruction sectors) at each time step is calculated as below:

$$POD_p^{ir}(t)=POD_p^{i,*}(t)\times\frac{\overline{POD}_p^{ir}\times\left(1-\gamma_r^C(t)\right)\times x_{ir}^a(t)}{\sum_r\overline{POD}_p^{ir}\times\left(1-\gamma_r^C(t)\right)\times x_{ir}^a(t)}. \tag{31}$$

Here $POD_p^{i,*}(t)$ is the target level of demand from client p for product i at time t. $\overline{POD}_p^{ir}$ is the pre-disaster level of demand from client p for product i in region r. $x_{ir}^a(t)$ is the actual production of sector i in region r at time t, which is defined by both the maximum production capacity and the total demand in the previous period (same as Equation (3) in Indicator 4.1.2).

For business clients, say a downstream production sector j in region s, $POD_p^{ir}(t)$ and $\overline{POD}_p^{ir}$ become $FOD_{js}^{ir}(t)$ and $\overline{FOD}_{js}^{ir}$, and the targeted demand for product i is equal to the gap between the targeted and the actual inventory levels of that product, i.e., $S_{js}^{i,G}(t)-S_{js}^{i}(t)$, which have been described by Equations (11) and (12) in Indicator 4.1.2.

For final clients, say the kth type of final users (i.e., domestic households, governments, investors, or foreign consumers) in region h, $POD_p^{ir}(t)$ and $\overline{POD}_p^{ir}$ become $HOD_{kh}^{ir}(t)$ and $\overline{HOD}_{kh}^{ir}$, and the targeted demand for product i is equal to the sum of final demand from different regions at the pre-disaster levels, i.e., $\sum_r\overline{HOD}_{kh}^{ir}$, which have been described by Equations (13) and (14). We also assume that the demands for restaurants, hotels, tourism and other outdoor entertainment services will decline in the flooded and epidemic regions following a similar principle as Guan, Wang [103].

For reconstruction clients, including both the production sector j in region s and the residential sector in region h, we assume that they set their targeted level of capital stock at the pre-disaster level $\bar{K}_{js}$ and $\bar{K}_{res,h}$, respectively. We use the capital matrix coefficients, d_s^{ir}, to express the quantities of product i in region r that are invested to formulate one unit of capital in region s. We assume that different sectors in the same region share the same capital matrix coefficients. Therefore, the targeted demand for product i to support reconstruction of sector j in region s and the residential sector in region h at time step t, $ROD_{js}^{i,*}(t)$ and $ROD_{res,h}^{i,*}(t)$, are calculated as below:

$$ROD_{js}^{i,*}(t) = \sum_r \left(\bar{K}_{js} - K_{js}(t)\right) \times d_s^{ir}, \tag{32}$$

and

$$ROD_{res,h}^{i,*}(t) = \sum_r \left(\bar{K}_{res,h} - K_{res,h}(t)\right) \times d_h^{ir}. \tag{33}$$

Here $K_{js}(t)$ and $K_{res,h}(t)$ are the capital stock held by sector j in region s and the residential sector in region h at time t, respectively, which are derived from Equations (21) and (22).

Then the orders issued by the reconstruction activities of sector j in region s and the residential sector in region h to the suppliers of product i in region r are as below:

$$ROD_{js}^{ir}(t) = ROD_{js}^{i,*}(t) \times \frac{d_s^{ir} \times \left(1-\gamma_r^C(t)\right) \times x_{ir}^a(t)}{\sum_r d_s^{ir} \times \left(1-\gamma_r^C(t)\right) \times x_{ir}^a(t)}, \tag{34}$$

and

$$ROD_{res,h}^{ir}(t) = ROD_{res,h}^{i,*}(t) \times \frac{d_h^{ir} \times \left(1-\gamma_r^C(t)\right) \times x_{ir}^a(t)}{\sum_r d_h^{ir} \times \left(1-\gamma_r^C(t)\right) \times x_{ir}^a(t)}. \tag{35}$$

Finally, the total orders received by sector i in region r are:

$$TD_{ir}(t) = \sum_s \sum_j FOD_{js}^{ir}(t) + \sum_k \sum_h HOD_{kh}^{ir}(t) + \sum_s \sum_j ROD_{js}^{ir}(t) + \sum_h ROD_{res,h}^{ir}(t). \tag{36}$$

At each time step, the economic agents on the supply and demand sides go through the above production, allocation and recovery and demand adjustment procedures. This discrete-time dynamic procedure can reproduce the economic equilibrium and simulate the propagation of exogenous shocks in the economic network. The direct cost of each sector due to the compound event DC_{ir} is defined as the capital damage in that sector caused by the flood, and the indirect cost IC_{ir} is the value-added loss of that sector caused by both the flood and epidemic control during the entire economic recovery, given by:

$$DC_{ir} = \sum_t \left(K_{ir}^D(t) + K_{res,r}^D(t)\right), \tag{37}$$

and

$$IC_{ir} = \sum_t \left(\overline{va}_{ir} - va_{ir}(t)\right). \tag{38}$$

Here $va_{ir}(t)$ and $\overline{va}_{ir}$ is the value-added of sector i in region r at time t and at the pre-disaster level, respectively, as defined in Equation (16) in Indicator 4.1.2.

Data

1. Data on physical or direct damage of the climate-related extreme events between 2017-2019 is sourced from the China Statistical Yearbooks on Environment[104] and that between 2020-2021 is from the reports of Ministry of Emergency Management of China[105,106]. We have excluded the

damage caused by earthquakes from the total damage of natural disasters, and the climate-related disasters in this report refer to droughts, floods, hailstorms and thunderstorms, cyclones, blizzards and extreme low temperatures. Data processing are in the same way as the 2021 report. The direct damage due to climate-related extreme events is first broken down into three industrial sectors (i.e., primary, secondary and tertiary industries) and a residential sector, according to the proportions based on empirical evidence of China's historical events between 1961-1990 sourced by Yin, Hu [107], and damages of the three industrial sectors are further disaggregated into the 20 production sub-sectors (see Table 32 in Indicator 4.1.2) in proportion to their value added of the relevant years.

2. Disaster data on Zhengzhou floods is collected by the "Flood Disaster Action Group" in Zhengzhou University[108].

3. The IO tables used for this indicator are from the same sources and processed in the same way as Indicator 4.1.2.

4. China's GDPs and currency exchange rates of the relevant years are obtained from China Statistical Yearbook 2021[85] and China's 2021 Statistical Bulletin on National Economics and Social Development[100]. Regional GDPs in Henan province and its capital city Zhengzhou in 2021 are collected from local bureaus of statistics[109,110].

Caveats

The model does not consider productivity losses of labours, another key productive factor, resulting from climate-related extreme events, as such data is not available at present. However, empirical evidence shows that compared to the percentage losses of capital, the relative losses of labour are usually much lower, so that they have little effect on the modelling results.

We do not consider the health costs caused by the coronavirus outbreak during the Zhengzhou's compound event, as we mainly focus on its economic impacts and the propagation effects through the production supply chain.

Future Form of Indicator

This indicator will be developed to provide more updated loss information on the provincial scale.

Additional Information

Table 37: China's economic losses from climate-related extreme events by sector and year. The direct and indirect costs are given in billions of US$ at 2020 prices, and the relative costs are given as percentages of China's GDP.

Year	Direct losses				Indirect losses			% GDP
	Primary industry	Secondary industry	Tertiary industry	Residential sector	Primary industry	Secondary industry	Tertiary industry	
2017	2.9	8.3	8.2	25.4	7.6	2.5	2.9	0.44%
2018	2.6	7.5	7.5	23.1	6.0	1.4	2.5	0.35%
2019	3.0	8.6	8.6	26.5	6.9	1.6	2.9	0.40%
2020	3.4	9.9	9.8	30.3	7.9	1.8	3.3	0.45%
2021	3.1	8.9	8.8	27.3	7.1	1.6	3.0	0.35%

Table 38: China's economic losses at the provincial level, in percent of regional GDP, from climate-related extreme events in 2019.

Provinces	Direct costs	Indirect costs	Total costs
Beijing	0.02%	0.01%	0.03%
Tianjin	0.00%	-0.04%	-0.04%
Hebei	0.06%	-0.03%	0.03%
Shanxi	0.65%	0.07%	0.72%
Inner Mongolia	0.25%	0.02%	0.28%
Liaoning	0.17%	-0.01%	0.17%
Jilin	0.30%	0.03%	0.33%
Heilongjiang	1.15%	0.89%	2.04%
Shanghai	0.01%	-0.05%	-0.04%
Jiangsu	0.02%	-0.03%	-0.02%
Zhejiang	0.94%	0.25%	1.19%
Anhui	0.25%	0.23%	0.48%
Fujian	0.32%	0.62%	0.94%
Jiangxi	1.42%	1.19%	2.61%
Shandong	0.51%	0.11%	0.62%
Henan	0.08%	0.09%	0.17%
Hubei	0.25%	0.08%	0.32%
Hunan	0.62%	0.33%	0.95%
Guangdong	0.05%	0.06%	0.11%
Guangxi	0.45%	0.22%	0.67%
Hainan	0.03%	-0.11%	-0.08%
Chongqing	0.09%	-0.02%	0.07%
Sichuan	0.64%	0.18%	0.82%
Guizhou	0.29%	0.03%	0.32%
Yunnan	0.52%	0.11%	0.63%
Tibet	0.11%	0.04%	0.15%
Shaanxi	0.23%	-0.02%	0.21%
Gansu	0.33%	0.13%	0.46%
Qinghai	0.24%	-0.23%	0.00%
Ningxia	0.07%	0.03%	0.10%
Xinjiang	0.30%	0.51%	0.81%
Macao	Null	Null	Null
Hong Kong	Null	Null	Null
Taiwan	Null	Null	Null
Total	0.32%	0.15%	0.47%

Table 39: Economic losses of Zhengzhou's compound event (in billions of 2020 US$).

Regions	Direct losses	Indirect losses		Total losses	% of local GDP
		Flood-related	Epidemic-related		

Zhengzhou	9.9	3.6	3.0	16.5	8.74%
Henan (except Zhengzhou)	-	1.1	0.7	1.8	0.26%
China (except Henan)	-	0.8	0.5	1.3	0.01%
Sum	9.9	5.5	4.2	19.6	0.12%

During the compound event of Zhengzhou's extreme rainfalls and COVID epidemic, the local lockdown to control the epidemic has increased the indirect losses by 77% and the indirect/direct loss ratio from 0.55 to 0.98. Zhengzhou's non-metallic mineral sector is also a critical sector with strong propagation effects. The reduction in its production has triggered US$1.6 billion of losses, which nearly doubled its value-added loss, in trades with other sectors and regions.

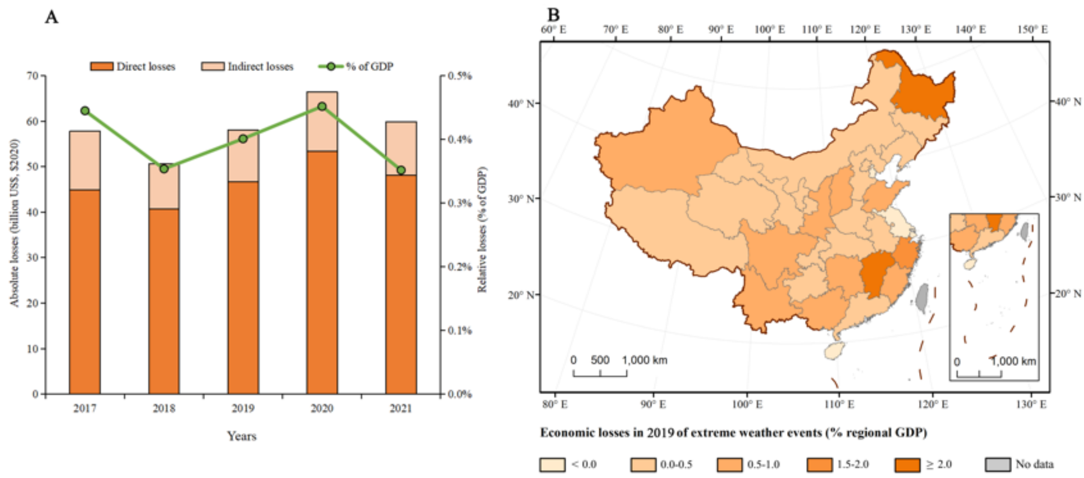


Figure 44: **Economic losses due to climate-related extreme events.**

(A) National-level results, by year, in billions of 2020 US$; (B) Provincial-level results in 2019, relative to provincial GDPs.

Note: Negative values indicate economic gains from the stimulus effects of post-disaster reconstruction and inter-provincial substitution.

Indicator 4.2: The economics of the transition to zero-carbon economics

Indicator 4.2.1: Investment in new coal and low-carbon energy

Methods

In this indicator 4.2.1, the methodology this year has followed the same methodology in previous year, and investment data was updated to the current 2021. Investment in each year indicate that new power generation facility is assigned to the year in which the power plant became operational. The main data is from the Wind Economic database[111]. Wind is a comprehensive and paid database which massively combines macro and sectoral data. It is commonly used for financial and macro analysis. Four categories of energy investment (Thermal, nuclear, hydro, and wind) are from Wind Economic database. Investment of Solar PV has been derived from new power generation facilities (Wind Economic database) and unit investment. Investment of Biomass is from National Energy Administration[112]. Six categories of energy investment are defined:

• Thermal power – investment in fixed capital information and constructing power generation facilities of coal-, gas-, and oil-fired electricity.

• Nuclear –investment in fixed capital information and constructing power generation facilities of nuclear electricity.

• Hydro power – investment in fixed capital information and constructing power generation facilities of hydroelectricity.

• Wind power – investment in fixed capital information and constructing power generation facilities of wind electricity.

• Solar PV – investment in fixed capital information and constructing power generation facilities of solar electricity.

• Biomass – investment in fixed capital information and constructing power generation facilities of biomass electricity.

• Grid – investment in fixed capital information of constructing overall power grid.

In 2021 report, we also updated data of new power capacity facilities in national and provincial level for thermal, nuclear, hydro, wind and solar PV from Wind Economic database. Due to unavailable public access of provincial investment. Thus, to analyze provincial investment of low-carbon energy, we process the national-level new investment of power generation (Table 40) and new capacity of power generation facilities (Table 41) to derive unit investment of each energy types from 2008 to 2021, and then we further calculated to have provincial investment data on new power generation facility (Table 42).

Data

1. New investment of power generation facility data in national-level, listed by wind, hydro, nuclear, thermal and overall power grid, is taken from the Wind Economic database[111].

2. New capacity of power generation facilities data in national and provincial-level, listed by thermal, nuclear, hydro, wind and solar PV, is taken from Wind Economic database[111].

3. Biomass data is taken from the National Energy Administration[112].

4. Currency exchange rate is based on 2021 RMB￥to 2021 US$, the value is further adjusted to CPI 2020=1 according to National Bureau of Statistics of China[113].

Caveats

Low-carbon energy investment here mainly includes centralized project but excludes investment in decentralized facilities. For biomass new investment, complete provincial-level data in 2021 is not available, only a few provinces have data from government official sources.

Future Form of Indicator

Future indicator may consider provincial-level grid investment. The regional grid capacity shall well-collaborate with low-carbon power generation facilities.

Additional Information

Table 40: New investment in power generation facilities from 2008 to 2021 (US$ billion, CPI 2020=1)

	Biomass	Nuclear	Hydro	Wind	Solar	Thermal	Total
2008		5.112	13.171	8.181		26.044	52.508
2009		9.664	14.35	12.936	0.032	25.542	62.524
2010		10.301	13.03	16.504	0.218	22.685	62.738
2011		11.91	15.13	14.069	2.139	17.668	60.916
2012	12.075	12.564	19.839	9.727	1.203	16.055	71.464
2013	15.375	9.753	19.955	10.104	12.673	14.862	82.721
2014	16.222	8.582	15.184	14.748	9.304	18.444	82.484
2015	18.619	9.156	12.785	19.446	14.538	18.846	93.39
2016	19.186	8.12	9.942	14.928	39.006	18.031	109.213
2017	21.477	7.342	10.059	11.014	60.426	13.876	124.195
2018	21.517	7.033	10.847	10.332	35.993	12.505	98.227
2019	23.985	7.793	14.451	24.512	19.057	12.136	101.933
2020	26.114	6.06	17.265	41.969	27.044	8.865	127.316
2021	38.512	8.548	15.697	31.49	28.8	10.677	133.723

Table 41: New power generation facilities from 2008 to 2021

	Biomass	Nuclear	Hydro	Wind	Solar	Thermal	Total
2008			21.483	4.991		65.545	92.019
2009			21.057	9.73	0.028	65.858	96.672
2010		1.737	16.428	14.573	0.196	58.306	91.24
2011		1.747	12.828	15.278	1.96	62.413	94.226
2012	0.5	0.66	16.76	12.96	1.073	52.36	84.313
2013	4.35	2.208	29.93	14.064	11.305	36.5	98.357
2014	0.9	5.472	21.797	21.006	8.251	47.906	105.332
2015	0.91	7.241	16.076	29.609	12.817	63.997	130.649
2016	1.83	7.2	11.74	18.73	34.59	48.36	122.45
2017	2.74	2.175	12.875	19.517	53.375	45.778	136.46
2018	3.05	8.84	8.54	21	44.73	41.19	127.35
2019	4.73	4.09	4.45	25.72	26.52	44.23	109.74
2020	5.43	1.12	13.13	72.11	48.2	56.6	196.59
2021	8.08	3.4	23.49	47.57	54.93	46.28	183.75

Table 42: Provincial level data of investment in power sector construction in 2020. (US$ billion)

	Low-carbon	Thermal

Beijing	0.133	0.002
Tianjin	0.378	0.152
Hebei	6.022	0.348
Shanxi	1.723	1.497
InnerMongolia	2.348	0.803
Liaoning	0.743	0.247
Jilin	1.663	0.035
Heilongjiang	1.721	0.311
Shanghai	0.333	0.138
Jiangsu	5.771	0.75
Zhejiang	4.008	0.364
Anhui	2.656	0.171
Fujian	2.495	0.328
Jiangxi	1.073	0.602
Shandong	6.996	0.791
Henan	4.196	0.611
Hubei	2.887	0.143
Hunan	1.242	0.551
Guangdong	5.823	1.158
Guangxi	1.21	0.302
Hainan	0.143	0.134
Chongqing	0.561	0.039
Sichuan	7.484	0.544
Guizhou	0.976	0.03
Yunnan	3.504	0.035
Shaanxi	2.154	0.03
Gansu	3.283	0.016
Qinghai	0.683	0.001
Ningxia	1.496	0.023
Xinjiang	1.735	0.526
Tibet	0.564	

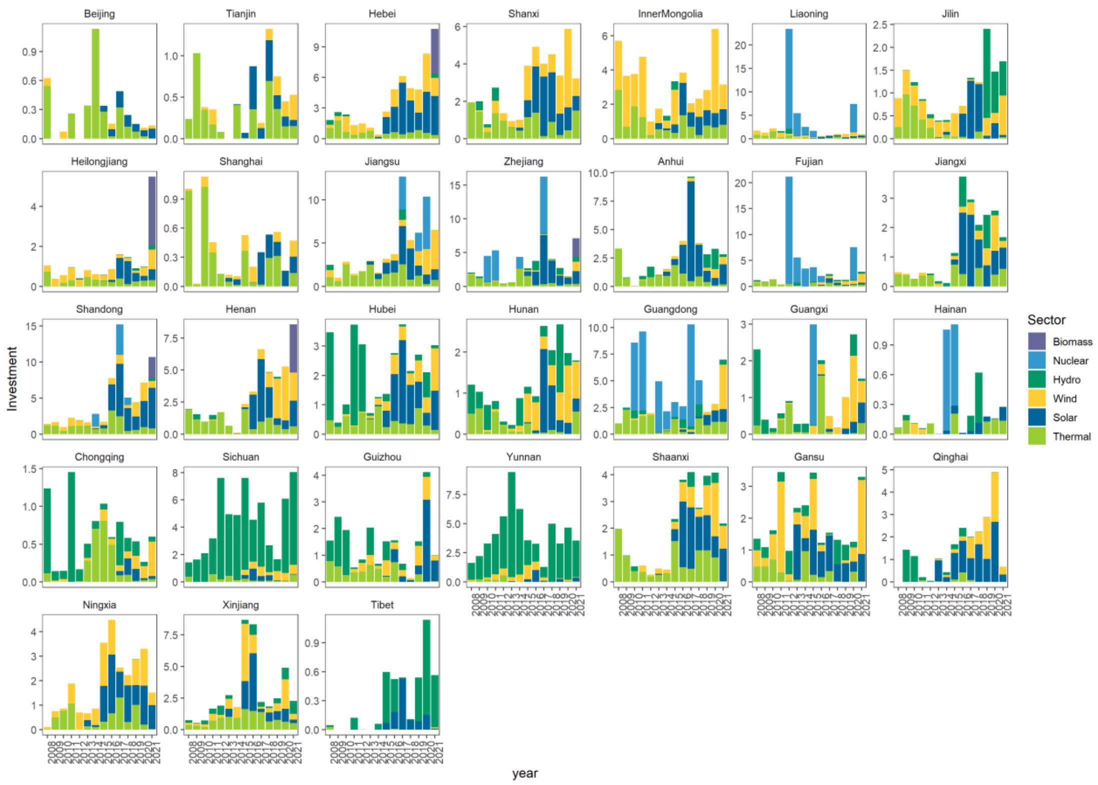


***Figure* 45: Investment in new power generation in China (US$ Billion).**

Indicator 4.2.2: Employment in low-carbon and high-carbon industries

Methods

This indicator presents China's direct employment in fossil fuel extraction industries, including coal mining, oil and gas exploration and extraction, as well as direct and indirect employment in renewable energy. The methodology for this indicator remains the same as in the 2021 China Lancet Countdown report.

The data for this indicator is sourced from IRENA Renewable Energy and Jobs Annual Review 2021[114] (renewables) and CEIC Data (2012-2020)[115] (fossil fuel extraction), National Bureau of Statistics of China[111].

Renewable industries included are:

- Solar energy;
- Wind energy;
- Bioenergy;
- Hydropower;
- Other technologies.

Bioenergy includes liquid biofuels, soil biomass and biogas. Solar energy includes solar heating/cooling; solar photovoltaic and concentrated solar power, 'Other technologies' includes geothermal energy, ground-based heat pumps, municipal and industrial waste, and ocean energy. Fossil fuel extraction includes coal mining, oil and gas exploration and production. Fossil fuel extraction values include direct employment, whereas renewable energy jobs include direct and indirect employment (e.g., equipment manufacturing), except for large hydropower (direct employment only).

Due to an improvement in data collection and estimation methodology, employment values reported for other technologies are unavailable in some years.

Data

1. Data on renewable energy employment is sourced from IRENA Renewable Energy and Jobs Annual Review 2021. [114]

2. Data on employment in fossil fuel extraction is from CEIC Data (2012-2020) [115], National Bureau of Statistics of China. [111]

Caveats

The caveats of this indicator can be described in three aspects. Provincial level data is not available for most recent years and employment in low-carbon industries data is only available from 2012. Both direct and indirect employment in renewable industries is counted, whereas only direct employment in fossil fuel extraction is considered for employment in fossil fuel industries.

Future Form of Indicator

An ideal future form of this indicator would track both direct and indirect employment from the renewables and fossil fuel extraction industries, along with the provincial level distribution in their change over time.

Additional Information

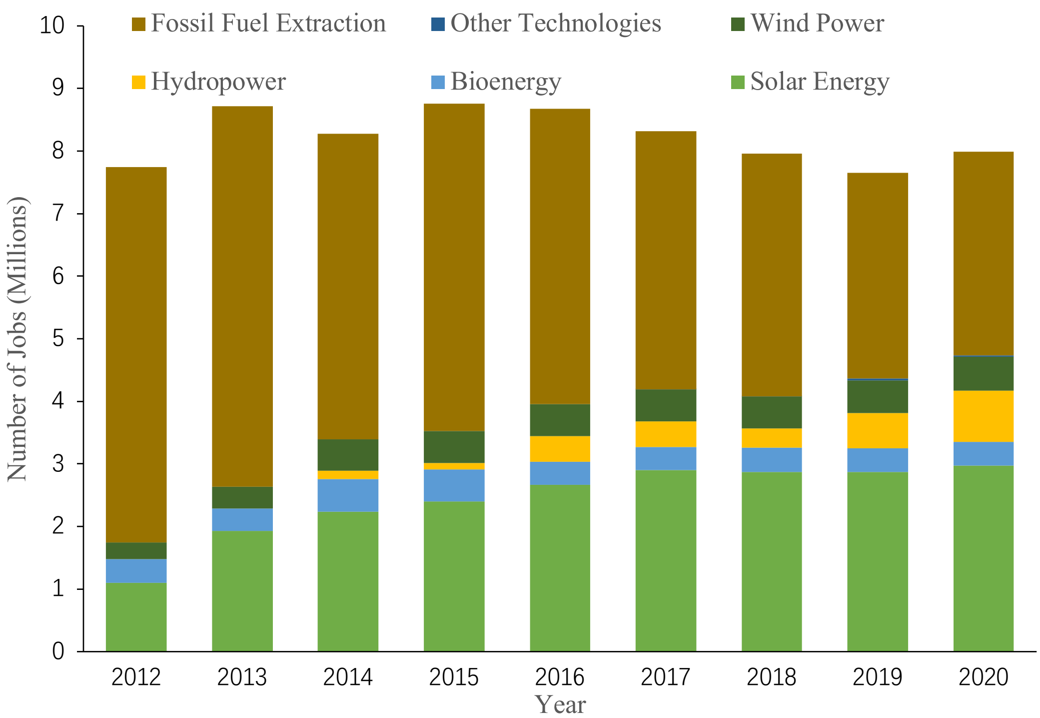


***Figure* 46: Employment in renewable energy and fossil-fuel extraction sectors**

Table 43: China employment in renewable energy and fossil-fuel extraction sectors (Million Jobs)

	2012	2013	2014	2015	2016	2017	2018	2019	2020
Solar Energy	1.1	1.93	2.241	2.395	2.663	2.897	2.875	2.87	2.97
Bioenergy	0.38	0.354	0.521	0.521	0.376	0.376	0.382	0.384	0.384
Hydropower	0	0	0.126	0.1	0.407	0.407	0.308	0.561	0.814
Wind Power	0.267	0.356	0.502	0.507	0.509	0.51	0.51	0.518	0.55
Other Technologies	0	0	0	0	0	0.002	0.003	0.028	0.014
Fossil Fuel Extraction	5.996	6.072	4.884	5.238	4.72	4.13	3.881	3.294	3.257

Indicator 4.2.3: Net value of fossil fuel subsidies and carbon prices

Methods

The methodology for this indicator is the same as described in the 2021 global and China Lancet Countdown report appendix.[11,19] The data for fossil fuel consumption subsidies is taken from the IEA[116], which is calculated based on the price-gap approach. As the most commonly applied methodology for quantifying consumption subsidies, the price-gap approach compares average end-user price paid by consumers with reference prices that reflect full cost of supply. Therefore, the price gap equals to the amount by which an end-use price falls short of the reference price, indicating the presence of a subsidy. Prices are presented in real 2020 US$. Original data and a detailed description of the calculation methodology can be obtained from the IEA (2022).[116] The data for carbon price of eight carbon emission trading markets are taken from the Wind Economics Database 2021[111]. Carbon price of national and eight pilot emission trading markets has been updated to the latest 2021 data, and carbon price between 2013 to 2021 has been converted to the 2020 constant price.

Data

1. IEA, Fossil Fuel Subsidies Database[116]

2. Wind Economic Database[111]

Caveats

Coal consumption subsidies for all the years during 2010 to 2020, and gas consumption subsidies for some years are unavailable, due to the lack of consistent data. Moreover, values do not include the economic value of the unpriced negative externalities.

National carbon price in China has started in 2021 July, available data is from July to December 2021. Data of carbon price and cumulative trading volume of eight pilot emission trading markets of Beijing, Shanghai, Shenzhen, Guangzhou, Tianjin, Hubei, Chongqing, and Fujian are from 2013 to 2021.

Future Form of Indicator

1. The consistent inclusion of production and consumption subsidies for all fuels, especially coal, available on an annual basis.

2. More focus on national carbon price trend as more data will be available in the future.

Additional Information

Carbon price appeared in great variance in eight pilot carbon emissions trading market in China, from US$ 9.53 per tCO_2 in Beijing, to US$ 1.82 per tCO_2 in Shenzhen in 2021[111]; however, price differentials between the trading markets have narrowed in 2021 compared with 2020. Guangzhou still stayed on the top of the cumulative trading volumes, reaching 177,930 kton in 2021, which is around10.84 times of the volumes of Beijing.

Table 44: Fossil fuel consumption subsidies in China, 2010-2020 (billion real 2020 US$)

Year	Oil	Electricity	Gas	Coal	Total
2010	12.78	32.06	-	-	44.84
2011	12.29	34.01	0.57	-	46.87
2012	11.89	25.24	1.14	-	38.27
2013	12.54	14.58	2.52	-	29.65
2014	11.60	11.26	3.24	-	26.10
2015	13.47	11.26	-	-	24.73
2016	15.71	32.86	-	-	48.57
2017	18.12	29.97	-	-	48.09
2018	16.75	32.27	1.46	-	50.48
2019	18.84	15.17	-	-	34.01
2020	21.72	3.77	-	-	25.49

Table 45: Average carbon price of eight carbon emission trading markets. (US$/ton)

	2013	2014	2015	2016	2017	2018	2019	2020	2021
Shenzhen	11.85	9.91	5.96	4.94	4.31	3.85	1.94	3.40	1.82
Shanghai	4.74	5.86	3.76	1.57	5.01	5.41	5.89	5.80	6.40
Beijing	8.34	8.89	7.58	7.29	7.47	8.38	11.46	12.63	9.53
Guangdong	9.71	8.21	3.01	1.84	2.03	2.14	3.19	3.95	6.11
Tianjin	4.66	4.77	3.64	3.17	1.74	1.82	1.98	3.27	4.33
Hubei	0.00	3.88	3.87	2.71	2.24	3.20	4.66	3.95	5.36
Chongqing	0.00	4.98	2.63	2.61	0.66	1.38	1.42	3.84	4.79
Fujian					4.47	2.84	2.35	2.51	2.62

Table 46: Carbon emission cumulative trading volume (1000 ton)

	2013	2014	2015	2016	2017	2018	2019	2020	2021
Shenzhen	197.328	2013.709	6339.757	16983.642	22229.572	34887.034	43311.279	44550.474	50543.34
Shanghai	23.27	1689.994	3166.102	7033.173	9401.501	12067.462	14704.684	16545.073	17925.117
Beijing	2.6	1074.105	2328.691	4795.59	7233.141	10429.578	13499.397	14551.591	16417.417
Guangdong	120.129	1175.671	7932.191	30165.186	46738.574	73599.032	118982.613	151095.054	177930.49
Tianjin	17.2	1028.54	2004.253	2372.049	3534.419	5409.624	6541.087	13715.65	18664.313
Hubei		7001.171	20905.271	32628.064	45116.956	53724.446	59863.309	74141.425	79703.12
Chongqing		145	277.099	737.05	8173.653	8443.098	8495.188	8657.559	9808.114
Fujian					2069.555	2934.769	4065.266	991.436	2217.05

Table 47:National carbon price from July to December 2021 (US$/ton).

	Jul	Aug	Sep	Oct	Nov	Dec
China	8.16	7.37	6.59	6.64	6.47	6.76

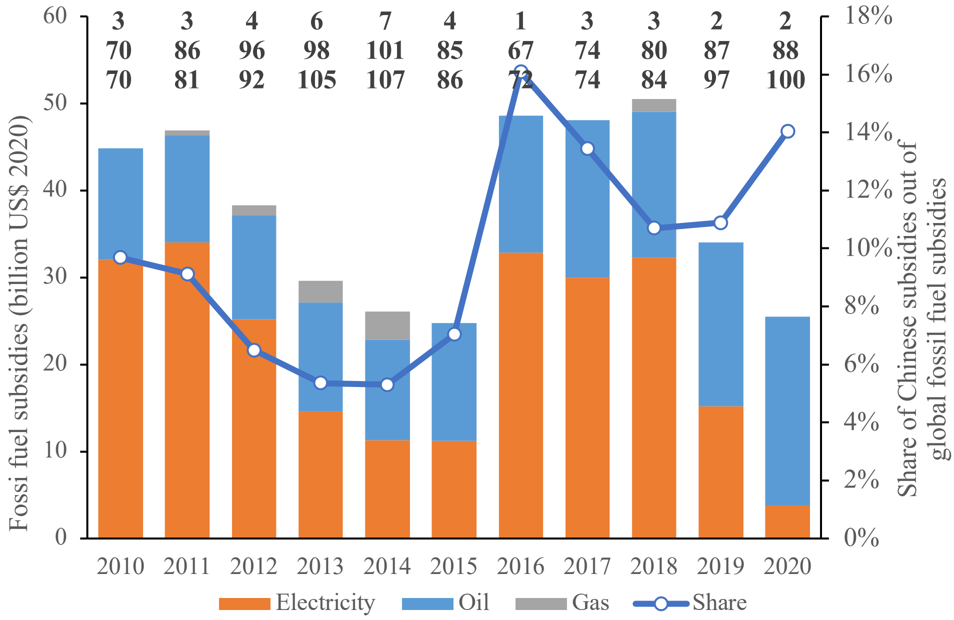


Figure **47: Fossil fuel and electricity consumption subsidies in China, 2010-2020**

Note: The number on top of each bar represents the rank of fossil fuel subsidy of China in the world on the corresponding year, the global ranking of fossil fuel consumption subsidies per capita of China in the world on the corresponding year, and the global ranking of fossil fuel consumption subsidies per unit of GDP of China in the world on the corresponding year.

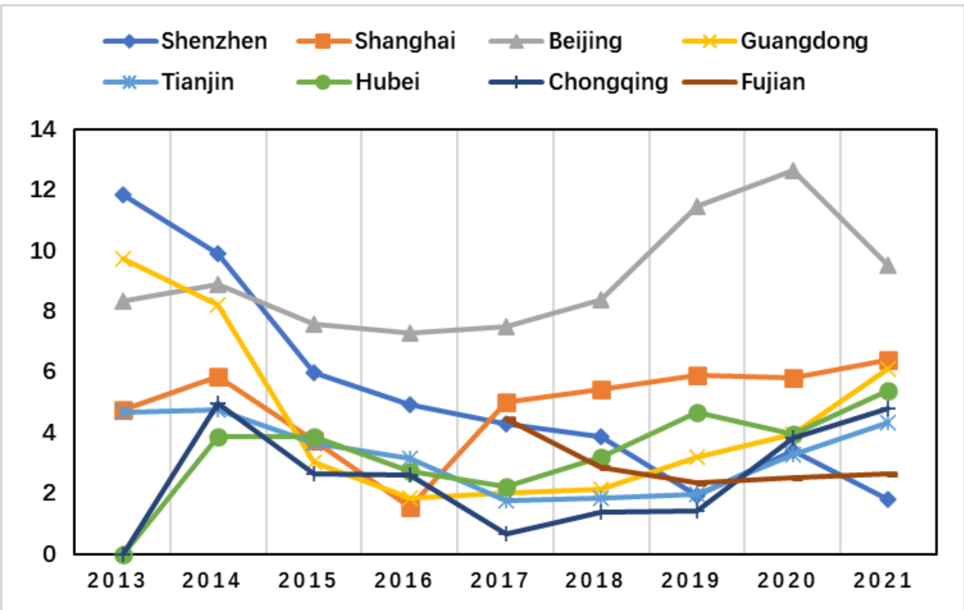


Figure 48: **Carbon price in eight pilot carbon emissions trading market in China.**

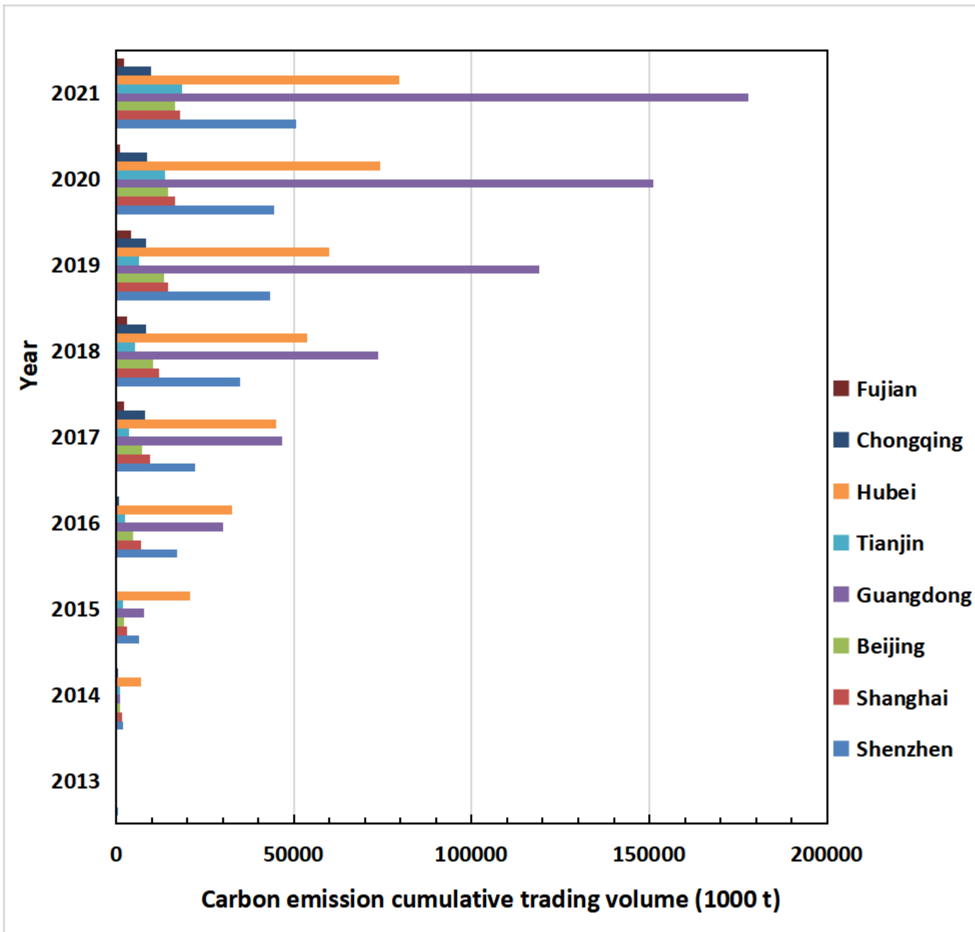


***Figure* 49: Carbon emission cumulative trading volume (1000t).**

Section 5: Public and political engagement

Indicator 5.1: Media coverage of health and climate change
Indicator 5.1.1: Social media

Method

Four steps to filter the posts, as shown below: Key words for the topics of (a) Climate Change, and (b) Health were identified as shown in **Table 48.**

Table 48 Chinese keywords for the search in Weibo

中文 Chinese		英文 English	
气候相关词汇	健康相关词汇	Key words for "Climate Change"	Key words for "Health"
气候变化	疟疾	Climate change	Malaria
全球变暖	腹泻	Global worming	Diarrhea
温室	感染	Greenhouse	Infected
极端天气	肺炎	Extreme weather	Pneumonia
全球环境变化	流行病	Global environment change	Epidemic
低碳	公共卫生	Low carbon	Public health
可再生能源	卫生	Carbon dioxide emissions	Hygiene
碳排放	发病	Renewable energy	Disease outbreak
二氧化碳排放	营养	Carbon Production	Nutrition

气候污染	精神障碍	Air pollution	Mental disorders
气候	发育	Climate	Growth
全球升温	传染	Global warming	Infection
再生能源	疾患	Renewable energy	Affection
CO2 排放	症	CO2 emissions	Symptom
~~污染~~	瘟疫	~~Pollution~~	Epidemic
极端气候	流感	Extreme weather	Flu
高温	流行感冒	High temperature	Influenza
变暖	治疗	Warming	Treatment
排放	保健	Emission	Health care
环境变化	健康	Environmental change	Health
升温	死亡	Warming	Death
全球温升	精神疾病	Global warming	Mental disease
热浪	精神病	Heat wave	Mental illness
暴雨	登革热	Rainstorm	Dengue
气温	饥饿	Temperature	Hunger
洪水	粮食	Flood	Food
洪灾	有害	Flood	Harmful
气候反常	皮肤病	Abnormal weather	Skin disease
野火	风湿	Wildfire	Rheumatism
山火	呼吸系统疾病	Mountain fire	Respiratory diseases
雪灾	人类健康	Snowstorm	Human health
低温	人体健康	Low temperature	Body health
年代际	身体健康	Interdecadal	Heart disease
冰雪	心脏病	Ice and snow	Diabetes
可持续发展	糖尿病	Sustainable development	Illnesses
海洋酸化	疾病	Ocean acidification	Heat death
静稳	热死	Stagnant	Mask
温室气体	口罩	Greenhouse gas	Protection
	防护		Survive

The detailed steps of the method used in 2021 is shown as below:

Step 1: Crawling all the climate change posts from 2010 to 2021 on Weibo

With a python-based crawler, all qualified posts published by seven Weibo accounts @People's Daily, @The Beijing News, @China Science Daily, @HealthTimes, @The Paper, @Xinhuanet, @China Meteorological News were collected from January, 2010 to December, 2021. 37 climate change related keywords were used, which is in accordance with the new climate change keywords used in the study of *Media coverage of health and climate change for People's Daily in China*[117]. The keywords are presented in the column of "Climate Change" in **Table 48**.

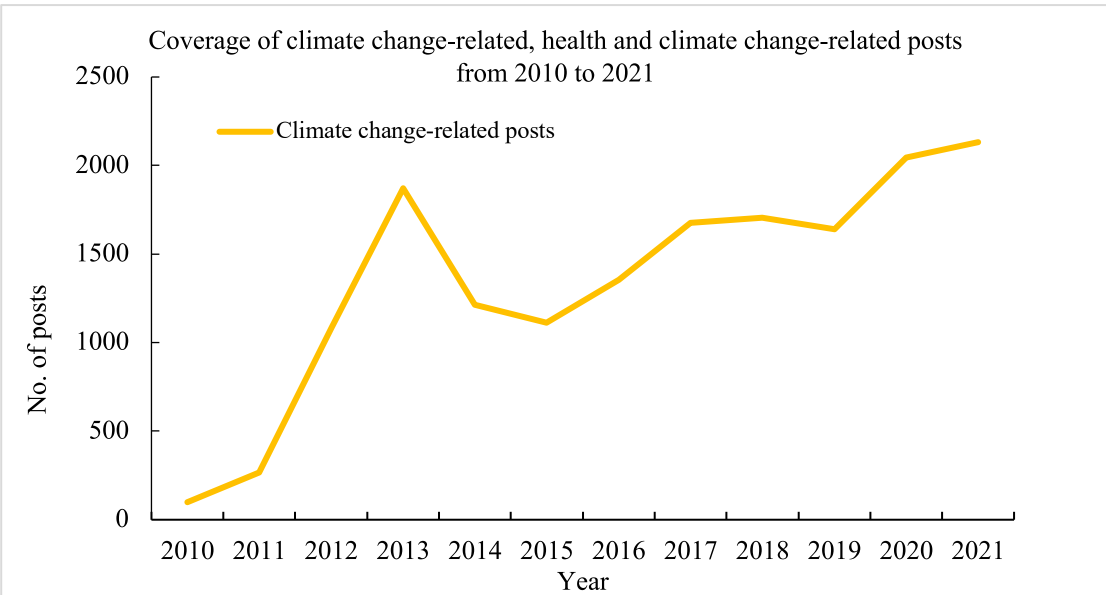


Figure 50: Coverage of climate change on Weibo between 2010 and 2021

Step 2: Searching for health-related posts

It was examined whether these posts show concern for public health by searching health-related keywords, which is presented in the column of "Health" in **Table 48**. Our choice of health keyword list followed previous research of Media coverage of health and climate change for People's Daily in China (Watts, et al., 2019)[117]. If a post contains at least 1 health-related word and word frequency ratio in the whole post is greater than 0.01, this post is regarded as relevant to health topics. Manual screening is also included in this step. The results are shown in **Figure 51**.

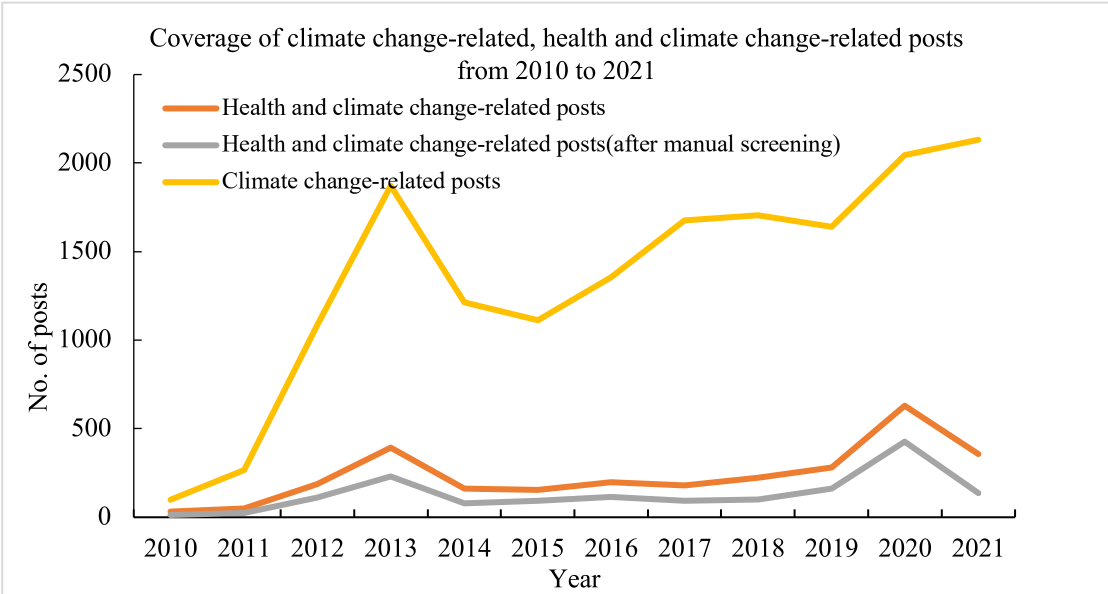


Figure 51: Coverage of climate change and health and climate change on Weibo between 2010 and 2021

Step 3: Manual screening was added to test the positive rate

We add manual screening process to test the data of health and climate change related posts and climate change related posts. 138 was selected from a total number of 357 posts related to health only and 1733 was selected from a total number of 2132 posts concerning climate change by seven media (@People's Daily, @The Beijing News, @China Science Daily, @Health Times, @The Paper, @Xinhuanet,

@China Meteorological News) in 2021, with a false positive rate at 0.61 and 0.19 respectively.

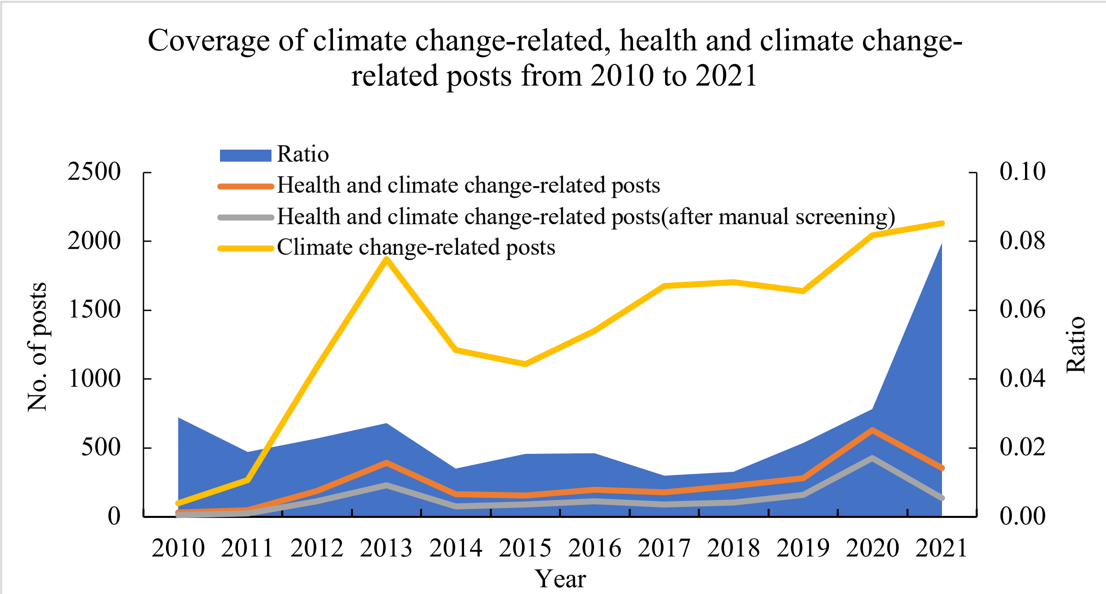


Figure 52: Coverage of climate change, health and climate change on seven media accounts on Weibo from 2020 to 2021

Step 4: With a python-based crawler, all qualified posts published by seven Weibo accounts @People's Daily, @The Beijing News, @China Science Daily, @HealthTimes, @The Paper, @Xinhuanet, @China Meteorological News were collected from January, 2021 to December, 2021. 11 COVID-19 related keywords were used, which are presented in **Table 49**. And the elderly related posts were selected from health and climate change-related posts by manual screening in 2021, which was showed in **Figure 53**.

Table 49: COVID-19 keywords for the search in Weibo

中文 Chinese	**英文 English**
	COVID Coronavirus Corona
新冠*（新冠病毒，新冠病毒肺炎，新冠疫情，新冠病毒肺炎疫情） 新型冠状病毒	COVID* coronavirus
疫情 冠状病毒 武汉肺炎 SARS COVID*（COVID-19，COVID 19，COVID19） Coronavirus SARS-CoV-2	COVID-19 COVID 19 COVID19 Coronavirus SARS-CoV-2 2019 novel coronavirus (for picking up very early occurrences)

Table 50: Elderly keywords

中文 Chinese	英文 English
老年	The elderly
老人	Old people
老龄	Aging population

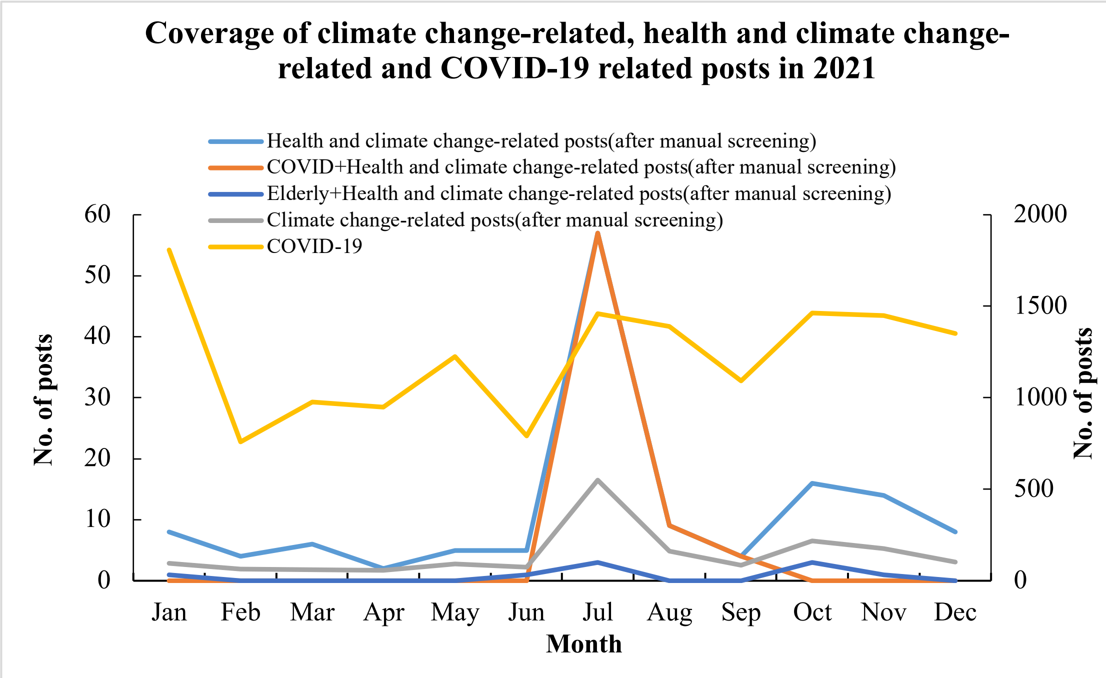


Figure 53 Coverage of elderly health and climate change of seven media (People's daily, Xinhuanet, The Paper, and The Beijing News, China Science Daily, Health Times, and China Meteorological News) on Weibo in 2021

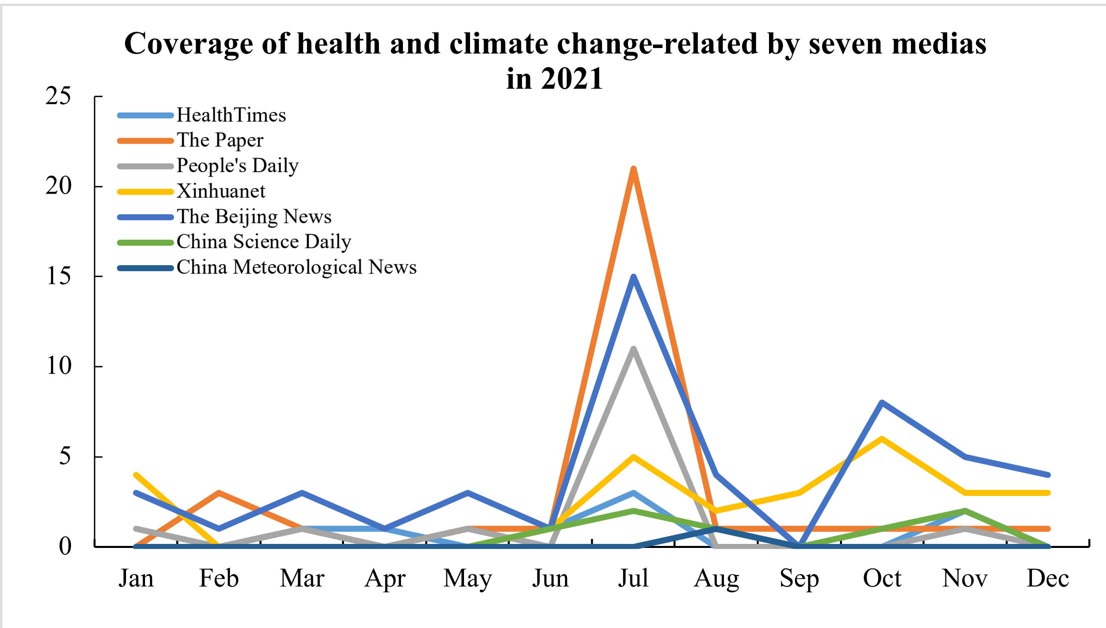


Figure 54 Coverage of health and climate change of seven media (People's daily, Xinhuanet, The Paper, and The Beijing News, China Science Daily, Health Times, and China Meteorological News) on Weibo in 2021

Data

Between 2010 and 2021, an average of 1350 posts per year were made about climate change, with human health accounting for 9.76 percent, or 132 posts per year (after manual filtering). Around 7470 COVID-19 posts were published in 2021, with just 18 (after manual filtering) relating to both COVID-19 and health. There were just roughly 9 entries addressing the elderly and health-related issues in 2021.

Future Form of Indicator

1. The keywords used in this research are obtained from the study of Media coverage of health and climate change for People's Daily in China after manual screen, which is a traditional media. Therefore, the keywords should be more in line with the characteristics of social media in the future research.

Additional Information

For the Lancet Countdown China 2022 Report, this study aims to find media coverage of health and climate change research on social media of China. Data was collected with a python-based crawler. The reasons are as follows:

First, selected the Chinese social media platform *Weibo* (https://weibo.com/), which has a very high usage rate in China.

Second, several types of media accounts on Weibo were selected, including official media such as @人民日报(People's Daily), @新华社(Xinhuanet), commercial media such as @新京报(The Beijing News), @澎湃新闻(The Paper), and professional media @健康时报(Health Times), @中国科学报(China Science Daily) and (中国气象报) China Meteorological News.

Lastly, due to the word limit of Weibo posts, posts are generally very short, so when searching for related posts, as long as a relevant keyword appears, it is regarded as a qualified post.

Indicator 5.1.2: Newspaper coverage of health and climate change in China

Methods

Due to the influence of mainstream media on social media agenda, public perceptions, and public engagement, [118-121] this year the most influential newspaper in each of the 34 provinces was again tracked for their coverage of health and climate change (**Table 51**). Data were assembled by accessing archives through CNKI and WiseNews databases. To keep data consistency and comparability between indicators, search terms were aligned to those used for the indicator 5.1.1 with Boolean searches in Chinese. The search strategy was refined for the 2021 report to exclude false positives while retaining true positive articles. Newspaper articles from January 2008 to December 2021 were searched and downloaded for analysis of health and climate change in 34 newspapers selected to provide a national spread of influential papers.

Table 51: List of the 34 Chinese provincial newspapers

Provincial region	Newspaper	English translation
Anhui	安徽日报	Anhui Daily
Beijing	北京日报	Beijing Daily

Chongqing	重庆日报	Chongqing Daily
Fujian	福建日报	Fujian Daily
Gansu	甘肃日报	Gansu Daily
Guangdong	南方日报	South Daily
Guangxi	广西日报	Guangxi Daily
Guizhou	贵州日报	Guizhou Daily
Hainan	海南日报	Hainan Daily
Hebei	河北日报	Hebei Daily
Heilongjiang	黑龙江日报	Heilongjiang Daily
Henan	河南日报	Henan Daily
Hong Kong	明报	Ming Pao Daily
Hubei	湖北日报	Hubei Daily
Hunan	湖南日报	Hunan Daily
Inner Mongolia	内蒙古日报	Inner Mongolia Daily
Jiangsu	新华日报	Xinhua Daily
Jiangxi	江西日报	Jiangxi Daily
Jilin	吉林日报	Jilin Daily
Liaoning	辽宁日报	Liaoning Daily
Macao	澳门日报	Macao Daily
Ningxia	宁夏日报	Ningxia Daily
Qinghai	青海日报	Qinghai Daily
Shaanxi	陕西日报	Shaanxi Daily
Shandong	大众日报	Dazhong Daily
Shanghai	解放日报	Liberation Daily
Shanxi	山西日报	Shanxi Daily
Sichuan	四川日报	Sichuan Daily
Taiwan	中国时报	China Times
Tianjin	天津日报	Tianjin Daily
Tibet	西藏日报	Tibet Daily
Xinjiang	新疆日报	Xinjiang Daily
Yunnan	云南日报	Yunnan Daily
Zhejiang	浙江日报	Zhejiang Daily

Firstly, climate change related keywords in accordance with the keywords in the 2021 global Lancet Countdown report, were used to track news articles of climate change. The keywords used are the same as indicator 5.1.1, and identical to last year’s keywords to ensure comparability between indicators. The result is shown in **Figure 55**.

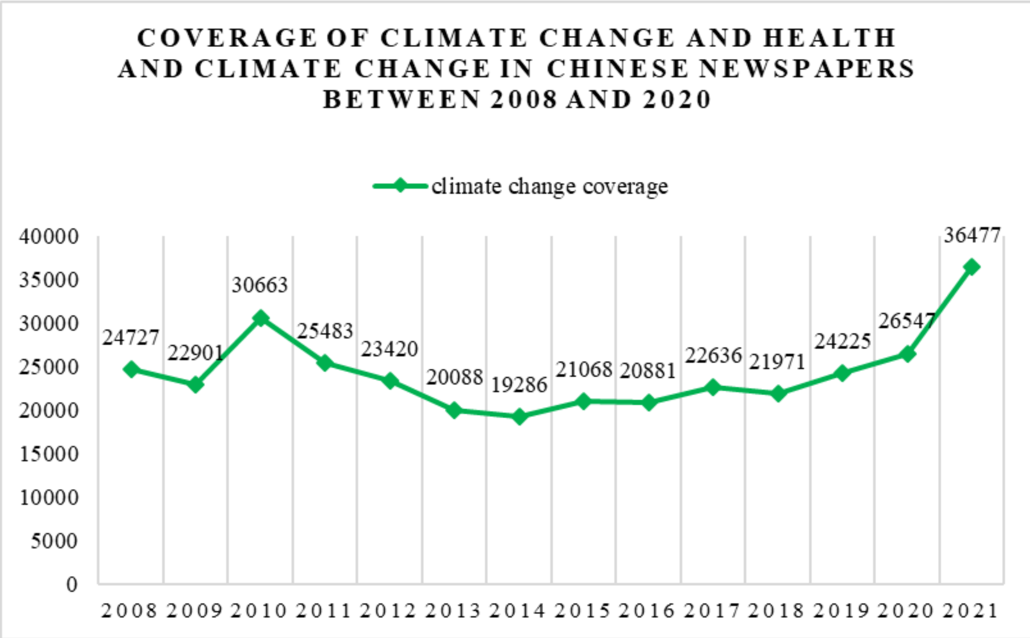


Figure 55 Number of climate-articles tracked in Chinese newspapers

Secondly, the climate-related and health-related key words were combined with Boolean searches. In the newspaper databases, the retrieval function was set as "keywords" and the relationship between the two groups of keywords as "and". The relevant articles published from 2008 to 2021 were retrieved respectively.

Thirdly, machine filtration was conducted based on the parameter setting regarding newspaper coverage in the global Lancet Countdown report. The threshold of score for each article is set to be 10, meaning the times of appearance of the keywords from both climate change and health in one article should be no less than 10. The threshold of ratio for each article is set to be no less than 1%, meaning in every 100 characters in the article, there should be no less than 1 keyword. The results before and after machine filtration are presented in **Figure 56.**

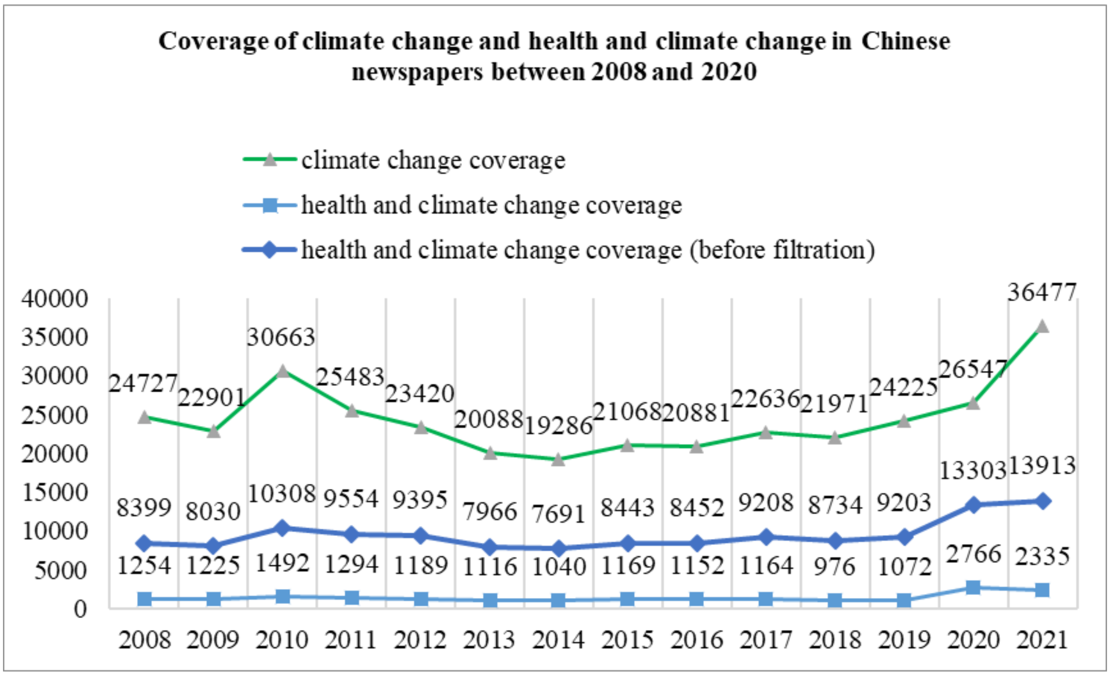


Figure 56: Numbers of climate-related articles (green line), health-related articles before machine

filtration (light blue line), and health-related articles after machine filtration (blue line)

Fourthly, with special attention paid to COVID-19 pandemic, COVID-19 keywords were used to search COVID-19 related articles within the newspaper coverage of health and climate change. The keywords (**Table 52**) which are in accordance with the 2021 global report, are slightly different from the keywords used in indicator 5.1.1.

Table 52: Keywords for the COVID-19 search in Chinese newspapers

Keywords for the COVID-19	English translation
COVID 新冠*（新冠病毒，新冠病毒肺炎，新冠疫情，新冠病毒肺炎疫情）	COVID Coronavirus Corona
COVID* 新型冠状病毒	COVID* coronavirus
COVID-19 COVID 19 COVID19 Coronavirus 冠状病毒 新冠肺炎 新冠疫情	COVID-19 COVID 19 COVID19 Coronavirus SARS-CoV-2 2019 novel coronavirus (for picking up very early occurrences)

Finally, this year articles on health and climate change that addressed the elderly or ageing population were identified in the 2022 report, with the keywords "the elderly, older people, or ageing population" ("老年" "老人" "老龄" in Chinese, seen **Table 53**) being used to search related articles within the newspaper coverage of health and climate change.

Table 53: Keywords for the elderly or aging population search in Chinese newspapers

Keywords for the elderly or aging population	English translation
老年	the elderly
老人	older people
老龄	ageing population

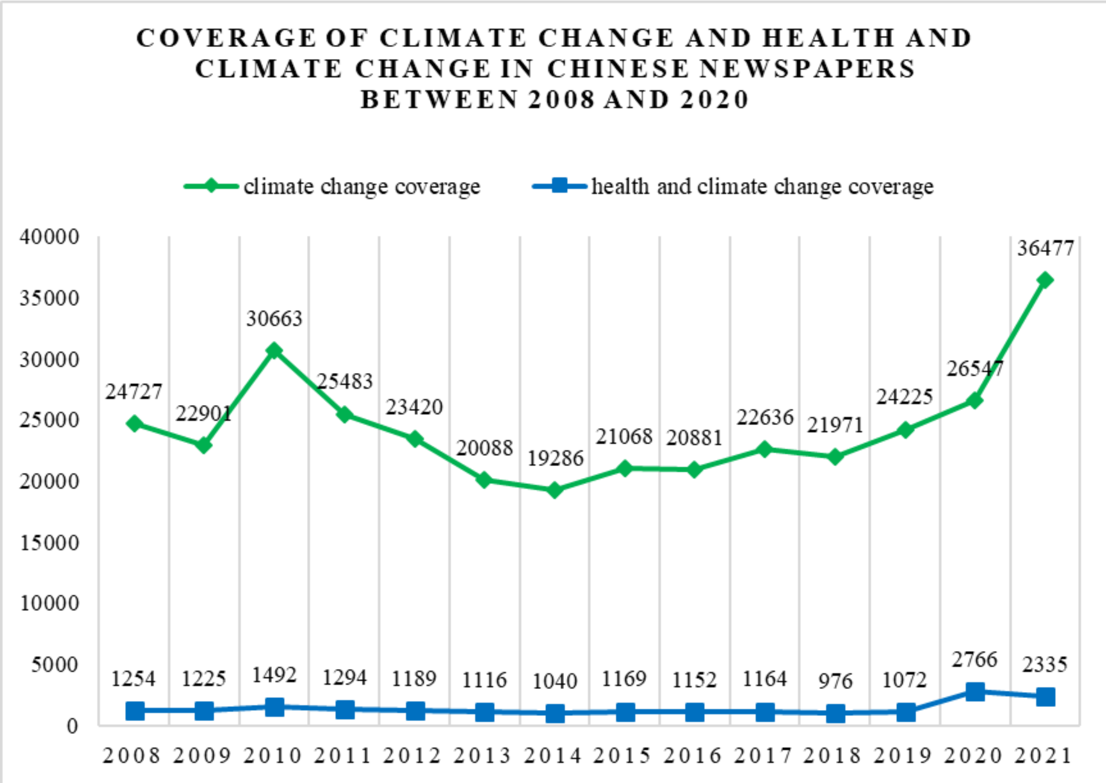


Figure 57: **Coverage of climate change and health and climate change in Chinese newspapers from 2008 to 2021**

Data

1. All the articles from 2008 to 2021 published on Chinese provincial newspapers (retrieved from CNKI and WiseNews Database);
2. Choice of keywords in accordance with previous research of media coverage of health and climate change for People's Daily in China in the global Lancet Countdown report.[11]

Caveats

Firstly, the most influential provincial newspaper in each province or administrative division was selected, while there might be more than one influential newspaper in some province or administrative division. Therefore, this indicator only reflected the media coverage of the selected newspapers which do not cover all newspapers in China.

Secondly, more than one newspaper databases were used to retrieve newspapers for data analyses, which may affect the comparability and consistency. CNKI and WiseNews as two main newspaper databases were used to retrieve newspaper data, since there is no single database include all the tracked newspapers. As for the two databases, the search function and format are not the same, which can affect the data retrieval and analysis of newspaper coverage.

Thirdly, provincial newspapers were used for data analyses, but national newspapers, such as People's Daily, as well as professional newspapers like China Meteorological News are not included. Analyses of provincial newspapers show provincial difference in newspaper coverage of health and climate change, while it is still possible to miss some coverage provided by national and professional newspapers.

Future Form of Indicator

In the future, the indicator of the media coverage of health and climate change based on newspaper data will continue to be a primary data source to track this indicator. In the future, both national newspaper such as People's Daily and provincial newspapers can be included to reflect national and local media coverage of health and climate change.

Indicator 5.2: Individual engagement in health and climate change

Methods

Partnered with Baidu Inc., we collected search queries on Baidu search engine to reflect the individual's public engagement in health and climate change, which is the same as the analysis of the 2020 [9] and 2021[19] China Lancet Countdown report. Baidu is the most popular Chinese search engine accounting for 83.97% of the market share in China in 2021 according to StatCounter [122]. A set of keywords were designed by this team of researchers to capture search queries related to health and climate change. Compared with the 2021 China report[19], we added a few keywords about extreme weather events, like drought, flood, and winter storm, into the climate change keywords, to increase the coverage of the climate change topic. We conducted special studies about the queries of the population ageing and the queries of the COVID-19. Additionally, we also examined individual engagement of different demographic groups. Especially, we analyzed the search queries about health and climate change to reveal the individual engagement of different age groups. All data is anonymized and no queries can be associated with an individual. All the queries were searched within the recent year (from 1st Jan. 2021 to 31st Dec. 2021).

The queries are identified as health queries, climate change queries, and health &climate change co-queries, if they contain at least one health keyword **Table 54**, at least one climate change keyword (Table 55), and contain both health and climate change keywords, respectively. The query proportion of climate change was calculated by using the number of identified climate change queries to divide the total number of queries in the year 2021. The formula of query proportion can be formulated as:

$$climate\ change\ query\ proportion\ = \frac{number\ of\ identified\ climate\ change\ queries}{number\ of\ total\ queries}$$

$$\frac{Health\,\&\,climate\ change\ co-queries}{Climate\ change\ queries} = \frac{number\ of\ identified\ health\&climate\ change\ co-queries}{number\ of\ iddentified\ climate\ change\ queries}$$

$$\frac{Health\,\&\,climate\ change\ co-queries}{Health\ queries} = \frac{number\ of\ identified\ health\&climate\ change\ co-queries}{number\ of\ identified\ health\ queries}$$

Table 54: Health-related keywords for the Baidu search

Health-related keywords in Chinese	Health-related keywords in English
健康	Healthy
疾病	Disease
养生	Health preservation
保健	Healthcare
公共卫生	Public health
疟疾	Malaria
死亡率	Mortality
营养	Nutrition
营养不良	Malnutrition
脱水	dehydration
发病	Morbidity
发病率	Morbidity
发育迟缓	Stunting
传染病	Communicable disease
慢性病	Chronic disease
高血压	Hypertension
肿瘤	Tumour
中风	Apoplexy
心脏病	Heart disease
肺炎	Pneumonia
癌症	Cancer
肺癌	Lung cancer
肝癌	Liver cancer
糖尿病	diabetes
肥胖	Obesity
身体超重	Overweight
非传染性疾病	Non-communicable diseases

流行病	Epidemic
流行病学	Epidemiology
腹泻	Diarrhoea
SARS	SARS
非典型肺炎	Atypical pneumonia
严重急性呼吸综合征	Severe acute respiratory syndrome (SARS)
重症急性呼吸综合症	Severe acute respiratory syndrome (SARS)
麻疹	Measles
早产	Premature
流产	Abortion
抑郁障碍	Depressive disorder
抑郁症	Depression
心理障碍	Psychological disorders
心理问题	Psychological problems
心理疾病	Mental illness
精神障碍	Mental disorders
精神病	Mental disease
精神疾病	Mental illness
精神健康	Mental health

Table 55: Climate change-related keywords

Climate change-related keywords in Chinese	Climate change-related keywords in English
气候变化	Climate change
气候变暖	Climate warming
全球变暖	Global warming
全球暖化	Global warming
全球温度升高	Global temperature rise
全球气温升高	Global temperature rise
地球温度升高	The rise of the earth's temperature
海平面上升	Sea level rise
冰川融化	Glacial melting
温室效应	Greenhouse effect
温室气体排放	Greenhouse gas emissions
碳排放	Carbon emission
二氧化碳排放	CO2 emission
碳减排	Carbon emission reduction
二氧化碳减排	Carbon dioxide reduction
温室气体减排	Greenhouse gas emission reduction

全球环境变化	Global environmental change
气候变异	Climate variability
极端天气	Extreme weather
干旱	Drought
洪灾	Flood disaster
水灾	Flood disaster
特大洪水	Cataclysm
雪灾	Snow disaster

To identify the COVID-19 queries, a set of keywords was also developed by this team of researchers, (**Table 56**). The queries that contain at least one COVID-19 keyword were identified as COVID-19 queries. Similar to the health &climate change co-queries, the queries with keywords from both (i) COVID-19, and (ii) climate change were identified as COVID19&climate change co-queries. The formula for calculating COVID19 query proportion and COVID19&climate change co-query proportion is:

$$COVID19\ query\ proportion\ = \frac{number\ of\ identified\ \text{COVID19}\ queries}{number\ of\ total\ queries}$$

$$COVID19\&climate\ change\ co-query\ proportion = \frac{number\ of\ identified\ \text{COVID19\&climate change}\ \ co-queries}{number\ of\ total\ queries}$$

Table 56: COVID-19 keywords

COVID-19 keywords in Chinese	**COVID-19 keywords in English**
新冠肺炎	Novel coronavirus pneumonia
新型冠状肺炎	The new type of coronary pneumonia
新型冠状病毒	Novel coronavirus
新冠病毒	Novel coronavirus
COVID	COVID

In this report, we also introduced a set of keywords to identify the queries about population ageing (Table 57). The queries that contain at least one population ageing keyword were identified as population ageing queries. The queries with keywords from both (i) population ageing, and (ii) climate change were identified as population ageing & climate change co-queries. The formula for calculating population ageing query proportion and population ageing &climate change co-query proportion is:

$$\text{population ageing}\ query\ proportion\ = \frac{number\ of\ identified\ \text{population ageing}\ queries}{number\ of\ total\ queries}$$

$$\text{population ageing\&}climate\ change\ co-query\ proportion$$

$$= \frac{number\ of\ identified\ \text{population ageing\&climate change}\ co-queries}{number\ of\ total\ queries}$$

Table 57: Population ageing keywords

中文 Chinese	**英文 English**
老年	The elderly
老人	Old people
老龄	Aging population

The designed indicator was also calculated in different demographic groups to show the demographical distribution of query proportion in China. Note that none of the queries of this study can be associated with a particular individual. For each demographic group (like the users with different ages) in China, the climate change query proportion and health query proportion were calculated with the number of identified health or climate change queries of this demographic group as the numerator, and with the number of total queries of this demographic group as the denominator. Similarly, for visualizing the query distribution in the province level, the query proportion was calculated with the number of identified queries in this province as the numerator, and with the number of total queries in this province as the denominator.

Data

The search query data were based on search query logs from the search engine provided by Baidu Inc. All the analytics of this indicator were conducted on Baidu's servers by researchers from Baidu. Each query record only contained the query, the submission time, the submission city, and a few demographical properties indicated by the submission user without any identifying information of the user. The demographical properties of users were determined through a deep learning user profiling prediction platform within Baidu using big data like user queries, location, and other data. Any of the original search logs are being processed and used with respect to Baidu's privacy policy (https://www.baidu.com/duty/yinsiquan.html).

Caveats

First of all, this indicator for individual engagement based on the search query data is biased towards attention from typical internet users. Though Baidu takes the majority of the market share in China, it does not cover all population groups in China. Some population groups do not actively use the search engine such as the elderly, children, and less educated people.

Second, the analysis of the demographical groups will be affected by the prediction accuracy of Baidu's user profiling platform. According to statistics, the accuracy of the education level label of the user profiling platform is 81%, the one of gender label is about 89%, and the one of age groups is about 79%. It is almost impossible to have 100% prediction accuracy. However, such prediction performance is high enough for many enterprise applications in the company.

Third, the coverage of keywords influences on the final results. All the queries were identified by keywords which have been enumerated with the best effort. However, it is still possible to miss some keywords to identify the related queries.

Future Form of Indicator

In the future, the indicator will continue to use search engine data as primary data to track individual engagement. More analysis about the co-query of climate change and some specific events (like extreme weathers and disasters) can be conducted to reflect different concerns between climate change and health.

Additional Information

Table 58: Queries (per hundred thousand) related to health and climate change in 2018-2021

Year	2018	2019	2020	2021
$\frac{\#\ of\ climate\ change\ queries}{\#\ of\ total\ queries}$	2.921	2.785	3.199	5.677
$\frac{Health\ \&\ climate\ change\ co-queries}{Climate\ change\ queries}$	93.217	124.374	318.219	471.438
$\frac{Health\ \&\ climate\ change\ co-queries}{Health\ queries}$	0.652	0.747	1.192	4.763

As shown in Table 58, there is a continuously rising trend from 2018 to 2021 for individual engagement in health and climate change. From 2020 to 2021, the climate change queries of 2021 increased by 77.5% compared with the ones of 2020, and the health & climate change co-queries over climate change queries of 2021 increased by 48.15% compared with the ones of 2020. While the proportion of queries related to climate change continued to increase in the past four years, the queries for health and climate change are still seldom co-searched by users, but have a notable rising trend.

One possible reason for such increase is that the Government of China has released two of the most significant policy documents (*Working Guidance for Carbon Dioxide Peaking and Carbon Neutrality in Full and Faithful Implementation of the New Development Philosophy* [123] and *Action Plan for Carbon Dioxide Peaking Before 2030* [124]) on its climate response plan. These documents form the basis of China's policy framework to achieve the goals of peaking carbon emissions and subsequent carbon neutrality. These actions from the government should draw much attention from individuals. The other possible reason is that the events like the COVID-19 pandemic and the 2021 Henan floods in China make more individuals pay attention to the relations between climate change and public health/safety.

Table 59: Queries (per hundred thousand) related to population ageing and climate change in 2018-2021

Year	2018	2019	2020	2021
$\frac{\#\ of\ population\ ageing\ queries}{\#\ of\ total\ queries}$	58.576	71.726	80.780	88.477
$\frac{population\ ageing\ \&\ climate\ change\ co-queries}{Climate\ change\ queries}$	9.927	9.688	14.313	6.875
$\frac{population\ ageing\ \&\ climate\ change\ co-queries}{population\ ageing\ queries}$	0.495	0.376	0.567	0.441

Future analysis in Table 59 also shows that the proportion of population ageing queries has a notable rising trend from 2018 to 2021. From 2019 to 2020 the population ageing queries of 2020 increased by 12.6% compared with the ones of 2019, and from 2020 to 2021 the population ageing queries of 2021 increased by 9.53% compared with the ones of 2020. This indicates that population ageing has been recognized as a topical issue in China. However, there is still no clear trend for the population ageing & climate change co-queries as shown in Table 59. It indicates that people in China seldomly realize the consequence challenges alongside the population aging and climate change.

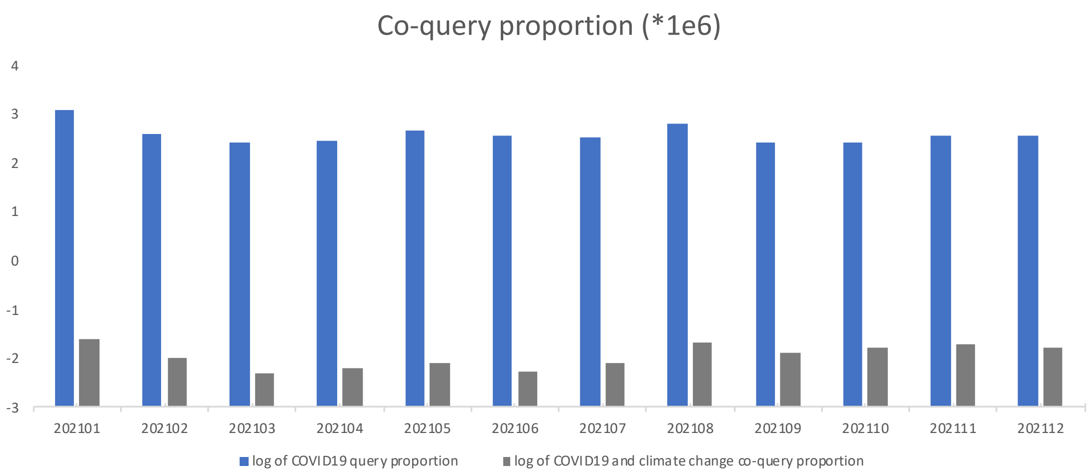


Figure 58 Queries (per million) from month to month in 2021 of COVID-19 and COVID-19&climate change (per million). Note that the Y- axes are logarithmic axes (with base 10).

Figure 59 shows the query proportion from month to month in 2021 of COVID-19 and COVID-19&climate change. In 2021, there were two peaks of the query proportion of COVID-19 which were at the beginning (January) and the middle (August) of 2021. These two peaks correspond to two waves of the outbreak of COVID-19 pandemic in mainland China. Whereas, the peaks of COVID-19&climate change co-queries also appeared in the same months. This indicates that the COVID-19 pandemic does draw more individual attention to the climate change challenge of our earth.

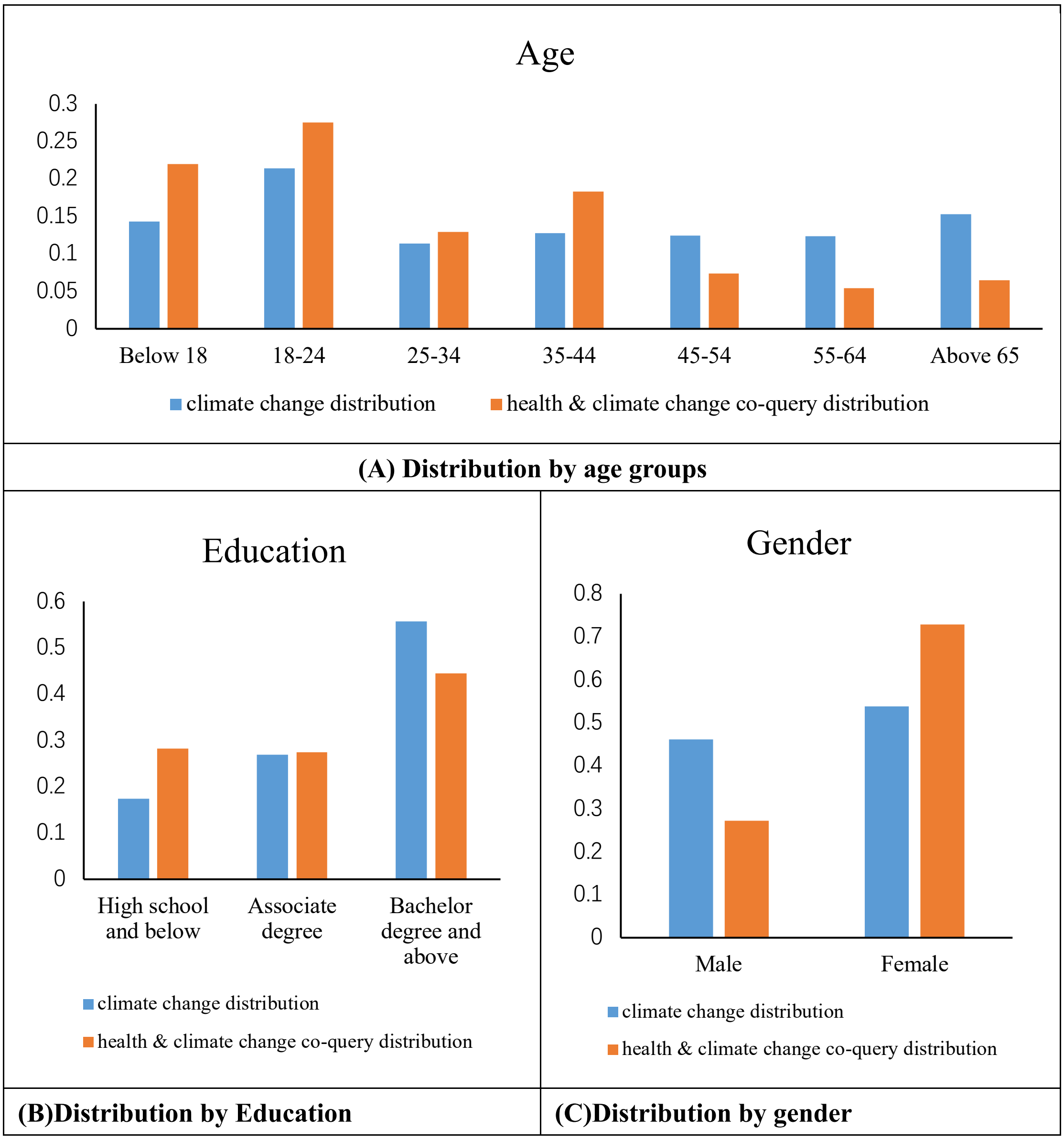


Figure 59 The distribution of the proportion of the queries related to climate change and health & climate change query of demographic groups in China in 2021. (Note that the figures show the histogram distribution of the queries per person with a partial demographical property. The sum of the distribution on each demographical group (with the same color) equals to one. For example, the climate change queries of male and female in figure (C) equals one.)

Analysis of different age groups indicated that the elderly was lack of awareness of health threat caused by climate change. As shown in *Figure 59* (a), compared with the other middle age groups (above 25), the elderly (above 65) had a relatively similar query proportion of the climate change queries, but had a much lower proportion of the health & climate change co-queries. Taking a look at the 35-44 age group, the number of climate change queries of the elderly was 119.68% of one of the 35-44 age group. Meanwhile, the number of the health & climate change co-queries of the elderly was only 35.57% of one of the 35-44 age group. Moreover, the analysis also shows that female people and people with tertiary education had a higher number of climate change queries and health &climate change co-queries. As shown in *Figure 59* (b), the number of health & climate change queries per person with bachelor degree or above was 157.86% and 162.36% of the person with high school or below degree and associate degree, respectively. And *Figure 59*(c) shows that the number of health & climate change co-query per female person was 268.69% of one of per male person.

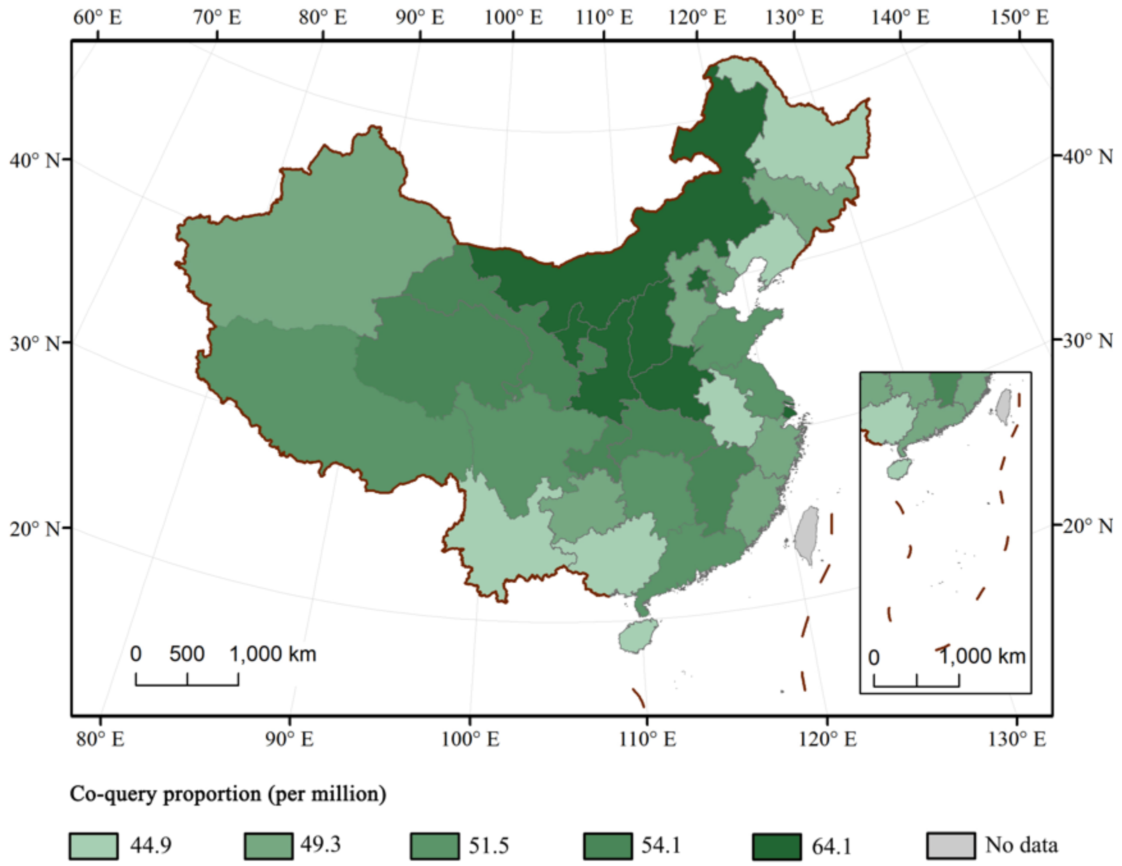


Figure 60 The distribution of the proportion of the queries related to climate change in different provinces in China in 2021

The figure illustrates the proportion of the queries related to climate change in different provinces. On the one hand, similar to the 2021 China Lancet Countdown report[19], Northern China (like Inner Mongolia) and Western China (like Ningxia and Gansu) have a substantial proportion of climate change queries. On the other hand, the Henan province, which had a flood disaster in 2021, and its nearby provinces Shaanxi province and Shanxi province, which also had floods in 2021, had a larger proportion of climate change queries than other areas in China. This indicates that extreme weather event makes more people engage in the climate change concern.

Indicator 5.3: Coverage of health and climate change in scientific journals

Method

This indicator tracked the coverage of climate change and health in both Chinese and English journals.

On English studies, this study used an algorithm to crawl articles containing concepts related to climate change and health in the titles, abstracts and keywords of the Scopus and Medline database from January 1, 2009 to December 31, 2021. And the titles and abstracts of the Web of Science Core Collections database contain concepts related to climate change and health in the same period. (as shown in **Table 60**)

After data scraping, this study used supervised machine learning to screen articles. First, we selected about 10% of the articles, cross-reviewed the categories by multiple team members, and finally determined whether the articles were relevant to climate change and health. Then we repeatedly train the machine with these samples, and finally make predictions on the entire data. The algorithm provides a score between 0 and 1, and articles with a score greater than 0.5 are included in the final research sample. In the end, a total of 19,287 eligible articles were collected.

Then, this study uses 'geoparsers' to identify the author's country. Geoparsers are dictionary-based methods or pre-trained models capable of extracting geographic place names from text. We will use geoparser to determine the country of the first author of a paper. In the end, 698 articles that were Chinese scholars were selected.

Table 60. Summary of search strings[1]

Theme	Key concepts	String (Scopus)
Climate change (contains at least one of the following climate terms, from any category)	General climate change terms	(climat* OR “global warming” OR “greenhouse effect*”)
	Greenhouse gasses, including short-lived greenhouse gasses, when linked to emission or mitigation. Some astronomy results are filtered out.	((“carbon dioxide” OR co2 OR methane OR ch4 OR “nitrous oxide” OR n2o OR “nitric oxide” OR “nitrogen dioxide” OR nox OR *chlorofluorocarbon* OR *cfc* OR refrigerant OR hydrofluorocarbon* OR hfc* OR *chlorocarbon* OR “carbon tetrachloride” OR ccl4 OR halogen* OR ozone OR o3 OR ammonia OR nh3 OR “carbon monoxide” OR co OR “volatile organic compounds” OR nmvoc OR “hydroxyl radical” OR “oh” OR “pm2.5” OR aerosol OR “black carbon” OR “organic carbon” OR “sulphur dioxide” OR “oxidized sulphur” OR “so2” OR “sox” OR “sulphuric acid” OR so4*) W/2 (emit* OR

[1] Each of the strings is connected by a boolean ‘OR’. The Scopus search string is given here; for Web of Science and Medline, the syntax is different, and some other minor changes were made, most notably removing left-truncated keywords. Search hits shown in the table were conducted on 9 April 2020. Note the following data search functions: * = any subsequent letters; W/# = maximum number of words allowed between the term directly to the left and that directly to the right of the W/#; and ? = any letter or space to replace the “?”.

		emission OR releas* OR mitigat*) AND NOT(star OR “solar system”))
	Climate variability indicators/climate indices	(temperature* OR precipitat* OR rainfall OR “heat ind*” OR “extreme-heat event*” OR “heat-wave” OR “extreme-cold*” OR “cold ind*” OR humidity OR drought* OR hydroclim* OR monsoon OR “el ni$o” OR enso OR SOI OR “sea surface temperature*” OR sst)
	Complex climate indices, including extreme weather events, floods, wildfire, and coastal changes. Some paleo-climatic events are excluded.	(snowmelt* OR flood* OR storm* OR cyclone* OR hurricane* OR typhoon* OR “sea-level” OR wildfire* OR “wild-fire*” OR “forest-fire*” OR ((extreme W/1 event*) AND NOT paleo*) OR “coast* erosion” OR “coastal change*” OR (disaster* W/1 (risk OR manag* OR natural)))
AND Health (contains at least one of the following health terms, from any category)	General health terms	(health* OR wellbeing OR ill OR illness OR disease* OR syndrome* OR infect* OR medical*)
	General health outcomes	(mortality OR daly OR morbidity OR injur* OR death* OR hospital* OR OR emergency OR emergencies OR doctor OR gp)
	Nutrition, including obesity and undernutrition	(obes* OR over?weight OR under?weight OR hunger OR stunting OR wasting OR undernourish* OR undernutrition OR anthropometr* OR malnutrition OR malnour* OR anemia OR anaemia OR “micronutrient*” OR “micro?nutrient*” OR diabet*)
	Cardio-vascular terms. Some studies on Chemical Vapour Deposition (CVD) are excluded.	(hypertension OR “blood pressure” OR stroke OR *vascular OR (cvd AND NOT(vapour or vapor)) OR “heart disease” OR isch?emic OR cardio?vascular OR “heart attack*” OR coronary OR chd)
	Renal health terms	(ckd OR renal OR cancer OR kidney OR lithogenes*
	Effects of temperature extremes	((heat W/2 (stress OR fatigue OR burn* OR stroke OR exhaustion OR cramp*)) OR skin OR fever* OR renal* OR rash* OR eczema* OR “thermal stress” OR hypertherm* OR hypotherm*)
	Maternal health outcomes	(pre?term OR stillbirth OR birth?weight OR lbw OR maternal OR pregnan* OR gestation* OR *eclampsia OR sepsis OR oligohydramnios OR placenta* OR haemorrhage OR hemorrhage)
	Vector-borne diseases	(malaria OR dengue* OR mosquito* OR chikungunya OR leishmaniasis OR encephalit* OR vectorborne OR pathogen OR zoonos* OR zika OR “west nile” OR onchocerciasis OR filiariasis OR lyme OR tick?borne)
	Bacterial, parasitic and viral infections, including waterborne and foodborne diseases	(waterborne OR “water borne” OR diarrhoea* OR diarrhe*l OR gastro* OR enteric OR *bacteria* OR viral OR *virus* OR parasit* OR vibrio* OR cholera OR protozoa* OR salmonella OR giardia OR shigella OR campylobacter OR food?borne OR aflatoxin OR pois
	Respiratory outcomes	(respiratory OR allerg* OR lung* OR asthma* OR bronchi* OR pulmonary* OR copd OR rhinitis OR wheez*)
	Mental health outcomes	(mental OR depress* OR *stress* OR anxi* OR

		ptsd OR psycho* OR *trauma* OR suicide* OR solastalgi*)
	Health systems	[no additional terms needed]

On Chinese studies, this study uses keywords, including climate change and climate change- and health related keywords in the titles, abstracts or keywords of papers from January 1, 2009 to December 31, 2021 in CNKI. Articles were retrieved from academic journals, master's and doctoral dissertation repositories, and conference papers. After searching, a total of 5777 articles with titles, abstracts or keywords containing climate change and health keywords were collected. Next, we manually removed the following articles: (1) unrelated to health, (2) without annotated authors, (3) articles in English. We ended up with 874 journal journals and conference papers.

Table 61: Keywords

Climate change related		**Climate change- and health related**	
English	**Chinese**	**English**	**Chinese**
Climate change	气候变化	Health Human health	（人类）健康
Global warming	全球变暖	Disease	疾病
Greenhouse gas emission Greenhouse effect	温室（气体排放、气体减排、效应、气体）	Infectious disease Non-communicable disease	（非传染性、传染）病
Carbon emissions	二氧化碳减排	Dengue	登革热
Drought	干旱	Heart disease	心脏病
Bushfire	野火	Mortality rate	死亡率
Tropical cyclone	热带气旋	Years of life lost	寿命损失年
Heatwave	热浪	Vector	媒介生物
Extreme weather	极端天气	Insect vector	虫媒
ozone	臭氧	Health risk	健康风险
Extreme high temperature Extreme low temperature	极端（高温、低温）	Emergency	急诊
Rainstorm	暴雨	Respiratory disease	呼吸系统疾病
Flood	洪水	Non-accidental	非意外死亡

		Coronary heart disease	冠心病
		Stroke	脑卒中
		Acute myocardial infarction	急性心肌梗死
		Death risk	死亡风险
		Die	死亡
		Adapt	适应
		Chronic	慢性病
		Nutrition	营养
		Dehydration	脱水
		Morbidity	发病
		Mental health	精神疾病
		Aging	老龄化
		Elderly	老年人

Indicator 5.4: Health and climate change in the Chinese government

Methods

Two steps to filter the articles, as shown below: Key words for the topics of (a) Climate Change, and (b) Health were identified as shown in Table 62.

Table 62: Chinese keywords for the search in Chinese government website

气候变化关键词	健康相关关键词
气候变化	疟疾
全球变暖	腹泻
温室	感染
极端天气	肺炎
全球环境变化	流行病
低碳	公共卫生
可再生能源	卫生
碳排放	发病
二氧化碳排放	营养
气候污染	精神障碍
气候	发育
全球升温	传染
再生能源	疾患
CO2 排放	症
温室气体	瘟疫
极端气候	流感

高温	流行感冒
变暖	治疗
排放	保健
环境变化	健康
升温	死亡
全球温升	精神疾病
热浪	精神病
暴雨	登革热
气温	饥饿
洪水	粮食
洪灾	有害
气候反常	皮肤病
野火	风湿
山火	呼吸系统疾病
雪灾	人类健康
低温	人体健康
年代际	身体健康
冰雪	心脏病
可持续发展	糖尿病
海洋酸化	疾病
静稳	热死
	口罩
	防护
	老人
	老龄
	老年

The detailed steps of the method are shown as below:

Step 1: Crawling all the climate change articles from 2021.1.1 to 2021.12.31 on Chinese government website

With a python-based crawler, all qualified articles published by four Chinese government official websites China Meteorological Administration, National Development and Reform Commission, National Health Commission of the People's Republic of China, Ministry of Ecology and Environment of the people's Republic of China were collected from January, 2008 to December, 2020. 11 climate change related keywords were used in the column of "Climate Change" in Table 62, which is in accordance with the new climate change keywords used in the *MJA-Lancet Countdown on health and climate change: Australian policy inaction threatens lives* (Zhang, et al., 2018). The keywords are presented in the column of "Climate Change" in Table 62.

Step 2: Searching for health-related articles

It was examined whether these posts show concern for public health by searching health-related keywords, which is presented in the column of "Health" in Table 62. Our choice of health keyword list followed previous research of Australia[117]. If a post contains at least 1 health-related word and word frequency ratio in the whole post is greater than 0.01, this article is regarded as relevant to health topics.

Step 3: Systematic sampling and manual screening was added to test the positive rate

We add manual screening process to test the data of health and climate change related articles. 181was selected from a total number of 821 articles by four government official websites in the year of 2021after manual screen with a false positive rate of 0.20. Systematic sampling was used to test the false positive rate of climate change related articles. 22 articles were selected from 2220 as a sample in the year of

2021of four government official websites and the false positive rate was 0.15.

Step 4: Searching for elderly articles inf health and climate change related articles.

We screen "the elderly, old people, aging population" 3 keywords in health and climate change related articles（after manual screening） as the Figure 2 below.

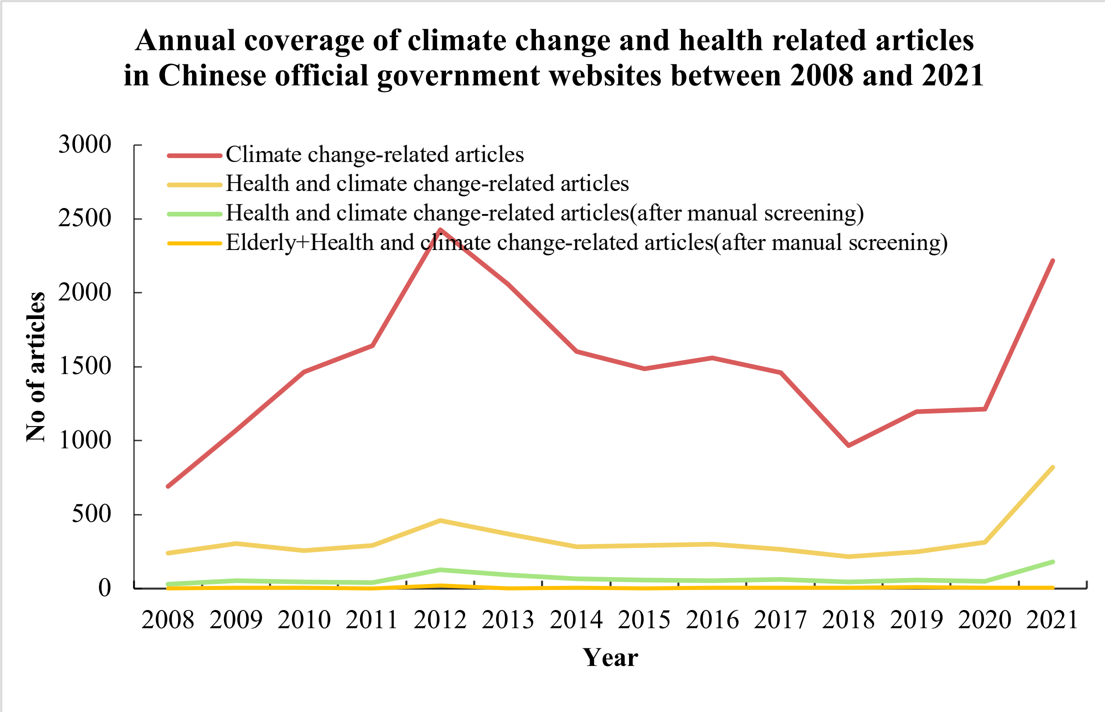


Figure 61: Coverage of climate change and climate change-health-elderly mentioned together（after manual screening）on Chinese government websites between 2008 and 2021.

Data

Across the 2008-2021 period, there was an average of 1504 articles per year discussing climate change, in which about 4.5% or 68 articles (after manual screening) per year were related to human health.It is clear that there is a rising trend in the year of 2021,which is 1.83 times higher in the data of climate change and 3.7 times higher in the data of health and climate change compared with last year.The number of elderly in health and climate change range from 1 to 21,the average articles is 6 per year.

Caveats

Some articles may be omitted because the key words were limited.

Future Form of Indicator

In order to further improve the accuracy and relevance of the research samples, keywords can be adjusted according to the Chinese context in the future.

Additional information to Figure 2 in the main text

Table 63: Description of indicators used in Figure 2

Indicator	Baseline period	Latest year
Heatwave-related mortality	1986-2005	2021
Change in labor capacity	1986-2005	2021
Heat and physical activities	1986-2005	2021
Wildfire exposure	2001-2005	2021
Population exposure to extreme rainfall	1986-2005	2020
Population exposure to drought	1986-2005	2020
Climate suitability to dengue fever	2001-2004	2020

Additional information to Figure 3 in the main text

The standardization score for each impact indicator is calculated as:

$$yearly\ score = \frac{year\ value}{baseline\ value}$$

The parameters and latest original data used for each indicator is provided in **Table 64**.

Table 64: Description of impacts indicators used in Figure 3

Indicator	Meaning	Baseline period	Baseline value	Latest year	Latest value
Heatwave-related mortality	The number of heatwave-related mortality in China	1986-2005	11513.67	2021	24698.65
Costs of heatwave-related mortality	The economic costs of heatwave-related mortality in China (million 2020 USD)	2001-2005	6380.87	2021	9269.25
Labor productivity loss	The annual heat-related work hours loss in China (billion working hours)	1986-2005	30.86	2021	33.04
Costs of	The economic costs	2012-2016	170.817	2021	285.76

labor productivity loss	of heatwave-related labor productivity loss in China (billion 2020 USD)				
Heat-related safe outdoor hours loss	Loss of safe hours per person per day	1986-2005	1.38	2021	2.05
Population exposure to extreme rainfall	Events per year	1986-2005	98.915	2020	218.258
Population exposure to drought	Months per year	1986-2005	995.569	2020	299.10
Climate suitability for dengue fever	VC	2004	0.25	2020	0.42
Exposure of wildfire	Satellite-observed exposure (person·day)	2001-2005	11825283	2021	19237914

The score for each response indicator is calculated as:

$$\text{yearly score} = \frac{original\ data - worst\ case\ value}{target\ value - worst\ case\ value}$$

The parameters and latest original data used for each indicator is provided in **Table 65**.

Table 65: Description of response indicators used in Figure 3

indicator	Original data	worst case value	worst case year	target value	target meaning	Latest year	Original data in the latest year
Health emergency management	National average health emergency score	0	\	100	Full score in health emergency management	2020	73
Adaptation planning	Number of mainland provinces having health adaptation plan	0	\	31	All provinces have adaptation planning	2020	6

Reduction of Carbon intensity	Carbon Intensity	1.22389	2005	0.630	NDC targets: decreasing 65% from 2005's level	2021	0.984
Coal phase-out	Share of Coal in TPES	0.725	2007	0	Total Coal Phase-out	2021	0.56
Low-carbon electricity	share of low-carbon electricity generation in total electricity generation	0.147874	2007	1	100% Low-carbon electricity	2021	0.277
Clean household energy use	Share of electricity in total household energy consumption	0.221352	2000	1	100% Electrification in household energy consumption	2018	0.4227
Reduction of urban air pollution	Number of cities reaching WHO interm-1 target of $PM_{2.5}$ concentrations (10μg/m^3)	0	\	337	Air qualities in all cities in China meet the WHO interm-1 target (35ug/m3)	2021	208
Fossil Fuel Subsidies	Fossil fuel subsidies value	50.94952	2018	0	Zero fossil fuel subsidies	2020	25.49

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