China key regions meet modest winter air quality targets, as cleaner heating offsets swelling industrial emissions

China's three key air pollution control regions met their modest winter targets as efforts to reduce heating-sector emissions and improved end-of-pipe controls in industrial plants offset a more than 10% increase in coal power and heavy industry output. However, more than 80 cities in 16 provinces experienced a substantial number of heavy pollution days in 2020, making the target to "basically eliminate" such days by 2025 a significant nationwide challenge: 10 provinces, including Beijing and Hebei, will need to realize reductions in PM2.5 levels of 20% or more during winter episodes to meet the target.

CREA has carried out detailed modelling to identify the source regions of pollution in cities that recorded a significant amount of heavy pollution days, showing where action needs to be taken to reduce emissions if the 2025 target is to be met.

Introduction

At the end of October 2020, China's Ministry of Ecology and Environment (MEE) published winter air quality action plans for the three key air pollution control regions. Because COVID-19 lockdowns had a significant impact on air quality in Spring 2020, the MEE set quarterly targets instead of their typical six-month targets. The targets for October to December 2020 were based on air pollution levels from 2019-Q4, and the targets for January to March 2021 were based on levels from two years prior.

The three key regions are as follows:

- Beijing, Tianjin and 26 surrounding cities: officially known as "Beijing-Tianjin-Hebei and surroundings", commonly referred to as the "2+26 cities"; in this document is referred to as "2+26" or the "Beijing region"

- Fenwei Plain: encompasses parts of Shaanxi, Shanxi and Henan provinces, around the city of Xi'an; here is referred to as "Fenwei" or the "Xi'an region"

- Yangtze River Delta: covers Shanghai, Jiangsu, Zhejiang and parts of Anhui province; here is referred to as "YRD" or the "Shanghai region"

According to our earlier analysis, targeted PM2.5 levels for winter 2020-2021 were understandably much higher than the levels experienced during Spring 2020, when COVID-19 lockdowns produced two months of unprecedentedly good air quality. However, meeting the 2020-2021 targets required only modest improvements in air quality compared to spring 2019.

For the Beijing region, averaged over the six month period, the targets imply a 2.5% reduction compared with 2019. Given the 1.5-year gap between the reference and target periods (1 year for quarter 4 and 2 years for quarter 1), this means an annual rate of improvement of about 1.7%. At this rate, it would take more than 25 years to meet the Chinese air quality standards. These standards are based on the World Health Organization's "first interim target", which is only the first step towards good air quality. For the Xi'an region, the targets translate to a 3.5% improvement, and for the Shanghai region, a 4.5% improvement.

The plans include air quality targets for each target region and city, as well as detailed measures to be taken, such as emissions control for unregulated small industries, the retrofit of steel plants with stronger emissions controls, limitations on steel, cement and other heavy industry output during air quality alerts at plants that fail to meet emissions standards, and replacement of household coal stoves with cleaner-burning coal briquettes, electricity or gas.

Key regions meet modest winter air quality targets and the number of 'heavy pollution' days in decline

We analysed official data compiled from China National Environmental Monitoring Centre to reveal the air quality trends. Our results are well in line with the latest MEE quarterly air quality evaluation and we further analysed the drivers that lead to the air quality changes. To more clearly understand how human-made emissions influenced air pollution, it is important to isolate other influencing factors, such as sandstorms and unusual weather conditions.

The occurrence of sandstorms was indeed significantly higher during spring 2021 compared with the previous two years (see Appendix). In this analysis, we exclude data for days affected by sandstorms.

We also apply "weather correction" algorithms.[1] This method links weather and air quality data at a given location and aims to correct for the effects of weather on air pollution. Data that has been corrected to eliminate the influence of weather is hereafter referred to as "de-weathered" data.

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[1] Centre for Research on Energy and Clean Air. (2020). Weather-correction of air pollution – Application to COVID-19. https://energyandcleanair.org/weather-correction-of-air-pollution-application-to-covid-19/

At the regional level (Table 1), air quality targets for each of the three key regions were met in 2020-Q4 and 2021-Q1. Limited improvement was seen for the period October-December 2020 in the three key regions compared with the same period in 2019. Air quality in the Beijing region did not show any improvement in 2020-Q4, as indicated in our earlier analysis that industrial emissions increased due to a surge in production by polluting industries and provinces failed to meet targets for controlling steelmaking capacity.

Average PM2.5 concentrations in the Beijing and Xi'an regions fell dramatically at sub-zero temperatures when heating sector emissions have the largest impact (Figure 1). This phenomenon is clear in the monthly data—the major improvements took place during the coldest months. This improvement is likely due to the effort to reduce residential coal burning in recent years. By the end of 2020, coal stoves had been replaced with gas or electricity in 25 million households.[2] This contributes to one third of the PM2.5 reduction in the atmosphere.[3]

At temperatures above 5°C, air pollution concentrations in fact increased, likely due to increased emissions from industry and transport. According to data from the National Bureau of Statistics of China, the production of steel, cement and thermal power increased nationwide by 17%, 12% and 14%, respectively, in the first quarter of 2021, compared with two years prior, outpacing the country's 10% increase in GDP.

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[2] 截至去年底，2+26城市和汾渭平原累计完成2500万户散煤替代, 2021-2-25,
https://www.chinanews.com/ny/2021/02-25/9418822.shtml

[3] 全国将新增清洁取暖面积约15亿平方米——今冬取暖更清洁了, 2020-11-23,
http://www.gov.cn/xinwen/2020-11/23/content_5563459.htm

Table 1. Targets and PM2.5 levels in the three key air pollution control regions in winter 2020-21

Region	2+26 Cities (Beijing region)		Fenwei (Xi'an region)		Yangtze River Delta (Shanghai region)	
Year-Quarter	2020-Q4	2021-Q1	2020-Q4	2021-Q1	2020-Q4	2021-Q1
Target for PM2.5, μg/m3	63	86	62	90	45	58
Observed data, PM2.5, μg/m3	63	65	59	65	39	41
De-weather data, PM2.5, μg/m3	50	52	48	51	34	34
Changes of observed PM2.5 compared with the baseline	-1%	-26%	-6%	-30%	-10%	-29%
Changes of de-weather pm2.5 compared with the baseline	0%	-20%	-3%	-16%	-6%	-16%

Notes: Considering the exceptional impact of the COVID-19 lockdown on air quality in Spring 2020, the MEE set 2019-Q4 and 2019-Q1 air quality as baselines for 2020-Q4 and 2021-Q1, respectively. We calculated changes in PM2.5 concentrations during winter 2020-2021 against the baseline air quality.

Figure 1. Average PM2.5 levels and temperature in the three key regions in 2019-Q1&Q4, 2020-Q4 and 2021-Q1
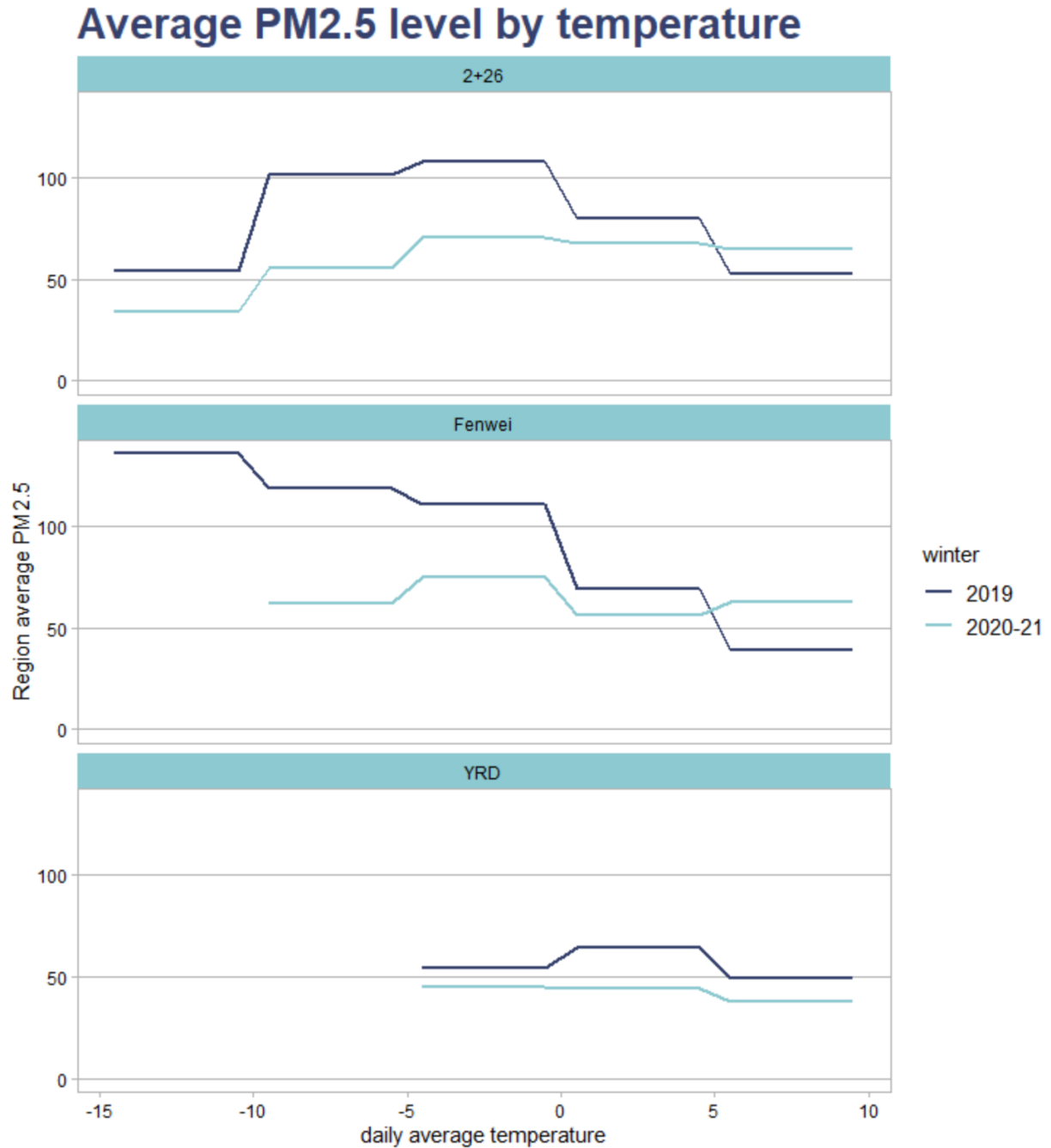
Average PM2.5 level by temperature

Figure 2. The number of heavy pollution days during winter in the three key regions from 2018-Q4 to 2021-Q1

Number of heavy pollution days in key regions
Average number of heavy pollution days per city per quarter

Source: CREA
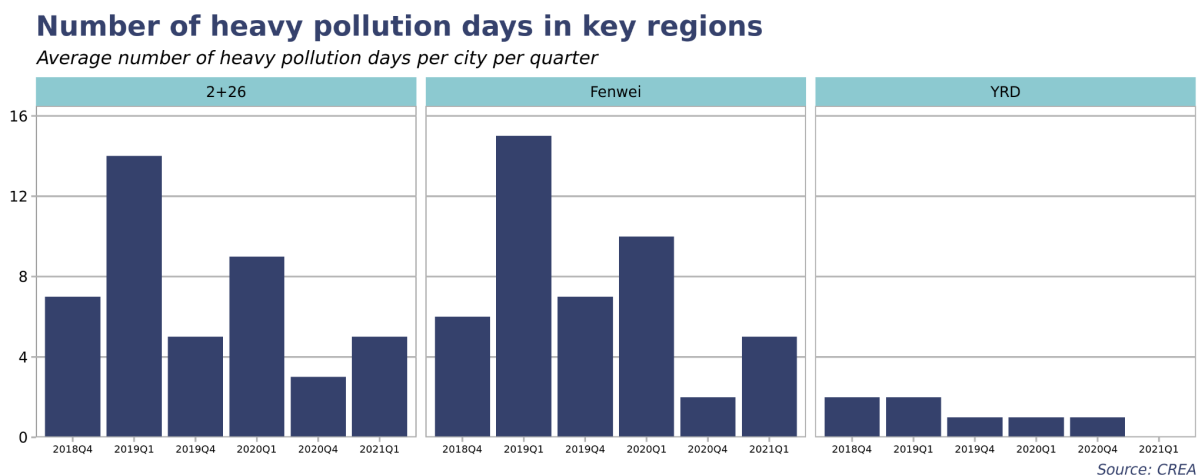
The heavy pollution days in the Beijing region and Xi'an region in the 2020-21 winter are both within the limits set by the MEE. Figure 2 shows the number of heavy pollution days during winter of the past years in the three key regions are in decline. The share of heavy pollution days has declined from 2.8% in 2015 to 1.2% in 2020 nationwide and dropped from 5% in 2015 to 1.9% in the pollution control key regions.[4]

At the city level, the analysis (see Figure 3) shows in 2020-Q4, 13 out of 28 cities (46%) in the Beijing region, 3 out of 11 cities (27%) in the Xi'an region, and 11 out of 41 cities (27%) in the Shanghai region failed to meet the PM2.5 concentration targets set by the MEE.[5] Five cities in Henan province within the air pollution transmission path to Beijing all failed to meet the target. Analysis of de-weathered data clearly shows that PM2.5 concentrations in these five cities did not see any reduction, but increased from 1% to 7% in 2020-Q4 compared to baselines.

In 2021-Q1, Beijing was the only city that failed to meet its air quality target among the three key regions. The average PM2.5 concentration in Beijing from January to March was 62 µg/m3, a 21% increase compared to 2019-Q1. However, when data are adjusted for weather conditions, PM2.5 in Beijing over the same period decreased by 15%.

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[4] 生态环境部：科学制定"十四五"各地重污染天数下降指标, 2021-2-25, https://news.cctv.com/2021/02/25/ARTII1g4PHaeTMOn5PVTwwgY210225.shtml?spm=C94212.P4YnMod9m2uD.ENPMkWvfnaiV.5

[5] The rules we set for target meeting based on MEE policy: 1) Observed PM2.5 < specific target; 2) for cities already meet annual 35ug/m3 standard in the earlier years, there is no specific target; 3) for continuous improvement, observed PM2.5 in 2020-Q4 < 2019-Q4.

Frequent unfavourable weather conditions, including stagnant air masses in February and March, prevented the diffusion of pollutants in Beijing. An increase in air pollutants from steel and other high emission industries in neighbouring cities also contributed to the increase.[6] An MEE inspection team found on March 11, 2021 that four steel mills in the top steelmaking city Tangshan, which is only 150 km away from Beijing, were operating illegally at high rates during the air pollution alert days and had falsified production records.[7]

Figure 4 shows, in provinces outside the key regions, significant PM2.5 increase in two western provinces during 2020-Q4. In Ningxia and Qinghai, PM2.5 levels increased 28% and 22%, respectively, compared to the same period in 2019.

For the period January to March 2021, southern and southwest provinces showed notable increases in PM2.5 levels, including Yunnan (+31%), Guangxi (+28%), Hainan (+17%), Guizhou (+16%), Fujian (+9%) and Guangdong (+2%). The de-weather analysis confirmed that the pollution increase resulted from an increase in actual emissions in Yunnan (+22%), Guangxi (+12%) and Guizhou (+14%).
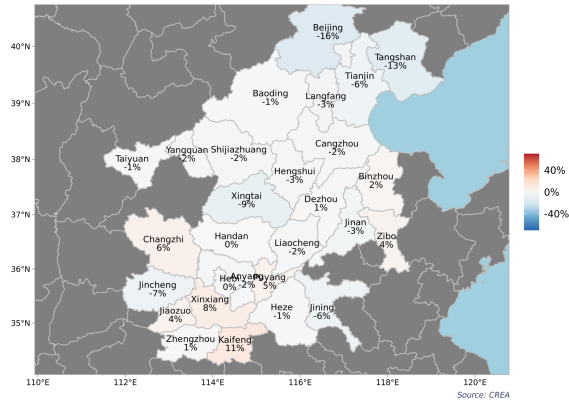
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[6] 一季度空气质量明显下降 未来保蓝天应从何处发力？, 2021-4-21, http://www.xinhuanet.com/politics/2021-04/20/c_1127353176.htm

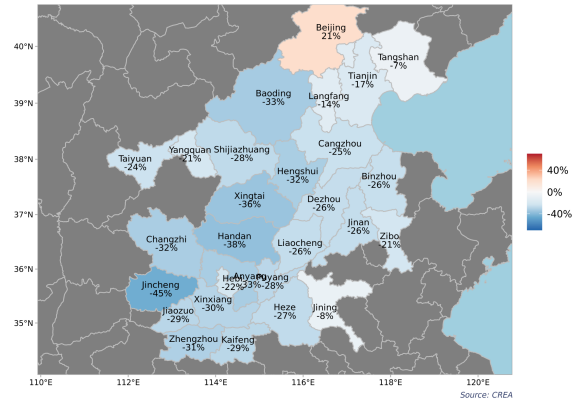[7] China environment minister urges crackdown on steel mills' illegal production, 2021-3-12, https://www.reuters.com/article/us-china-tangshan-steel-idUSKBN2B407Q

Figure 3. Changes in PM2.5 levels of the cities in the three key regions in winter 2020-21
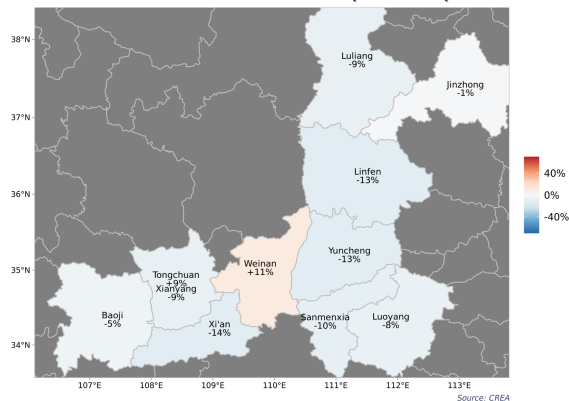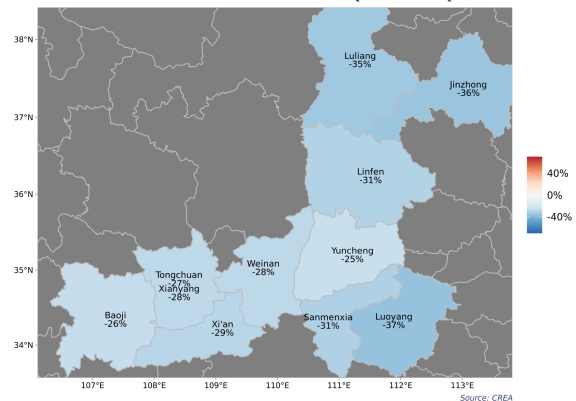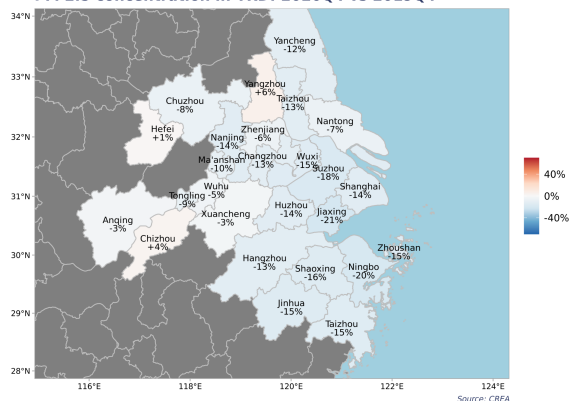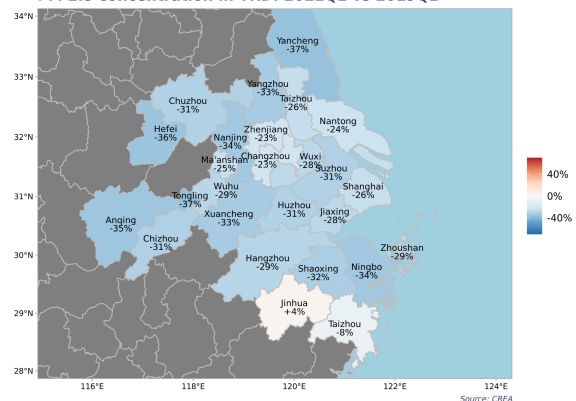
Figure 4. Changes in provincial PM2.5 levels in winter 2020-21 compared with baseline

PM 2.5 concentration: 2020Q4 vs 2019Q4

Source: CREA

PM 2.5 concentration: 2021Q1 vs 2019Q1

Source: CREA
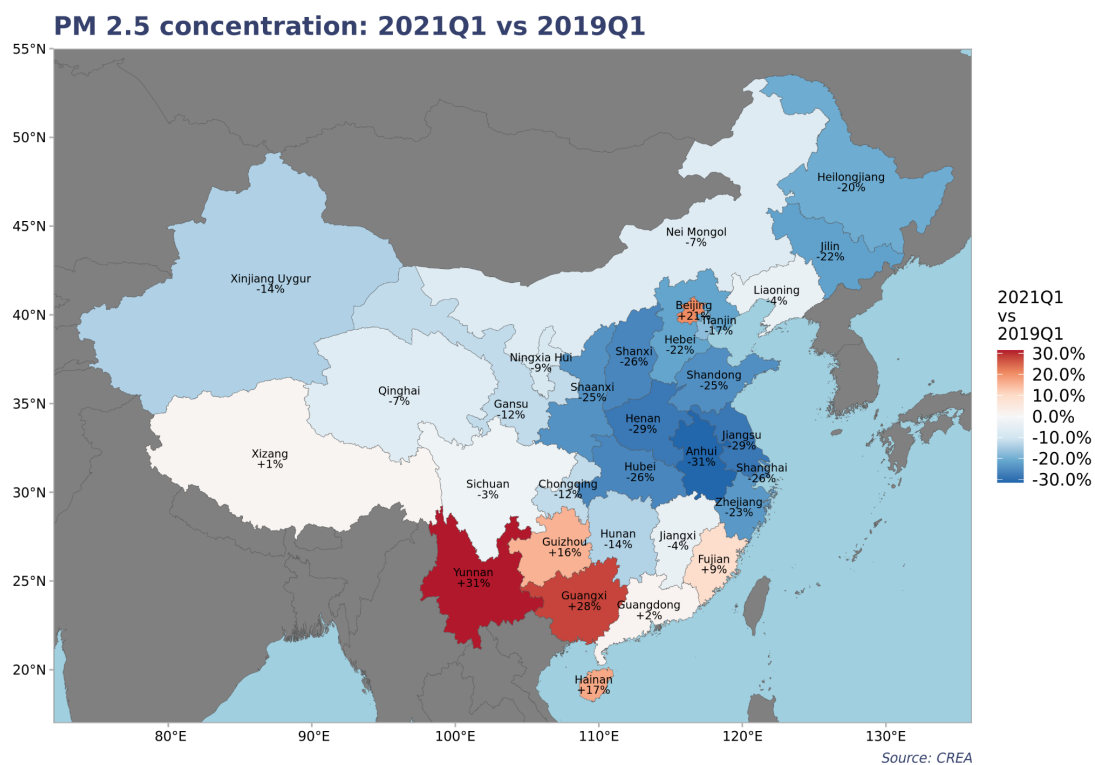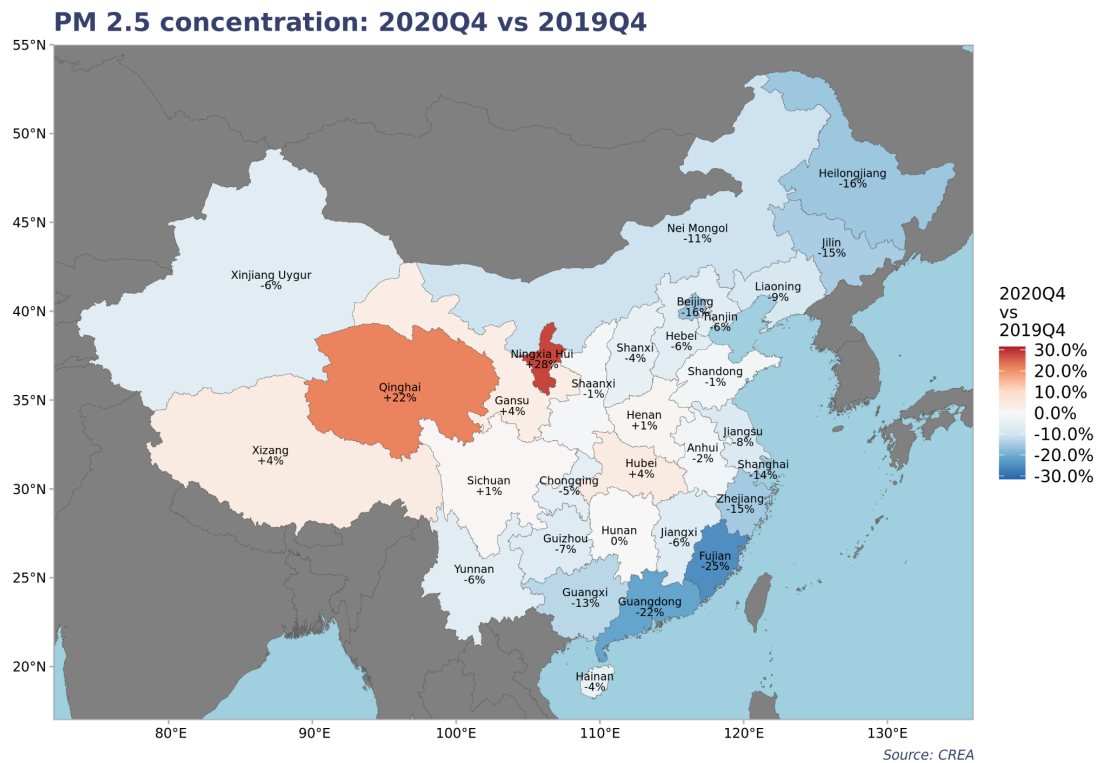
'Basically eliminating' heavy pollution days by 2025 will require major emissions cuts

The five-year target for 2025 is to "basically eliminate days of heavy pollution". This is a nationwide target requiring action both within the current priority regions and in other cities and provinces: 86 cities in 16 provinces had five or more days of heavy pollution in 2020 (Figure 5), despite good air quality during the COVID-19 lockdowns. Only 35 out of the 86 cities are located in the air quality control regions. In particular, the northeast region, especially Heilongjiang, southern Henan, and the areas of Xinjiang and Inner Mongolia that are affected by industrial pollution, will need to be prioritized to meet the target.

There are two possible ways to reduce the number of heavy pollution days: systemic emissions reductions during the winter months, or limits on factory operation and other targeted actions during the smog-prone periods. One expert from the National Urban Environmental Pollution Control Technology Research Center estimated the total emissions in North China need to be cut by 70-80% from the current level in order to eliminate the days of heavy pollution in the Beijing region.[8]

To project how much emissions need to be reduced during smog-prone conditions to meet the target, we carried out simple statistical modeling. We fitted log-normal distributions to the daily PM2.5 levels of each city in 2019-2020, and assumed that the target is met when less than 1% of days have heavy pollution, consistent with [the way the World Health Organization applies](link) 24-hour PM2.5 and PM10 limits.

The analysis in Table 2 indicates that the average PM2.5 levels during episodes have to be reduced by around 25% in Beijing, Hebei and Shandong, by 30% in Shaanxi, Anhui and Heilongjiang and 35% in Henan. Tianjin, Liaoning and Shanxi need an about 20% reduction, and a 10–15% reduction would be sufficient in Hunan, Jilin, Inner Mongolia and Sichuan. A more than 50% reduction would be required in the heavily industrialized Wujiaqu town and Urumqi city in Xinjiang.

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[8] "十四五"要基本消除重污染天气 专家：华北污染排放需再降七成, 2021-3-9,
https://finance.sina.com.cn/china/gncj/2021-03-09/doc-ikkntiak6624129.shtml

Figure 5. Number of heavy pollution days in 2020 by city

Source: CREA

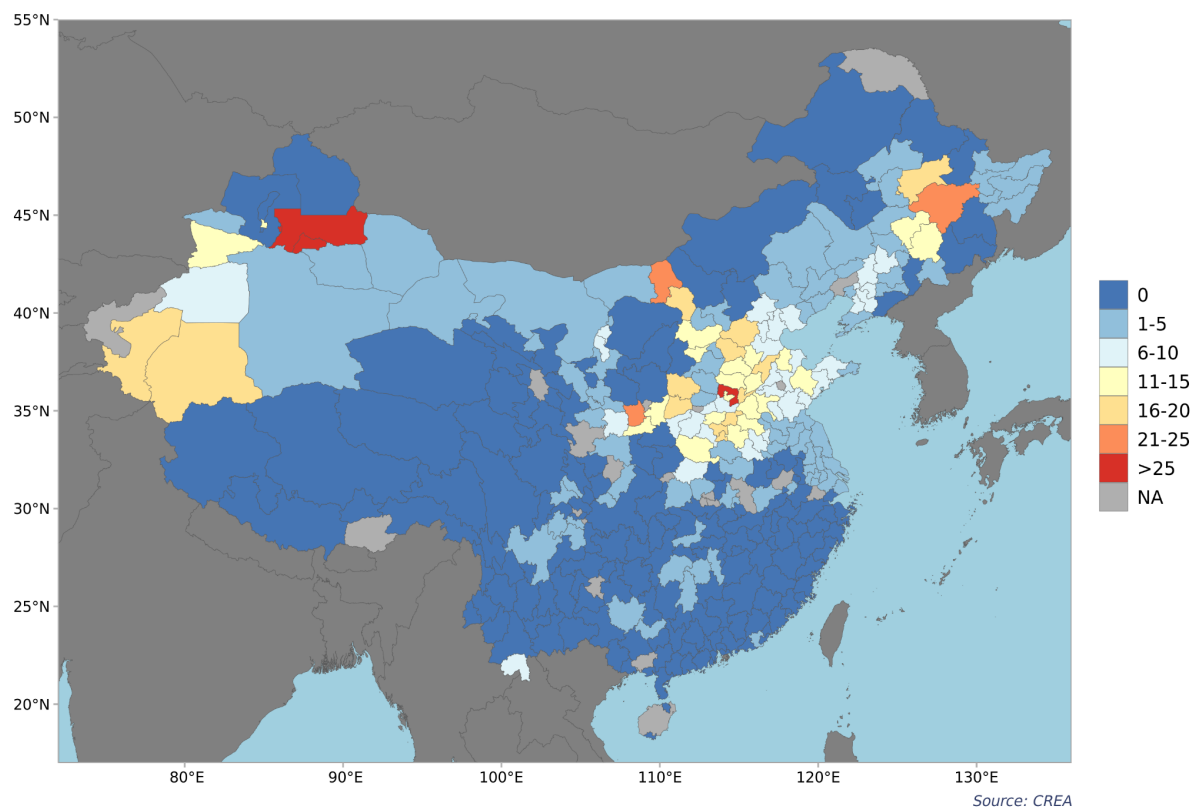**Table 2. Reductions that need to be achieved in the PM2.5 levels during days with the highest pollution, in order to limit the average number of days above the 'heavy pollution' threshold to no more than three per year. Includes only provinces which experienced heavy pollution days in 2019-2020.**

Province	Required reduction in average PM2.5 on worst days, to enable all cities to meet target	Number of heavy pollution days in 2020, highest number among the cities	City furthest away from the target
Anhui	-31.1%	14	Fuyang
Beijing	-23.9%	6	Beijing
Hebei	-24.8%	20	Shijiazhuang
Heilongjiang	-30.6%	22	Harbin
Henan	-36.1%	28	Anyang
Hubei	-21.8%	6	Xiangyang
Hunan	-12.7%	3	Yiyang
Jiangsu	-2.3%	5	Xuzhou
Jilin	-10.9%	15	Changchun
Liaoning	-18.8%	8	Jinzhou
Inner Mongolia	-13.6%	21	Hohhot
Shaanxi	-30.2%	22	Xianyang
Shandong	-23.2%	16	Dezhou
Shanxi	-20.6%	18	Yuncheng
Sichuan	-9.2%	2	Yibin
Tianjin	-19.1%	10	Tianjin
Xinjiang	-57.4%	50	Wujiaqu

Figure 6. Monthly average number of heavy pollution days by province in 2020. Includes only provinces which experienced heavy pollution days in 2020.

Number of heavy pollution days in provinces in 2020
Average number of heavy pollution days per city per month
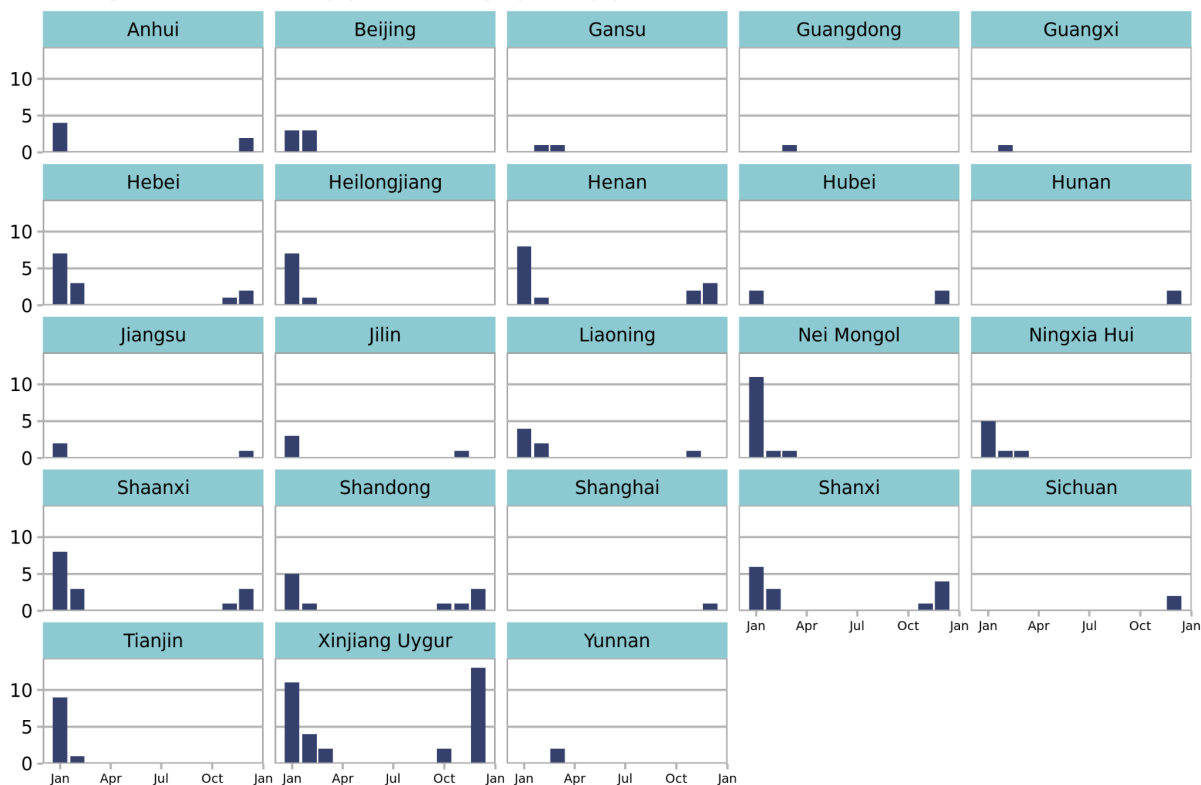
Source: CREA

Identifying the sources of heavy smog

To effectively address heavy smog days, it's helpful to identify the main emissions source regions that contribute to the episodes. CREA analysed data on wind directions and air pollution readings and used the HYSPLIT model to identify the source regions. The HYSPLIT model tracks the movement of air masses and can be run "backwards" to pin down the trajectory of an air mass that arrived in a city at a specific time. We ran these backward trajectories for all days of heavy pollution in 2020-21, for provincial capitals that experienced such days. The trajectories show where the polluted air masses came from—addressing air pollutant emissions in these areas is critical to eliminating days of heavy smog.

Figure 7 shows the wind directions during heavy pollution days in provincial capital cities. In Beijing region cities, heavy pollution days are associated with airflow from the south, showing the importance of further action on emissions sources in the 2+26 region and areas to the south of it—southern Shandong and Henan. A more detailed picture for Beijing is shown in Figure 8, implicating southern Hebei, north Shandong, east Shanxi, west Henan and Anhui as the source regions affecting air quality during smog episodes, largely consistent with the designation of key control regions.

Shanghai experienced heavy pollution with wind from the west and Nanjing from the east, showing the impact of the highly industrialized and populated Yangtze Delta area between the two cities. Northeastern region cities were affected by heavy pollution during airflow from the south and west, consistent with the location of the main industries in the region. (Figure 7.) For Shanghai, Harbin and Shijiazhuang, the heavy pollution episodes are also highly regional, with the polluted air masses moving across several provinces before arriving in the city, as shown in Figure 8.

Xi'an's smog days took place with airflow from the south, east and west and were quite local in nature—the polluted air masses travelled only 100–200km in the 72 hours before arriving in the city (Figure 8). This area of 100–200km around the city should be the focus of the efforts if Xi'an is to eliminate heavy pollution days.

We also built an interactive map with the trajectories for all the cities overlaid with satellite-based NO2 measurements which show the locations of major emissions sources and source areas[9].

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[9] https://energyandcleanair.org/china-winter2020-trajectories

Figure 7. Wind directions in provincial capital cities during heavy pollution days (last three winter seasons).
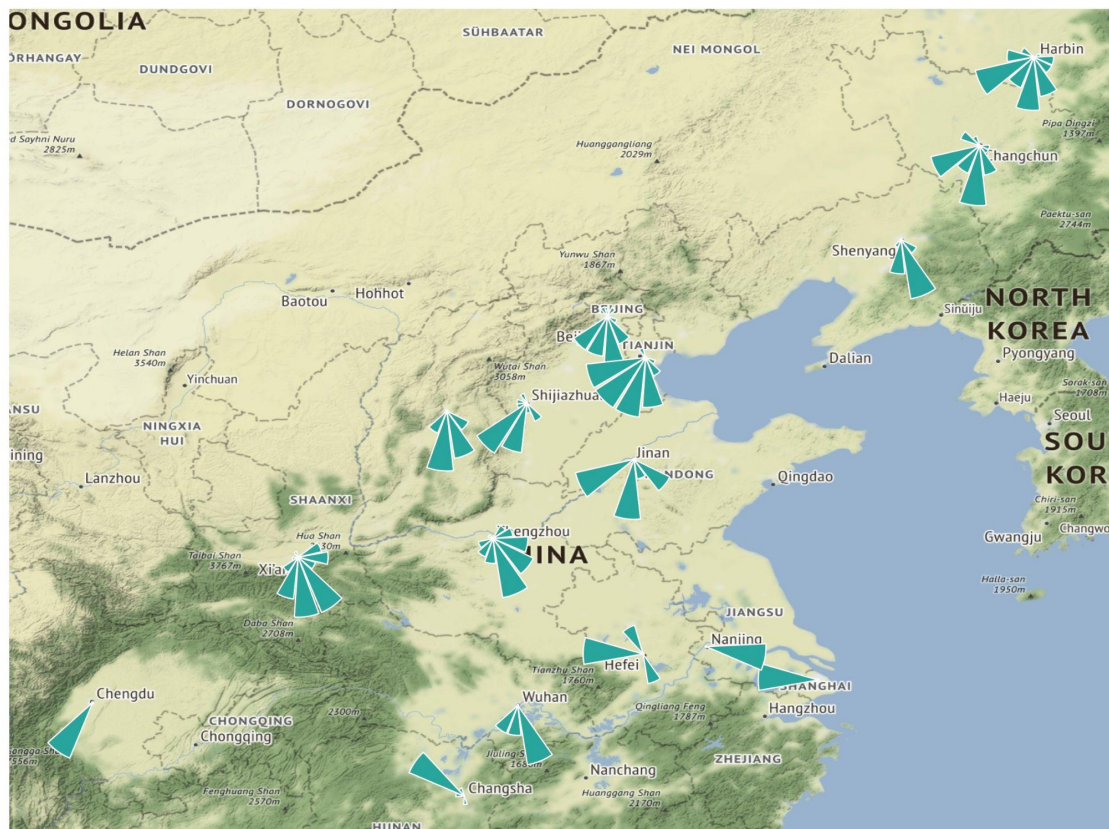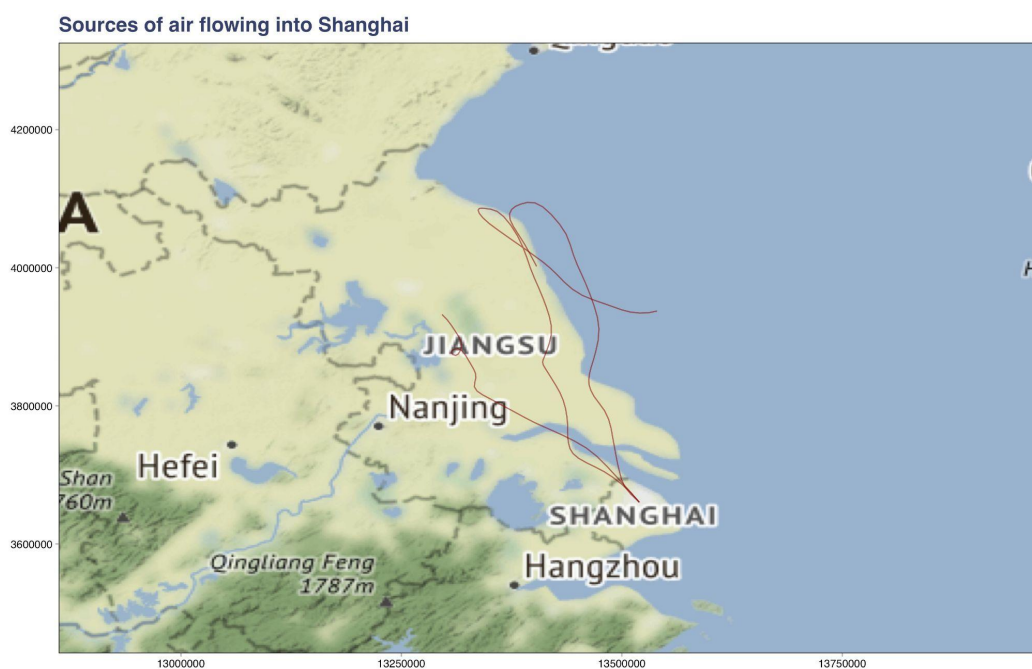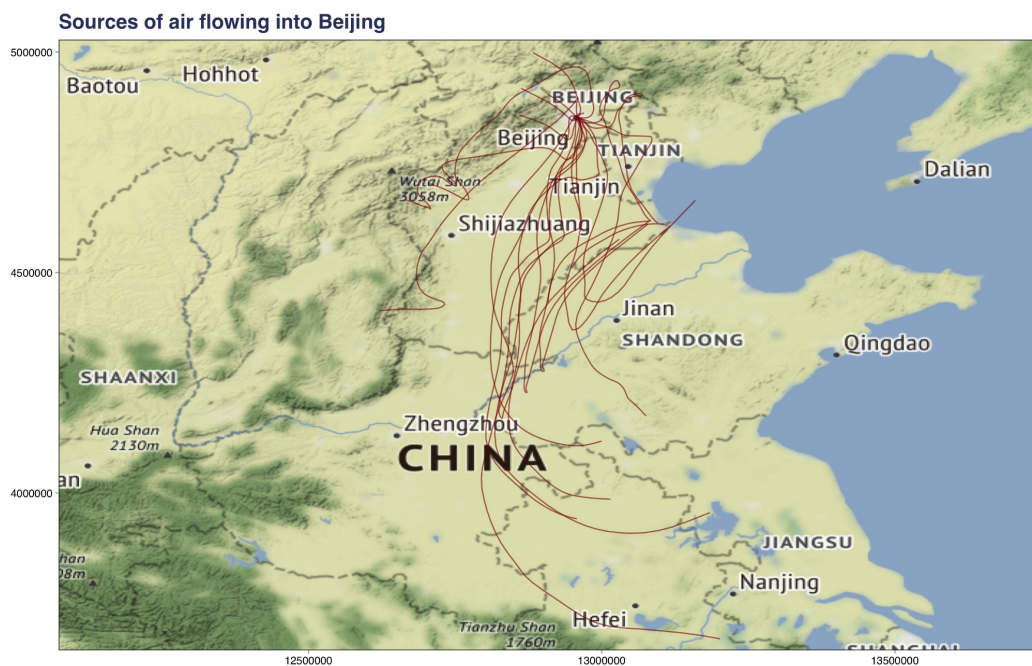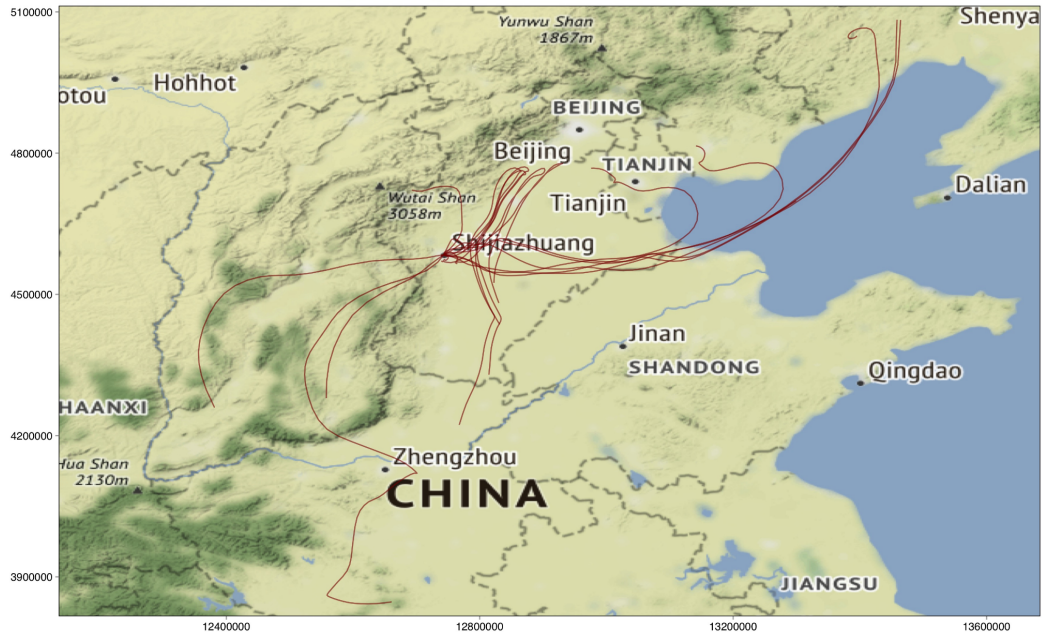
Figure 8. Trajectories of air masses arriving in Beijing, Shanghai, Shijiazhuang, Harbin and Xi'an during heavy pollution days during the 2020-2021 winter season. Emissions sources in the areas that the air masses passed through affected each city's air quality during heavy pollution conditions.

Sources of air flowing into Beijing

CREA based on MEE and HYSPLIT.
HYSPLIT parameters: 72h | gdas1 | 50m.

Sources of air flowing into Shanghai

CREA based on MEE and HYSPLIT.
HYSPLIT parameters: 72h | gdas1 | 50m.

Sources of air flowing into Shijiazhuang

CREA based on MEE and HYSPLIT.
HYSPLIT parameters: 72h | gdas1 | 50m.

Sources of air flowing into Harbin

CREA based on MEE and HYSPLIT.
HYSPLIT parameters: 72h | gdas1 | 50m.

Sources of air flowing into Xi'an

CREA based on MEE and HYSPLIT.
HYSPLIT parameters: 72h | gdas1 | 50m.

Disclaimer: The designations employed and the presentation of the material on maps contained in this report do not imply the expression of any opinion whatsoever concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries.

Appendix

- **Sandstorm days**

Sandstorm days were excluded from the study and weren't counted as 'heavy pollution' days. In the absence of an official list of sandstorm days, we used the following criteria:

- PM 10 > 400 μg/m3
- PM 2.5 / PM 10 < 0.8

In other words, sandstorm days are identified as days with very high PM 10 levels but relatively lower PM 2.5 levels, indicating that the pollution level is driven by relatively coarser particles.
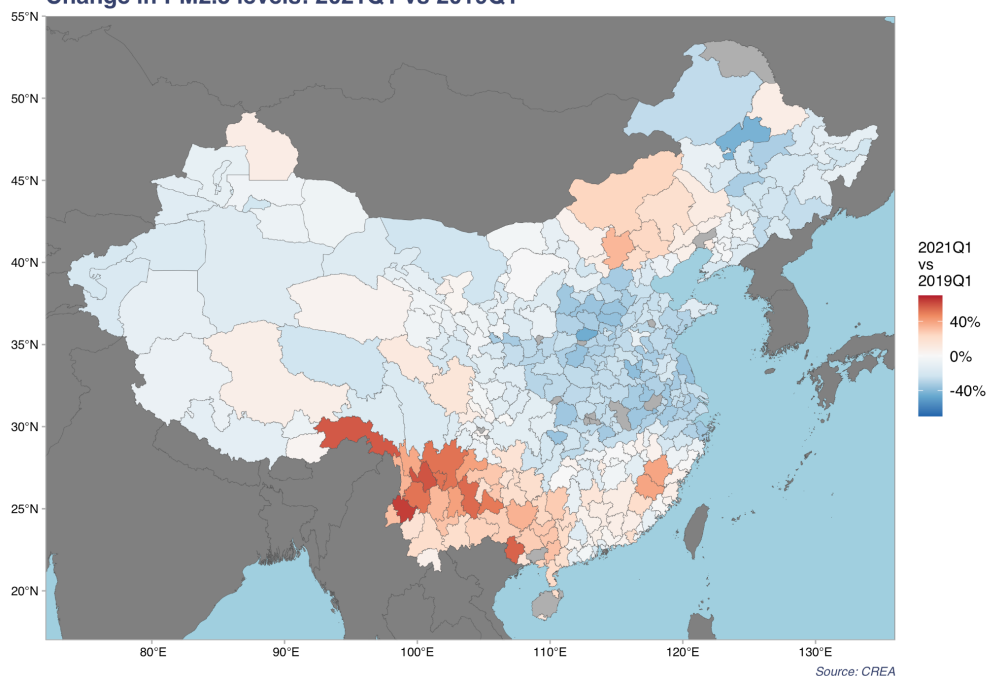
Occurence of sandstorms in key regions
Number of sandstorm days in winter

Source: CREA
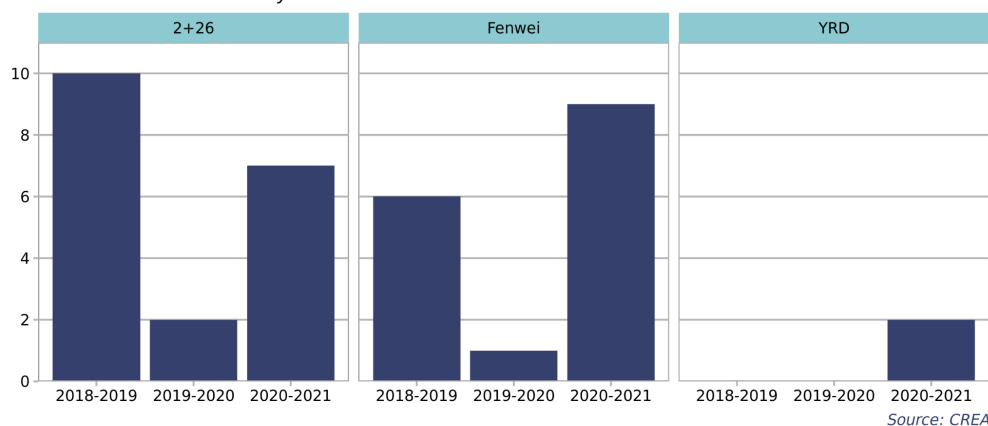
- **Changes in PM2.5 levels of Chinese cities in winter 2020-21 compared with baseline**

Change in PM2.5 levels: 2021Q1 vs 2019Q1

Source: CREA

Change in PM2.5 levels: 2020Q4 vs 2019Q4

Source: CREA