

## Supplementary materials

Table S1 Comparison of carbon dioxide and air pollutant emissions calculated by LEAP model with Henan official inventory

|                      | CO <sub>2</sub> | SO <sub>2</sub> | NO <sub>x</sub> | VOC <sub>s</sub> | PM <sub>10</sub> | PM <sub>2.5</sub> | NH <sub>3</sub> | CO     |
|----------------------|-----------------|-----------------|-----------------|------------------|------------------|-------------------|-----------------|--------|
|                      | Mt              | kt              | kt              | kt               | kt               | kt                | kt              | kt     |
| Official inventories | 531.48          | 310.8           | 1103.5          | 560.4            | 423.4            | 277.9             | 38.1            | 3919.4 |
| LEAP results         | 575.19          | 381.1           | 889.1           | 425.3            | 433.7            | 268.6             | 32.7            | 3417.7 |
| Deviation rate       | 7.59%           | 18.4%           | -24.1%          | -31.7%           | 2.4%             | -3.4%             | -16.5%          | -14.7% |

Table S2 Exposure response relationship coefficient of each health endpoint  $\beta$  and baseline mortality or incidence rate

| Project         | Health endpoint        | $\beta$ average value (95% confidence interval) | Reference | E/%     | Reference |
|-----------------|------------------------|-------------------------------------------------|-----------|---------|-----------|
| Death           | Mortality              | 0.00038(0.00031, 0.00045)                       | [1]       | 0.00711 | [2]       |
| Hospitalization | Respiratory diseases   | 0.00051(0.00030, 0.00073)                       | [3]       | 0.0413  | [2]       |
|                 | Cardiovascular disease | 0.00044(0.00033, 0.00054)                       | [1]       | 0.0102  | [2]       |
|                 | Acute bronchitis       | 0.00103(0.00087, 0.00122)                       | [4]       | 0.017   | [4]       |
| Morbidity       | Chronic bronchitis     | 0.0101(0.0037, 0.0156)                          | [5]       | 0.0007  | [5]       |
|                 | Asthma                 | 0.0021(0.00145, 0.00274)                        | [3]       | 0.0094  | [3]       |

Table S3 The setting of key socioeconomic development parameters for Henan Province.

| Key parameters        |                                                        | 2020   | 2025     | 2030     |
|-----------------------|--------------------------------------------------------|--------|----------|----------|
| Population parameters | Permanent resident population (10 <sup>4</sup> people) | 9936.6 | 10021.76 | 10026.53 |
|                       | Floating population (10 <sup>4</sup> people)           | 127.37 | 146.48   | 168.68   |
| Economic parameters   | Annual GDP* (trillion Chinese Yuan)                    | 5.5    | 6.8      | 8.6      |
|                       | Share of the secondary industry in GDP* (%)            | 41.59  | 39.71    | 36.86    |
|                       | Share of the tertiary industry in GDP* (%)             | 48.67  | 52.97    | 56.58    |
|                       | Share of manufacturing industry in the industry (%)    | 80     | 80       | 80       |

\*GDP represents the gross domestic product.

Table S4 The basic characteristics and sectoral emission reduction efforts of three different scenarios in this study

| Emission reduction efforts | Business as usual (BAU) | Energy saving and low carbon scenario (ESLC) | Reinforcement scenario (RS) |
|----------------------------|-------------------------|----------------------------------------------|-----------------------------|
|----------------------------|-------------------------|----------------------------------------------|-----------------------------|

|                         |                                                                                                                                                                                                                                              |                                                                                                                                                                                                                                        |                                                                                                                                                                                                                                            |
|-------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Overall governance      | Maintain the current climate governance path                                                                                                                                                                                                 | We will strengthen Climate Governance, accelerate technology promotion, and introduce new policies for energy conservation and emission reduction                                                                                      | Strengthen Climate Governance and make more ambitious efforts in the fields of transportation and construction                                                                                                                             |
| Electricity and heating | Reduce the share of coal-fired power generation; Energy efficiency transformation of existing plants                                                                                                                                         | Accelerate the elimination of coal-fired power plants; Construction of gas and CCHP plants (distributed gas-fired cogeneration system); Photovoltaic demonstration project                                                             | Further improve the utilization rate of renewable energy                                                                                                                                                                                   |
| Industry                | Maintain the current speed and promote advanced energy efficiency and energy management technologies<br>The energy efficiency level of various transportation departments is gradually improved,                                             | Accelerate the popularization of advanced energy efficiency technologies; "Oil to gas" of industrial boilers                                                                                                                           | Comprehensively promote cleaner production                                                                                                                                                                                                 |
| Transportation          | the fuel is adjusted to the direction of electricity, and the proportion of transportation modes is adjusted based on the existing policies and plans<br>The energy efficiency level of the construction sector has been gradually improved, | The level of energy efficiency has been further improved, higher than the BaU scenario, the adjustment of fuel to electricity has been accelerated, and the planning and adjustment of transportation modes have been further deepened | The energy efficiency level is higher than that in the ESLC scenario, the fuel is further adjusted to the direction of electricity, the existing policies are fully implemented, and the existing transportation modes are deeply adjusted |
| Building                | and the energy structure has been adjusted to clean energy                                                                                                                                                                                   | Speed up the energy-saving transformation of existing buildings; Speed up the implementation of stricter standards for new buildings                                                                                                   | Improve energy efficiency standards for new buildings; Accelerate energy efficiency monitoring and intelligent management                                                                                                                  |
| Service industry        | The existing energy consumption                                                                                                                                                                                                              | Coal was gradually replaced by natural gas, electricity                                                                                                                                                                                | Accelerate the process of replacing coal with                                                                                                                                                                                              |

|             |                                                                                                                                                                                                                                                                                                                |                                                                                                                                                                                             |                                                                                                                                                   |
|-------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------|
|             | structure was basically maintained, and the proportion of coal decreased slightly<br>With the improvement of living standards and economic development, the use intensity and duration of main energy consuming equipment have increased rapidly, and the energy intensity of service industry has accelerated | and heat                                                                                                                                                                                    | natural gas, electricity and heat                                                                                                                 |
| Resident    | The level of energy efficiency in the agricultural sector has been gradually improved, and the energy structure has been adjusted to clean energy                                                                                                                                                              | The use intensity and duration growth of main energy consuming equipment are lower than the benchmark scenario, and the growth rate of energy intensity in the service industry is moderate | The use intensity and duration of main energy consuming equipment increased slowly, and the energy intensity of service industry increased slowly |
| Agriculture |                                                                                                                                                                                                                                                                                                                | The improvement of energy efficiency and energy structure in the agricultural sector is higher than that in the BaU scenario                                                                | The improvement of energy efficiency and energy structure in the agricultural sector is higher than that in the ESLC scenario                     |

Table S5 Comparison of estimated emissions in this study, MEE database and MEIC in 2017  
(kg/capita, CO<sub>2</sub>: t/capita)

| Reference                    | Primary<br>PM <sub>2.5</sub> | SO <sub>2</sub> | NO <sub>x</sub> | NH <sub>3</sub> | CO <sub>2</sub> | Primary<br>PM <sub>10</sub> | CO           | VOC <sub>s</sub> | Study domain                                           |
|------------------------------|------------------------------|-----------------|-----------------|-----------------|-----------------|-----------------------------|--------------|------------------|--------------------------------------------------------|
| Our estimate                 | <b>2.81</b>                  | <b>3.98</b>     | <b>9.3</b>      | <b>0.34</b>     | <b>6.02</b>     | <b>4.53</b>                 | <b>35.75</b> | <b>4.45</b>      | Henan Province                                         |
| MEE<br>database              | <b>2.05</b>                  | <b>1.98</b>     | <b>4.92</b>     | <b>2.89</b>     | --              | --                          | --           | --               | "2+26" Cities                                          |
| MEIC<br>(Li, et al.<br>2017) | <b>3.12</b>                  | <b>4.57</b>     | <b>9.74</b>     | <b>3.62</b>     | <b>6.33</b>     | --                          | --           | --               | Beijing, Tianjin, Hebei,<br>Henan, Shandong and Shanxi |

Table S6 Available technologies or measures used to mitigate CO<sub>2</sub> and air pollution emissions of Henan in this study<sup>[6,7]</sup>

| Sectors                      | Technologies or measures on CO <sub>2</sub> emission mitigation                                                                                                                                                                                                      | Technologies or measures on air pollution prevention                                                       |
|------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------|
| Power generation and heating | (1) Energy efficiency retrofits of existing coal-fired plants                                                                                                                                                                                                        | (1) Upgrading of coal yard in existing coal-fired plants                                                   |
|                              | (2) Energy efficiency retrofits of existing gas-fired plants                                                                                                                                                                                                         | (2) Upgrading of low nitrogen burner and retrofit of flue gas denitrification in existing gas-fired plants |
|                              | (3) Reducing the share of existing coal-fired power generation while raising that of gas-fired power generation                                                                                                                                                      | (3) Accelerate the elimination of coal-fired plants                                                        |
|                              | (4) New construction of the gas-fired plants, combined cooling heating and power (CCHP) plants, and waste incineration plants                                                                                                                                        | (4) Upgrading of flue gas treatment systems of waste incineration power plants                             |
|                              | (5) Accelerate the elimination of coal-fired plants                                                                                                                                                                                                                  | (5) Continuously improve the heating capacity of cogeneration                                              |
|                              | (6) Utilization of coal resources by quality, classification and cascade                                                                                                                                                                                             | (6) Accelerate the alternative utilization of clean energy                                                 |
|                              | (7) Construct the centralized PV demonstration projects                                                                                                                                                                                                              |                                                                                                            |
|                              | (8) Promote the large-scale installment of distributed rooftop photovoltaic (PV) Stations                                                                                                                                                                            |                                                                                                            |
|                              | (9) Realize the power supply and coal consumption of coal-fired generating units in service, and reach the advanced level of similar units in China                                                                                                                  |                                                                                                            |
|                              | (10) Accelerate the development of wind power, encourage the development and construction of large-scale wind power bases in northwest, southwest and South Henan with better resource conditions, and actively promote the development of wind power in plain areas |                                                                                                            |
|                              | (11) Promote the construction of village level photovoltaic poverty alleviation power stations below 300 kW                                                                                                                                                          |                                                                                                            |

---

(12) Improve the development and utilization of biomass energy, orderly develop agricultural and forestry biomass power generation, and give priority to biomass cogeneration projects

(13) Promote central heating and waste heat to warm the people

---

|                        |                                                                                                                                                                                                                      |                                                                                                         |
|------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------|
| Manufacturing industry | (1) Promote the application of advanced control & management technologies or equipment                                                                                                                               | (1) Complete removal of boilers using highly polluted fuels, such as coal, firewood, and heavy oil      |
|                        | (2) Promote the application of advanced general mechanical technologies or equipment                                                                                                                                 | (2) Use cleaner fuels instead of diesel to make boilers                                                 |
|                        | (3) Promote the application of advanced combustion heating technology or equipment                                                                                                                                   | (3) Low NOx burner retrofits of gas-fired boilers                                                       |
|                        | (4) Promote the application of advanced lighting, temperature controlling, and material scheduling technologies or equipment                                                                                         | (4) Prohibit the use of raw or auxiliary materials with high volatile organic compounds (VOCs) contents |
|                        | (5) Carry out cleaner production technology transformation and mandatory cleaner production audit                                                                                                                    | (5) Prohibit the use of coating, printing ink and adhesive with high VOCs contents                      |
|                        | (6) Energy saving transformation of industrial boiler (kiln) and motor system                                                                                                                                        | (6) Air dispersion prevention, ground loss prevention and underground leakage prevention                |
|                        | (7) Waste heat and pressure utilization, industrial waste heat warming people, energy system optimization, energy-saving transformation of park system                                                               | (7) The production line is completely closed with solvent based raw materials                           |
|                        | (8) New dry process cement replaces traditional cement, new alloy materials or renewable materials replace traditional steel, organic fertilizer or slow-release fertilizer replaces traditional chemical fertilizer |                                                                                                         |
|                        | (9) Using natural gas instead of oil to make boilers                                                                                                                                                                 |                                                                                                         |

---

|                |                                                                                                                                                                                                                                       |                                                                                                                                                    |
|----------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------|
| Transportation | (1) Improve fuel economy of vehicles                                                                                                                                                                                                  | (1) Promote the application of EVs in on-line booking vehicles                                                                                     |
|                | (2) Improve energy efficiency of urban rail transit                                                                                                                                                                                   | (2) Accelerate the elimination of old vehicles                                                                                                     |
|                | (3) Improve the comprehensive transportation system, give priority to the development of public transportation, optimize the energy consumption structure of transportation, and vigorously develop intelligent transportation system | (3) Develop railway freight and multimodal transport                                                                                               |
|                | (4) Enhance the application of low-carbon fuels, such as electricity and natural gas, in freight vehicles                                                                                                                             | (4) Continue to crack down on inferior oil sales                                                                                                   |
|                | (5) Optimize the structure of urban freight transport                                                                                                                                                                                 | (5) Encourage the purchase and application of freight vehicles that use clean fuels                                                                |
|                | (6) Accelerate the construction of low-emission zones and strengthen traffic demand management                                                                                                                                        | (6) Promote the installment of diesel particulate filter (DPF) on medium- and heavy-duty diesel vehicles                                           |
|                | (7) Encourage low-carbon travel                                                                                                                                                                                                       | (7) Accelerate the construction of remote sensing monitoring and network platform<br>(8) Strengthen pollution control of non road mobile machinery |
| Building       | (1) Strengthen the planning and management of urban and rural construction and improve the energy efficiency of new buildings                                                                                                         | (1) Building materials shall be covered and sealed to prevent dust pollution                                                                       |
|                | (2) Expand the scale of green buildings, promote green building materials, and promote the development of prefabricated buildings                                                                                                     | (2) It is not allowed to burn toxic, harmful and pungent substances on the construction site                                                       |
|                | (3) Implement stricter standards for energy efficiency on newly built residential buildings                                                                                                                                           | (3) Strengthen the on-line monitoring and control of dust emission from construction projects                                                      |

|                  |                                                                                                                                                                                         |                                                                                              |
|------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------|
|                  | (4) Intelligent building energy management systems                                                                                                                                      | (4) Promote the application of fully enclosed dump truck                                     |
|                  | (5) Implement key projects such as new wall materials for energy conservation and waste utilization, thermal insulation materials, and demonstration of recycling of construction waste |                                                                                              |
| Service industry | (1) Strengthen technology transformation services and promote the application of low-carbon technologies                                                                                | (1) Upgrading of domestic waste incineration facilities                                      |
|                  | (2) Promote the standardization of low-carbon services                                                                                                                                  | (2) Install fume treatment facilities in catering places                                     |
|                  | (3) Strengthen the construction of key low-carbon service projects                                                                                                                      | (3) Accelerate the development of "double substitution" heating                              |
| Resident life    | (1) Create a low-carbon family                                                                                                                                                          | (1) Construction of special flue for domestic oil fume emission in new residential buildings |
|                  | (2) Reasonably control the indoor air conditioning temperature and reduce the standby energy consumption of ineffective lighting and electrical equipment                               | (2) Carry out VOCs control of living sources                                                 |
| Agriculture      | (1) Vigorously develop low-carbon agriculture                                                                                                                                           | (1) Use pesticides in accordance with relevant national regulations                          |
|                  | (2) Efforts to increase forest carbon sequestration                                                                                                                                     | (2) Improve fertilization methods                                                            |
|                  | (3) Strengthen energy conservation of agricultural machinery                                                                                                                            |                                                                                              |
|                  | (4) Guide the application of high-efficiency slow (controlled) release fertilizer, biological fertilizer and organic fertilizer                                                         |                                                                                              |
|                  | (5) Promote ecological circulation breeding mode                                                                                                                                        |                                                                                              |

Table S7 Setting of industrial structure in Henan Province

| Sectors                 | 2020  | 2025  | 2030  |
|-------------------------|-------|-------|-------|
| High-tech               | 5.18% | 6.05% | 6.76% |
| Energy conversion       | 0.87% | 0.74% | 0.60% |
| Other energy production | 2.10% | 1.37% | 0.86% |
| Light industry          | 9.50% | 9.40% | 8.89% |
| Steel                   | 1.67% | 1.53% | 1.34% |
| Chemical industry       | 2.87% | 2.70% | 2.42% |

|                        |       |       |       |
|------------------------|-------|-------|-------|
| Building material      | 4.49% | 3.49% | 2.59% |
| Other heavy industries | 7.02% | 6.83% | 6.35% |
| Nonferrous industry    | 2.53% | 1.93% | 1.40% |

## References

- [1] Shang, Y.; Sun, Z.; Cao, J.; Wang, X.; Zhong, L.; Bi, X.; Li, H.; Liu, W.; Zhu, T.; Huang, W. Systematic review of Chinese studies of short-term exposure to air pollution and daily mortality[J]. *Environment International*. 2013, 54, 100-111.
- [2] National Health and Family Planning Commission. China Health Statistical Yearbook 2018[EB/OL]. <https://www.yearbookchina.com/navibooklist-n3018112802-1.html>. (accessed on 1 June 2022).
- [3] Desheng, H.; Shiqiu, Z. Health benefit evaluation for PM<sub>2.5</sub> pollution control in Beijing-Tianjin-Hebei region of China[J]. *Chinese Environmental Science*. 2013, 33, 166-174.
- [4] Chen, J.; Li, W.; Cheng, H.G.; Xie, Y. Evaluation of emission reduction potentials of key air pollutants and health benefits for residents of Beijing. *Res. Environ. Sci.* 2015, 28, 1114–1121.
- [5] Tong, M.K.; Xi, G.J.; Tian, M.R.; Ping, J.I. Subduction of PM<sub>2.5</sub> by road green space in Beijing and its health benefit evaluation. *China Environ. Sci.* 2015, 35, 2861–2867.
- [6] The People's Government of Henan Province. Notice of the General Office of Henan Provincial People's Government on Printing and Distributing the Implementation Plan of Air Pollution Prevention and Control in 2018 in Henan Province. Available online: <http://www.henan.gov.cn/2018/02-23/249520.html> (accessed on 1 June 2022).
- [7] The People's Government of Henan Province. Notice of the General Office of Henan Provincial People's Government on Printing and Distributing the Implementation Plan of Controlling Greenhouse Gas Emission in the 13th Five Year Plan of Henan Province. Available online: <http://www.henan.gov.cn/2017/04-20/248915.html> (accessed on 1 June 2022).