Beautiful China "35 Goals" and "50 Vision" Scenario Simulation Postprint

Authors: Zhu Huiyi, Yang Linsheng, Qi Wei, Xu Erqi, Chen Jiewei, Ge Quansheng

Date: 2024-03-27T00:00:00+00:00

Abstract

Fully building a Beautiful China and achieving modernization featuring harmonious coexistence between humanity and nature is the overarching goal of China' s ecological civilization construction for the next 30 years. The overarching goal comprises two phased targets: the "35 Goals" and the "50 Vision." This article first elaborates on the understanding of the Beautiful China targets from the perspectives of ecosystem elements, structure, processes, and functions, then constructs an indicator system to characterize these targets, and employs scenario simulation methods to model the Beautiful China "35 Goals" and "50 Vision" under trends of climate change, population decline, and economic growth. The results indicate that by 2035, the national total population will be 1.44 billion, the Gross Domestic Product (GDP) will reach 200 trillion yuan, and China will enter the ranks of moderately developed countries. The national forest coverage rate will reach 26%, comprehensive grassland vegetation coverage will reach 60%, and desertified land treatment rate will reach 75%; surface water quality will reach Class III or above, coastal seawater quality will reach Class II or above; urban air quality will meet national excellent standards. By 2050, the national total population will be 1.365 billion, GDP will reach 380 trillion yuan, and China will enter the ranks of high-income countries. Forest coverage will reach 30%, comprehensive grassland vegetation coverage will reach 65%, and all desertified land will be effectively treated; both surface water and coastal seawater quality will meet Class II standards; urban air quality will reach the level of developed countries. There remains a significant gap between the current reality and the target vision. To achieve the Beautiful China target vision on schedule, it is necessary to vigorously promote pollution reduction, carbon emission reduction, green expansion, grain increase, and green development in the future.

Full Text

Preamble

Scenario Simulation and Intelligent Management and Regulation on Building of a Beautiful China

Citation: Zhu H Y, Yang L S, Qi W, et al. Scenario simulation of "35 goals" and "50 vision" for Beautiful China Initiative. *Bulletin of Chinese Academy of Sciences*, 2023, 38(12): 1754-1766, doi: 10.16418/j.issn.1000-3045.20230915004. (in Chinese)

Authors: Zhu Huiyi, Yang Linsheng, Qi Wei, Xu Erqi, Chen Jiewei, Ge Quansheng*

Affiliation: Key Laboratory of Land Surface Pattern and Simulation, Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing 100101

*Corresponding author

Abstract

Achieving a Beautiful China and realizing the modernization of harmonious coexistence between humanity and nature constitute the overarching goal of China' s ecological civilization construction for the next 30 years. This overall objective encompasses two phased targets: the "35 goals" (for 2035) and the "50 vision" (for 2050). This article first elaborates on the understanding of the Beautiful China goals from the perspectives of ecosystem elements, structure, processes, and functions. It then constructs an indicator system to characterize these goals and employs scenario simulation methods to model the "35 goals" and "50 vision" under projected trends of climate change, population decline, and economic growth.

The results indicate that by 2035, China' s total population will reach 1.44 billion, with a Gross Domestic Product (GDP) of 200 trillion yuan, placing it among moderately developed countries. The national forest coverage rate will reach 26%, comprehensive grassland vegetation coverage will hit 60%, and desertified land treatment rate will achieve 75%. Surface water quality will meet Class III standards or above, coastal water quality will reach Class II or above, and urban air quality will attain national excellent standards. By 2050, the national population will be 1.365 billion, with GDP reaching 380 trillion yuan, entering the ranks of high-income countries. Forest coverage will increase to 30%, grassland comprehensive vegetation coverage to 65%, and all desertified land will be effectively treated. Both surface water and coastal water quality will meet Class II standards, and urban air quality will reach the level of developed countries.

A significant gap remains between current conditions and the envisioned targets. To achieve the Beautiful China goals on schedule, China must vigorously promote five key initiatives in the coming years: pollution reduction, carbon reduction, green expansion, grain increase, and green development.

Keywords: Beautiful China Initiative, "35 goals" , "50 vision" , scenario simulation

---

1. Understanding the Vision of a Beautiful China

In 2020, the *Proposal of the Central Committee of the Communist Party of China on Formulating the 14th Five-Year Plan for National Economic and Social Development and the Long-Range Objectives Through the Year 2035* elevated "beauty" alongside "prosperity," "democracy," "civilization," and "harmony," proposing to build China into a great modern socialist country that is prosperous, strong, democratic, civilized, harmonious, and beautiful by the middle of the 21st century. The concept of "Beautiful China" differs fundamentally from other national aspirations: "prosperity" targets economic and military strength; "democracy" addresses political systems; "civilization" reflects cultural development; and "harmony" depicts social conditions. "Beautiful China" possesses its own unique connotation, pointing to the state of the ecological environment upon which the nation' s survival and development depend. The ecological environment is a complex composite of multiple elements with distinct structure, processes, and functions. A beautiful ecological environment must exhibit "beauty" across all dimensions—elements, structure, processes, and functions.

From these four dimensions, the vision of a Beautiful China encompasses four layers of meaning:

(1) Element Level: Restoring the Original Colors of Blue Skies and Green Lands. Environmental elements possess their own evolutionary processes and are naturally endowed with distinct aesthetic colors. The first layer of the Beautiful China vision involves restoring the fresh and vibrant base colors of the natural environment and recovering the distinctive natural essence of ecological elements to highlight their inherent beauty. Environmental elements include water, soil, air, and living organisms. Blue skies, green lands, clear water, clean soil, and flourishing biodiversity represent their natural colors. Restoring these natural colors fundamentally requires reducing anthropogenic pollution of the atmosphere, water bodies, and soil; restoring forest, grassland, and vegetation cover; and improving environmental quality—not completely returning to historical natural states. Modern human-environment relationships have changed dramatically compared to historical periods due to population growth, technological advancement, and climate change. A complete return to historical conditions is neither possible nor consistent with the people-centered principle of meeting public demand for a beautiful environment.

(2) Structure Level: Making Mountains, Rivers, Forests, Farmlands, and Lakes a Harmonious Living Community. The ecological environment forms a living community composed of landscape entities including mountains, rivers, forests, farmlands, lakes, grasslands, and deserts, which have developed specific quantitative and spatial structures through natural evolution. The second layer of the Beautiful China vision involves reshaping the structure of regional natural systems to demonstrate structural harmony. China' s territory spans 9.6 million square kilometers. The region southeast of the Hu Huanyong Line, accounting for 43% of the country' s land area and dominated by plains, river networks, and low mountains and hills, supports 94% of China's population and over 95% of its economic output, creating intense human-land conflicts and enormous environmental pressure. The northwestern region, comprising 57% of the territory and characterized by grasslands, deserts, oases, and snow-covered plateaus, hosts fragile ecosystems that support only 6% of the population and less than 5% of the national economy. Building a Beautiful China across such spatially differentiated territory requires profound understanding of regional environmental differentiation laws, precise spatial planning for production, living, and ecological spaces, and arranging the spatial structure of mountains, rivers, forests, farmlands, lakes, grasslands, deserts, glaciers, and coastal waters to better conform to natural distribution patterns.

(3) Process Level: Permanently Preserving Natural Ecological Beauty on Chinese Lands. Beautiful China construction concerns the sustainable development of the Chinese nation. Its elemental beauty and structural harmony must not be fleeting but enduring and permanent. Both Beautiful China construction and natural ecological conservation represent long-term, never-ending processes. The third layer of the vision involves maximizing restrictions on inappropriate human intervention in the natural environment, protecting natural ecology to the highest degree possible, and permanently preserving natural ecological beauty on Chinese lands. This requires adhering to green development pathways, limiting economic activities and human behavior within the carrying capacity of natural resources and ecological environments, thereby allowing natural ecosystems time and space to recuperate.

(4) Function Level: Safeguarding People' s Health and Comprehensive Development. Ensuring public health and comprehensive development represents both the original intention and ultimate purpose of Beautiful China construction. The fourth layer of the vision involves fully leveraging the ecological, economic, and social functions of natural ecosystems. Natural ecosystems provide functions including food production, water conservation, sand fixation, carbon sequestration, air purification, support for tourism and other industries, and cultural functions that enhance public aesthetic appreciation. The most fundamental functions are ensuring food security and protecting people' s health from harm caused by air, water, and soil pollution, as well as natural disasters.

Creating the distinctive beauty, harmonious beauty, enduring beauty, and healthy beauty of Beautiful China is a cause for all people to participate in, build, and share collectively. Only by transforming Beautiful China construction into conscious action across society, enhancing public awareness of conservation, environmental protection, and ecology, cultivating ecological ethics and behavioral norms, and launching nationwide green initiatives can Beautiful China ultimately be achieved.

The holistic nature of ecosystems determines that Beautiful China construction must be a coordinated process across the four dimensions of elements, structure, processes, and functions. However, different phases emphasize different objectives. **Phase 1 (Before 2035)** focuses on the element and structure levels, addressing long-accumulated prominent environmental problems and ecological degradation through pollution prevention battles and territorial spatial governance to achieve fundamental environmental improvement. **Phase 2 (2035-2050)** emphasizes the process and function levels, fundamentally resolving root causes of Beautiful China construction through comprehensive green development and lifestyle transformation, elevating the ecological environment from fundamental improvement to the beautiful level expected by the people.

2. Scenario Simulation of "35 Goals" and "50 Vision"

2.1 Indicator System

Based on the four-dimensional understanding of the Beautiful China vision and drawing upon the *Beautiful China Construction Assessment Indicator System and Implementation Plan* issued by the National Development and Reform Commission in 2020 (containing 22 indicators) and the UN *2030 Agenda for Sustainable Development* indicators (comprising 17 goals, 169 targets, and 247 specific indicators), we constructed an indicator system for the Beautiful China goals (Table 1). This is an open system that can be supplemented with urban and rural living environment indicators, environmental quality indicators for water-soil-air, and biodiversity conservation indicators. However, more indicators, while providing more detailed characterization, often lose focus and make quantification more difficult.

2.2 Scenario Setting

Scenario setting forms the logical starting point for simulation. This study' s scenario simulation revolves around three scenarios: (1) **Climate change scenario**: Using global climate system models from the IPCC Sixth Assessment Report (AR6), we obtained values, spatial distributions, and changes for five indicators in 2035 and 2050—annual mean temperature, annual precipitation, sea level height, latitude-longitude positions of climate zones, and spring phenology period—to reflect the climate change background for the next 30 years. (2) **Population scenario**: From existing population projection models, we selected those with strong applicability and relatively high prediction accuracy to forecast national population totals for 2035 and 2050. (3) **Economic scenario**: Based on the economic development targets in the *Outline of the 14th Five-Year*

Plan for National Economic and Social Development and Long-Range Objectives Through the Year 2035 of the People' s Republic of China and per capita GDP levels of moderately developed and developed countries, we determined national economic totals for 2035 and 2050.

2.3 Simulation Algorithms

Using the projected climate, population, and economic conditions for 2035 and 2050 as premises, we employed domestic and international empirical data, multi-factor neural network models, and machine learning algorithms to construct quantitative relationships between population change, economic development, product demand, energy demand, and land demand in the post-industrial era and future climate change context. This allowed simulation of changes in China' s major ecosystems (forests, grasslands, etc.) and estimation of key Beautiful China indicators including forest coverage rate, comprehensive grassland vegetation coverage, wetland protection rate, and desertified land treatment rate. Simultaneously, we built econometric models linking energy consumption, raw material consumption, and fertilizer/pesticide consumption in industrial and agricultural production to atmospheric, soil, surface water, and coastal pollutants, quantitatively estimating environmental indicators for the next 15 and 30 years.

Machine learning algorithms incorporated relevant national planning targets as learning content. Consequently, final simulation results may or may not align with planning targets but should not fall below them in principle.

2.4 Model Credibility Testing

To ensure simulation validity, we used 2010 as the base year and 2020 as the target year to test major models including climate models, population models, and multi-factor neural network models. Test results showed: temperature simulations correlated extremely highly with observations (R^2 = 0.98, spatial correlation coefficient = 0.952), with correlation coefficients exceeding 0.8 nationwide and above 0.9 in most areas of North, Northeast, and Northwest China; population total error and spatial error ranged from -4.04% to 5.67% and -8.74% to 9.42% respectively; average economic total error was approximately 10%; urbanization rate and energy consumption simulation results deviated less than 5% from National Bureau of Statistics data; forest distribution credibility was 0.893; grassland distribution credibility was 0.941; cropland distribution credibility was 0.960; and construction land distribution credibility was 0.930.

2.5 "35 Goals" Scenario Simulation

Simulation results (Table 2) show that by 2035, compared with 1961–1990, national annual mean temperature will increase by 1.5–2.6°C, precipitation will increase by 3–5%, sea level will rise by 10–40 cm, climate zones will shift northward by 100 km from 2020 positions, spring phenology will advance by two weeks, and the Tibetan and Mongolian plateaus will become warmer and wetter. New forests will be added on the Loess Plateau and Taihang Mountains, increasing national forest coverage to 26%; comprehensive grassland vegetation coverage will rise to 60%; desertification will be effectively controlled; and wetland protection rate will increase to 60%.

By 2035, total population will reach 1.44 billion, GDP will be 200 trillion yuan, placing China among moderately developed countries. Energy consumption will be 6 billion tons of standard coal equivalent, with non-fossil energy accounting for 30%. Urbanization rate will exceed 70%, with 19 urban agglomerations concentrating 80% of the population and 90% of GDP. The national high-speed railway network will extend 70,000 km, highways 260,000 km, high-grade waterways 25,000 km, with 63 major ports and 400 transport airports. The "Eight Vertical and Eight Horizontal" high-speed rail network and comprehensive three-dimensional transportation network will be essentially completed.

Following completion of the middle route follow-up project of the South-to-North Water Diversion and the "Tibetan Water to Xinjiang" project, new water transfer capacity will reach 60 billion cubic meters, increasing northern water resources by 10%. Northwest regions like Xinjiang will add 2 million hectares (30 million mu) of cropland. Multiple cropping indices in Northeast and North China will increase by 10–20%, enhancing national resource-environment carrying capacity by 10%, making "North-to-South grain transport" a long-term pattern. National surface water quality will reach Class III or above, coastal water quality Class II or above, polluted cropland safety utilization rate will increase to 100%, and urban air quality will meet national excellent standards.

2.6 "50 Vision" Scenario Simulation

Simulation results (Table 3) show that by 2050, compared with 1961–1990, national annual mean temperature will increase by 2.3–3.1°C, precipitation by 5–12%, and sea level by 12–50 cm. Climate zones will shift northward by 150–200 km from current positions, spring phenology will advance by over three weeks, and Northwest China will become warmer and wetter overall. New forests will be added in Northwest and East China, increasing national forest coverage to 30%; comprehensive grassland vegetation coverage will reach 65%; desertified land will be effectively treated; and northwestern lake areas will show increasing trends, with over 200 important wetlands.

By 2050, total population will be 1.365 billion, GDP will reach 380 trillion yuan, entering the ranks of high-income countries. Energy consumption will total 5.5 billion tons, with non-fossil energy exceeding 70%. National urbanization rate will surpass 80%. Transportation will achieve comprehensive three-dimensional, networked, and intelligent development. The Beijing-Hangzhou Grand Canal will be fully connected, integrating the five major water systems of Haihe, Yellow River, Huaihe, Yangtze, and Pearl Rivers. Building on the 2035 scenario, new water transfer capacity will increase by 40 billion cubic meters, allowing an additional 1.33 million hectares (20 million mu) of cropland and further enhancing resource-environment carrying capacity by 5%. Both surface water and coastal water quality will meet Class II standards; heavy metal-polluted cropland will be effectively treated; and urban air quality will reach developed country levels.

3. Reality Gap and Path to Achieving the Vision

Currently, a clear gap exists between reality and the envisioned targets, though efforts are actively underway. Comparing 2020 baseline values with the "2035 goals"and "2050 vision"reveals substantial disparities (Table 4). In 2020, the proportion of days with excellent urban air quality was only 87%, over 8 percentage points short of the 95% target for 2035 and 100% for 2050. PM2.5 concentration remained high at 33 g/m^3, not yet meeting national excellent standards. Surface water quality above Class III accounted for 83.5%, and coastal water quality above Class II represented 77.4%, leaving 16.5% of surface water and 22.6% of coastal waters requiring treatment. Ten percent of polluted cropland had not yet achieved safe utilization. Forest coverage was 3 and 7 percentage points below the 2035 and 2050 targets respectively. Comprehensive grassland coverage was 4 and 9 percentage points below targets. Cropland protection still faced pressures from construction occupation and ecological restoration. Wetland protection rate had just reached 51.9%, 8 and 28 percentage points below the targets. Desertified land still covered 1.72 million km^2, making comprehensive treatment an arduous task. Energy consumption remained in a growth phase, with non-fossil energy accounting for only 15.9%. Energy and water use efficiency needed substantial improvement, with energy consumption per unit GDP at 0.37 tons standard coal/10,000 yuan and water consumption at 0.56 m^3/10,000 yuan. Economic and living standards remained at upper-middle levels, with permanent population urbanization at just 64% and life expectancy at 79.4 years, still far from target levels and developed country standards.

These gaps represent the challenges that must be gradually addressed. To narrow these disparities and achieve the "35 goals" and "50 vision" on schedule, five initiatives must be pursued synergistically:

(1) Pollution Reduction. Restoring blue skies and green lands requires fundamentally reducing anthropogenic pollution of air, water, and soil. Major air pollutants include PM2.5, PM10, SO_2, NO_2, O_3, and CO. Water pollutants comprise chemical oxygen demand, total phosphorus, permanganate, sulfates, and ammonia nitrogen. Coastal pollutants are mainly inorganic nitrogen and phosphate, while soil contaminants are primarily heavy metals like cadmium, mostly originating from industrial/agricultural production and daily life. Based on scenario simulations, PM2.5 must be reduced from 33 g/m^3 in 2020 to 29.7 g/m^3 by 2035 and 15 g/m^3 by 2050 to achieve the Beautiful China environmental quality goals.

(2) Carbon Reduction. Achieving carbon peak before 2030 and carbon neutrality before 2060 represents a major strategic decision. Carbon emissions correlate highly with pollutant emissions, as CO_2 formation and release generally accompany other air pollutants. Key to carbon reduction is transforming China' s energy consumption structure and increasing the non-fossil energy share. As GDP grows from 101.6 trillion yuan in 2020 to 200 trillion yuan by 2035 and 380 trillion yuan by 2050, energy consumption is projected to rise from 4.98 billion tons standard coal equivalent in 2020 to 6 billion tons by 2035 before declining by 2050. Scenario simulations indicate non-fossil energy must increase from 15.9% in 2020 to 30% by 2035 and over 70% by 2050.

(3) Green Expansion. Making mountains, rivers, forests, farmlands, and lakes a harmonious living community requires reshaping regional natural system structures. This involves increasing forest and grassland cover, protecting wetland ecosystems, and intensifying treatment of desertification and land degradation. Scenario results show forest coverage must increase from 23.04% in 2020 to 26% by 2035 and 30% by 2050; comprehensive grassland vegetation coverage from 56.1% to 60% and 65%; wetland protection rate from 51.9% to 60% and 80%; and desertified land area must be reduced from 1.72 million km^2 to below 430,000 km^2 for gradual comprehensive treatment.

(4) Grain Increase. The core of Beautiful China construction is enhancing ecosystem functions to safeguard people' s health and comprehensive development. Food security forms the foundation, requiring strengthened cropland protection, quality improvement, and exploitation of unused land like saline-alkali wasteland to expand agricultural production space. Scenario simulations suggest that with additional water transfers of 60 billion m^3 by 2035 and 100 billion m^3 by 2050 in northern regions, cropland could increase by 3.33 million hectares (50 million mu).

(5) Green Development. Permanently preserving natural ecological beauty requires adhering to green, high-quality development. Only through green development can pollutant emissions be controlled, resource use efficiency improved, carbon goals achieved, and human activities restricted within natural carrying capacity, thereby improving ecosystem structure and function. Scenario simulations show that without green development, the projected GDP of 200 trillion and 380 trillion yuan, per capita GDP of 139,000 and 278,000 yuan, urbanization rates of 70% and 80%, and life expectancy over 82 years would be unsustainable under resource and environmental constraints.

Historical precedent demonstrates China' s capacity to achieve ambitious goals: the "Three-Step"strategy proposed in 1987 successfully doubled GDP by the late 1980s and quadrupled it by 1995; the 2015 goal of eliminating rural poverty by 2020 was achieved on schedule, with 98.99 million rural poor lifted out of poverty and a moderately prosperous society comprehensively built. These achievements testify that with the ambition and capability of the Chinese government and people, the Beautiful China vision will certainly be realized.

References

1. Xi J P. *Excerpts from Xi Jinping' s Discussion on the Construction of Socialist Ecological Civilization*. Beijing: Central Party Literature Press, 2017: 1-15. (in Chinese)
2. Fang C L, Wang Z B, Liu H M. Exploration on the theoretical basis and evaluation plan of Beautiful China construction. *Acta Geographica Sinica*, 2019, 74(4): 619-632. (in Chinese)
3. Zou Y L. A preliminary discussion on processes and features of environmental changes during historical period in China. *Journal of Anhui Normal University*, 2002, 30(3): 292-297. (in Chinese)
4. Ling D X. The evolution of forest resources in China. *Agricultural History of China*, 1983, (2): 26-36. (in Chinese)
5. He F N, Ge Q S, Dai J H, et al. Quantitative analysis on forest dynamics of China in recent 300 years. *Acta Geographica Sinica*, 2007, 62(1): 30-40. (in Chinese)
6. Li Z P, Yue L P, Guo L, et al. Holocene climate change and desertification in northern China. *Northwestern Geology*, 2007, 40(3): 1-29. (in Chinese)
7. Hua T, Wang X M, Ci Z, et al. Responses of desertification to climate change in arid and semiarid regions of China over the past millennium. *Journal of Desert Research*, 2012, 32(3): 618-624. (in Chinese)
8. Hu H Y. The distribution, regionalization and prospect of China' s population. *Acta Geographica Sinica*, 1990, 45(2): 139-145. (in Chinese)
9. Hu H Y. Distribution of China' s population: Accompanying charts and density map. *Acta Geographica Sinica*, 1935, 2(2): 33-74. (in Chinese)
10. Wang Z, Xia H B, Tian Y, et al. A big-data analysis of HU line existence in the ecology view and new economic geographical understanding based on population distribution. *Acta Ecologica Sinica*, 2019, 39(14): 5166-5177. (in Chinese)
11. Wan J R, Pan J H, Lv Z M, et al. Commentaries: Ecological civilization and "Beautiful China" . *Social Sciences in China*, 2013, (5): 4, 204-205. (in Chinese)
12. Huang X J. Beautiful China and the land space use control. *Journal of China University of Geosciences (Social Sciences Edition)*, 2018, 18(6): 1-7. (in Chinese)
13. Wan J R. The philosophical wisdom and action significance of Beautiful China. *Social Sciences in China*, 2013, (5): 5-11. (in Chinese)
14. Li Z. Building a Beautiful China to achieve sustainable development. *Economic Research Journal*, 2013, 48(2): 17-19. (in Chinese)

15. Li J H, Cai S W. The scientific connotation and strategic significance of "Beautiful China" concept. *Journal of Sichuan University (Philosophy and Social Science Edition)*, 2013, (5): 135-140. (in Chinese)

16. Zhang W, Li H L. Environmental challenges and green technology innovation strategy for building "Beautiful China" . *Theory Journal*, 2013, (1): 64-68. (in Chinese)

17. Xie B G, Chen Y L, Li X Q. The "Beautiful China" evaluation system based on niche theory. *Economic Geography*, 2015, 35(12): 36-42. (in Chinese)

18. Xiang Y B, Xie B G. Design of evaluation index system for regional construction of "Beautiful China" . *Statistics & Decision*, 2015, (5): 51-55. (in Chinese)

19. Hu Z Y, Zhao L K, Liu Y W. The construction and evidence of the evaluation index system of "Beautiful China" . *Statistics & Decision*, 2014, (9): 4-7. (in Chinese)

20. Deng W, Song X X. Reflections on the construction of the system of the Beautiful China. *Chinese Journal of Nature*, 2018, 40(6): 445-450. (in Chinese)

21. Huang L, Shao C F, Sun Z S, et al. Research on the evaluation index system of "Beautiful Village" . *Ecological Economy*, 2014, 30(1): 392-394. (in Chinese)

Appendix: Multi-Factor Neural Network Simulation

A specially designed multi-factor neural network for Beautiful China scenario simulation includes five modules: climate, population, economy, energy, and ecological environment, used to simulate the "35 goals" and "50 vision" of Beautiful China characteristics.

1. Climate Module

We selected the internationally influential and widely applied Earth System Models CNRM-CM6 and FGOALS-g to simulate China' s climate change scenarios for 2035 and 2050. CNRM-CM6 simulates future temperature and precipitation changes, while FGOALS-g simulates climate change impacts on the ecological environment.

The climate model uses gridded greenhouse gas emissions as input to simulate and calculate the distribution of climate elements. Greenhouse gas emissions are divided into natural and anthropogenic components.

Natural emissions are primarily influenced by land use:

$$\text{Emis}_{\text{NAT}} = \sum \text{Emis}_{\text{LU}i} \times \text{Area}(\text{LandType}_i)$$

where Emis_{LU} represents emissions per unit area for corresponding land use types (can be negative), and Area represents the area of corresponding land use types.

Anthropogenic emissions mainly come from energy consumption and chemical production. Summing by sector yields total emissions, with sector classification consistent with the PRIMAP-hist dataset, including energy (fuel combustion, oil and gas, other energy production), industry (mining, chemicals, metals, electronics), agriculture (livestock, non-livestock agriculture), and others. Subtracting anthropogenic carbon sequestration from Carbon Capture, Utilization, and Storage (CCUS) technology yields total national anthropogenic emissions:

$$\text{Emis}_{\text{ANT}} = \sum \text{Emis}_{\text{Sec}i} \times \text{GDP}(\text{Sector}_i) - \text{CCUS}$$

Total emissions equal the sum of natural and anthropogenic emissions:

$$\text{Emis}_{\text{TOT}} = \text{Emis}_{\text{NAT}} + \text{Emis}_{\text{ANT}}$$

The gridding method allocates national total emissions across the country according to population grids:

$$\text{Emis}_{\text{grid}}(i) = \text{Emis}_{\text{TOT}} \times \frac{\text{POP}(i,j)}{\sum \text{POP}(i,j)}$$

Policy parameterization is crucial for Earth System Model operation. In parameterizing policy implementation capacity, we primarily adopt exponential forms. For example, after setting a forest coverage target, the coverage change $a(t) = a_0 \times e^{-\mu t}$, where μ represents policy implementation strength—larger μ values mean earlier achievement of policy targets. Constraints include rigid and soft limits during policy formulation. Rigid constraints are physical limits that cannot be exceeded, such as total land area being fixed at 100%—planned land use proportions cannot exceed this value. In practice, due to suitability issues (e.g., land suitable for forests may also be suitable for cultivation), total planned area proportions are smaller, represented as Area_{max}, with all planned land summing to Area_{max}. Soft constraints represent limits achievable due to technological restrictions; when technological breakthroughs occur, constraints are eliminated. For example, oil and gas emissions will gradually decrease due to technological progress: $\text{Emis}_{\text{Sec}_{\text{oil}}} = A \times e^{-at}$, where a represents emission reduction rate from technology, with an upper limit a_{max} that itself can change when technological leaps occur.

2. Population Module

Population changes are projected using the cohort-component method, with the basic equation:

$$P_t = P_0 + B - D + I - O$$

where P_t represents permanent population at time t for a cohort, P_0 represents permanent population at initial time t_0, B and D represent births and deaths within the cohort between initial and final times, and I and O represent in-migration and out-migration.

Parameters in population projection (fertility rate, mortality rate, and migration parameters) are primarily influenced by economic factors. Fertility and mortality rates are affected by urbanization rate, while migration rates are influenced by economic disparities between regions. Natural climate conditions also affect these parameters, indirectly altering population trends. Based on this logic, we use per capita GDP to measure economic impacts, expressing population-related parameters as:

Fertility rate parameter: $F_1(\text{per capita GDP, urbanization rate}) \times F_2(\text{temperature, precipitation})$

Mortality rate parameter: $G_1(\text{per capita GDP, urbanization rate}) \times G_2(\text{temperature, precipitation})$

Migration parameter: $H_1(\text{Gini coefficient, per capita GDP difference}) \times H_2(\text{temperature, precipitation})$

Through scenario design, corresponding parameters are set under different fertility, mortality, and migration scenarios to achieve population projections for all cohorts, enabling predictions of total population and future age-sex pyramid structures.

3. Economic Module

Using IPCC' s Shared Socioeconomic Pathways (SSPs) GDP growth rate projections for China, we calculate future national GDP totals. We select a "Night-time Light (NTL)-population spatial disaggregation method"for higher-precision GDP gridding:

$$\text{LitPop} = \begin{cases} 0 & \text{if Lit} \times \text{Pop} \leq 0 \\ \text{Lit} \times \text{Pop} & \text{if Lit} \times \text{Pop} > 0 \text{ and Pop} > 0 \end{cases}$$

$$\text{GDP}_{\text{LitPop}} = \frac{\text{GDP}}{\sum \text{LitPop}} \times \text{LitPop}_{\text{pixel}}$$

where LitPop represents the value of each pixel in the LitPop image, generated by multiplying NTL imagery data with Landscan population dataset data, with SLP_i being the sum of LitPop data for administrative unit i.

4. Energy Module

Energy is influenced by climate conditions. Regarding energy demand, greenhouse effects from greenhouse gas emissions increase demand for air conditioning and cooling while decreasing heating demand. Regarding energy supply, greenhouse effects impact thermal power plant efficiency and renewable energy supply (hydro, wind, solar). These impacts can be simulated by adjusting shift coefficients in energy demand functions:

$$\text{Energy demand impact} = \sum_i \sum_s \sum_t \text{Energy}_{i,s,t} \times [(1 + \Delta T_{s,t})^{\beta_{i,s,t}} - 1]$$

Energy consumption changes for different energy types i are influenced by seasonal temperature changes s, while energy consumption also affects greenhouse gas emissions:

$$\text{Emis} = \sum_i E_i \times \alpha_i$$

Different energy types have different emission intensities. Energy consumption provides feedback to climate change through emissions.

In energy supply, efficiency of different energy types is affected by natural factors (temperature, precipitation, wind speed). As these relationships require deeper research, our model uses adaptive algorithms to identify relevant factors, obtains quantitative relationships through neural networks, and applies them to future scenario predictions.

5. Ecological Environment Module

Ecological environment simulation employs system dynamics modeling, an iterative process requiring continuous hypothesis formation, testing, and model refinement based on test results. The model uses first-order differential equations:

State variable equation (L):

$$\text{lv}_S(t) = S(t_0) + \int_{t_0}^{t} \text{rate}_S(t)\, dt = S(t_0) + \int_{t_0}^{t} [\text{inflow}_S(t) - \text{outflow}_S(t)]\, dt$$

where $\text{lv}_S(t)$ represents state variable value at time t, and $\text{rate}_S(t)$ represents the change rate of this state variable.

Rate equation (R):

$$\text{rate}_S(t) = g[\text{lv}_S(t), \text{aus}(t), \text{exo}(t), \text{const}]$$

where $\text{rate}_S(t)$ is state variable change rate, $\text{lv}_S(t)$ is state variable value at time t, $\text{aus}(t)$ is auxiliary variable value, $\text{exo}(t)$ is exogenous variable value, and const represents constants.

Auxiliary equation (A):

$$\text{aux}(t) = f[\text{lv}_S(t), \text{aux}^*(t), \text{exo}(t), \text{const}]$$

where $\text{aux}^*(t)$ represents auxiliary variables other than the one being solved.

Constant (C): Requires assigning a fixed numerical value.

Table function (T): Relationships among certain variables in the system may be nonlinear and difficult to express with mathematical equations. Table functions can represent these nonlinear relationships through graphical patterns.

Based on these foundations, decision variables are adjusted, different development strategies are set, and quantitative simulation of the ecological environment is conducted.

Note: Figure translations are in progress. See original paper for figures.

Source: ChinaXiv —Machine translation. Verify with original.