Supplementary material

Geographically, the NPSC was divided into eight river basins (excluding the Southeast river basins) by the Ministry of Water Resources and the National Bureau of Statistics.This study posited that each river basin operates as a self-contained system for accumulating carbon density pools within their respective areas.

Table S1. Carbon storage in diverse river basins

LULC	AGC	BGC	SOC	DOC	References
Pearl River Basin					
Cropland	40.5	26.8	102.19	5.2	[1-3]
Forest	37.68	8.85	104.97	7.6	
Shrub	4.51	3.36	123.39	0	
Grassland	1.63	1.34	134.01	4.8	
Water	0	0	0	0	
Snow/Ice	0	0	0	0	
Barren	11.1	2.2	37.1	1.0	
Impervious	5.6	1.1	25.3	0	
Wetland	13.6	3.56	204.13	0	
Yangtze River Basin					
Cropland	16.49	10.89	99.33	2.11	[1,4]
Forest	45.45	9.63	99.64	2.78	
Shrub	3.43	1.46	100.22	0	
Grassland	0.73	6.40	72.77	7.28	
Water	0	0	0	0	
Snow/Ice	0	0	0	0	
Barren	10.36	2.07	34.42	0.96	
Impervious	7.61	1.52	34.33	0	
Wetland	4.19	11.81	140.10	3.98	
Southwest Basin					
Cropland	2.00	0.40	6.56	0	[1,5]
Forest	80.05	19.75	116.97	0	
Shrub	5.65	6.22	23.23	2.12	
Grassland	0.42	9.20	75.91	0	
Water	0	0	0	0	
Snow/Ice	0	0	1.10	0	
Barren	0	0	4.2	0	
Impervious	0	0	4.05	0	
Wetland	13.45	59.85	7.32	0	
Songhua and Liaohe River Basin					
Cropland	21.09	9.07	117.40	0	[1,6]
Forest	45.28	10.99	121.01	2.15	
Shrub	4.61	1.18	88.11	0	
Grassland	0.70	4.91	83.24	0.24	
Water	6.94	6.88	42.35	0.76	
Snow/Ice	0	0	0	0	
Barren	9.14	11.74	21.50	0	
Impervious	10.51	8.24	41.78	0.58	
Wetland	3.55	4.47	210.38	0	

Continental Basin					
Cropland	4.56	7.45	65.46	0	[1,7,8]
Forest	33.80	7.06	114.87	0	
Shrub	1.52	2.01	77.42	0	
Grassland	0.5	5.91	87.32	0	
Water	0.93	0.66	82.20	1.23	
Snow/Ice	0	0	0	0	
Barren	0.66	1.54	57.68	0	
Impervious	3.29	2.11	78.20	0	
Wetland	1.86	9.19	246.01	0	
Yellow River Basin					
Cropland	3.00	0.68	63.29	0.07	[1,9-11]
Forest	28.46	7.22	74.90	1.90	
Shrub	3.48	2.36	64.82	0.80	
Grassland	1.00	6.38	78.60	0.45	
Water	1.59	0	0	0	
Snow/Ice	0	0	0	0	
Barren	0.69	9.37	28.42	0	
Impervious	1.32	0	70.61	0	
Wetland	2.14	13.87	61.84	0	
Huaihe River Basin					
Cropland	6.5	1.12	84.82	0	[1,2,12,13]
Forest	35.38	7.45	57.14	0	
Shrub	19.4	3.88	127.3	1.94	
Grassland	6.5	20.34	40.81	0	
Water	0.6	0.12	0	0	
Snow/Ice	0	0	0	0	
Barren	0.01	0	0	0	
Impervious	5.7	0.7	0	0	
Wetland	5.70	2.26	61.00	0	
Haihe River Basin					
Cropland	4.02	0.76	69.23	0	[1,14-17]
Forest	35.17	8.92	95.88	3.00	
Shrub	5.40	2.08	108.34	2.47	
Grassland	0.90	7.15	67.84	0.47	
Water	0.04	0	64.03	0	
Snow/Ice	0	0	0	0	
Barren	0.01	0	58.89	0	
Impervious	0.01	0	57.63	0	
Wetland	3.86	5.55	87.34	0	

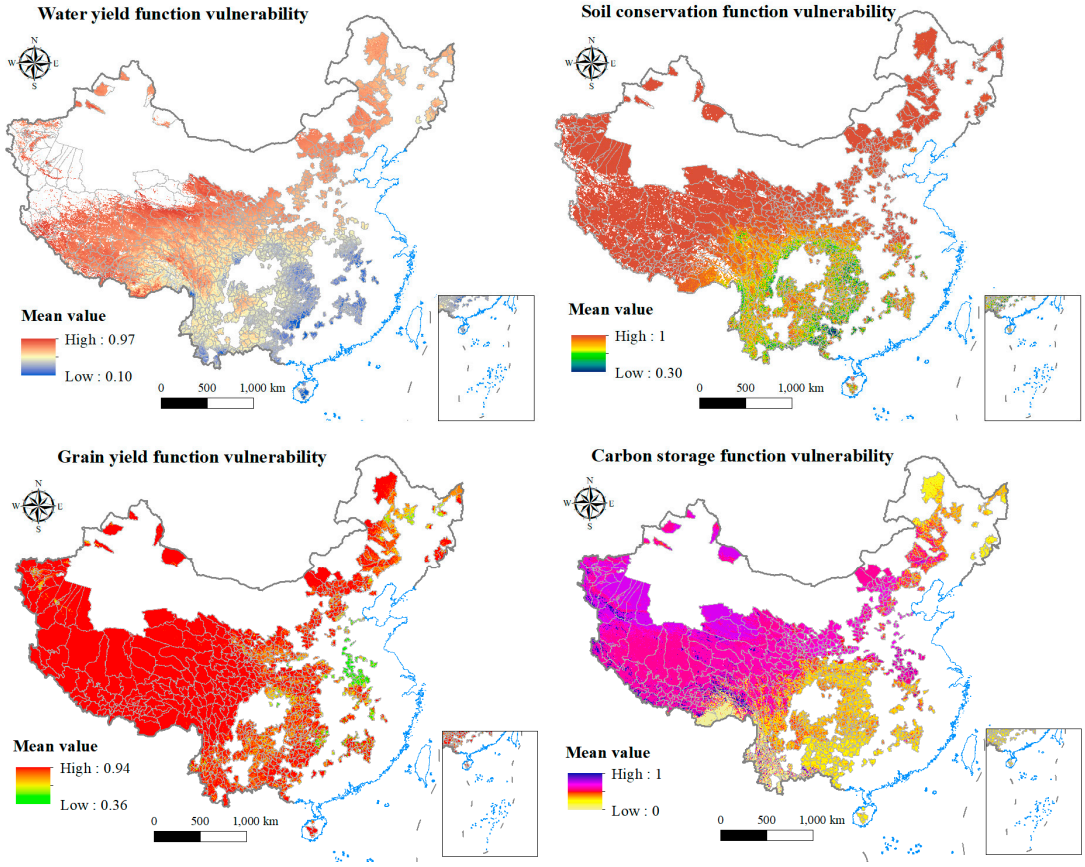


Figure S1. Ecosystem function vulnerability of water yield, soil conservation, grain yield and carbon storage.

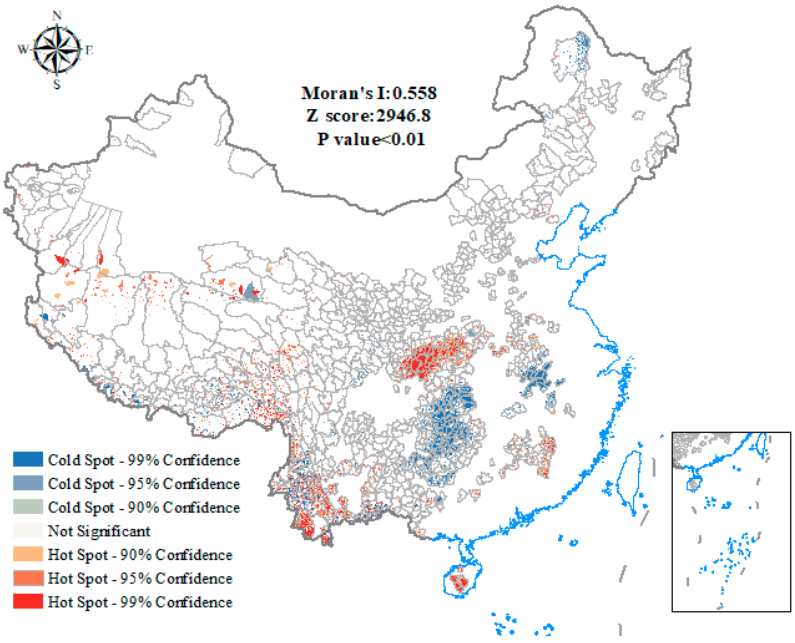


Figure S2. Distribution of cold and hot spots of ecosystem vulnerability in the NPSC.

Table S2. The variable resolution, descriptions, and data sources

Variable Category	Indicator	Variable	Resolution	Data Sources
Dependent variable	EVI(Y)	Ecosystem vulnerability index	1km×1km	Calculated from Eq.(6)
Natural environment driving forces	AMP(X1)	Annual total precipitation(mm)	1km×1km	National Earth System Science Data Center(https://www.geodata.cn/main/)
	AMT(X2)	Annual average temperature(℃)	1km×1km	
	PWL(X3)	Proportion of woodland(%)	1km×1km	Extracted from land use/land cover(LUCC) data
Socioeconomic driving forces	PD(X4)	Population density data(persons/km2)	1km×1km	WorldPOP Datasets (https://hub.worldpop.org/geodata/)
	PBL(X5)	Proportion of build land(%)	1km×1km	Extracted from land use/land cover(LUCC) data
	GDP(X6)	GDP(Chines Billion Yuan/km2)	1km×1km	A Big Earth Data Platform for Three Poles(https://poles.tpdc.ac.cn/)

Table S3. List of areas that significantly increase ecosystem vulnerability

Provinces	County	Mean ΔEVI（2005-2020）	Multiples of national variation	Main ecosystem vulnerability modes	Key counties for rural revitalization
Shannxi	Ziyang	0.017	-3.98	$HCI_{down}ESI_{down}EFI^{up}$	YES
	Xunyang	0.010	-2.29		NO
	Shiquan	0.014	-3.41		NO
	Pingli	0.007	-1.56		NO
	Langao	0.011	-2.62		YES
	Hanyin	0.017	-4.06		NO
	Hanbin	0.011	-2.63	$HCI^{up}ESI_{down}EFI_{down}$	YES
	Baihe	0.007	-1.71		YES
	Danfeng	0.006	-1.33		YES
	Shangnan	0.010	-2.36		YES
	Zhenan	0.010	-2.47		YES
	Xixiang	0.015	-3.56		NO

	Zhenba	0.024	-5.62	YES
	Bazhou	0.014	-3.12	NO
Sichuan	Nanjiang	0.011	-2.52	NO
	Pingchang	0.015	-3.66	NO
	Tongjiang	0.018	-4.18	NO
	Wanyuan	0.020	-4.75	NO
	Xuanhan	0.016	-3.83	NO
Chongqing	Chengkou	0.011	-2.68	YES
Henan	Tongbai	0.012	-2.81	NO
Yunnan	Lancang	0.005	-1.24	YES
	Menghai	0.015	-3.56	NO
	Menglian	0.007	-1.65	NO
Hainan	Baisha	0.013	-3.12	NO
	Baoting	0.019	-4.50	NO
	Qiongzhong	0.011	-2.61	NO
	Wuzhishan	0.014	-3.43	NO

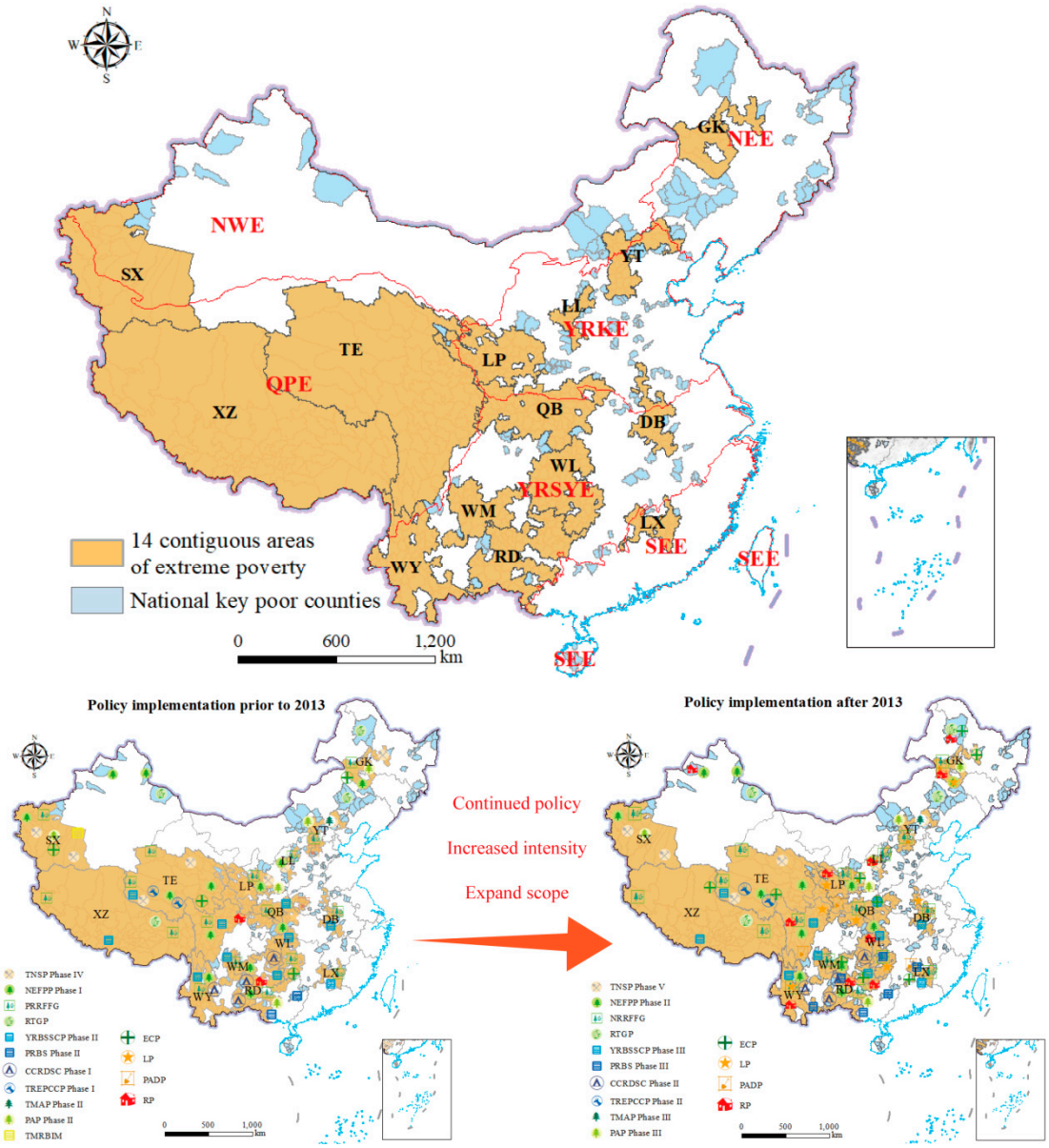


Figure S3. Poverty alleviation and ecological protection policies in impoverished areas before and after 2013. 14 contiguous areas of extreme poverty：XZ (Xizang), SX (Three prefectures of South Xinjiang), TE (Tibetan area of four provinces), LP (Liupan), WY (Border area of western Yunnan), WM (Wumeng), RD (Rocky desertification of three provinces), WL (Wuling), QB (Qinba), DB (Dabie), LX (Luoxiao), LL (Lvliang), YT (Yanshan-Taihang), GK (Southern area of Great Khingan). TNSP: Three-North Shelterbelt Program, NFRPP: Natural Forest Resource Protection Project, PRRFFG: Previous Round of Returning Farmland to Forests and Grasslands, NRRFFG: New Round of Returning Farmland to Forests and Grasslands, RTGP: Returning Trees to Grassland Project, YRBSSCP: Yangtze River Basin Shelterbelt System Construction Project, PRBS: Pearl River Basin Shelterbelt, CCKRDSC: Comprehensive Control of Karst Rocky Desertification in Southwest China, TREPCCP: Three-River-Source Ecological Protection and Construction Project, TMAP : Taihang Mountain Afforestation Project, PAP: Plain Afforestation Project, TMRBIM: Integrated Management of the Tarim River Basin, ECP, Ecological Compensation Policy, LP:

Land Policy (e.g. support policies for rural land used for industrial development), PADP: Poverty Alleviation and Development Policy, RP: Relocationt Policy.

Table S4. Poverty alleviation and ecological protection policies before and after 2013

Project	Phrase	Scope	Achievement	Characteristics
TNSP	TNSP IV (2001-2010)	13 provinces in the Northwest, North, and Northeast regions, totaling 600 counties. Total project land area 39.99 million hectares.	A total of 7.909 million hectares of afforestation was completed, with a central government investment of 8.4 billion yuan, resulting in an increase of nearly 4 percentage points in the forest coverage rate	Phase IV project prioritizes forest management, with national, local, and collective levels of protection for public welfare and commercial forests, guided by classified management principles.
	TNSP V (2011-2020)	13 provinces, 725 counties, total project land area 435.8 million hectares.	The project area's forest coverage rose from 12.40% to 13.84%, significantly improving eco-management in key regions, aiding 15 million farmers out of poverty, and generating 48 billion yuan from forest tourism attracting 385 million visitors annually.	The project, emphasizing tree planting and forest restoration, transitioned from quantity to balanced quality and scale, yielding substantial ecological, economic, and social advantages.
NFRPP	NFRPP I (2000-2010)	The project spans 17 provinces, mainly in the upper reaches of the Yangtze River and the upper and middle reaches of the Yellow River, involving 724 counties, 160 key enterprises, and 14 nature reserves.	The newly added forest area amounts to 8.67 million hectares, and the forest coverage rate has increased from the original 17.5% to 21.2%. A total of 765,000 employees from state-owned forestry enterprises have been transferred and resettled.	Control the consumption of natural forest resources, and completely stop the commercial logging of natural forests in the upper reaches of the Yangtze River and the upper and middle reaches of the Yellow River.
	NFRPP II (2011-2020)	On the basis of the first-phase scope, an additional 11 counties in the Danjiangkou Reservoir area have been included, of which 7 are	A 2440.2 billion yuan investment, with 2195.2 billion from the central government and 245 billion local, expanded forests by 5.2 million	Continue to halt the commercial logging of natural forests, and provide subsidies for the social insurance of state-owned enterprise

		in Hubei Province and 4 are in Henan Province.	hectares, added 1.1 billion cubic meters of stock, and sequestered 416 million tons of carbon, creating 648,500 jobs.	employees and for government and social expenditures.
RRFFG	PRRFFG (1999-2013)	Covering 2,422 counties in 25 provinces.	From 2002-2006, 22 million hectares shifted from cropland to forest and grass. Since 2008, 958.65 billion yuan has funded consolidating these gains.	The initiative aims to enhance ecological health by preventing soil erosion, desertification, and salinization, and by planting trees tailored to local environments. Converting low-yield cropland to forests and grasslands is key to boosting domestic demand and farmers' incomes.
	NRRFFG (2014-2020)	Expand the scale of cropland-to-forest and grassland conversion, prioritizing ecologically vulnerable areas and integrating poverty alleviation. Increase conversion tasks, focusing on steep slopes above 25 degrees, and ensure full policy coverage for eligible poor villages and households.	By 2019, 33.67 million hectares were converted from cropland to forest and grassland. By 2020, participating households averaged over 9,000 yuan in central government subsidies, expanding income channels and stabilizing farmers' earnings.	Boost support for new cropland-to-forest/grassland conversions in impoverished areas, prioritizing these regions for added tasks, and ensuring comprehensive coverage for eligible poor villages and households.
RTGP	RTGP(2003-2011)	Covering 8 provinces including Inner Mongolia, Sichuan, Qinghai, and key regions like Menggan Ning's western desert steppe, Inner Mongolia's eastern degraded grassland, Xinjiang's northern grassland, and the Qinghai-Tibet Plateau's eastern river source.	Construction of grassland fences over 51.87 million hectares is finished, alongside reseeding 12.4 million hectares of degraded grasslands. A central government investment of 20.9 billion yuan has benefited 181 counties and over 900,000 rural households.	The project enhanced the grassland household contract system, establishing basic protection, balance, and grazing control measures. This aims to shift farmers' and herders' practices, advancing ecological objectives.

	RTGP(2012-2015)	Inner Mongolia, Tibet, Xinjiang, and 10 other key grassland provinces host 152 of the country's 268 pastoral regions, which are national poverty alleviation priorities.	By 2018, the central government's cumulative investment of 295.7 billion yuan resulted in an 830 million ton increase in fresh grass, nearly matching the annual output of five Inner Mongolia grasslands.	Adjust project scope and enhance support; boost central subsidy ratios and standards, prioritizing poor areas; improve management and enforce a hierarchical responsibility system.
YRBSSCP	YRBSSCP II (2001-2010)	The 1035 counties in the 17 provinces and cities involved in the Yangtze and Huaihe River basins have a total land area of 216.15 million hectares.	A cumulative total of 3.523 million hectares of afforestation has been completed.	China's "upstream water conservation, midstream soil retention, downstream farmland networking" model exemplifies river basin management, initiating comprehensive governance for major rivers and basins.
	YRBSSCP III (2011-2020)	Continuing from the scope of the second phase, it is divided into 16 management areas, with a focus on Dongting Lake, Poyang Lake, and Danjiangkou Reservoir, covering a total land area of 220.6 million hectares.	By 2020, a cumulative completion of 1.808 million hectares had been achieved.	Increase investment standards, employ more scientific planting methods and management techniques, and establish a stable, high-quality, and efficient forest ecosystem.
PRBS	PRBS IV (2010-2020)	The scope has been expanded to cover 37 cities in 6 provinces (Guangdong, Guangxi, Hunan, Yunnan, Guizhou, Jiangxi).	The project added 1.53 million hectares of forest, boosting coverage to 60.5% and forest stock to 920 million cubic meters, improving disaster resilience and water quality.	The focus is on controlling soil erosion and desertification by protecting existing vegetation, speeding up reforestation, enhancing forest quality, and bolstering their role in soil and water conservation.

CCKRDSC	CCKRDSC I (2008-2015)	Spanning 451 counties in Guizhou, Yunnan, Guangxi, Hunan, Hubei, Chongqing, Sichuan, and Guangdong, the karst region encompasses 44.99 million hectares, with 12.96 million hectares impacted by rocky desertification.	From 2008-2013, the state invested 7.7 billion yuan in the project, achieving significant results. The area affected by rocky desertification shifted from continuous increase to net decrease from 2005 to 2011.	Holistically integrate rocky desertification control with economic, social development, and poverty alleviation, using comprehensive methods including biological, engineering, and technical measures tailored to local conditions.
	CCKRDSC(II 2016-2020)	Across 8 provinces including Guizhou, Yunnan, and Guangxi, 455 counties cover a karst area of 45.3 million hectares, with 12 million hectares suffering from rocky desertification.	Taking Libo County (Guizhou Province) as an example, rocky desertification was 75,000 hectares pre-2011. Post-2011, control efforts and agricultural development raised forest coverage to 75.98%, lifting over 10,000 people out of poverty via tourism.	Annually, the central budget allocates special funds to 200 key impoverished counties, while the remaining 255 counties with minimal desertification (under 17% of the national total) finance environmental initiatives locally through established programs (like shelterbelt construction, farmland-to-forest conversion, and soil and water conservation).
TMAP	TMAP III (2010-2020)	4 provinces (Beijing, Hebei, Shanxi, Henan) encompass a total of 110 counties, of which 39 are poverty-stricken counties.	In 2020, the project area added 0.796 million hectares of new forest, increasing the forest coverage rate by 9.7 percentage points.	To achieve the goal of "double increase" in forest area and volume, ensure the ecological security of Beijing, Tianjin, and the North China region, and promote the economic and social development of the old revolutionary areas.

PAP	PAP III (2010-2020)	The project planning and construction task for 923 counties, including plain counties, semi-plain counties, and some plain counties in 24 provinces, is 7.0619 million hectares.	The forest coverage rate in the plain areas has reached 18.7%, an increase of 1.6 percentage points; the control rate of the forest network in basic farmland has reached over 95%.	The construction of the farmland forest network in six functional areas has been improved to enhance the comprehensive functions of the protective forest system in the plain agricultural regions.
ECP	ECP（2005-2015）	Seven ecological compensation demonstration areas are being constructed, including Qilian Mountain, Qinling-Liupan Mountain, Wuling Mountain, Southeastern Guizhou, Northwestern Sichuan, Northwestern Yunnan, and Northern Guangxi.	A preliminary ecological compensation system framework is established with boosted investment, seeing central government funds rise from 2.3 billion yuan in 2001 to 78 billion yuan in 2012, totaling around 250 billion yuan.	Pilot projects in key areas are testing the development of ecological compensation standards, funding sources, channels, methods, and security systems, aiming to inform the comprehensive establishment of an ecological compensation mechanism.
	ECP(2016-2020)	National key areas such as forests, grasslands, wetlands, deserts, oceans, water bodies, and cultivated land, as well as prohibited development zones and key ecological function areas.	From 2016 to 2018, tasks for converting cultivated land back to forest and grassland in poverty-stricken areas were arranged for 1.93 million hectares, and subsidies totaling 140.418 billion yuan were implemented for these areas.	Over two-thirds of the nation's afforestation and greening efforts will target poverty-stricken areas, with investments scaling 15% above provincial averages. Poverty-stricken counties will receive 80% of new land conversion tasks to forest and grasslands.
LP	LP (2001-2010)	Nationwide land	Since 2001, land reclamation has created 2.761 million hectares of new arable land and over 13.333 million hectares of high-yield farmland, boosting farmers' average annual income by 700	In line with the principle of occupation and compensation balance, the policy promotes land development and consolidation to enhance the sustainable utilization capacity of cultivated land resources.

LP (2011-2015)	Nationwide land	yuan, with total income from these projects exceeding 15 billion yuan. Nationwide, 35.33 million hectares were converted to 26.87 million hectares of high-standard farmland, with a 550 billion yuan investment, earning farmers 110 billion yuan and aiding 101 million people. Farmers' annual income rose by over 900 yuan. The 100 key counties for poverty alleviation are among 500 demonstration areas, targeting impoverished regions.	With ensuring national food security as the primary goal, government strengthen the construction of cultivated land quality and build high-standard farmland.
LP (2016-2020)	Nationwide land	Since 2016, 15.47 million hectares of high-standard farmland have been created. By 2020, over 0.04 million hectares from deeply impoverished areas were transferred across provinces, with funds exceeding 180 billion yuan. Land reclamation efforts have intensified, focusing on restoring degraded and damaged land.	Adhering to the principles of targeted poverty alleviation and precise poverty eradication, the government vigorously promotes comprehensive land management in poverty-stricken areas, enhances policy, project, and financial support, and assists in the fight against poverty.

PADP	PADP (2001-2010)	Take the poor population in poverty-stricken areas who have not yet solved the problem of food and clothing as the primary target for poverty alleviation and development.	From 2000 to 2010, the rural poor population fell from 94.23 million to 26.88 million, and the poverty rate dropped from 10.2% to 2.8% (under the poverty alleviation standards of 865 yuan per person). In national poverty counties, the poor population decreased from 56.77 million to 16.93 million. Farmers' per capita net income rose from 1,277 yuan to 3,273 yuan, with an 8.07% annual growth rate, exceeding the national average.	The government's goal is to solve the food and clothing problem for the minority poor population as soon as possible, further improve the basic production and living conditions in poverty-stricken areas, gradually change the backward economic, social, and cultural conditions in these areas, and create conditions for achieving a well-off standard.
	PADP (2011-2020)	In the 14 contiguous areas of extreme poverty and the 832 national poverty-stricken counties, rural residents who are below the poverty alleviation standard and have the labor capacity.	Under the poverty alleviation standard of 1,274 yuan per person, the number of rural poor in the country decreased by a cumulative total of 98.99 million people, with an average annual reduction of 12.37 million people from 2013 to 2020. The poverty incidence rate decreased by an average of 1.3 percentage points per year. In 2020, the per capita disposable income of rural residents in poverty-stricken areas was 12,588 yuan.	Poverty alleviation and development has shifted from the phase where solving hunger and basic needs was the primary task to a new stage of consolidating the achievements of food and clothing security, accelerating the process of shaking off poverty and becoming prosperous, improving the ecological environment, enhancing development capabilities, and narrowing the development gap.
RP	RP (2006-2010)	The scope is the poor rural areas in the western region, with a focus on the national poverty-stricken counties in the western region.	The government has arranged for central budget investment of 7.6 billion yuan for the relocation of poverty alleviation, along with	The government continues to increase its efforts in poverty alleviation, further adopt targeted poverty alleviation policies, and

		local investments totaling 10.6 billion yuan, to relocate 1.627 million people.	actively and steadily implement relocation for poverty alleviation.
RP (2011-2015)	Rural poor populations living in areas with harsh environments, lacking basic conditions for production and development, and where "the land cannot sustain the people," such as deep mountainous regions, stone desert areas, desert regions, and areas prone to endemic diseases.	The government has arranged 23.1 billion yuan of central budget investment, which has led to the relocation of 3.94 million people from poverty-stricken areas, while also mobilizing nearly 80 billion yuan from other central government departments, local investments, and funds raised by the public.	The government adheres to the policy of development-oriented poverty alleviation, with contiguous areas of extreme poverty as the main battlefield. It further increases investment, raises the income level of the relocated population, and ensures that the people can move out, settle down, develop, and become prosperous. This is done in sync with the nationwide goal of entering a moderately prosperous society in all respects.
RP (2015-2020)	The scope covers nearly 1,400 counties in 22 provinces, including more than 800 counties in deep mountainous and stony areas, over 30 counties in desertification areas, and more than 70 counties in high-altitude areas.	The government implemented the relocation of poverty-stricken households for poverty alleviation, registering a total of 9.81 million people. At the same time, plans were made to relocate an additional 6.47 million people concurrently. The relocation targets primarily concentrated in the state's poverty-stricken counties.	The government takes targeted poverty alleviation and targeted poverty eradication as the basic strategy, focusing on the registered poor population. It fully respects the wishes of the people and adheres to a strategy that combines the relocation of poverty-stricken areas with new urbanization and the construction of agricultural modernization.

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