

Article

Crop Farming Green Transition Under Ecological Fragility: Performance Assessment, Spatiotemporal Dynamics and Barriers in the Northwest Arid Region of China

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Abstract

Amid the growing need to reconcile agricultural development with ecological security in ecologically fragile regions, CFGT has become a critical pathway for shifting agricultural systems from vulnerability toward resilience. The NARC is a typical ecologically fragile area. It faces unprecedented pressure from natural conditions and unsustainable agricultural practices. Developing a rigorous, logically coherent indicator system, together with a systematic assessment of the spatiotemporal evolution of regional CFGT, is essential for objectively identifying its current developmental stage, revealing key bottlenecks, and forming policy optimization and transition acceleration. This paper constructs a comprehensive evaluation indicator system based on the Driver–Pressure–State–Impact–Response (DPSIR) framework. Using panel data from six provinces in the NARC from 2004 to 2023, the Entropy Weight Method is applied to quantify CFGT performance. Kernel Density Estimation and the Coefficient of Variation Method are further employed to examine the spatiotemporal evolution, distributional dynamics, and regional disparities of CFGT. In addition, an obstacle severity model is used to identify the key constraints affecting CFGT. The results show that (1) the CFGT performance of the NARC exhibited a substantial improvement during 2004–2023. Its temporal evolution indicates a transition from an initial adjustment phase to steady advancement phase, followed by a more rapid improvement phase after 2017. (2) The overall enhancement of CFGT performance was mainly driven by improvements in the Driving Force and Impact subsystems. (3) CFGT performance exhibited marked regional heterogeneity across the six provinces. Qinghai, Shaanxi, and Xinjiang formed the leading group, Ningxia and Inner Mongolia occupied intermediate positions, while Gansu consistently recorded the weakest performance. (4) The major constraints on CFGT were concentrated in resource-state conditions and governance response capacity. Overall, this paper provides an assessment framework based on evidence for understanding CFGT in ecologically fragile arid regions, offering policy implications for promoting resilient agricultural green development.



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Keywords: crop farming green transition; DPSIR framework; regional heterogeneity; Northwest Arid Region of China; obstacle severity model

1. Introduction

Arid regions account for around 41% of the global land surface [1] and exhibit typical ecological fragility. This fragility stems from three key factors, which include the extremity

of natural conditions, the sensitivity of local ecosystems, and the cumulative impacts of human activities. In recent decades, agricultural lands in arid regions have rapidly expanded [2], and agricultural production has long been highly dependent on chemical inputs such as fertilizers and pesticides to ensure food security [3], further exacerbating the ecological fragility of these regions. As a central component of the principle of harmonious coexistence between humanity and nature, crop farming green transition (CFGT) provides a strategic pathway for safeguarding the dual objectives of national food security and ecological security [4]. CFGT in this paper means less pressure on water, soil and chemical inputs, with better productivity and stronger protection measures. For ecologically fragile regions, CFGT is not merely a practical requirement for improving crop farming resource allocation efficiency and mitigating environmental externalities, but also an inherent choice for advancing sustainable crop farming development.

The Northwest Arid Region of China (NARC) is a typical example of arid regions. Its fragility arises from the interplay of harsh physical conditions, highly sensitive ecosystems, and cumulative human impacts. As one of China's three major physiographic regions, the NARC accounts for 35.9% of China's total land area [5], spanning six provincial level administrative units—Shaanxi, Gansu, Qinghai, Inner Mongolia, Ningxia and Xinjiang. With abundant land resources and favorable light–thermal conditions, the NARC serves as an important national agricultural production base and strategic reserve area for cultivated land. However, owing to the arid climate and limited precipitation, together with the expansion of farmland development and the growing reliance on agrochemicals such as pesticides, chemical fertilizers, and plastic mulch, agricultural systems in the NARC have long faced severe land desertification and salinization problems [6,7]. Therefore, promoting CFGT is of great significance for sustaining economic development and maintaining ecological balance in the NARC.

China's institutional commitment to accelerating the CFGT in the NARC is underpinned by a cohesive suite of national policy directives. The Central No. 1 Documents over the years have consistently anchored CFGT within the strategic agenda, complemented by targeted frameworks such as the Opinions on Innovating Institutional Mechanisms to Promote Agricultural Green Development to put into specific implementation pathways. More recently, the preliminary guidelines for the 15th Five-Year Plan sustain this momentum by emphasizing the imperative to consolidate and further deepen CFGT outcomes. From this point on, given the natural environmental conditions and agricultural economic development of the NARC, it is essential to establish a scientifically sound indicator system, clarifying the spatiotemporal derivation characteristics of regional CFGT. It is therefore critical to objectively assess progress and diagnose systemic constraints in order to systematically advance the transition process.

Against the backdrop of global climate change, CFGT has become an important area of scholarly inquiry. Conceptually, CFGT denotes a systemic shift in agricultural development from an input-intensive and environmentally burdensome model toward a resource-conserving, environmentally friendly, and productivity-enhancing pathway [8,9]. Existing studies have substantially advanced the measurement and explanation of CFGT. One major strand of research evaluates CFGT performance, or the low-carbon green transition of crop farming, and examines its spatiotemporal evolution. These studies have been conducted at multiple spatial scales, including the national and provincial levels, as well as in key strategic regions such as the Yangtze River Economic Belt, the Yellow River Basin, and major agricultural production areas [10–12]. In terms of evaluation design, most studies have constructed comprehensive indicator systems encompassing resource utilization, environmental friendliness, ecological protection, and economic development [8,13]. Commonly used methods include the entropy weight method, analytic hierarchy process,

principal component analysis, and grey relational analysis [14–19]. Another strand of research examines the determinants and policy effects of CFGT. For example, some studies assess the effects of government subsidies, cleaner production policies, and other policy instruments on CFGT [4,20], whereas others explore the role of green innovation and technological progress in promoting agricultural sustainability [21]. Overall, these studies indicate that China has made notable progress in CFGT [22], although substantial regional disparities remain in transition performance and driving mechanisms [13].

While the established literature provides a valuable baseline for CFGT evaluation research, there is still room for further exploration. Extant evaluation frameworks are predominantly optimized for generalized agricultural systems, rendering them ill-suited for arid and ecologically fragile regions where acute water scarcity and land degradation fundamentally dictate the parameters of transition. Beyond this conceptual mismatch, prevailing methodologies rely heavily on static measurements or broad regional comparisons, thereby obscuring the long-term spatiotemporal evolution of CFGT dynamics in specific vulnerable contexts in the NARC. Moreover, although the academic community has already discussed many factors influencing CFGT, further discussion is needed on how socioeconomic development, resource endowments, environmental pressures, and policy responses collectively shape the trajectory of this transition.

Based on the above considerations, in this paper, we construct an “aridness–water resources–land degradation–governance response” CFGT indicator system under the Driver–Pressure–State–Impact–Response (DPSIR) framework. We use the provincial panel data from 2004 to 2023 to depict the long-term evolution of CFGT performance in the NARC rather than single-period comparison. Our objectives are to (1) diagnose historical changes in CFGT performance in the NARC; (2) explore the regional differentiation characteristics of CFGT in various provinces of the ARNC; and (3) identify the “resource status–governance response” type obstacle structure of CFGT in the NARC. The findings are expected to offer theoretical and practical implications for promoting high-quality CFGT in ecologically fragile areas and comparable arid agricultural regions worldwide.

2. Materials and Methods

2.1. Study Area Overview

The NARC, an important part of China’s three natural divisions, is bordered by the Beishan Gobi and Badain Jaran Desert to the north, the Qaidam arid basin to the south, the Kumtag Desert to the west, and the Loess Plateau to the East. The region accounts for 35.9% of China’s total land area. Ecologically, this region, located deep in the Eurasian hinterland, receives limited maritime moisture and is characterized by a typical arid to semi-arid climate. Mean annual precipitation is generally below 400 mm, and in inland desert areas it is often less than 50 mm, whereas annual evaporation commonly exceeds 1500 mm and may surpass 3000 mm in some locations. Problems such as land desertification, salinization, and soil erosion are widespread, making it one of the most ecologically fragile regions in China. This paper focuses on the six provinces within the administrative divisions of the NARC, encompassing Shaanxi, Gansu, Qinghai, Inner Mongolia, Ningxia, and Xinjiang. Affected by strong natural differentiation, crop farming in the NARC displays a clear spatial pattern. Oasis irrigated agriculture is mainly distributed along the northern and southern foothills of the Tianshan Mountains in Xinjiang, the margins of the Tarim Basin, and the Hexi Corridor in Gansu. Valley agriculture is concentrated in the Huangshui Valley and the Yellow River Valley in Qinghai. Rainfed agriculture is mainly found in the semi-arid areas of eastern Inner Mongolia, northern Shaanxi, and southern Ningxia. This pronounced regional heterogeneity provides an important basis for exploring differentiated pathways of the CFGT in the NARC.

2.2. Methods

2.2.1. Analytical Framework

CFGT in ecologically fragile arid regions is shaped not only by economic growth and production demand, but also by strict resource constraints, vulnerable ecological conditions, and continuous policy intervention. The DPSIR framework clearly illustrates the logical relationships among human activities, environmental pressures, ecological conditions, resulting impacts, and societal responses [23]. Therefore, the DPSIR framework was adopted to characterize the relationships among development dynamics, production pressures, resource–ecological conditions, transition outcomes, and governance responses. Different from strict statistical causality, this framework provides a systematic perspective to reveal the internal interactions of complex CFGT processes in the NARC. Specifically, the driving forces of crop farming development generate resource and environmental pressures, which alter the state of crop farming ecosystems, produce corresponding ecological and economic impacts, and ultimately trigger governance responses that feed back to the entire system. The research framework is shown in Figure 1.

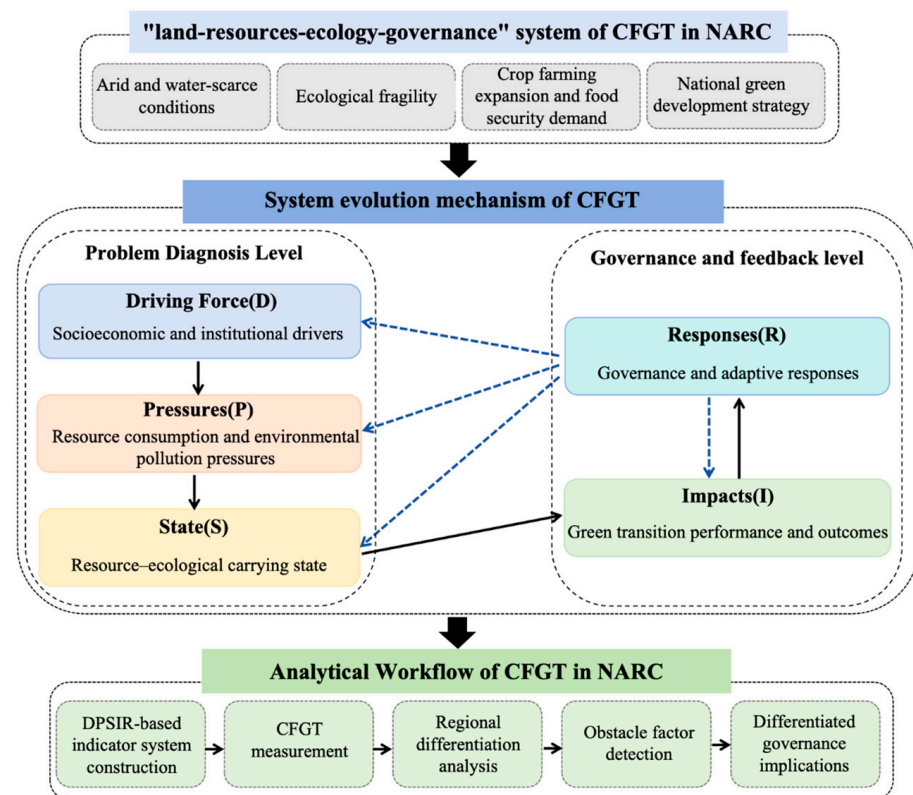


Figure 1. Analytical framework for diagnosing the CFGT in the NARC.

2.2.2. Establishment of Evaluation System

Based on the DPSIR framework established above, this paper constructs an indicators system to evaluate CFGT performance in the NARC. We employ a top-down approach to select evaluation indicators. The first step is to summarize the indicators selected in existing studies on the evaluation of green agricultural development. We primarily drew on references [8–17,20] and selected 38 initial indicators. Due to space limitations, readers may contact the author to obtain earlier versions of the indicator system and the data. The second step is to sort out the target requirements mentioned in policy documents such as the “Opinions on Innovating Mechanisms and Systems to Promote Green Development in Agriculture” and the “National Agricultural Green Development Plan for the 14th Five-Year Plan”. The goals and requirements for the green development of agriculture in the

above-mentioned documents generally cover four aspects, including the level of resource utilization, the quality of the production environment, the agricultural ecosystem, the supply of green products, and the capacity for emission reduction and carbon sequestration. The third step is to further screen the indicators according to the actual situation in the NARC. In this step, we excluded the general indicators that reflect the level of green development in agriculture and rural areas as defined at the macro level. Based on practical considerations regarding the strict water resource constraints and ecological fragility of the NARC, and ensuring that provincial-level panel data for 2004–2023 can be obtained with a high degree of completeness, a total of 23 indicators were selected.

As shown in Table 1, this paper categorizes these 23 specific indicators into five subsystems based on the DPSIR framework, respectively: (1) The Driving Force subsystem includes four indicators describing the socioeconomic and technological conditions that provide momentum for crop farming development and shape the direction of green transition. (2) The Pressure subsystem includes six indicators reflecting resource consumption and environmental burdens generated by production, with particular emphasis on water use pressure, cropland use intensity, planting-structure concentration, and chemical input intensity under arid conditions. (3) The State subsystem contains four indicators describing the carrying condition of land and water resources and the agricultural production environment under the combined effects of drivers and pressures. (4) The Impact subsystem includes four indicators measuring the consequences of these state changes for CFGT performance, especially in terms of production stability, carbon pressure, and water use efficiency. (5) The Response subsystem contains five indicators reflecting policy support, technological adoption, ecological restoration, and cropland improvement measures implemented to mitigate resource and environmental constraints and promote transition.

Table 1. Evaluation Indicator system for the CFGT performance in the NARC.

DPSIR Category	Indicator	Definition	Unit	Direction	Weights Under the EWM	Weights Under the Equal-Weight Method
Driving Force (D)	Cropland output efficiency (D ₁)	Ratio of crop output value at constant prices to cultivated land area, reflecting unit-area agricultural productivity	CNY/mu	Positive	0.065	0.050
	Rural per capita disposable income (D ₂)	Per capita disposable income of rural residents, reflecting the rural income base	CNY	Positive	0.059	0.050
	Urban–rural income ratio (D ₃)	Ratio of urban per capita disposable income to rural per capita disposable income, indicating the urban–rural income gap	—	Negative	0.021	0.050
	Agricultural mechanization level (D ₄)	Total agricultural machinery power per unit crop sown area, reflecting the capital and technology support capacity of modern agriculture	kW/ha	Positive	0.035	0.050

Table 1. Cont.

DPSIR Category	Indicator	Definition	Unit	Direction	Weights Under the EWM	Weights Under the Equal-Weight Method
Pressure (P)	Multiple cropping index (P ₁)	Ratio of total crop sown area to cultivated land area, reflecting land use intensity	—	Negative	0.012	0.033
	Agricultural water use pressure (P ₂)	Ratio of agricultural water consumption to total regional water resources, reflecting water resource pressure	%	Negative	0.012	0.033
	Percentage of grain crop sown area (P ₃)	Ratio of grain crop sown area to total crop sown area, used as a proxy for planting-structure concentration	%	Negative	0.055	0.033
	Pesticide application intensity (P ₄)	Pesticide input per unit crop sown area, reflecting chemical input intensity	kg/mu	Negative	0.01	0.033
	Chemical fertilizer application intensity (P ₅)	Chemical fertilizer input per unit crop sown area, reflecting chemical input intensity	kg/mu	Negative	0.02	0.033
	Agricultural plastic film application intensity (P ₆)	Agricultural plastic film input per unit crop sown area, reflecting plastic input intensity	kg/mu	Negative	0.02	0.033
State (S)	Per capita cultivated land area (S ₁)	Cultivated land area per capita, reflecting the land resource endowment required for agricultural production	mu/person	Positive	0.089	0.050
	Per capita water resources (S ₂)	Regional water resources per capita, reflecting the water resource endowment required for agricultural production	m ³ /person	Positive	0.124	0.050
	Share of effective irrigated area (S ₃)	Ratio of effectively irrigated area to total crop sown area, reflecting irrigation security and drought resistance capacity	%	Positive	0.078	0.050
	Crop disaster-affected area share (S ₄)	Ratio of disaster-affected crop area to total crop sown area, reflecting exposure to agricultural natural disasters	%	Negative	0.013	0.050

Table 1. Cont.

DPSIR Category	Indicator	Definition	Unit	Direction	Weights Under the EWM	Weights Under the Equal-Weight Method
Impact (I)	Coefficient of variation of grain yield (I_1)	Five-year rolling coefficient of variation of grain yield per unit area, reflecting grain production stability	%	Negative	0.008	0.050
	Crop disaster-hit area share (I_2)	Ratio of disaster-hit crop area to total crop sown area, reflecting the depth of agricultural disaster losses	%	Negative	0.009	0.050
	Agricultural carbon emission intensity (I_3)	Greenhouse gas emissions from crop cultivation per unit crop output value at constant prices, reflecting agricultural carbon pressure	t/ 10,000 CNY	Negative	0.009	0.050
	Agricultural water productivity (I_4)	Crop output value per unit agricultural water consumption, reflecting agricultural water use efficiency	CNY/m ³	Positive	0.093	0.050
Response (R)	Agricultural fiscal support intensity (R_1)	Ratio of local fiscal expenditure on agriculture, forestry and water affairs to general public budget expenditure, reflecting government support intensity	%	Positive	0.015	0.040
	Water-saving irrigation area share (R_2)	Ratio of water-saving irrigation area to total crop sown area, reflecting adoption of water-saving technology	%	Positive	0.052	0.040
	Soil erosion control intensity (R_3)	Ratio of soil erosion control area to total territorial area, reflecting the intensity of soil and water conservation efforts	%	Positive	0.077	0.040
	Returning cropland to forest intensity (R_4)	Ratio of cropland converted to forest area to total cultivated land area, reflecting the intensity of ecological restoration	%	Positive	0.08	0.040
	High-standard farmland construction intensity (R_5)	Ratio of the cumulative area of newly built high-standard farmland and renovated medium- and low-yield farmland to total cultivated land area, reflecting the intensity of farmland system upgrading	%	Positive	0.042	0.040

Accordingly, positive and negative directions of these indicators were assigned according to the connotation of CFGT in arid regions. Specifically, indicators reflecting improvements in resource efficiency, production conditions, ecological restoration, and governance capacity were treated as positive indicators, whereas indicators representing resource overuse, environmental pressure, disaster exposure, and ecological burden were treated as negative indicators. It should be noted that this paper sets the directions of the multiple cropping index (P_1) and percentage of grain crop sown area (P_3) as negative and sets the returning cropland to forest intensity (R_4) as a positive indicator. This is primarily based on practical considerations regarding the strict water resource constraints and ecological fragility of the NARC. Excessive crop rotation intensity and an overly high proportion of grain crops often result in higher irrigation, fertilizer, and pesticide inputs, as well as increased pressure on land use, which is not conducive to optimizing crop structures or enhancing resource and environmental carrying capacity [8,24,25]. Furthermore, implementing the “converting farmland to forests” program on lands unsuitable for sustained cultivation, reduce soil erosion, improve the ecological environment [26]. Therefore, with a view to restoring ecosystem functions, this paper sets R_4 as a positive indicator. In addition, given that the directional properties of these indicators depend on the research objectives, this paper further conducts directional sensitivity tests. The operational definitions, units, directions, and weights of all indicators are reported in Table 1.

2.2.3. Data Sources

In 2003, China introduced the concept of green agriculture at the International Seminar on Market Channel Construction for Green Food and Organic Agriculture in the Asia-Pacific Region [27]. To highlight this year as a key milestone for the implementation of relevant policies, this paper comprehensively evaluated the performance of CFGT in the NARC based on relevant statistical data from 2004 to 2023 for six provinces and autonomous regions in China’s arid northwest, including Inner Mongolia, Shaanxi, Gansu, Qinghai, Ningxia, and Xinjiang. The calculation methods for the 23 specific indicators are shown in Table 1. The original data for calculating various indicators, including cultivated land, crop planting, irrigation, output value, and rural environment, were collected from the EPS Database, sourced from the China Statistical Yearbook, China Rural Statistical Yearbook, China Environmental Yearbook, and China Urban–Rural Construction Statistical Yearbook. Agricultural carbon emission data were calculated based on the six agricultural carbon sources, including pesticides, chemical fertilizers, diesel, agricultural plastic film, tillage, and irrigation. The raw data were obtained from the China Statistical Yearbook, while the emission factors for each carbon source and the specific calculation steps were adapted from [28]; To calculate the intensity of high-standard farmland construction, this paper follows the approach taken by [29]. Policy on the construction of high-standard farmland has been implemented in a standardized manner since 2011. Therefore, the data on the area of high-standard farmland prior to that year represent the renovated medium- and low-yield farmland; the data on the high-standard farmland area during 2011–2023 represent the sum of newly constructed high-standard farmland and the renovated medium- and low-yield farmland and are sourced from the China Fiscal Yearbook. It should be noted that the China Fiscal Yearbook does not include data on the high-standard farmland area for 2018 and beyond. Therefore, we collect the data in this section from relevant news reports. Furthermore, due to missing data on water-saving irrigation area and cultivated land area for certain years, we use interpolation methods to impute values for the missing years for these indicators.

2.3. Data Processing

2.3.1. Evaluation of the CFGT Performance

To objectively determine the weights of the 23 indicators in the evaluation system, this paper employed the Entropy Weight Method (EWM). The EWM is widely used and calculates the weight of each indicator based on the degree of dispersion in its data [30].

Step 1: Standardize the original data. This paper adopts the min–max normalization method to convert the evaluation values of each indicator into the range of 0–1. The normalization formulas for positive indicators and negative indicators are expressed, respectively, as Equations (1) and (2). Therefore, for any given indicator, the larger the evaluation coefficient, the greater its contribution to the CFGT composite index.

Step 2: Calculate the proportion P_{ij} of the i -th evaluation object under the j -th indicator based on Equation (3).

Step 3: Calculate the entropy e_j of each indicator according to Equation (4).

Step 4: Calculate the weight W_j of each indicator according to Equation (5).

Step 5: Use the linear weighting method to measure the provincial CFGT composite index and five subsystem indexes. The specific method is to calculate the composite score by multiplying the standardized indicator values X'_{ij} with their corresponding entropy weights W_j according to Equation (6).

This composite score is defined as the composite index of CFGT Performance in this paper. The values of various indices range from 0 to 1, and the closer to 1, the higher the high-quality development level. These values of various V indices range from 0 to 1. A value closer to 1 indicates a more remarkable CFGT performance. The indicators of each subsystem share identical implications. Indices calculated via this method can not only compare the relative rankings of CFGT performance across provinces but also analyze their historical evolutionary trends. The specific formulas are as follows:

$$X'_{ij} = \frac{X_{ij} - \min(X_{ij})}{\max(X_{ij}) - \min(X_{ij})} \quad (1)$$

$$X'_{ij} = \frac{\max(X_{ij}) - X_{ij}}{\max(X_{ij}) - \min(X_{ij})} \quad (2)$$

$$P_{ij} = \frac{X'_{ij}}{\sum_{i=1}^n X'_{ij}} \quad (3)$$

$$e_j = -k \sum_{i=1}^n P_{ij} \ln(P_{ij}), k = \frac{1}{\ln n} \quad (4)$$

$$W_j = \frac{1 - e_j}{\sum_{j=1}^m (1 - e_j)} \quad (5)$$

$$V = \sum_{i=1}^m W_j X'_{ij} \quad (6)$$

2.3.2. Inter-Provincial Differentiation Analysis

The coefficient of variation (CV) is used to measure the annual degree of regional disparity in CFGT performance across the six provinces. The CV value (%) is calculated as:

$$CV_t = \frac{SD_t}{\bar{X}_t} \times 100$$

where SD_t denotes the standard deviation of the CFGT index across provinces in year t , and $\bar{X}_t$ is the corresponding mean value. A larger CV_t indicates a higher degree of relative dispersion and, therefore, stronger regional differentiation.

2.3.3. Obstacle Factor Detection

To further identify the key constraints affecting CFGT in the NARC, this paper employs an obstacle factor detection model based on the standardized indicator values and entropy-derived weights [31]. After data standardization, all indicator values are transformed into dimensionless scores ranging from 0 to 1, with larger values indicating better performance. On this basis, the deviation degree of indicator j for province i in year t is defined as:

$$D_{ijt} = 1 - Z_{ijt}$$

where Z_{ijt} denotes the standardized value of indicator j for province i in year t , and D_{ijt} represents the distance between the observed value and the ideal state. A larger deviation degree indicates that the indicator remains farther from the desirable level and may therefore exert a stronger constraining effect on CFGT.

The contribution of each indicator is determined by its weight in the evaluation system. Let W_j denote the entropy weight of indicator j . The obstacle degree of indicator j for province i in year t is then calculated as:

$$O_{ijt} = \frac{W_j D_{ijt}}{\sum_{j=1}^n W_j D_{ijt}} \times 100\%$$

where O_{ijt} represents the proportionate obstacle effect of indicator j on the CFGT performance of province i in year t . A higher value of O_{ijt} indicates that the indicator constitutes a more important barrier to CFGT.

To facilitate interpretation at a broader level, the obstacle degrees of individual indicators are further aggregated into the five DPSIR subsystems. The subsystem obstacle degree is calculated as:

$$SO_{mt} = \sum_{j \in m} O_{ijt} SO_{mt}$$

where SO_{mt} denotes the total obstacle degree of subsystem m in year t , and $j \in m$ indicates that indicator j belongs to subsystem m .

3. Results

3.1. Overall Temporal Evolution of CFGT Performance of the NARC

3.1.1. Evolution of CFGT Comprehensive Performance

The comprehensive evaluation results indicate a sustained increase in the CFGT composite index of the NARC from 2004 to 2023. As shown in Figure 2, the regional average value the CFGT composite index increased from 0.260 to 0.444, with a growth rate of 70.83%. These results suggest a marked enhancement in regional CFGT over the past two decades. However, the overall composite index level is still relatively low, and there is still considerable room for improvement.

Temporally, the evolution of the CFGT composite index in the NARC can be divided into three stages based on the change in index growth rate. As shown in Table 2, during the initial adjustment phase (2004–2008), the CFGT composite index declined modestly, with an absolute decrease of 4.33% and an average annual growth rate of -0.95% , reflecting the early adjustment phase of regional CFGT. In the steady promotion phase (2009–2016), the CFGT composite index increased by 21.54%, with an average annual growth rate of 3.05%. The accelerated improvement phase (2017–2023) exhibited significantly accelerated

growth, the CFGT composite index increased 35.00% cumulatively, with an annual average growth nearly 1.6 times that of the previous phases. This three-stage trajectory is not a statistical coincidence but a direct reflection of China's evolving national strategy for agricultural and ecological development. The initial slow start corresponds to a period when “green agriculture” was still a nascent concept with limited policy traction. The subsequent acceleration during the comprehensive promotion stage was propelled by a suite of landmark national policies, most notably the National Agricultural Sustainable Development Plan (2015–2030) and the 2017 central government's Opinion on Promoting Agricultural Green Development. These directives elevated green transition to a national priority and initiated concrete, widespread actions. Finally, the recent high-level consolidation stage aligns with the implementation of the Rural Revitalization Strategy and China's ambitious ‘dual carbon’ targets.

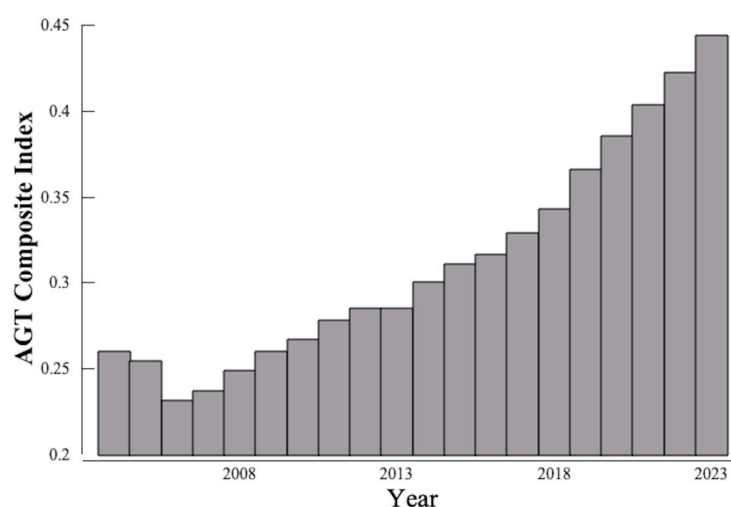


Figure 2. Temporal evolution of the CFGT composite index in the NARC.

Table 2. Stage characteristics of CFGT performance in the Northwest Arid Region.

Stage	Period	Mean Composite Index at Start	Mean Composite Index at End	Total Growth Rate (%)	Annual Average Growth Rate (%)
Initial adjustment	2004–2008	0.260	0.249	−4.33	−0.95
Steady promotion	2009–2016	0.260	0.316	21.54	3.05
Accelerated improvement	2017–2023	0.329	0.444	35.00	4.99

3.1.2. Evolution of the DPSIR Subsystems Performance

The results of the measurements at the subsystem level show that the improvement in the CFGT composite index of the NARC was shaped primarily by changes in the Driving Force subsystem and Impact subsystem dimensions. As shown in Figure 3, the Driving Force subsystem index increased from 0.014 to 0.112 during 2004–2023, accounting for 52.9% of the total increase in the composite index. The Impact subsystem also rose markedly, from 0.014 to 0.055, contributing 22.2% of the overall gain. By contrast, the Pressure subsystem index declined slightly from 0.078 to 0.071, which suggests that the improvement in environmental pressure arising from crop cultivation in the NARC remains limited.

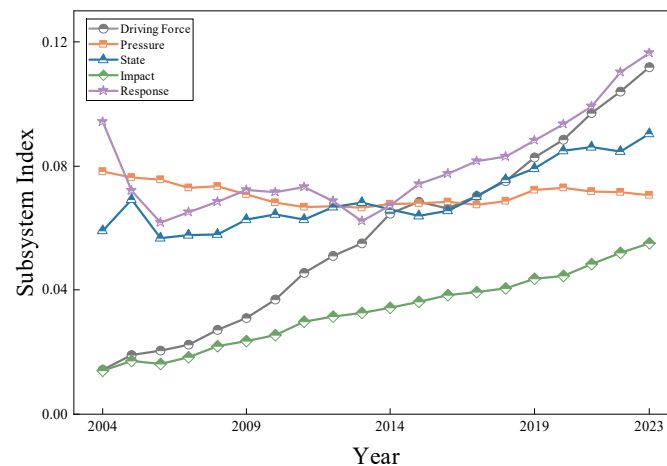


Figure 3. Temporal evolution of DPSIR subsystem indices.

The subsystem trajectories indicate that CFGT improvement in the Northwest Arid Region was not a synchronized advance across DPSIR dimensions, but an uneven transition shaped by the enhancement of socioeconomic driving forces and governance responses. In 2004, the Response subsystem index had already reached 0.094, the highest among the five subsystems. This suggests that policies and governance interventions were introduced comparatively early in the study region, yet their effects were constrained by the fragile environmental conditions, and the weak socioeconomic foundations. By 2023, the Driving Force subsystem index increased sharply from 0.014 to 0.112, assuming a much larger role in the improvement of the composite index. However, the Pressure subsystem index fell from 0.078 to 0.071 during the study period. Taken as a whole, these results implies that it takes a considerable amount of time for policy interventions to translate into substantial improvements in agricultural resource and environmental conditions in the Northwest Arid Regions of China.

3.2. Regional Heterogeneity in the CFGT Performance in the Northwest Arid Regions of China

Table 3 reveals a general upward trend in the CFGT performance of the six provinces across the NARC from 2004 to 2023. Their CFGT composite index, initially spanning 0.193~0.323 in 2004, elevated to a range of 0.355~0.513 in 2023. By 2023, Qinghai, Shaanxi, and Xinjiang emerged as the leading cohort, recording indices of 0.513, 0.489, and 0.459, respectively. Ningxia and Inner Mongolia occupied an intermediate tier, recording values of 0.431 and 0.420, whereas Gansu remained the lowest-performing province at 0.355. The ranking changes further reveal both adjustment and persistence within this provincial structure. Qinghai maintained its primacy at both temporal endpoints, despite a transient displacement by Xinjiang in 2017. The ranking of Shaanxi ascending from third to second position. Conversely, Xinjiang receded from second to third place over the same horizon. Moreover, Ningxia fluctuated within the intermediate tier, while Inner Mongolia stagnated in fifth place, and Gansu remained anchored at the nadir. These results indicate substantial disparities in the CFGT performance across provinces in the NARC.

To further analyze the regional heterogeneity in CFGT performance across the NARC, this paper uses the coefficient of variation to trace distributional evolution and dispersion from 2004 to 2023. The coefficient of variation in Figure 4 yields a consistent picture. During 2004 to 2010, dispersion remained high and fluctuated substantially, approaching or exceeding 25% in some years. Inter-provincial disparities were therefore especially pronounced in the early years of the study period. After 2011, the coefficient of variation declined in general, suggesting a gradual narrowing of provincial differences. Yet the value still stood above 10% in 2023, which indicates that inter-provincial disparities still

exist. The two sets of result shows that CFGT performance in the NARC underwent marked inter-provincial differentiation in the early period, followed by a tendency toward convergence in the middle and later years. Although persistent disparities continued to shape the regional pattern.

Table 3. Composite index of the CFGT performance in Provinces in the NARC.

Year	Qinghai	Shaanxi	Xinjiang	Ningxia	Inner Mongolia	Gansu
2004	0.3231	0.2606	0.3047	0.2594	0.2197	0.1932
2005	0.3640	0.2095	0.3107	0.2296	0.2140	0.1947
2006	0.2802	0.2149	0.3063	0.2097	0.2047	0.1694
2007	0.3078	0.2252	0.3126	0.2048	0.1986	0.1724
2008	0.3156	0.2386	0.3012	0.2264	0.2277	0.1837
2009	0.3673	0.2424	0.3046	0.2447	0.2152	0.1866
2010	0.3444	0.2582	0.3203	0.2486	0.2370	0.1913
2011	0.3536	0.2854	0.3337	0.2503	0.2508	0.1941
2012	0.3648	0.2678	0.3433	0.2631	0.2694	0.2002
2013	0.3358	0.2786	0.3545	0.2544	0.2835	0.2015
2014	0.3743	0.2983	0.3447	0.2901	0.2814	0.2114
2015	0.3515	0.3230	0.3638	0.3026	0.2926	0.2320
2016	0.3685	0.3242	0.3753	0.3081	0.2824	0.2386
2017	0.3884	0.3369	0.3889	0.3174	0.2870	0.2566
2018	0.4243	0.3452	0.3838	0.3279	0.3065	0.2713
2019	0.4463	0.3866	0.4018	0.3514	0.3314	0.2800
2020	0.4689	0.3988	0.4114	0.3743	0.3554	0.2983
2021	0.4563	0.4417	0.4149	0.3883	0.4000	0.3149
2022	0.4774	0.4543	0.4469	0.4184	0.4023	0.3345
2023	0.5126	0.4885	0.4593	0.4308	0.4196	0.3554

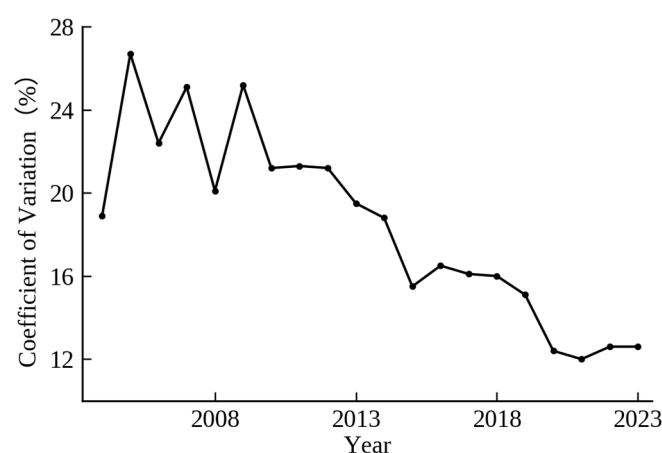


Figure 4. Coefficient of variation plot of CFGT performance in NARC.

Coefficients of variation for the five DPSIR subsystems were examined to clarify the structural sources of inter-provincial differentiation in CFGT performance, as detailed in Table 4. These calculations reveal that the State subsystem constitutes the primary source of inter-provincial differentiation. Its average value is 67.41%, substantially higher than

those of the remaining four subsystems. This finding indicates that persistent disparities in resource endowments and environmental conditions continue to shape provincial CFGT outcomes. The Driving Force subsystem exhibits the strongest convergence, with its coefficient of variation plummeting from 65.12% to 17.84%—a 72.60% reduction over the study period. The Response subsystem also narrowed overall, declining by 31.00%. Moreover, the pattern was different for the Impact and Pressure subsystems. Their CV values increased by 41.20% and 10.10%, respectively, pointing to widening inter-provincial differences in outcome effects and pressure mitigation performance. Notably, while the Pressure subsystem maintains the lowest mean coefficient of variation across all five subsystems, its marginal increase suggests that pre-existing modest disparities in this dimension have not narrowed further over time.

Table 4. Coefficient of variation of DPSIR subsystem indices.

Subsystem	Initial Value (2004)	Final Value (2023)	Average Value	Change Rate (%)
Driving force (D)	65.12	17.84	26.07	−72.60
Pressure (P)	21.68	23.88	24.31	10.10
State (S)	80.32	60.29	67.41	−25.00
Impact (I)	40.89	57.73	42.91	41.20
Response (R)	45.29	31.26	32.37	−31.00

3.3. Relative Constraints of the CFGT Performance in the NARC

To identify the relative constraints on CFGT performance, this paper applies the obstacle degree model at both the subsystem and indicator levels in the NARC. Specifically, we calculated the obstacle degree of each indicator for each province from 2004 to 2023 based on the obstacle degree model, and calculated the average obstacle degree for 20 years. On this basis, the obstacle degrees of five subsystems of the NARC were obtained. As shown in Figure 5, the average obstacle degrees of the five DPSIR subsystems follow the order State, Response, Driving Force, Impact, and Pressure, with annual mean values of 0.341, 0.273, 0.176, 0.126, and 0.084, respectively. The State and Response subsystems constitute the two dominant sources of obstruction, accounting for 34.11% and 27.26% of the total obstacle degree. Notably, although Pressure subsystem performance showed limited improvement in the CFGT performance evaluation results, it did not constitute the dominant source of relative constraints in the obstacle degree results. This pattern suggests that the principal relative constraints on CFGT in the NARC lie primarily in resource-state limitations and remaining gaps in governance response capacity and implementation effectiveness. Although pressure-related performance showed limited improvement over the study period, it was not the dominant source of relative constraints when compared with the State and Response subsystems.

Provincial obstacle profiles indicate that agricultural resource and environmental constraints pervade the NARC, yet exhibit substantial inter-provincial variation in severity. Figure 6 illustrates that the State subsystem emerges as the dominant constraint source of the CPGT performance of Shaanxi, Ningxia, Gansu and Qinghai. Ranks second in Inner Mongolia and Xinjiang, where its obstacle degree remains higher than that of most other subsystems. Moreover, the constraints hindering the CFGT in Inner Mongolia and Xinjiang are also concentrated in the Response subsystem, with obstacle degrees are 33.01% and 33.51%, respectively. This spatial pattern confirms that resource and environmental endowments represent a fundamental structural constraint on CFGT. Notably, the obstacle degree of the State subsystem of Shaanxi exhibiting the highest level among the six provinces.

While the obstacle degree of the Impact subsystem of Shaanxi exhibiting the lowest level. Collectively, CFGT in the NARC is primarily constrained by fragile resource endowments and environmental conditions, while response-related weaknesses represent a secondary, spatially heterogeneous source of impediment.

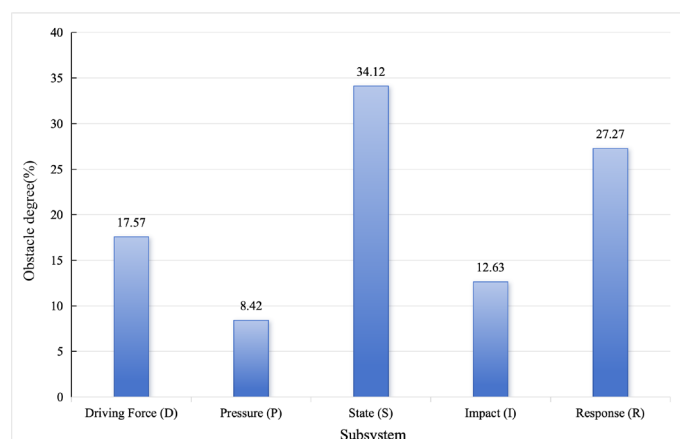


Figure 5. Obstacle degree of CFGT of the NARC at the subsystem level.

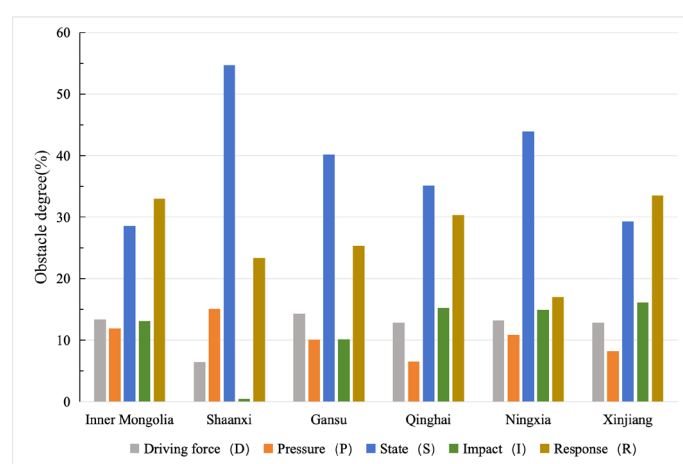


Figure 6. The provincial structure of CFGT obstacle factors.

The indicator-level results clarify how subsystem constraints were articulated across provinces. Figure 7 show that, over the study period, the relative constraints were consistently shaped by water and land endowments, irrigation conditions, and ecological governance. Per Capita water resources constituted the leading constraint in five of the six provinces, with average obstacle degrees ranging from 15.13% in Xinjiang to 17.75% in Ningxia. Qinghai diverged from this pattern, as Per Capita cultivated land area represented its main constraint, reaching an average obstacle degree of 14.22%. Agricultural water productivity also occupied a salient position, ranking among the top five relative constraints in all provinces except Shaanxi. The share of effective irrigated area remained a major constraint across the region, with Xinjiang as the only exception. These results indicate that CFGT constraints during the study period were closely associated with water scarcity, limited land endowment, and uneven irrigation security. Response-related indicators, particularly cropland-to-forest conversion intensity and soil erosion control intensity, further contributed to provincial differentiation. The principal bottlenecks of CFGT therefore did not arise mainly from conventional production pressure indicators, but from the more persistent constraints imposed by resource endowment, water use efficiency, irrigation capacity, and ecological governance.

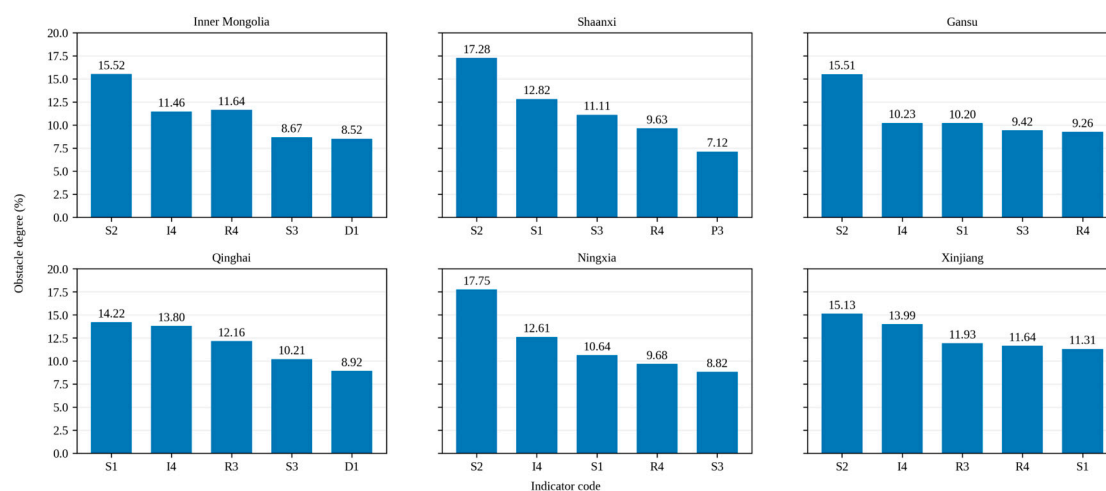


Figure 7. Top five indicator-level obstacle factors of CFGT by province. Note: S₂—per capita water resources; I₄—agricultural water productivity; S₁—per capita cultivated land area; R₄—returning cropland to forest intensity; S₃—share of effective irrigated area; D₁—cropland output efficiency; P₃—percentage of grain crop sown area; R₃—soil erosion control intensity.

3.4. Sensitivity Analysis

3.4.1. Sensitivity Analysis of Controversial Indicator Direction

Given that the directional properties of some indicators depend on the research objectives, this paper further conducts directional sensitivity tests on three indicators, including the multiple cropping index (P₁), percentage of grain crop sown area (P₃), and returning cropland to forest intensity (R₄). This paper constructs alternative indicator orientation scenarios as shown in Table 5. Scenario S₀ represents the baseline setting, whereas S₁–S₆ adjust the direction of one or more controversial indicators or exclude them from the evaluation system. Under each scenario, this paper re-standardized the indicators, recalculated their weights, and estimated the corresponding composite performance index. Subsequently, for provincial performance rankings, Spearman rank correlation, average absolute rank change, maximum absolute rank change, and top-three overlap rates are used to evaluate ranking stability [32]. For obstacle factor identification, the top-five obstacle factor overlap rate is used to assess whether the leading constraints remain consistent across scenarios. The results are calculated by comparing the provincial rankings under each alternative scenario with those under the baseline scenario S₀.

Table 5. Indicator orientation scenarios for sensitivity analysis.

Scenario	Multiple Cropping Index (P ₁)	Percentage of Grain Crop Sown Area (P ₃)	Returning Cropland to Forest Intensity (R ₄)
S ₀	Negative	Negative	Positive
S ₁	Negative	Positive	Positive
S ₂	Positive	Negative	Positive
S ₃	Negative	Negative	Negative
S ₄	Positive	Positive	Negative
S ₅	Excluded	Excluded	Excluded
S ₆	Negative	Negative	Positive
S ₆	Negative	Negative	Positive

The results regarding the stability of provincial rankings under different indicator direction scenarios are presented in Table 6. The Spearman rank correlation coefficients for each alternative scenario generally remained high, accompanied by minor changes in the average absolute rankings and a substantial overlap among the top three provinces. This indicates that changing the direction of the controversial indicators did not substantially alter the overall pattern of provincial performance rankings. It should be noted that in some years, individual provinces experienced fluctuations of one or two positions, suggesting that their evaluation results were somewhat sensitive to the direction of the controversial indicators. See Table S1 for details on each province.

Table 6. Stability of provincial rankings under indicator direction scenarios.

Scenario	Spearman Rank Correlation: Mean	Spearman Rank Correlation: Minimum	Average Absolute Rank Change	Maximum Absolute Rank Change	Top-Three Overlap Rate
S ₁	0.87	0.71	0.55	2	0.90
S ₂	0.97	0.83	0.18	2	0.95
S ₃	0.95	0.71	0.25	2	0.97
S ₄	0.86	0.60	0.58	2	0.88
S ₅	0.93	0.77	0.38	2	0.95
S ₆	0.88	0.60	0.48	3	0.88

As shown in Table 7, the overlap rate of the top five obstacle factors was higher than 0.8 under six scenarios. Furthermore, under S₁ and S₆, the top five obstacle factors for all provinces are exactly same as under S₀, with an overlap rate of 100%. These results indicate that the main obstacle factors have remained generally stable.

Table 7. Stability of obstacle factor rankings under indicator direction scenarios.

Scenario	Overlap Rate of the Top Five Obstacle Factors
S ₁	1
S ₂	0.93
S ₃	0.8
S ₄	0.83
S ₅	0.83
S ₆	1

3.4.2. Sensitivity to Evaluation Methods

To determine the sensitivity of the comprehensive evaluation results to the choice of weighting method, this paper uses the EMM method's estimates as a basis to recalculate the composite index for 2004–2023 using the equal-weighting method, and then compares the results obtained from the two methods. The results in Table 8 show that there are some numerical differences in the composite indices calculated using the two evaluation methods. The values obtained using the equal-weighting method are generally higher than those obtained using the EMM method, indicating that different weighting methods affect the absolute magnitude of the composite index.

Table 8. Composite index of the CFGT performance of the NARC under different evaluation methods.

Year	Composite Index Under the EMM Method	Composite Index Under the Equal-Weighting Method
2004	0.260	0.351
2005	0.254	0.363
2006	0.231	0.335
2007	0.237	0.351
2008	0.249	0.375
2009	0.260	0.387
2010	0.267	0.406
2011	0.278	0.418
2012	0.285	0.430
2013	0.285	0.429
2014	0.300	0.441
2015	0.311	0.458
2016	0.316	0.464
2017	0.329	0.481
2018	0.343	0.501
2019	0.366	0.530
2020	0.385	0.540
2021	0.403	0.552
2022	0.422	0.577
2023	0.444	0.592

However, in terms of trends over time, the results obtained from the two methods show a high degree of consistency. Specifically, under the EMM method, the composite index rose from 0.260 in 2004 to 0.444 in 2023, an increase of approximately 70.77%. Under the equal-weighting method, the composite index rose from 0.351 in 2004 to 0.592 in 2023, an increase of approximately 68.66%. This indicates that overall CFGT performance of the NARC was improved continuously under the two evaluation methods.

4. Discussion

The results show that CFGT in the NARC has progressed to a certain extent over the past two decades. This progress points to the combined influence of sustained policy direction, agricultural modernization, and improvements in rural socioeconomic conditions in the NARC. Compared with studies on green agricultural development in the Yellow River Basin, the evaluation results in this paper reflect common trends while also revealing the regional specificity of the NARC. Research by Cha and others found that while the level of green agricultural development in the Yellow River Basin has improved overall from 2012 to 2018, resource conservation and efficient development remain major shortcomings, and there are significant differences across provinces [12]. The findings in this paper also indicate that the comprehensive performance of CFGT in the provinces of the NARC generally increased from 2004 to 2023. This suggests that the region's CFGT has achieved some success. Notably, among the five DPSIR subsystems, gains are most pronounced in the Driving Force and Impact subsystems, and the performance of the Pressure subsystem has lagged the overall system transition.

Much of the existing literature emphasizes the role of agricultural modernization, income growth, technological progress, and policy support in improving CFGT performance. The findings of this paper are consistent with these views, but we suggest that these drivers operate under stronger ecological constraints in arid and semi-arid regions. The CFGT performance of the NARC is not limited by development capacity alone. It is also shaped by the rigidity of water scarcity, land resource conditions, and ecological vulnerability. The high and persistent contribution of the State subsystem to inter-provincial differentiation reinforces this point. This suggests that, in arid regions, the ecological baseline is not merely a background condition but an active determinant of the pace and quality of transition.

The obstacle analysis provides a more precise reading of this pattern. State and Response constituted the two dominant sources of obstruction, whereas Pressure contributed least to the overall obstacle structure. This distinction is analytically important. The limited improvement of the Pressure subsystem indicates that pressure mitigation performance has lagged behind the broader CFGT process. Yet the obstacle model suggests that the more entrenched structural constraints are concentrated in resource-state limitations and unresolved deficiencies in governance response capacity. Research on green agricultural development in the Yellow River Basin has highlighted shortcomings in resource conservation and efficient development [12]. The identification of obstacle factors in this paper further reveals that the core constraints on CFGT in the NARC are primarily manifested as compound constraints involving water resources, arable land, and irrigation conditions. Together, these indicators delineate a coherent constraint structure organized around water endowment, land availability, irrigation capacity, water use efficiency, and ecological restoration. The evidence therefore indicates that the principal bottlenecks of CFGT in the NARC arise from the interaction between natural scarcity and the effectiveness of governance responses.

These findings have broader implications for CFGT in arid regions. In humid or relatively resource-abundant areas, CFGT may rely more directly on input reduction, technological substitution, or production efficiency improvement. However, in arid regions, the transition process is more tightly constrained by the availability and allocation of water and land resources. Policy responses therefore need to move beyond a general emphasis on agricultural modernization and place greater weight on the conversion of governance investment into measurable environmental outcomes.

5. Conclusions

This paper, based on the DPSIR framework, assessed the performance, spatial differentiation, and obstacle structure of CFGT in the NARC from 2004 to 2023. The evaluation Results show that the CFGT performance of C exhibited a substantial improvement over the study period. The regional CFGT composite index rose from 0.260 in 2004 to 0.444 in 2023. Its temporal evolution suggests a transition from an initial adjustment phase to steady advancement phase, followed by a more rapid improvement phase after 2017. The overall improvement in CFGT performance is primarily driven by the increment of the Driving Force and Impact subsystems. Furthermore, performance in the CFGT varies across the six provinces in the NARC. By 2023, Qinghai, Shaanxi, and Xinjiang constituted the leading group, Ningxia and Inner Mongolia occupied intermediate positions, and Gansu continued to record the weakest performance. The coefficient of variation further indicates that the State subsystem remained the primary source of inter-provincial differentiation. These findings suggest that socioeconomic disparities narrowed to a certain extent, whereas differences in resource endowments and environmental conditions continued to shape the uneven spatial pattern of CFGT. Moreover, the obstacle analysis shows that the main constraints on CFGT were concentrated in resource-state conditions and governance re-

sponse capacity. At the subsystem level, State and Response accounted for the largest shares of the total obstacle degree, respectively, reaching 34.11% and 27.26%. At the indicator level, the average obstacle degrees over the study period were concentrated in Per Capita water resources, agricultural water productivity, Per Capita cultivated land area, cropland-to-forest conversion intensity, and the share of effective irrigated area. Therefore, water scarcity, limited land endowment and ecological governance capacity constitute the main bottlenecks of CFGT in the NARC.

These findings imply that future CFGT Policy efforts in the NARC should place water security, irrigation reliability, and water use efficiency at the center of green transition. At the same time, it is important to differentiate policy instruments according to provincial obstacle profiles. For Gansu, it is necessary to strengthen investment in infrastructure construction, improve the basic conditions for agricultural production and ecological protection. Regional governments should link agricultural water use quotas with irrigation efficiency targets, accelerate the upgrading of effective and water-saving irrigation systems. For Xinjiang and Inner Mongolia, it is necessary to improve the policy implementation and supervision mechanism of agricultural green development and increase the support for grass-roots policy implementation.

Several limitations should also be acknowledged. (1) The DPSIR framework is useful for organizing the relationships among driving forces, pressures, state conditions, impacts, and responses, but it cannot fully capture feedback effects among subsystems. (2) This paper still has certain limitations regarding the construction of the indicator system. The evaluation indicator system was developed primarily based on the existing literature, policy documents, the actual conditions of the study area, and data availability. Although the proposed index system captures the multidimensional connotation of CFGT, some indicators may contain overlapping information. In addition, the EMM method depends on the variability of the data, so an indicator with a larger change may receive more weight. (3) The obstacle factors model identifies relative constraints within the evaluation system, yet it does not establish causal relationships. (4) This paper focuses on provincial-level patterns, which may mask substantial heterogeneity within provinces, especially between oasis agricultural areas, pastoral zones, and ecologically fragile transition areas. (5) The analysis of inter-provincial differences is based solely on panel data from six provinces spanning 20 years, with a limited sample size. Future research could expand the sample scope and further verify the significance of regional differences in CFGT pathways.

Supplementary Materials: The following supporting information can be downloaded at: <https://www.mdpi.com/article/10.3390/agriculture16141487/s1>, Table S1. Comprehensive performance index and provincial rankings under alternative indicator-orientation scenarios; Table S2. CFGT performance in Provinces in the NARC under the equal-weighting method.

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Data Availability Statement: All baseline data for the evaluation indicators discussed in this study are openly available in publicly published official statistical yearbooks (e.g., China Statistical Yearbook, and Provincial Statistical Yearbook). Readers can download these data for free from the official

website of the National Bureau of Statistics of China (<https://www.stats.gov.cn>) and corresponding provincial statistical platforms. Further inquiries can be directed to the first author.

Conflicts of Interest: The authors declare no conflicts of interest.

Abbreviations

The following abbreviation is used in this manuscript:

CFGT Crop Farming Green Transition
NARC Northwest Arid Region of China

References

1. Yao, J.Y.; Liu, H.P.; Huang, J.P.; Gao, Z.M.; Wang, G.Y.; Li, D.; Yu, H.P.; Chen, X.Y. Accelerated dryland expansion regulates future variability in dryland gross primary production. *Nat. Commun.* **2020**, *11*, 1665. [[CrossRef](#)] [[PubMed](#)]
2. Chen, B.M.; Jing, X.; Liu, S.S.; Jiang, J.; Wang, Y.G. Intermediate human activities maximize dryland ecosystem services in the long-term land-use change: Evidence from the San gong River watershed, northwest China. *J. Environ. Manag.* **2022**, *319*, 115708. [[CrossRef](#)] [[PubMed](#)]
3. Wang, L.; Garland, G.M.; Ge, T.; Guo, S.Q.; Kebede, E.A.; He, C.G.; Hijri, M.; Plaza-Bonilla, D.; Stringer, L.C.; Davis, K.F.; et al. Integrated strategies for enhancing agri-food productivity, lowering greenhouse gas emissions, and improving soil health. *Innovation* **2025**, *6*, 101006. [[CrossRef](#)] [[PubMed](#)]
4. Chen, L.J.; Gao, Y. How to implement the government subsidy policy in promoting the green development of agriculture in Hebei province. *J. Clean. Prod.* **2025**, *496*, 145141. [[CrossRef](#)]
5. Deng, M.J.; Wang, Q.J.; Tao, W.H.; Wang, Z.T.; Cao, J.J. Exploration on the development mode of improving quality and efficiency of modern agriculture in the arid area of Northwest China. *Chin. Eng. Sci.* **2023**, *25*, 59–72.
6. Li, D.; Zhu, Z.; Xu, E.; Zhang, H. Desertification sensitivity and its impacts on land use change in the Tarim Basin, Northwest China. *Sci. Total Environ.* **2024**, *957*, 177601. [[CrossRef](#)] [[PubMed](#)]
7. Dzvene, A.R.; Zhou, L.; Slayi, M.; Dirwai, T.L. A scoping review on challenges and measures for climate change in arid and semi-arid agri-food systems. *Discov. Sustain.* **2025**, *6*, 151. [[CrossRef](#)]
8. Wei, Q.; Zhang, B.; Jin, S.Q. Construction of China's agricultural green development index and regional comparison study. *Agric. Econ.* **2018**, *11*, 11–20. [[CrossRef](#)]
9. Tan, S.H. Promoting Green Agricultural Development in China with the Concept of Green Development. *People's Forum Acad. Front.* **2021**, *13*, 68–76.
10. Zhao, H.J.; Yu, F.W. Evaluation of agricultural green development level in major grain-producing areas based on entropy weight method. *Reform* **2019**, *11*, 136–146.
11. Zhou, J. Evaluation, regional difference analysis and optimization path of agricultural green development in the Yangtze River Economic Belt. *Rural Econ.* **2021**, *12*, 99–108.
12. Cha, J.P.; Zhou, X.; Zhou, Y.X. Comprehensive evaluation and analysis of agricultural green development level in the Yellow River Basin. *Chin. J. Agric. Resour. Reg.* **2022**, *43*, 18–28.
13. Gai, M.; Yang, Q.F.; He, Y.N. Spatiotemporal evolution and influencing factors of agricultural green development level in major grain-producing areas of Northeast China. *Resour. Sci.* **2022**, *44*, 927–942. [[CrossRef](#)]
14. Gong, Q.W.; Li, X.M. Construction and measurement of agricultural green development index: 2005–2018. *Reform* **2020**, *1*, 133–145.
15. Fan, S.Y.; Li, Y.L.; Ma, X.J.; Liu, H. An empirical study on the impact of digitalization level on agricultural green development—Based on panel data of 30 provinces in China. *World Agric.* **2021**, *12*, 4–16. [[CrossRef](#)]
16. Xu, X.; Song, W. Evaluation of agricultural green development from the perspective of rural revitalization. *Stud. Explor.* **2021**, *3*, 130–136.
17. Cui, N.B.; Ba, X.Z. Evaluation of agricultural green development level in Heilongjiang Province. *North. Horticulture* **2021**, *8*, 157–163.
18. Liu, H.L.; Xiao, H.M.; Liu, H.F. Measurement of rural revitalization level and its driving factors based on green development. *J. Cent. South Univ. For. Technol.* **2023**, *43*, 202–210. [[CrossRef](#)]
19. Yu, L.J.; Yang, M.L.; Lyu, J.; Xia, Y.H.; Wang, Y.P. Temporal and spatial variation evaluation of ecological environment quality in the Xingyun Lake Basin. *Admin. Tech. Environ. Monit.* **2023**, *35*, 35–41+48. [[CrossRef](#)]
20. Tian, C.H.; Li, L.; Liao, B. Evaluation of the green development effects of heterogeneous agricultural cleaner production place-based policy. *J. Clean. Prod.* **2024**, *442*, 140969. [[CrossRef](#)]

21. Chi, N.T.K. Driving factors for green innovation in agricultural production: An empirical study in an emerging economy. *J. Clean. Prod.* **2022**, *368*, 132965. [[CrossRef](#)]
22. Gao, J.; Ge, Z.H. Regional Differences and Trend Analysis of Agricultural Green Development Level in Jiangsu Province. *Chin. J. Agric. Resour. Reg.* **2020**, *41*, 14–22.
23. Maxim, L.; Spangenberg, J.H.; O'Connor, M. An analysis of risks for biodiversity under the DPSIR framework. *Ecol. Econ.* **2009**, *69*, 12–23. [[CrossRef](#)]
24. Yang, P.; Qiu, Q. Measurement of agricultural green development level and regional difference analysis in East China. *Chin. Agric. Resour. Reg.* **2026**, 1–15.
25. Li, C.S.; Zhou, Y.X. Study on the spatio-temporal coupling relationship between agricultural water resource vulnerability and food security in major grain producing areas of China. *J. Ecol. Rural Environ.* **2022**, *38*, 722–732. [[CrossRef](#)]
26. Wang, R.; Li, Y.B.; Shao, J.A.; Zheng, L.S.; Chen, Y.; Wang, Q.R.; Zhao, W.X. Evolution mechanism of human-land coupled land system in the hinterland of the Three Gorges Reservoir Area from 2000 to 2020. *Trans. Chin. Soc. Agric. Eng.* **2024**, *40*, 255–264. [[CrossRef](#)]
27. Li, Y.L.; Xian, Y.R.; Yin, X.G.; Mo, F.; Wang, X.L. Construction and empirical research of evaluation index system for green cropping system. *J. China Agric. Univ.* **2025**, *30*, 306–320.
28. Fan, D.S. Agricultural technological progress, rationalization of agricultural structure and agricultural carbon emission intensity. *Stat. Decis.* **2022**, *38*, 154–158. [[CrossRef](#)]
29. Peng, C.S.; Liu, Y.; Zhong, Y. The impact of high-standard farmland construction policy implementation on the climate resilience of grain production. *Chin. Rural Econ.* **2025**, *11*, 42–62. [[CrossRef](#)]
30. Guo, J.; Xue, H.; Feng, P.; Yang, Y. Efficiency and resilience: Common and differentiated priorities for agricultural sustainable development goals. *J. Clean. Prod.* **2025**, *459*, 143965. [[CrossRef](#)]
31. Wu, Q.; Chen, J.L.; Jiao, Y.B. Study on temporal-spatial evolution and obstacle factors of provincial rural tourism ecological security in China based on DPSIR framework. *Tour. Sci.* **2025**, *39*, 109–127.
32. Magrini, A.; Giambona, F. A composite indicator to assess sustainability of agriculture in European Union countries. *Soc. Indic. Res.* **2022**, *163*, 1459–1485. [[CrossRef](#)]

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