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Research on Strategies to Enhance the Efficiency and Sustainable Development of Rural Infrastructure Construction Based on Intelligent Technology

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Abstract China's rural infrastructure construction is an important foundation for promoting sustainable rural economic development. This study uses data envelopment analysis, total factor productivity index and spatial econometric model to evaluate the efficiency of rural infrastructure construction in China, and proposes a sustainable development strategy based on intelligent technology. The study uses the Super-SBM model, Malmquist index, Thiel index and Moran index to analyze the static characteristics, dynamic changes and spatial differences of China's rural infrastructure construction efficiency from 2015 to 2024. The results show that: the efficiency of rural infrastructure construction shows a regional gradient distribution of East>Central>Northeast>West, with a national average efficiency value of 0.74 in 2024, and the provinces of Beijing, Shanghai, Shandong, Guangdong, Qinghai, and Liaoning realize effective DEA; the total factor productivity index is generally greater than 1 during the 12th Five-Year Plan period, and intra-regional disparities in the western region are the main cause of the overall disparity, accounting for more than The total factor productivity index in the 12th Five-Year Plan period is generally greater than 1, and intra-regional differences in the western region are the main reason for the overall differences, accounting for more than 70% of the total differences. Based on the results of the study, we should strengthen the infrastructure construction, optimize the mechanism of talent cultivation and introduction, strengthen the top-level design and policy support, promote the application of digital technology, and build a sustainable rural governance system, so as to improve the efficiency of rural infrastructure construction and sustainable development capacity.

Index Terms Rural infrastructure, construction efficiency, spatial difference, intelligent technology, sustainable development, total factor productivity

I. Introduction

In modern society, science and technology are developing rapidly, and intelligence has become one of the main development directions of modern society, and the strategy of enhancing the efficiency and sustainable development of rural infrastructure construction based on intelligent technology is of great significance for promoting rural development and improving the quality of life of farmers [1]-[4].

At present, China's rural infrastructure intelligent construction as a whole is still in the initial stage, although in some developed areas have realized the intelligent transformation of some rural infrastructure, but most of the rural areas still have problems such as aging facilities, poor information, and low service level [5]-[8]. In the intelligent construction of rural infrastructure, it is necessary to renovate multifaceted facilities, such as water conservancy facilities, communication facilities, transportation facilities, etc., in order to improve their intelligent level and meet the needs of rural development [9]-[11]. Of course, it is also necessary to strengthen the construction of rural informatization and establish a sound rural information network to provide more information services for farmers [12]. However, the intelligent construction of rural infrastructure faces difficulties and challenges in this financial, technical and natural conditions difficulties [13], [14]. Therefore, in order to promote the intelligent construction of rural infrastructure, funds should be actively guided toward the intelligent construction of rural infrastructure, relevant policies and plans should be formulated, and enterprises should be encouraged to participate in the intelligent construction of rural areas [15]-[17].

At the same time, it should also strengthen the technical training in rural areas, improve the technical level of farmers, and promote the pace of rural infrastructure intelligent construction [18], [19]. Promoting the intelligent construction of rural infrastructure can not only improve the efficiency and quality of rural infrastructure, but also reduce the management cost and improve the rural economic efficiency [20], [21]. At the same time, intelligent facilities can also bring more employment opportunities for rural areas, promote the development of rural economy, promote the transformation and upgrading of rural industries, improve the production level and quality of life of farmers, so as to enhance the ability of rural sustainable development [22]-[25].

Rural infrastructure is an important support for promoting rural economic development and improving farmers' production and living conditions, and plays a fundamental role in realizing the comprehensive revitalization of the countryside. In recent years, China has attached great importance to the construction of rural infrastructure, and has achieved remarkable results in the construction of rural infrastructure by increasing investment, innovating the construction mode, improving the policy system and other ways. However, in the process of rapid development, China's rural infrastructure construction is still facing many challenges: unbalanced regional development, inefficient resource allocation, uneven construction quality, imperfect maintenance and management mechanisms and other problems are becoming increasingly prominent. Especially between the eastern and western regions, the gap between the level of infrastructure construction is obvious, and the western region is less efficient in rural infrastructure construction due to factors such as natural condition limitations and relatively backward level of economic development. At the same time, intelligent technology is profoundly changing the traditional rural infrastructure construction model, and new-generation information technologies such as 5G, Internet of Things, big data, artificial intelligence and other new-generation information technologies provide new ideas, new methods and new means for rural infrastructure construction. The application of intelligent technology in the whole process of rural infrastructure planning, construction, operation and maintenance can not only improve the construction efficiency and reduce the cost, but also realize the optimal allocation of resources and precise service supply, thus enhancing the sustainable development capacity of rural infrastructure. This study focuses on the evaluation of rural infrastructure construction efficiency and its sustainable development strategy, with a view to providing theoretical and practical references for promoting the implementation of rural revitalization strategy. This study firstly constructs a rural infrastructure construction efficiency evaluation index system containing three first-level indicators, namely capital investment, information foundation and service level, and adopts the Super-SBM model to statically evaluate the rural infrastructure construction efficiency of 30 provinces in China from 2015 to 2024; secondly, it analyzes the changes and influencing factors of the rural infrastructure construction efficiency from a dynamic perspective by using the Malmquist Total Factor Productivity Index model. infrastructure construction efficiency changes and influencing factors; again, the regional differences and spatial agglomeration characteristics of rural infrastructure construction efficiency are analyzed through the Terrell Index and Moran Index; finally, based on the evaluation results, a sustainable development strategy for rural infrastructure construction based on intelligent technology is proposed in terms of infrastructure construction, talent cultivation and introduction, policy support, application of digital technology and rural governance, which provides a reference for promoting rural revitalization and sustainable development.

II. Research Design

Rural infrastructure is the foundation for promoting the sustainable and healthy development of rural economy, and in recent years, urbanization is hotly staged, and the construction of rural infrastructure is unprecedented. This chapter will propose a relevant research design for rural infrastructure construction efficiency evaluation based on the latest research results of rural infrastructure construction efficiency evaluation.

II. A.Data sources and processing

The sample data are selected from 30 regions in China, and the data sources are all publicly published or released statistics, including China Statistical Yearbook, China Rural Statistical Yearbook, China Urban and Rural Construction Statistical Yearbook, China Rural Poverty Monitoring Report, National Evaluation Report of County Agricultural and Rural Informatization Development Levels, as well as the official websites of the governmental departments and the internal documents of the governmental departments. Except for a small number of indicators for which only real-time data can be obtained, the time point of the study is from 2015 to 2024; in some regions, such as Tibet, there are problems of missing indicators, which are dealt with by the method of mean substitution; and for a small number of indicators for which it is difficult to obtain the data, the data of 2023 are used as a substitute.

II. B.Selection of input-output evaluation indicators

The input and output indicators for the evaluation of the efficiency of rural infrastructure construction are selected, as shown in Table 1. It can be seen that the input level indicators include capital investment, information base and service level, and each input level indicator covers three secondary indicators respectively. The output-level indicators include industrial development, which also covers three secondary indicators.

Table 1: Evaluation index system of rural construction efficiency

Types of indicators	First-level indicators	Secondary indicators
Input	Investment of funds	Investment in agricultural production
		Agricultural financial investment
		Investment in information technology applications such as IoT
	Information base	Smartphone penetration rate
		Computer penetration rate
		Internet penetration rate
	Service level	The service scope of information technology applications such as the Internet of Things
		Digital talent service team
		Consumption level of digital services
Output	Industrial development	National modern agriculture demonstration project
		Digital transaction level
		The level of network payment

II. C.Research methodology

The research methods involved in this paper are: static perspective and dynamic perspective evaluation modeling, Thayer's index and Moran's index.

II. C. 1) Evaluation model

(1) Evaluation model construction in static perspective

Data envelopment analysis method (hereinafter referred to as DEA method) has great advantages in avoiding subjective factors, simplifying algorithms, reducing errors, etc., and is mostly used to measure the production efficiency of a certain subject [26]. Compared with principal component analysis and regression analysis, the DEA method can be applied for the relative effectiveness of decision-making units in the case of multiple inputs and multiple outputs and scale efficiency.

SBM model as an extension model of DEA method, the slack variable will be taken into account, based on the non-angle, non-radial good solution to the drawbacks existing in the traditional DEA method, the non-expected outputs as a part of the outputs are categorized into the evaluation system, which is more in line with the actual situation, and it has gradually become one of the mainstream method models to measure the efficiency. However, SBM-DEA also has a drawback that cannot be ignored, its measured efficiency value is between 0 and 1, and it is impossible to further compare the part of the efficiency value higher than 1. Therefore, in this study, after considering the actual situation of China's rural infrastructure construction and the advantages and disadvantages between the models, the Super-SBM model under global reference and current frontier is selected, and its principle is as follows:

There are several decision-making units (DMUs), and each decision-making unit has input vectors, output vectors and undesired output vectors, and three sets of vectors are defined as $x \in R^m$, $y^a \in R^{s1}$, and $y^b \in R^{s2}$, where m, a, and b represent m input factors, a expected outputs, and b undesired outputs, respectively. The definition matrix is as follows:

$$X = [x_1, \cdots, x_n] \in R^{m \times n} \tag{1}$$

$$y^a = [y_1^a, \cdots, y_n^a] \in R^{s1 \times n} \tag{2}$$

$$y^b = [y_1^b, \cdots, y_n^b] \in R^{s2 \times n} \tag{3}$$

where $X > 0$, $y^a > 0$, and $y^b > 0$, the production set of the system can be defined as $P = \{(x, y^a, y^b) \mid x \geq X\lambda, y^a \geq Y^a\lambda, y^b \geq Y^b\lambda, \lambda \geq 0\}$:

$$\min P^* = \frac{1 - \frac{1}{m}\sum_{i=1}^{m}\frac{s_i^-}{x_{i0}}}{1 + \frac{1}{s1+s2}\left(\sum_{r=1}^{s1}\frac{s_r^a}{y_{r0}^a} + \sum_{r=1}^{s2}\frac{s_r^b}{y_{r0}^b}\right)} \tag{4}$$

$$s.t. x_0 = X\lambda + s^-,\ y_0^a = Y^a\lambda - s^a,\ y_0^b = Y^b\lambda + s^b \tag{5}$$

$$s^- \geq 0, s^a \geq 0, s^b \geq 0, \lambda \geq 0 \tag{6}$$

where s denotes the slack variable, λ denotes the weight variable, P^* is the efficiency value, and $P^* \in [0,1]$; $P^* = 1$ indicates that DMU is effective, $s^- = s^a = s^b = 0$, and $P^* < 1$ indicates that there is a loss of efficiency in DMU.

(2) Evaluation model construction in dynamic perspective

Total Factor Productivity (TFP) is the ratio of output to all input factors, including capital, labor, resources and other intangible inputs, because most of the actual production activities are multi-input factors and need to allocate the proportion of each input factor, the calculation of TFP can analyze the contribution of various factors to the economic results. The advantage of the Malmquist-Luenberger Total Factor Productivity Index (TFPI) model is that the TFPI is calculated for dynamic comparison by measuring productivity from one period to the next.

First assume that the Malmquist index of DMU in period t is:

$$M_0^t(x_t, y_t, x_{t+1}, y_{t+1}) = \frac{D_0^t(x_{t+1}, y_{t+1})}{D_0^t(x_t, y_t)} \tag{7}$$

where x is the input variable and y is the output variable, the Malmquist index based on the $t+1$ period is:

$$M_0^{t+1}(x_t, y_t, x_{t+1}, y_{t+1}) = \frac{D_0^{t+1}(x_{t+1}, y_{t+1})}{D_0^{t+1}(x_t, y_t)} \tag{8}$$

Second, the Malmquist exponents for periods t and $t+1$ are geometrically averaged to obtain a Malmquist exponent of:

$$M_0(x_t, y_t, x_{t+1}, y_{t+1}) = \left[\frac{D_0^t(x_{t+1}, y_{t+1})}{D_0^t(x_t, y_t)} \times \frac{D_0^{t+1}(x_{t+1}, y_{t+1})}{D_0^{t+1}(x_t, y_t)}\right]^{\frac{1}{2}} \tag{9}$$

Finally, its further decomposition can be obtained:

$$M_0 = Effch \times Tech = Pech \times Sech \times Tech \tag{10}$$

where Effch represents the comprehensive technical efficiency index, Tech represents the technical progress index, Pech represents the pure technical efficiency index, Sech represents the scale efficiency index, according to the decomposition of the factors that cause changes in the efficiency of the specific analysis, if the value of the efficiency index is greater than 1, indicating that the efficiency of the positive growth in the state of the relevant indicators of the factors of the construction of the efficiency of the positive role, and vice versa.

II. C. 2) Tyrell's index

The Thiel index is an important indicator of the degree of inequality between regions, and can scientifically measure intra-group and inter-group disparities. Therefore, this study adopts the Tel Index to analyze inter- and intra-regional differences in rural digital infrastructure development. The formula is:

$$T = \frac{1}{n}\sum_{i=1}^{n} \frac{y_i}{\bar{y}} \log\left(\frac{y_i}{\bar{y}}\right) \tag{11}$$

In Equation (11), T is the Thiel index of the level of rural digital infrastructure development, y_i denotes the development level of the i th province, and $\bar{y}$ is the mean value of the national development level. Inter- and intra-regional variability is further analyzed with the help of the Thiel index decomposition formula:

$$T = T_b + T_w = \sum_{k=1}^{K} y_k \log\frac{y_k}{n_k / \bar{n}} + \sum_{k=1}^{K} y_k \left(\sum_{k=1}^{K} \frac{y_i}{y_k} \log\frac{y_i}{y_k / n_k}\right) \tag{12}$$

In Equation (12), T_b represents inter-regional gaps, T_w represents intra-regional gaps, and $k = 1, 2, \cdots, K$. Based on Eq. (11) and Eq. (12), the contribution of intra-regional gaps D_k and inter-regional gaps D_b are calculated:

$$D_k = y_k \times \frac{\sum_{k=1}^{K} \frac{y_i}{y_k} \log \frac{y_i / y_k}{1/n_k}}{T} \tag{13}$$

$$D_b = \frac{T_b}{T} \tag{14}$$

II. C. 3) Moran's index

Moran index is an important indicator of spatial correlation, which is divided into global Moran index and local Moran index, and can assess spatial patterns and measure spatial variability. Therefore, this study adopts the global Moran index (I) and local Moran index (I_i) to analyze the spatial agglomeration characteristics of rural infrastructure construction in each province, with the formula:

$$I = \frac{n\sum_{i=1}^{n}\sum_{j=1}^{n}\omega_{ij}(y_i - \bar{y})(y_j - \bar{y})}{\left(\sum_{i=1}^{n}\sum_{j=1}^{n}\omega_{ij}\right)\sum_{i=1}^{n}(y_i - \bar{y})^2} \tag{15}$$

$$I_i = \frac{y_i - \bar{y}}{\frac{1}{n}\sum(y_i - \bar{y})^2}\sum_{j\neq i}^{n}\omega_{ij}\left(y_j - \bar{y}\right) \tag{16}$$

In Eq. (15) and Eq. (16), n is the total number of provinces, y_i is the index of the level of rural digital infrastructure development of province i, $\bar{y}$ is the mean value of the national development index, and ω_{ij} denotes the spatial weight matrix of the provinces' adjacency.

III. Evaluation and analysis of the efficiency of rural infrastructure construction

This chapter will evaluate and analyze the efficiency of China's rural infrastructure development and discuss the challenges and opportunities faced in China's rural infrastructure development.

III. A. Static analysis of the efficiency of rural infrastructure development

III. A. 1) Efficiency analysis

The efficiency of rural infrastructure construction in China's provinces is evaluated from 2015 to 2024, and the specific results are shown in Table 2. From the data in the table, it can be seen that Beijing, Shanghai, Shandong, Guangdong, Qinghai and Liaoning have realized DEA effective in most years, indicating that the efficiency values of rural infrastructure construction in these regions are on the frontier, the inputs and outputs are in the effective state, and the optimal allocation has been reached, and the ratio of the inputs of capital investment, information base and service level is reasonable. Other provinces with higher efficiency values are Anhui, Henan, Hunan and Sichuan, indicating that although these provinces have not reached the DEA efficiency, the efficiency of inputs and outputs is very close to the frontier, and there may be a slight lack of inputs. The provinces with lower efficiency values are Fujian, Shanxi, Jiangxi, Hubei and most western provinces, which indicates that the efficiency of rural infrastructure construction in these provinces is low, the input and output cannot be matched, and it is more difficult to improve the efficiency.

The efficiency of China's digital village infrastructure construction has obvious geographical characteristics, the overall presentation of the East > Central > Northeast > West characteristics, the eastern region due to the development of better, with strong science and technology, capital, labor resources, so that these areas in the construction of digital villages in the country's leading position; the central region is close to the eastern region, can be very good cooperation and interaction with the eastern region, resource exchange and cooperation, to achieve efficient digital village infrastructure construction. The central region is close to the eastern region, which can cooperate and interact with the eastern region to exchange resources and realize efficient digital village infrastructure construction; the northeastern region is an important agricultural production base in the country, and its efficiency is second only to that of the eastern region; the western region is more backward in terms of economic, scientific and technological, and cultural development, and most of them are located in the mountainous areas, and they are facing more and more difficulties in the development of rural infrastructure construction, so their efficiency value is the lowest and there is a big gap between them and other regions.

Over time, the efficiency of China's rural infrastructure construction has shown a tendency to improve, and with the passage of time and the accumulation of experience, the input-output structure of digital rural infrastructure construction has gradually been rationalized, and the development mode has gradually become more scientific.

Table 2: The efficiency of rural construction in different provinces of China

Provinces	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Beijing	1.00	1.00	1.00	0.72	0.84	1.00	1.00	1.00	1.00	1.00
Tianjin	0.66	0.74	0.58	0.63	0.69	0.90	0.87	0.83	0.71	0.69
Hebei	0.70	0.84	0.69	0.65	0.70	0.74	0.74	0.61	0.60	0.67
Shanghai	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Jiangsu	0.56	0.83	0.90	0.87	0.71	0.72	0.70	0.60	0.62	0.61
Zhejiang	0.54	0.61	0.53	0.79	0.79	0.67	0.72	0.58	0.48	0.50
Fujian	0.90	0.82	0.54	0.87	0.84	0.61	0.55	0.52	0.42	0.54
Shandong	0.74	0.92	0.82	0.94	1.00	1.00	1.00	1.00	1.00	1.00
Guangdong	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Hainan	0.70	0.76	0.65	0.68	0.72	0.74	0.76	0.73	0.82	0.84
Shanxi	0.44	0.61	0.42	0.66	0.67	0.76	0.76	0.64	0.62	0.74
Anhui	0.80	0.85	0.79	0.89	1.01	0.86	0.88	0.67	0.68	0.63
Jiangxi	0.77	0.94	0.80	1.03	0.81	0.78	0.74	0.67	0.65	0.72
Henan	0.80	1.00	1.00	1.00	0.92	1.00	1.00	0.91	0.83	1.00
Hubei	1.00	0.94	0.54	0.81	0.94	0.85	0.84	0.61	0.70	0.78
Hunan	0.82	0.94	1.00	1.00	1.00	1.00	1.00	0.87	0.79	0.80
Chongqing	0.64	0.78	0.49	0.63	0.74	0.90	0.81	0.61	0.62	0.68
Sichuan	1.00	1.00	0.83	0.86	0.86	0.78	0.77	0.73	0.86	0.76
Guizhou	0.39	0.72	1.00	0.90	0.81	0.80	0.73	0.60	0.63	0.58
Yunnan	0.70	1.00	0.45	0.62	0.80	0.94	0.85	0.61	0.65	0.65
Guangxi	0.42	0.60	0.41	0.54	0.61	0.69	0.60	0.59	0.52	0.59
Inner Mongolia	0.64	0.69	0.51	0.58	0.65	0.66	0.70	0.69	0.64	0.63
Shaanxi	0.23	0.29	0.21	0.37	0.39	0.50	0.49	0.48	0.40	0.48
Gansu	0.54	1.00	0.82	0.79	0.78	0.71	0.65	0.65	0.67	0.77
Qinghai	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Ningxia	0.19	0.32	0.31	0.36	0.55	0.58	0.74	0.60	0.38	0.33
Xinjiang	0.88	0.97	1.00	0.94	0.77	0.86	0.88	0.72	0.59	0.61
Heilongjiang	0.76	1.00	1.00	1.00	0.95	1.00	0.99	0.84	0.73	0.77
Jilin	0.51	0.56	0.63	0.76	0.61	0.74	0.73	0.70	0.82	0.76
Liaoning	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
National average	0.71	0.82	0.73	0.80	0.80	0.83	0.82	0.73	0.72	0.74

III. A. 2) Redundancy analysis of input indicators

In order to find the reasons for the lower efficiency of rural infrastructure construction in other provinces, and to clarify the direction of future improvement, this paper analyzes the redundancy of proportional improvement of inputs in 2024 in the 24 provinces with ineffective DEA, as shown in Table 3. As can be seen from the table, in terms of capital investment, Tianjin and Zhejiang in the eastern region, and Inner Mongolia, Shaanxi, Ningxia and Xinjiang in the western region, there is a lack of investment, and individual provinces, such as Shaanxi and Xinjiang, have an optimization space of more than 100%, and the lack of investment in digital capital is an important reason for the inefficiency of the construction of these two provinces. In terms of information foundation, all regions have been relatively well constructed in terms of digital information. With the continuous development of the digital economy, the penetration rate of digital technologies and devices such as the Internet, cell phones and computers in rural areas has been greatly improved, and a good digital information base has laid the foundation for the improvement of the efficiency of digital rural infrastructure construction. In terms of service level, digital services are the main cause of regional inefficiency, and there is room for improvement in most regions, with a smaller proportion of eastern and central regions in need of improvement, while the vast majority of provinces in western and northeastern regions are in dire need of improvement.

Overall, individual provinces in the eastern and western regions need to strengthen digital funding, and the vast majority of provinces need to pay attention to improvements in digital services, and be equipped with a comparable level of services under conditions of adequate funding and complete digital information in order to improve the efficiency of rural infrastructure.

Table 3: The input indicators of DEA relatively ineffective provinces

Region	Provinces	Investment of funds	Information base	Service level
Eastern region	Tianjin	-0.171	0	-0.108
	Hebei	0	0	-0.014
	Jiangsu	0	0	-0.193
	Zhejiang	-0.097	0	-0.314
	Fujian	0	0	-0.156
	Shandong	0	0	-0.289
	Hainan	0	0	0
Central region	Shanxi	0	0	-0.301
	Anhui	0	0	-0.082
	Jiangxi	0	0	-0.148
	Hubei	0	0	-0.215
	Hunan	0	0	-0.123
Western region	Chongqing	0	0	-0.249
	Sichuan	0	0	-0.401
	Guizhou	0	0	-0.381
	Yunnan	0	0	-0.439
	Guangxi	0	0	-0.292
	Inner Mongolia	-0.008	0	-0.37
	Shaanxi	-0.937	0	-0.318
	Gansu	0	0	0
	Ningxia	-0.088	0	-0.169
	Xinjiang	-0.547	0	-0.483
Northeast region	Heilongjiang	0	0	-0.312
	Jilin	0	0	-0.202

III. B. Dynamic analysis of the efficiency of rural infrastructure development

In order to observe the dynamic efficiency of rural infrastructure construction, this paper dynamically analyzes the efficiency of digital rural infrastructure construction in 30 provinces in China from 2015 to 2024 based on the scale reward invariant and output-oriented Malmquist index model, and obtains the Malmquist Total Factor Productivity Index (MPI) and its decomposition index for each province from 2015 to 2024,. Where MPI>1 indicates productivity increase, MPI=1 indicates no change in productivity, and MPI<1 indicates productivity decrease.MPI can also be decomposed into the product of the rate of change of technical efficiency (reflecting the rate of resource utilization) and the rate of change of technology (reflecting technological progress), and the sub-index is greater than 1 indicates that the sub-index plays a facilitating role for MPI, otherwise it plays an inhibiting role.

According to China's five-year plan is divided into the period of the 12th Five-Year Plan (2015-2019) and the 13th Five-Year Plan (2020-2024), the efficiency of rural infrastructure construction in each province in the two five-year plan periods is compared by taking the average value, and the results are shown in Table 4. The results are shown in Table 4. From the table, it can be seen that in the 12th Five-Year Plan period, the MPI values of all provinces are greater than 1, and the situation of rural infrastructure construction has been improved, which is mainly caused by the improvement of technical efficiency. In the 13th Five-Year Plan period, the MPIs of Shandong, Anhui, Hunan and Guizhou are less than 1, and the situation of rural infrastructure construction has worsened, which is caused by the low rate of change of technical efficiency, i.e., inefficient utilization of resources; the MPIs of the other regions are greater than 1, which is mainly due to the influence of technical efficiency, i.e., technological progress.

Table 4: Efficiency of digital rural construction in China 's provinces

Provinces	2015-2019			2020-2024		
	MPI	Change rate of technical efficiency	Technical change rate	MPI	Change rate of technical efficiency	Technical change rate
Beijing	1.386	0.984	1.51	1.387	1.028	1.367
Tianjin	1.282	0.992	1.308	1.054	1.03	1.056
Hebei	1.631	0.994	1.564	1.069	1.013	1.054
Shanghai	1.851	1	1.846	1.033	1	1.03
Jiangsu	1.617	1.097	1.445	1.06	0.964	1.104
Zhejiang	1.525	1.126	1.404	1.03	0.916	1.139
Fujian	1.326	1.036	1.424	1.016	0.942	1.092
Shandong	1.69	1.08	1.522	1.001	0.959	1.034
Guangdong	1.408	1	1.404	1.02	1	1.022
Hainan	1.477	1.008	1.465	1.057	1.029	1.024
Shanxi	1.561	1.147	1.422	1.076	1.029	1.072
Anhui	1.547	1.051	1.455	0.952	0.923	1.041
Jiangxi	1.54	1.033	1.451	1.038	0.972	1.053
Henan	1.697	1.033	1.593	1.048	1.025	1.038
Hubei	1.305	1.049	1.334	1.007	0.961	1.054
Hunan	1.672	1.056	1.541	0.94	0.946	0.996
Chongqing	1.512	1.092	1.432	1.064	1.007	1.065
Sichuan	1.434	0.964	1.473	1.008	0.972	1.026
Guizhou	1.894	1.256	1.445	0.991	0.926	1.077
Yunnan	1.426	1.079	1.328	1.012	0.967	1.06
Guangxi	1.705	1.234	1.441	1.05	1.009	1.049
Inner Mongolia	1.495	1.11	1.509	1.124	1.02	1.104
Shaanxi	1.683	1.193	1.43	1.083	1.026	1.076
Gansu	1.662	1.122	1.419	1.041	1.01	1.022
Qinghai	1.605	1	1.606	1.323	1	1.313
Ningxia	1.782	1.25	1.409	1.005	0.967	1.088
Xinjiang	1.544	0.976	1.544	1.055	0.952	1.103
Heilongjiang	1.792	1.074	1.611	1.017	0.952	1.072
Jilin	1.652	1.046	1.572	1.094	1.048	1.043
Liaoning	1.942	1	1.931	1.03	1	1.035

III. C. Decomposition Analysis of Differences in the Efficiency of Rural Infrastructure Development

III. C. 1) One-Stage Decomposition of the Western Terrier Index

In order to understand the specific causes of the differences in the efficiency of regional rural infrastructure construction in the western region, the overall differences in the western region are decomposed into intra-regional and inter-regional differences through the one-stage decomposition of the Thiel index, and the specific decomposition results are shown in Table 5. From the one-stage decomposition results of the Thiel index in the western region, the trend of intra-regional differences in the western region is the same as that of the overall regional differences, and the intra-regional differences in the western region have been larger than the inter-regional differences from 2013 to 2024. This indicates that intra-regional differences are the main reason for the differences in regional rural infrastructure construction efficiency in the western region during this period.

III. C. 2) Overall one-phase Tyrrell's index for the East and West regions

Then the size of regional differences between the eastern and western regions and in the western region are compared, and the one-stage decomposition of the eastern and western Terre indexes is shown in Figure 1. It can be found that the regional differences between the eastern and western regions have been larger than the regional differences in the western region from 2013 to 2024. This indicates that reducing the regional differences between the east and the west remains a priority for promoting coordinated regional development.

Table 5: One-stage Theil index decomposition

Year	Theil index		
	Overall regional differences	Intraregional differences	Interregional differences
2013	0.03044	0.0234	0.00704
2014	0.0316	0.0249	0.0067
2015	0.02977	0.0224	0.00737
2016	0.02576	0.0243	0.00146
2017	0.03234	0.0261	0.00624
2018	0.0247	0.0243	0.0004
2019	0.02841	0.026	0.00241
2020	0.02552	0.0243	0.00122
2021	0.02638	0.0248	0.00158
2022	0.02066	0.0157	0.00496
2023	0.02893	0.0247	0.00423
2024	0.02231	0.0178	0.00451

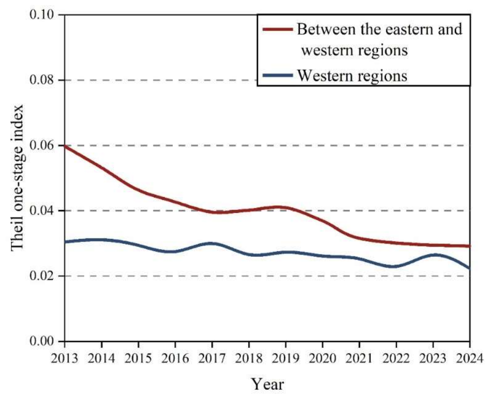


Figure 1: The results of Theil's one-stage exponential decomposition

III. C. 3) Analysis of the contribution of the south-west and north-west regions

Adding the proportion of each region's GDP to the rural infrastructure development in the western region as a weight, we can get the contribution rate of the Thiel index in the southwest and northwest regions, which can reflect the level of rural infrastructure development in a region to a certain extent, and the contribution rate of the southwest and northwest regions is shown in Figure 2. The contribution rate of the southwest region are greater than the contribution rate of the northwest region, which indicates that the coordinated regional development of the southwest region needs more attention. Although the Thiel index of the Northwest region is larger than the Thiel index of the Southwest region after 2013, the contribution rate of the Southwest is larger than that of the Northwest after adding the share of rural infrastructure development as a weight. From an overall perspective, even though there are large regional differences within the Northwest, its contribution to the entire western region is not high, so there is a greater need to pay attention to the issue of coordinated regional development within the Southwest.

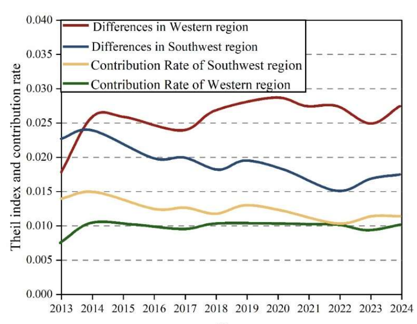


Figure 2: The Theil index and its contribution rate

III. D. Evolution of spatial patterns of differences in the efficiency of rural infrastructure development

III. D. 1) Global spatial autocorrelation

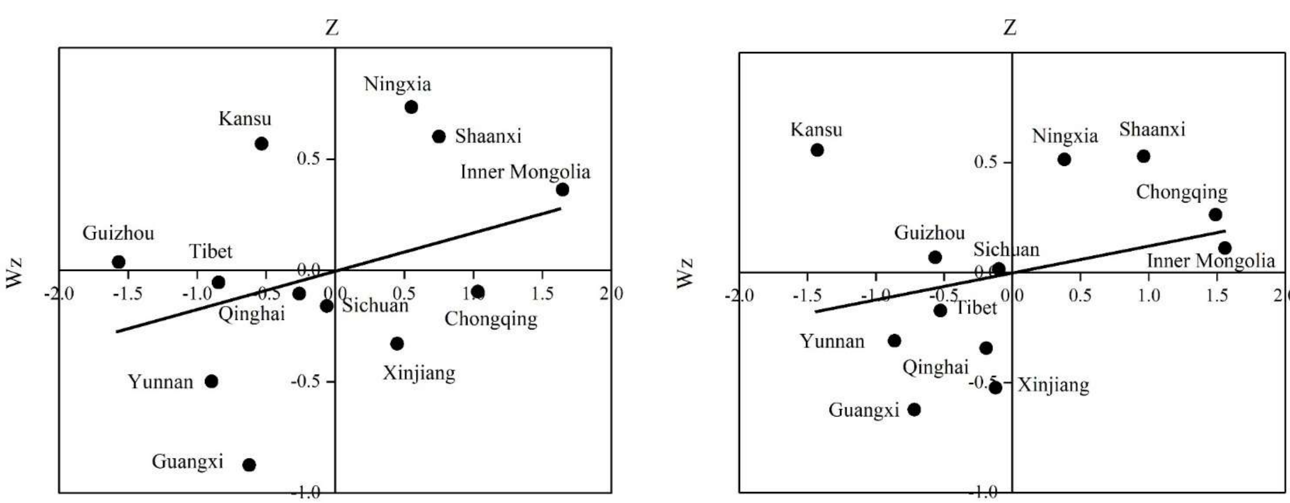
This paper derives the global spatial autocorrelation results in the western region according to the global Moran index calculation formula, as shown in Table 6. As can be seen from the table, the global Moran index values are all positive without considering the Z-value, which indicates that there is a positive correlation and spatial agglomeration in the development of rural infrastructure development in the western region from 2013 to 2024, i.e., provinces with high (low) values tend to cluster spatially with neighboring provinces with high (low) values.

Table 6: Global Moran 's index

Variables	I	$E(I)$	$SD(I)$	Z	$P-value$
Rho2013	0.223	-0.082	0.156	1.859	0.028
Rho2014	0.126	-0.082	0.184	1.202	0.13
Rho2015	0.117	-0.082	0.166	1.171	0.125
Rho2016	0.132	-0.082	0.166	1.237	0.065
Rho2017	0.128	-0.082	0.166	1.16	0.08
Rho2018	0.08	-0.082	0.163	0.965	0.155
Rho2019	0.078	-0.082	0.147	1.04	0.122
Rho2020	0.137	-0.082	0.171	1.334	0.059
Rho2021	0.125	-0.082	0.172	1.288	0.135
Rho2022	0.059	-0.082	0.166	0.929	0.176
Rho2023	0.025	-0.082	0.166	0.723	0.196
Rho2024	0.039	-0.082	0.168	0.773	0.234

III. D. 2) Local spatial autocorrelation

In order to further illustrate the neighborhood spatial clustering of the economic development of the 12 western provinces (urban areas) in the local area, the scatter plots of the Moran index for the five years of 2013, 2020, 2021, 2023 and 2024 are plotted by STATA software, as shown in Figure 3. Figures (a) to (e) correspond to 2013, 2020, 2021, 2023 and 2024 in turn. As can be seen from the figure, the number of provinces located in the first and third quadrants is significantly larger than the number of provinces located in the second and fourth quadrants, showing strong spatial correlation. The number of provinces with high - high agglomeration located in the first quadrant increases from three in 2013 to four in 2024, and the number of provinces with low - low agglomeration located in the third quadrant is always more than the number of provinces with high - high agglomeration. The number of provinces with low-high and high-low agglomerations located in the second and fourth quadrants is consistently small and does not change much, suggesting that there is no significant negative spatial correlation in the western region, and that the regional extent of heterogeneity is small. Overall, the spatial correlation patterns of most provinces in the western region have not changed significantly over the 12-year period.



(a)2013 (b)2020

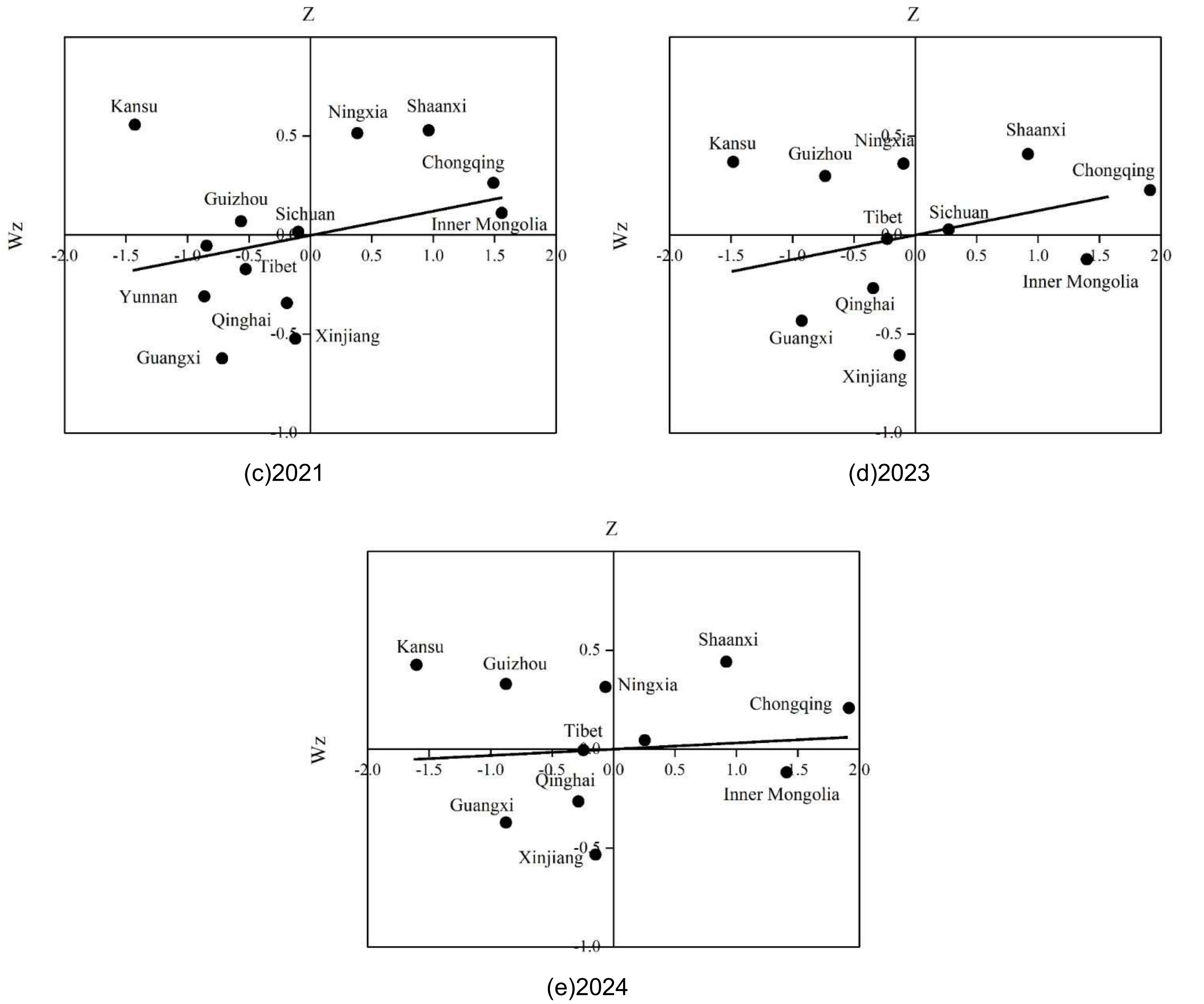


Figure 3: Local spatial autocorrelation scatter plot

IV. Strategies for Sustainable Development of Rural Infrastructure Construction

Based on the evaluation and analysis of the efficiency of China's rural infrastructure construction, this chapter will propose strategies for the sustainable development of rural infrastructure construction in terms of talent cultivation and policy support.

(1) Further strengthening infrastructure construction

Through large-scale investment and systematic planning, the government has continued to strengthen the construction of rural roads, especially in remote mountainous areas and poor areas, and has implemented the "Village to Village" project to ensure convenient road connections. As for water conservancy projects, the construction of efficient water-saving irrigation systems and water conservancy pivots has improved agricultural water use efficiency and flood and drought prevention.

(2) Optimizing the mechanism of cultivating and introducing talents

Supporting rural revitalization with talents. A rural talent revitalization plan has been implemented to enhance farmers' modern agricultural knowledge and technology through vocational education and skills training. The government has cooperated with universities, research institutions and enterprises to establish talent training bases and promote the integration of industry and education. For example, the Ministry of Agriculture and Rural Development and the China Agricultural University have jointly launched the "Agricultural Manager" training program to train farmers with both technical, managerial and business skills. In addition, scholarships and subsidies have been set up to encourage university graduates to work in the countryside and provide livelihood security to attract talents.

(3) Strengthen top-level design and policy support

The government implements measures such as financial subsidies, tax incentives and financial support to encourage social capital to invest in rural development. Enhanced investment in rural revitalization covers a number of key areas such as agricultural production, infrastructure and public services. At the same time, the government has established an assessment mechanism to incorporate rural revitalization performance into the annual assessment of local governments to ensure the effective implementation of policies and the smooth promotion of rural revitalization strategies.

(4) Promoting the wide application of digital technology in the countryside

The application of human-machine technology in pesticide spraying and fertilizer application has effectively reduced the amount of medicine and fertilizer used, and improved production efficiency and environmental standards. Internet of Things (IoT) technology enables farmers to monitor soil conditions in real time, realizing precision agriculture and enhancing the quality and yield of agricultural products. The construction of rural e-commerce platforms helps farmers sell their products directly, optimizing the efficiency of agricultural product circulation.

(5) Building a sustainable rural governance system

The implementation of the villagers' deliberation system under the leadership of village-level party organizations has effectively enhanced the enthusiasm of villagers to participate in village management. The government has strengthened rural legal services and established legal counselors and workstations to protect villagers' rights and interests. At the same time, through moral education and cultural construction in villages, it has promoted socialist core values and facilitated the harmonious development of villages.

V. Conclusion

By evaluating and analyzing the efficiency of rural infrastructure construction in China, the following conclusions are drawn:

The efficiency of rural infrastructure construction in China shows obvious geographical differences, generally characterized by East > Central > Northeast > West. Provinces such as Beijing, Shanghai, Guangdong, Qinghai and Liaoning realize DEA efficiency in most years, while the overall efficiency value of the western region is relatively low.

Dynamic efficiency analysis shows that the Malmquist Total Factor Productivity Index (TFPI) of all provinces in the 12th Five-Year Plan period is greater than 1, indicating a general improvement in rural infrastructure development; while in the 13th Five-Year Plan period, the MPIs of Shandong, Anhui, Hunan, and Guizhou are less than 1, which is mainly due to the lower rate of change in technical efficiency.

The analysis of regional differences shows that the intra-regional differences in the western region are always larger than the inter-regional differences, and the Tel index of intra-regional differences in 2024 is 0.0178, with a contribution rate of more than 79%, which indicates that narrowing the intra-regional differences is the key to promoting the balanced development of the western region.

The results of spatial autocorrelation analysis show that there is a significant spatial agglomeration characteristic of rural infrastructure development in the western region from 2013 to 2024, and the number of provinces with high - high agglomeration and low - low agglomeration changes from 3 and 5 in 2013 to 4 and 4 in 2024, respectively. In the face of these realities, it is necessary to comprehensively improve the efficiency and sustainable development of rural infrastructure construction by strengthening infrastructure construction, optimizing the mechanism for training and introducing talents, enhancing policy support, promoting the application of digital technology and building a sustainable rural governance system.

References

[1] Wu, X. (2022, November). Application of Intelligent Technology in Integrated Urban-Rural Water Supply Project. In 2022 8th International Conference on Hydraulic and Civil Engineering: Deep Space Intelligent Development and Utilization Forum (ICHCE) (pp. 1211-1218). IEEE.

[2] Zhou, F., Guo, X., Liu, C., Ma, Q., & Guo, S. (2023). Analysis on the influencing factors of rural infrastructure in China. Agriculture, 13(5), 986.

[3] Zhou, X. (2023, October). Application research of BIMVR based on intelligent construction in rural road construction. In Proceedings of the 2023 4th International Conference on Computer Science and Management Technology (pp. 914-917).

[4] Liu, Y., Zhang, H., Ning, M., & Wang, L. (2024). Has digital village construction narrowed the urban–rural income gap: evidence from Chinese counties. Sustainability, 16(13), 5330.

[5] Ren, J., Chen, X., Shi, L., Liu, P., & Tan, Z. (2024). Digital village construction: A multi-level governance approach to enhance agroecological efficiency. Agriculture, 14(3), 478.

[6] Jiang, A., Zhang, Y., & Ao, Y. (2022). Constructing inclusive infrastructure evaluation framework—analysis influence factors on rural infrastructure projects of China. Buildings, 12(6), 782.

[7] Aliev, R. A. (2023). INFRASTRUCTURE OF SMART VILLAGES WITH APPLICATION OF ARTIFICIAL INTELLIGENCE AND SENSORS WITH NEW TECHNOLOGIES. Proceedings of IAM, 12(1), 33-51.

[8] Nie, S. (2021). Influence of rural infrastructure construction on agricultural total factor productivity. Agric. For. Econ. Manag, 4(1), 65-68.

[9] Wu, W., Ji, Z., & Liang, H. (2023). The impact of new infrastructure construction on optimization and upgrading of industrial structure. Buildings, 13(10), 2580.

[10] Wang, X., & Jiang, B. (2022). Research on the Management of China's Rural Infrastructure Projects under the Background of Rural Revitalization Strategy. Journal of Sustainable Urbanization, Planning and Progress, 6(1), 29-34.

[11] Zeng, Y., Zhu, C., Xu, B., & Lin, Z. (2023). Built to last: Re-engaging indigenous infrastructure in China's rural development. Journal of Landscape Architecture, 18(2-3), 34-53.

[12] Zhang, M. (2015). Agricultural and rural informatization construction in China. Asian Agricultural Research, 7(10), 22.

[13] Chang, G. K., Xu, G., Correia, A. G., & Nazarian, S. (2021, September). Intelligent construction for infrastructure—the framework. In Advances in Transportation Geotechnics IV: Proceedings of the 4th International Conference on Transportation Geotechnics Volume 3 (pp. 193-204). Cham: Springer International Publishing.

[14] He, Q., Ghofrani, F., Gao, T., Wang, P., He, C., Li, Y., & Ai, C. (2022). Intelligent construction for the transportation infrastructure: a review. Intelligent Transportation Infrastructure, 1, liac007.

[15] Chen, K., Zhou, X., Bao, Z., Skibniewski, M. J., & Fang, W. (2024). Artificial intelligence in infrastructure construction: A critical review. Frontiers of Engineering Management, 1-15.

[16] Lu, C., Liu, J., Liu, Y., & Liu, Y. (2019). Intelligent construction technology of railway engineering in China. Frontiers of Engineering Management, 6(4), 503-516.

[17] Wang, M., & Yin, X. (2022). Construction and maintenance of urban underground infrastructure with digital technologies. Automation in construction, 141, 104464.

[18] Ghinaiya, D., & Vaghasiya, A. (2025). Artificial Intelligence in Infrastructure Construction: A Critical Review. Available at SSRN 5117387.

[19] Shah, B., & Shukla, P. (2019). The Role Of Vocational Education And Skill Development Inrevitalizing The Sustainable Growth Of Rural Areas. Disciples India Global Journal of Applied Management, 1(1), 8-24.

[20] Guo, J., & Li, B. (2018). The application of medical artificial intelligence technology in rural areas of developing countries. Health equity, 2(1), 174-181.

[21] Zhao, S., Li, M., & Cao, X. (2024). Empowering Rural Development: Evidence from China on the Impact of Digital Village Construction on Farmland Scale Operation. Land, 13(7), 903.

[22] Xiao, M., Luo, S., & Yang, S. (2024). Synergizing Technology and Tradition: A Pathway to Intelligent Village Governance and Sustainable Rural Development. Journal of the Knowledge Economy, 1-56.

[23] Yuan, X., Zhao, L., Chang, C., Wang, Z., & Yu, X. (2020, April). Intelligent Rural Planning Management Based on MATLAB Simulation. In Journal of Physics: Conference Series (Vol. 1533, No. 3, p. 032063). IOP Publishing.

[24] Mhlanga, D. (2021). Artificial intelligence in the industry 4.0, and its impact on poverty, innovation, infrastructure development, and the sustainable development goals: Lessons from emerging economies?. Sustainability, 13(11), 5788.

[25] Zhao, W., Liang, Z., & Li, B. (2022). Realizing a rural sustainable development through a digital village construction: experiences from China. Sustainability, 14(21), 14199.

[26] Madjid Tavana,Mehdi Toloo,Francisco J. Santos Arteaga,Hajar Farnoudkia & Violeta Cvetkoska. (2025). Time envelopment analysis: A new method for effectively incorporating time series in data envelopment analysis. Expert Systems With Applications,282,127791-127791.