

Article

Land-Use Change and Efficiency in Laos' Special Economic Zones

Dongxue Li and Xingping Wang * 

School of Architecture, Southeast University, Si Pai Lou No. 2, Nanjing 210096, China; lidx@seu.edu.cn

* Correspondence: wxpsx@seu.edu.cn

Abstract: Special economic zones (SEZs) are important in Laos due to their ability to attract foreign investment, realize industrialization, and promote economic globalization. Based on Laos' SEZs in operation, this study explored land-use intensity, structural evolution and land-use efficiency in Laos' SEZs via the land-use dynamic degree, information entropy, super-efficiency data envelopment analysis (DEA) and gray relational analysis (GRA). The study determined that the total land-use area in Laos' SEZs continuously increased from 2014 to 2020. The land-use intensity changes in the SEZs can be divided into three types, i.e., high intensity, medium intensity and low intensity, and most SEZs belonged to the medium-intensity type. The proportion of land used in production systems in Laos' SEZs increased the most, and the proportion of infrastructure land notably decreased. The overall information entropy of the land-use structure exhibited an initial downward and then an upward trend. In 2018, the land-use efficiency in the Savan-Seno SEZ, Vientiane Industrial and Trade Area, Dongphosy SEZ, and Golden Triangle SEZ was relatively optimal. The basic factors of the industrial space and the factors reflecting international cooperation attributes were highly related to the land-use efficiency in Laos' SEZs.

Keywords: special economic zone; international cooperation; land-use change; land-use efficiency; Laos



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1. Introduction

Special economic zones (SEZs) and industrial parks have become an important means of promoting economic development in many developing countries. At present, the number of SEZs and industrial parks in Southeast Asian countries has increased rapidly [1]. Countries such as Japan, China, and Singapore have also actively participated in the development of SEZs and industrial parks in certain Southeast Asian countries. Laos has implemented reform and opening-up policies since 1986 [2]. To promote the reform of economic mechanisms, improve the domestic business environment and attract foreign investment, Laos designated the development of SEZs as one of its national strategies and included this objective in the 7th Five-Year National Socioeconomic Development Plan (2011–2015) [3]. SEZs can facilitate the integration of Laos' economy into regional and international markets, establish a domestic industrial base and promote the modernization of Laos' economy as an important part of the policy of turning land into capital [4]. With the assistance of the Japan International Cooperation Agency (JICA) and the Asian Development Bank (ADB), the Lao government adopted the concept of the SEZ after 2000 [5]. In 2003, the Prime Minister of Laos signed a decree establishing the Savan-Seno SEZ, which officially launched the construction of SEZs. According to a report issued by the Ministry of Planning and Investment of Laos, as of 2017, 352 Lao and overseas companies had settled in Laos' SEZs, with a total registered capital of US \$8 billion. SEZs have created US \$17 million in revenue for the Lao government and 18,000 jobs for both local residents and foreign workers [6]. After nearly two decades of development and exploration, while the construction of Laos' SEZs has promoted economic and social development in Laos, the SEZs is also facing a series of problems, such as quantity over quality issues, enclosure of settled enterprises [7], and a high land vacancy rate [5]. Therefore, it is necessary to

examine the actual development of the SEZs in Laos and to provide a reference and basis for the sustainable development of the SEZs in Laos by studying their land-use changes and efficiency.

The current research focuses on the social problems caused by Laos' SEZs and the development of border SEZs. During the construction of SEZs in Laos, the lack of government services and control, absence of charity, and improper handling by developers have caused certain areas hosting SEZs to face issues regarding the resettlement and endangerment of the livelihoods of indigenous people [8], marginalization of local groups [9], class differentiation and re-farming of residents [5], illegal wildlife trade [10,11], proliferation of casinos [12] and other issues. These issues have raised widespread concern. Border SEZs [13] established in Laos also provide a new perspective for related research, among which the Savan-Seno and Golden Triangle SEZs have become typical cases of research on Laos' border SEZs. The development of SEZs in border areas is an important strategy for Laos to build an economic gateway and enhance the economic competitiveness of border areas [5]. James [14] focused on the operating mechanism of the Savan-Seno SEZ as a border territory linking Laos to the regional and global economy. The border SEZ, developed under the Belt and Road initiative, is a concrete application of China-Laos economic cooperation that embodies the symbiotic bilateral relationship between these economies [15], but the border SEZ inevitably experiences the problem of multiscale border shielding [16]. In regard to the land use in Laos' SEZs, only a few studies have analyzed land acquisition and income methods in specific cases. At the national level, Laos achieves sectoral development goals through reserved land for the construction of SEZs [17]. At the local level, the encouragement of foreign direct investment (FDI) in Laos has resulted in certain SEZs occupying original planned protected land and urban green land areas, thus affecting the implementation of local land-use planning [18]. At the SEZ level, Chen et al. [19] analyzed the land development income mode of the Saysettha Development Zone, a representative Chinese International Cooperation Park in Laos, and found that the SEZ realized land appreciation mainly through land leasing and selling and provided basic supporting services.

The research topics on land-use change and efficiency have been quite extensive. The study of land-use change is of great importance for the promotion of land resource protection [20] and regional sustainable development [21]. Existing research on land-use change involves spatiotemporal changes in land use, single land-use changes, land-use structure evolution and driving factors. The research on land-use change has more commonly used remote sensing (RS) and GIS technology [22], while the land use transfer matrix [23] and information entropy [24–26] are widely used in land-use structure research because they can quantify changes in the internal structure of the land system. Land-use efficiency is a representative concept that follows the paradigm of sustainable development [27] and is an important indicator that reflects the extent of land use [28]. The evaluation of land-use efficiency can provide scientific guidance for the determination of the reasonable scale of development and promotion of the intensive and economical use of land [29]. At present, the research methods used for land-use efficiency evaluation mainly include stochastic frontier analysis (SFA) [28], data envelopment analysis (DEA) [30], super-efficiency DEA [31], slack-based measure (SBM) [32], undesirable SBM [33] and super-SBM models [34]. However, the existing research on land-use change and efficiency largely focuses on the scales of continents [35], countries [36,37], typical regions [38], and cities [39], and there is insufficient land-use research focusing on policy implementation areas such as SEZs.

In summary, an in-depth analysis of the development and governance of Laos' SEZs has been carried out in the relevant research, but there is insufficient literature focusing on land-use change and efficiency evaluation. In addition, the existing reports and literature focus on economic and social data pertaining to SEZs, but there are few horizontal comparisons of Laos' SEZs. Therefore, this study focuses on land-use change, land-use efficiency and its influencing factors in Laos' SEZs. The objectives of this study are (1) to analyze the dynamic evolution characteristics of the land-use intensity and structure of Laos' SEZs and

to conduct comparative studies on the various SEZs. (2) This study further aims to evaluate the land-use efficiency based on the actual development of Laos' SEZs and to analyze its influencing factors to provide recommendations for the sustainable development of SEZs. This study enriches the understanding of land use in Laos' SEZs, provides a basis for the realization of sustainable land use and SEZ management, and offers a case study on land-use change and efficiency in policy implementation zones.

2. Materials and Methods

2.1. Study Area

This study adopts the ten SEZs in operation in Laos as the research objects. The Lao Government Office, the Lao National Committee for SEZs (NCSEZ) and its secretariat office (S-NCSEZ), with technical support from the United Nations Industrial Development Organization (UNIDO), issued the Development Strategy for Special and Specific Economic Zones in the Lao PDR, 2011–2020, in 2012. According to the plan, Laos should establish twenty-three SEZs in 2015 and continue to establish and develop other SEZs from 2015–2020. However, as of 2020, Laos has only established thirteen SEZs. Among these SEZs, the Champasak Province SEZ, the Xiengkhuang SEZ and the Luang Prabang SEZ remain at the preparatory stage, and no substantial land development and utilization have been executed, so these SEZs are not considered within the scope of this study.

Figure 1 shows that the establishment of SEZs in Laos was mainly concentrated from 2009–2012, which is consistent with the time when Laos introduced relevant laws, regulations and policies, and their effects were observed. The study period ranges from 2014 to 2020, starting at the point when land use was generally initiated in the ten SEZs. The SEZ Promotion and Management Office (SEZO) divides Laos' SEZs into the following three categories: industrial and commercial SEZs, logistics and trade SEZs, and urban central SEZs. From the perspective of the spatial distribution, the SEZs in Laos are clustered in the capital and scattered in the north and south (Figure 2). Five of the SEZs are located in Vientiane but are relatively small and cover an area of 0.54–10.00 km². Of the remaining eight scattered SEZs, three are located in general cities, with a large area ranging from 8.00–261.96 km² (Figure 3), and five SEZs are located in border areas facing China or Thailand to seek wide markets.

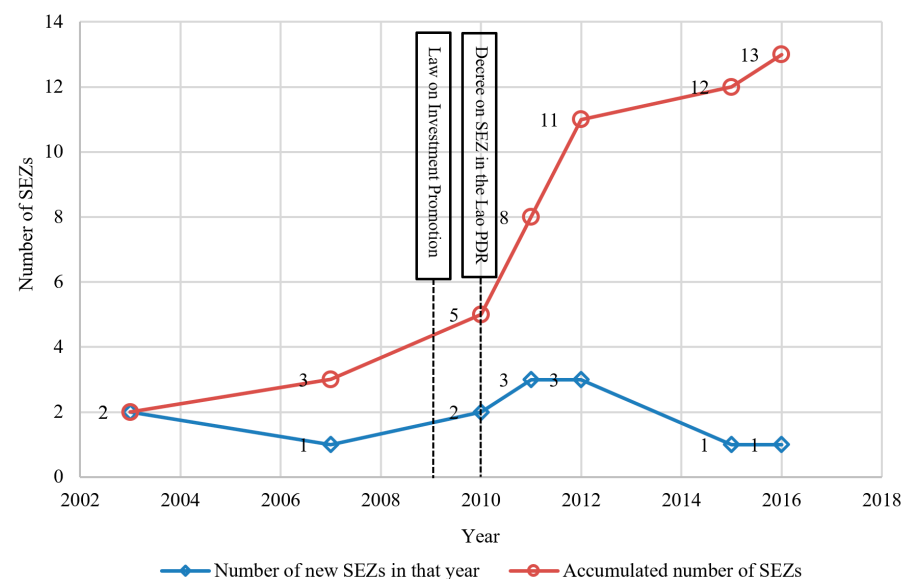


Figure 1. Changes in the number of SEZs in Laos.

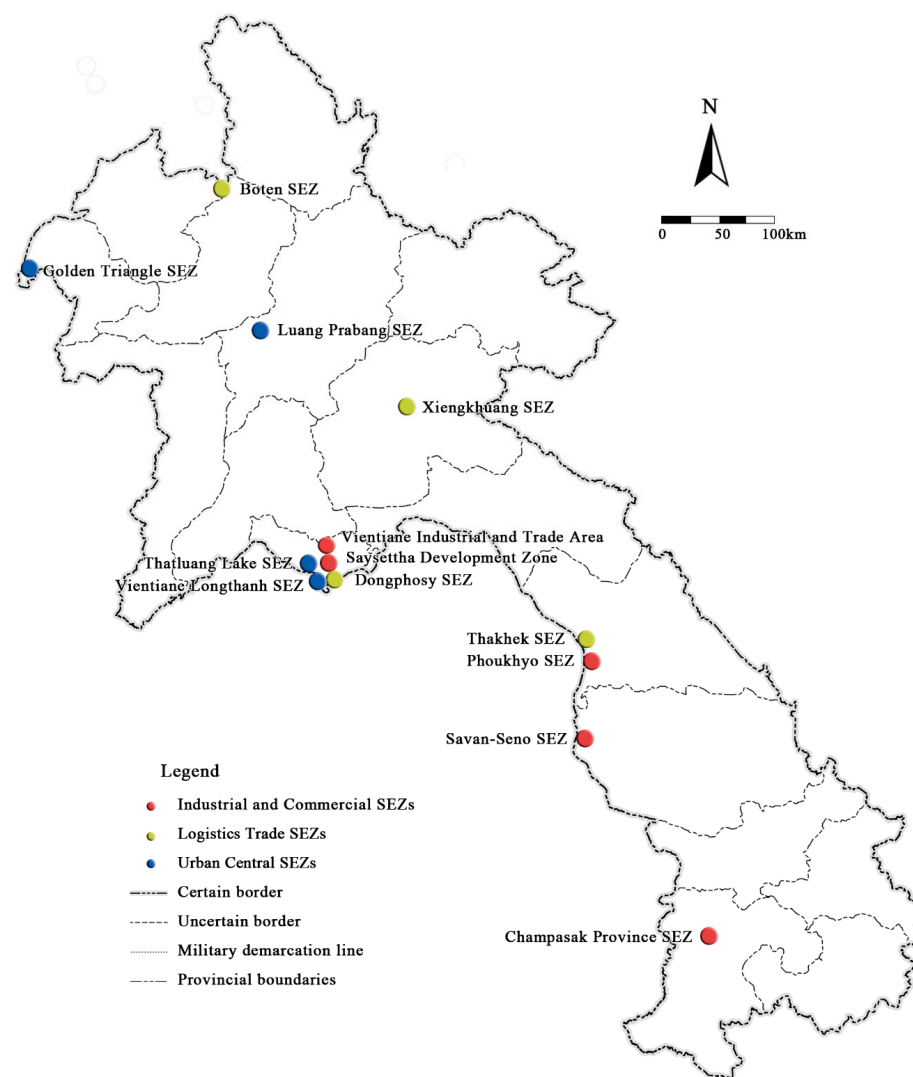


Figure 2. Spatial distribution of the SEZs in Laos.

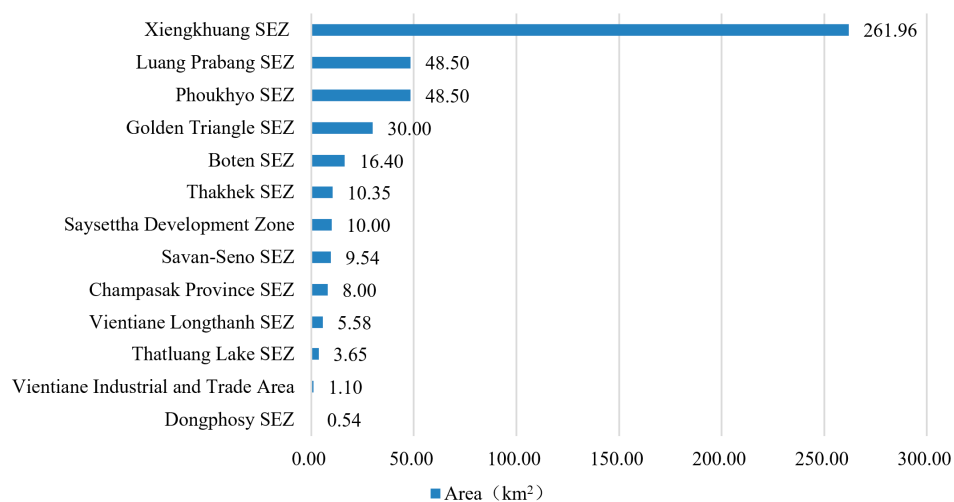


Figure 3. Area of the SEZs in Laos.

2.2. Data Sources

Google Earth is a virtual earth platform that can provide users with free high-resolution satellite images [40], so it has been widely used in land use/cover [41] research. Google has been actively updating its global image database, and currently, its image data within Laos have been updated to 2021. This study uses Google Earth to capture historical images and manually outlines the land use situation of the SEZs in Laos over the years. Manual interpretation is a key link in the mapping of this study, and the manual analysis of Google Earth images has already been used in existing studies [42,43]. In this study, each SEZ was divided into small units, and the fine images of each unit were downloaded and combined before manual interpretation was carried out. The various land types in the SEZs have strong regularity in terms of volume, color, and organization of the buildings. The researchers in charge of interpreting the images have conducted field investigations in various SEZs in Vientiane, Laos, and in industrial parks, development zones and SEZs in other countries and have accumulated knowledge of land feature identification in SEZs, which has helped increase the accuracy of the manual interpretation utilized in this study. For some areas where the specific land types are uncertain, we use the planning maps and official information issued by the SEZs to confirm the results of land use types.

We randomly sampled 450 pixels and used confusion matrices to conduct an accuracy assessment of the interpretation of land use types in the study area. Due to the impact of COVID-19, the inspection data of our test samples come from three sources. First, the data come from marking results compiled from a field survey conducted in 2019. Second, part of the inspection data were obtained with the assistance of the staff of the SEZ with whom we have established contacts. Third, we obtained the help of the Environment Research and Natural Disaster Prevention Division (EDPD) of the Public Works and Transport Institute (PTRI) under the Lao Ministry of Public Works and Transport (MPWT) and determined other sample land types based on the information they had. We compared the sample inspection data with the interpretation results of Google Earth imagery and established a confusion matrix to calculate the overall accuracy (OA). The OA is the ratio of the number of correctly classified samples to the number of all samples and is calculated as follows:

$$OA = \frac{1}{N} \sum_{i=1}^n x_{ii}$$

where n is the sample size, n is the total number of columns in the confusion matrix, and x_{ii} is the number of samples on the i -th row and column in the confusion matrix.

The OA of the land use type interpretation in this study is 93.78%, and the main errors come from two aspects. On the one hand, some industrial land was incorrectly classified as warehouse land. The main reason was that a small number of industrial enterprises had a high ratio of internal parking lot area to factory floor area, which made it difficult to accurately distinguish land types. On the other hand, part of the municipal utilities land was incorrectly classified as unused land. The main reason was that the images did not have time information, and the shading characteristics of municipal facilities in a few images were not obvious, which led to misjudgment.

The input and output data required for the evaluation of the land-use efficiency and the data required for the analysis of the influencing factors are mainly derived from the Laos Statistics Yearbook 2018 released by the Lao Statistics Bureau in 2019 and the official websites of the SEZs. In addition, due to the lack of publicly available financial expenditure data for Laos' SEZs in 2018, this study relies on 2017 fiscal expenditure data pertaining to the capital and provinces of Laos contained in the Public Expenditure and Financial Accountability (PEFA) Assessment 2018 issued by the World Bank.

2.3. Methods

2.3.1. Land-Use Dynamic Degree

Chen [44] and Wang [45] suggested that the land-use dynamic degree can be considered to quantify the change in comprehensive land use or a certain land type within the research area over a period of time. This study adopts the land-use dynamic degree to measure the magnitude of land-use changes in Laos' SEZs. The equation is as follows:

$$K = \frac{U_b - U_a}{U_a} \times \frac{1}{T} \times 100\% \quad (1)$$

where U_a and U_b are the areas of a certain land type at the beginning and end, respectively, of the study period, $U_b - U_a$ denotes the range of change, and T is the study period.

2.3.2. Information Entropy

Land-use expansion research based on RS and GIS technology usually examines construction land as a whole and cannot examine the internal structure of the land. To measure the uncertainty in the information content of a system, information entropy was proposed by American mathematician Shannon [46] based on information theory. By introducing information entropy into the study of land use structures, in-depth quantitative analysis of the structure of land use systems can be performed. Information entropy can reflect the number of elements of the land use system and reflect the order and diversity of the land use system in a certain area. Assuming that the total land area of a region is S , the region contains m land-use types, and the area of each land-use type is S_i , we have the following equation:

$$S = \sum_{i=1}^m S_i(1, 2, \dots, m) \quad (2)$$

where P_i is the proportion of land-use type i in the area, as expressed in Equation (3) below:

$$P_i = \frac{S_i}{S}, \quad \sum_i P_i = 1 \quad (3)$$

According to the principles of information theory and referring to the information entropy index, the information entropy equation of the land-use structure is as follows Equation (4):

$$H = - \sum_{i=1}^m P_i \ln P_i \quad (4)$$

where H is the information entropy (the natural logarithm is determined for the convenience of calculation), and the unit is Nat. Its value reflects the differentiation and degree of randomness in the land-use structure. According to the principle of the maximum and minimum entropy, when a given region occurs in the original state, $H_{\min} = 0$. When the region is mature and the land is completely balanced, $S_1 = S_2 = \dots = S_m = S/m$, and $H_{\max} = \ln m$. According to the above, the more land types and the smaller the area difference between the land types, the higher the orderliness of the land-use system and the higher the entropy value.

2.3.3. Super-Efficiency DEA Model

The super-efficiency DEA model is adopted to measure the land-use efficiency in Laos' SEZs. DEA was first proposed by Charnes et al. [47] in 1978 and is a relatively effective system analysis method for evaluating multi-input and multi-output decision-making units (DMUs). This method does not require any weight assumptions or dimensionless processing of data, so it is highly objective. The basic principle is to determine the production frontier with the help of a linear model and then determine the relative efficiency value of each DMU by comparing the degree of deviation of each DMU from the production frontier. The efficiency value is between 0 and 1. The larger the value, the higher the

efficiency, and vice versa. A value of 1 indicates that it is on the production frontier [48]. In the application of the DEA method, there are mainly two basic models, i.e., CCR (Charnes, Cooper and Rhodes) with fixed return to scale and BCC (Banker, Charnes and Cooper) with variable return to scale. However, in the analysis results of the above basic models, DMUs are usually evaluated in terms of their efficiency, and the maximum efficiency value is 1. As such, the efficiency of effective DMUs cannot be further distinguished. To solve this problem, Anderson et al. [49] proposed the super-efficiency DEA model, which generally results in more than 1 super-efficiency values of effective DMUs, and the efficiency values of effective DMUs can thus be distinguished and ranked [50]. The super-efficiency DEA model can distinguish the efficiency levels of high-efficiency DMUs and has been widely applied [51,52].

Suppose there are n DMUs. Each DMU has i types of inputs and s types of outputs. x_{ij} denotes the i -th resource input of the j -th DMU, and y_{sj} denotes the s -th output of the j -th DMU. In the input-oriented model, the super-efficiency DEA model of the j -th DMU is expressed as follows [31]:

$$\begin{aligned} \min & [\theta - \varepsilon (\sum_{i=1}^m s_i^- + \sum_{r=1}^s s_r^+)] \\ \text{s.t.} & \begin{cases} \sum_{j=1}^n X_{ij} \lambda_j + s_i^- = \theta X_0 \\ j \neq k \\ \sum_{j=1}^n Y_{sj} \lambda_j - s_r^+ = Y_0 \\ j \neq k \\ \lambda_j \geq 0, j = 1, 2, \dots, n, s_r^+ \geq 0, s_i^- \geq 0 \end{cases} \end{aligned} \quad (5)$$

where θ is the efficiency evaluation index, X and Y are the input and output variables, respectively, λ_j is the weight vector of the input and output in each region, n is the number of DMUs, and s_r^+ and s_i^- are slack variables.

Due to the limitation of the data availability, this study considers the cross-sectional data of Laos' SEZs in 2018 in the land-use efficiency evaluation. A land-use efficiency measurement model is constructed by adopting the area of developed land and the amount of investment as input indicators and adopting the taxation amount, import and export trade volumes and employment levels in the SEZs as output indicators in the land-use process of SEZs. This study calculates the super technical efficiency (STE), technical efficiency (TE), pure technical efficiency (PTE) and scale efficiency (SE) of each SEZ.

2.3.4. Gray Relational Analysis (GRA)

The influencing factors of the land-use efficiency in Laos' SEZs were studied via GRA. The theory of GRA, proposed by Deng [53] in 1982, is mainly employed to analyze the similarity or difference in the development trend between factors in a gray system, which is an important method to measure the degree of close correlation between factors. The higher the gray correlation is, the greater the impact of the influencing index on the land-use efficiency, and vice versa. The calculation steps are as follows:

1. Determination of reference and comparison sequences. The reference sequence is an ideal comparison standard that comprises either the optimal or inferior values of each indicator; other reference values can also be selected for evaluation purposes, which are usually expressed as x_0 .
2. Dimensionless processing of index data. To ensure the equivalence and the same sequence between the chosen factors, the reference and original sequences should be standardized to yield dimensionless sequences, and the mean method is selected

for processing. $x_i(k)$ denotes the k -th sample of the i -th index, and the equation is as follows:

$$x'_i(k) = \frac{x_i(k)}{\bar{x}_i} \quad (6)$$

3. One-by-one calculation of the absolute difference between the comparison and reference sequences.

$$\Delta_i(k) = |x'_0(k) - x'_i(k)|$$

4. Calculation of the relational coefficient. The relational coefficient between each comparison sequence and each reference sequence is calculated separately. ρ is the resolution coefficient, and the value interval is (0, 1), while the general ρ value is 0.50.

$$\gamma(x_0(k), x_i(k)) = \frac{\min_j \min_k \Delta_i(k) + \rho \max_j \max_k \Delta_i(k)}{\Delta_i(k) + \rho \max_j \max_k \Delta_i(k)} \quad (7)$$

5. Calculation of the gray relational degree. For each evaluation object (comparison sequence), the mean value of the relational coefficient between each index and each reference sequence is calculated to reflect the relational degree of each evaluation object and each reference sequence, after which the indices are sorted. The specific equation is as follows:

$$\gamma(x_0, x_i) = \frac{1}{n} \sum_{k=1}^n \gamma(x_0(k), x_i(k)) \quad (8)$$

Figure 4 shows the analytical framework in this study.

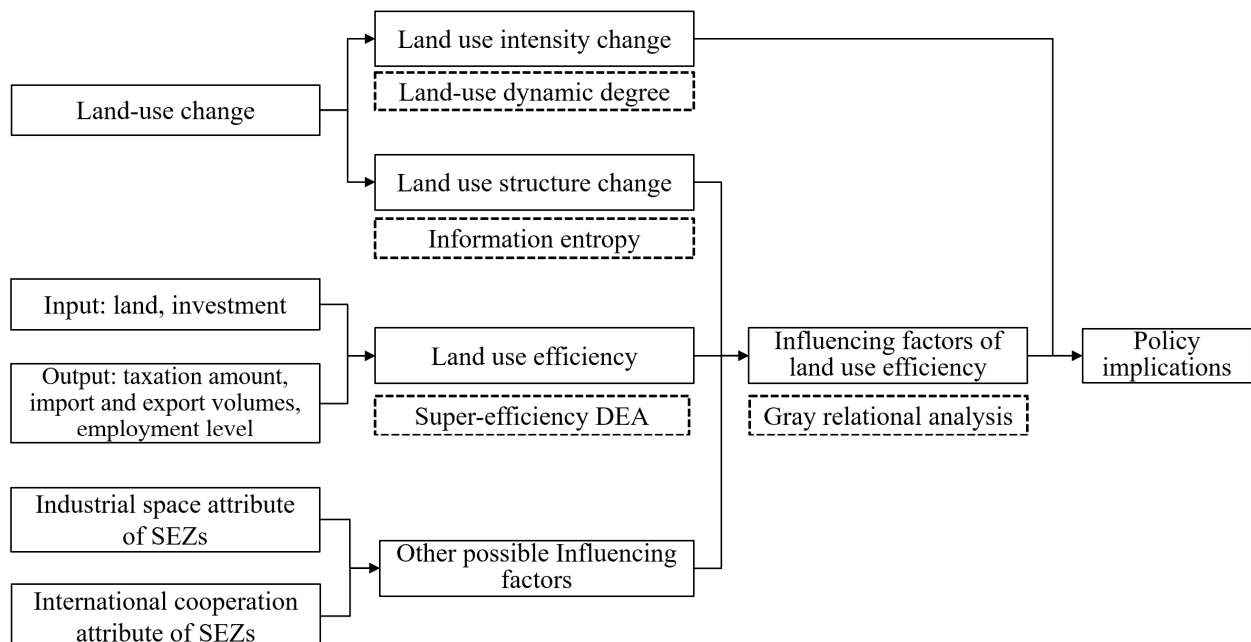


Figure 4. Analytical framework.

3. Results

3.1. Comprehensive Land-Use Changes in Laos' SEZs

During the study period, the total land-use area of Laos' SEZs continued to increase from 4.83 km² in 2014 to 13.37 km² in 2020, with a net increase of 8.54 km² and an average annual growth rate of 29.45%. This study further analyzes the comprehensive land-use dynamic degree in each SEZ from 2014 to 2020 and selects 2016, 2018, and 2020 as the

research cross-sections. Based on the results of the comprehensive land-use dynamic degree (Table 1), this study uses GIS to divide the land-use intensity changes of the SEZs into three categories, i.e., high intensity, medium intensity, and low intensity, according to the natural break method. Those whose land-use dynamic degree is above 61.8800% belong to the high-intensity type, those within the range of 16.8101–61.8800% belong to the medium-intensity type, and those below 16.8101% belong to the low-intensity type.

Table 1. Comprehensive land-use dynamic degree in Laos' SEZs (unit: %).

SEZ	2014–2020	2014–2016	2016–2018	2018–2020
Savan-Seno SEZ	15.86	23.13	13.69	2.38
Vientiane Industrial and Trade Area	32.06	40.93	9.83	17.17
Saysettha Development Zone	253.77	301.29	9.18	47.56
Phoukhyo SEZ	61.88	61.34	55.83	0
Boten SEZ	/	/	27.33	25.06
Dongphosy SEZ	/	/	1.87	0
Thakhek SEZ	4.42	1.96	10.27	0.51
Golden Triangle SEZ	26.49	9.06	20.97	27.22
Thatluang Lake SEZ	24.88	27.04	15.53	11.72
Vientiane Longthanh SEZ	16.81	49.83	0.00	0.29

Only the land-use intensity change in the Saysettha Development Zone is of the high-intensity type. The land-use dynamic degree in the Saysettha Development Zone during the study period reached as high as 253.77%, and the intensity change exhibited a V-shaped characteristic. From 2014 to 2016, the Saysettha Development Zone focused on early infrastructure construction, and land utilization progressed relatively fast. From 2016 to 2018, based on the area amounting to 400 ha that achieved three supply goals and one leveling goal (supply of water, electricity and road and ground leveling), the development zone changed its focus from land development to enterprise investment attraction to maintain a financial balance, and the land use progress decelerated. After 2018, the construction of factories and infrastructure construction in the development zone were promoted simultaneously.

Most SEZs, such as the Phoukhyo SEZ, Vientiane Industrial and Trade Area, Boten SEZ, Golden Triangle SEZ, and Thatluang Lake SEZ, belong to the medium-intensity type. Among these SEZs, the land-use dynamic degree of the Phoukhyo SEZ remained above 50% before 2018, but land development was suspended from 2018–2020, which was related to the slow progress of investment attraction. The land use in the Vientiane Industrial and Trade Area exhibited a V-shaped intensity change. The industrial land development area in the Vientiane Industrial and Trade Area remained relatively small from 2016 to 2018, which was consistent with the trend whereby both the number of FDIs and the number of foreign enterprises attracted in Laos revealed a trough in 2016.

The Vientiane Longthanh SEZ, Savan-Seno SEZ, Dongphosy SEZ and Thakhek SEZ belong to the low-intensity type. Among them, the development of the Vientiane Longthanh SEZ and that of the Savan-Seno SEZ entered mature periods. The land-use dynamic degree of the Savan-Seno SEZ declined significantly between 2018 and 2020. In the Vientiane Longthanh SEZ, the development of leisure and entertainment facilities was basically completed in 2016 and then only a limited number of resort residence facilities and other supporting facilities were added. The Thakhek SEZ and the Dongphosy SEZ are experiencing relatively slow development progress, but the Thakhek SEZ remains under continuous development. The Dongphosy SEZ realized no progress other than small-scale development from 2016–2018. The reason is that the Malaysian developer and Chinese general contractor are involved in an equity dispute, which caused the construction of the SEZ to be suspended.

3.2. Land-Use Structure Change

From 2014 to 2020, the proportion of land used for production systems, such as industrial land and warehouse land, in Laos' SEZs increased the most. The proportion of land used for infrastructure, such as transportation land and municipal utilities land, decreased notably. The land used for living systems, such as public facilities land, residential land and administrative land, exhibited a limited decline (Figure 5). In terms of the land-use structure in Laos' SEZs, the proportion of transportation land, industrial land and public facilities land exceeded 25%. During the study period, transportation land always dominated, accounting for 28.40–35.72% of all land-use types. The proportion of industrial land increased from 11.91% to 25.08%. The proportions of administrative land, municipal utilities land and warehouse land were all relatively low, accounting for 2.23–3.55%, 1.43–3.25%, and 0.13–1.58%, respectively, of all land-use types (Table 2).

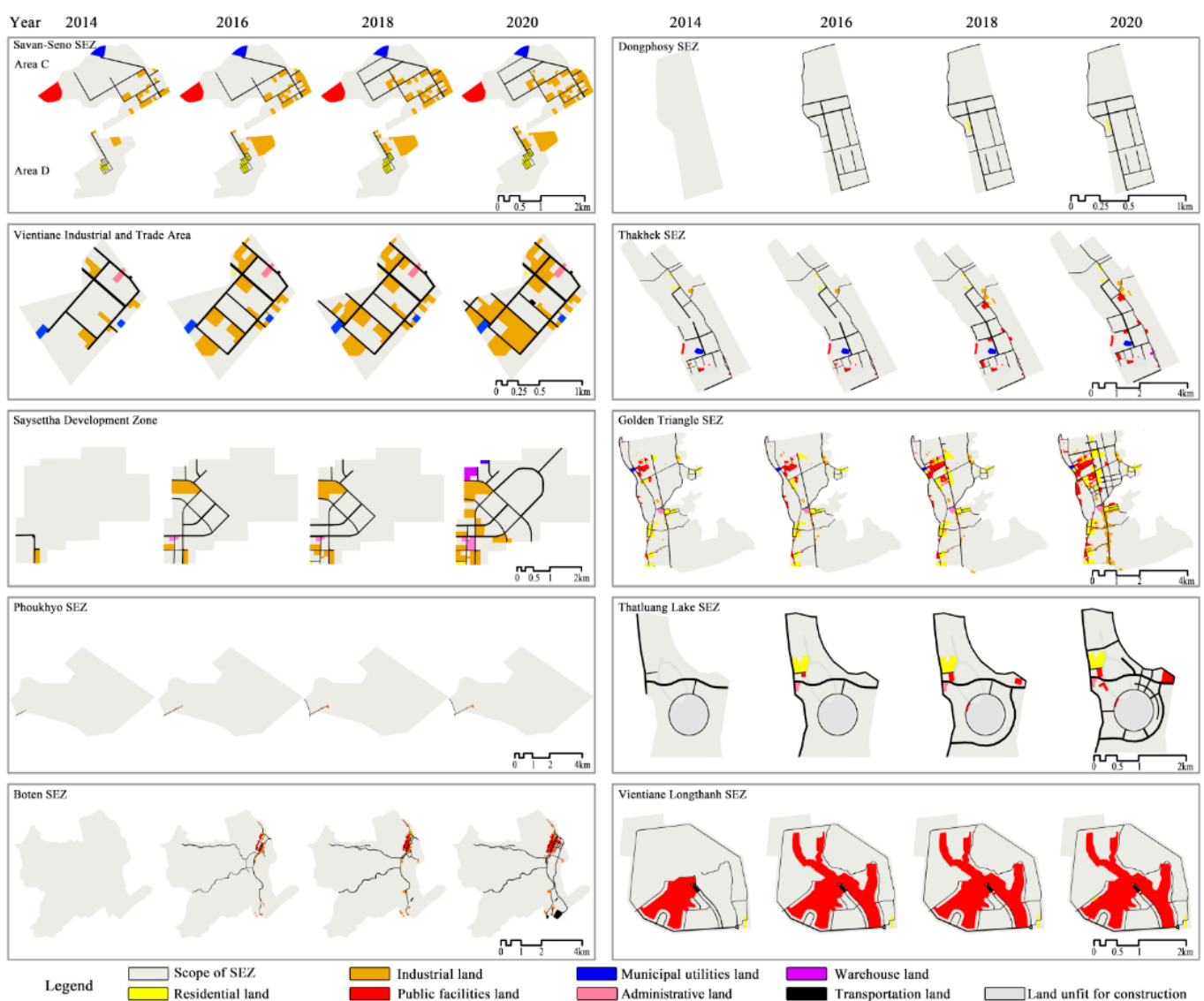


Figure 5. Evolution of the land-use structure in Laos' SEZs. The development rates in Zones A and B of the Savan-Seno SEZ are low, and the evolution of the land-use structure is not obvious, so the data are not shown in the figure.

Table 2. Land-use structure types in Laos' SEZs from 2014 to 2020 (unit: %).

Time (Year)	2014	2015	2016	2017	2018	2019	2020
Administrative land	3.54	3.55	2.98	2.74	2.51	2.42	2.23
Public facilities land	25.97	24.27	28.77	28.08	27.78	26.88	25.03
Residential land	19.33	17.94	15.52	16.76	18.23	17.10	16.24
Industrial land	11.91	16.14	18.88	20.38	19.76	22.04	25.08
Transportation land	35.72	34.85	31.65	30.01	29.99	29.35	28.40
Municipal utilities land	3.25	3.00	2.04	1.87	1.61	1.67	1.43
Warehouse land	0.27	0.25	0.17	0.15	0.13	0.55	1.58

During the study period, the information entropy of the land-use structure types in Laos' SEZs revealed an initial downward and then an upward trend, with the highest information entropy value reaching 1.557 Nat in 2020 (Figure 6). Based on the overall evolution process of the information entropy, it is determined that the SEZs in Laos have experienced an orderly–disorderly–stable land-use structure evolution process. Since 2018, the information entropy value has continuously increased from 1.517 to 1.557 Nat at the end of the period, indicating that the order of the land-use structure and the diversity and complexity in land use in Laos' SEZs were continuously enhanced from 2018 to 2020. In addition, Figure 6 shows that the growth rate of the total area and the information entropy of the SEZs during the study period exhibited an opposite trend (Figure 6), which also indicates that newly added SEZ land-use area is the main reason for the change in the information entropy of the land structure. From 2014 to 2019, the growth rate of the land-use area in the SEZs increased, causing a decline in information entropy. By 2020, a turning point occurred, and the land-use area rate and the information entropy changes exhibit common upward trends.

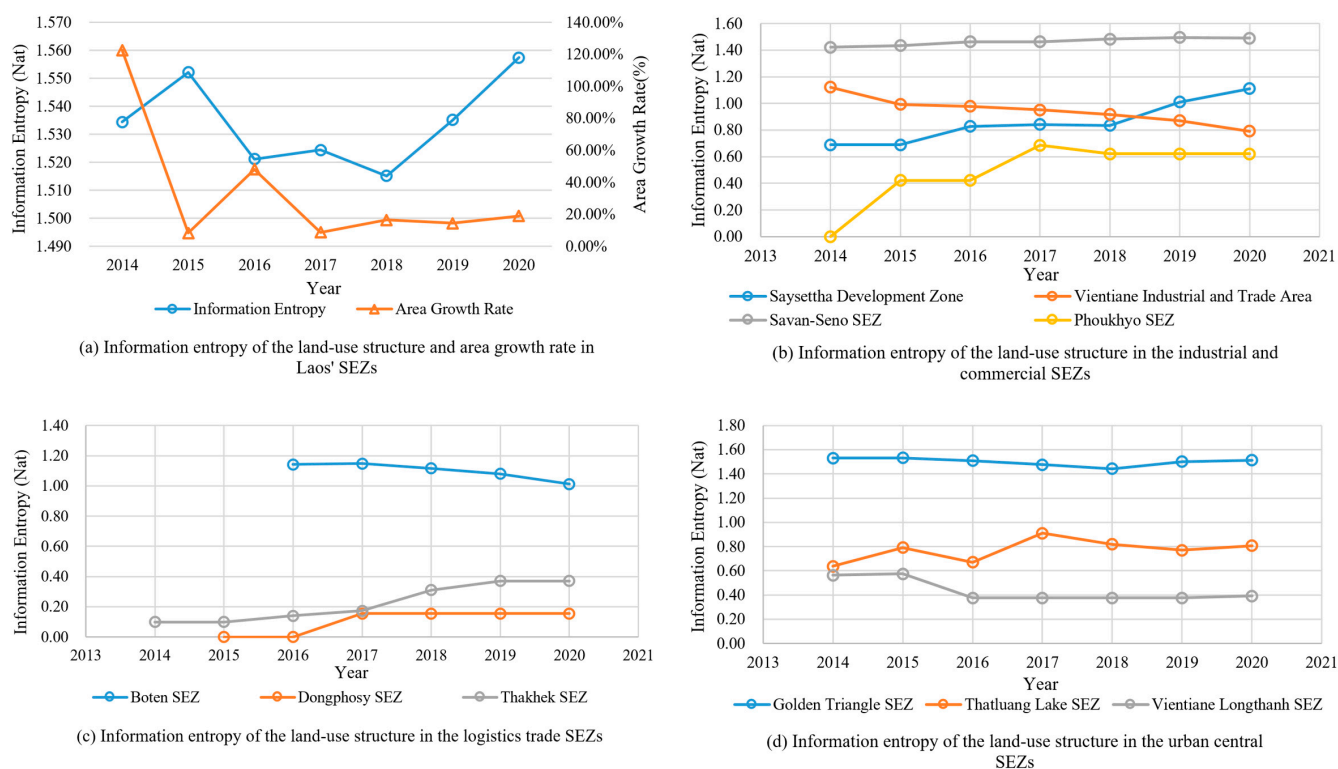


Figure 6. Annual change in the information entropy of the land-use structure in Laos' SEZs from 2014 to 2020. (a) Information entropy of the land-use structure and area growth rate in Laos' SEZs, (b) information entropy of the land-use structure in the industrial and commercial SEZs, (c) information entropy of the land-use structure in the logistics trade SEZs, and (d) information entropy of the land-use structure in the urban central SEZs.

In this study, the information entropy of the land-use structure in each SEZ is divided into high-value intervals (above 1.2 Nat), medium-value intervals (0.6–1.2 Nat) and low-value intervals (below 0.6 Nat). Overall, half of the SEZs are in the high- and medium-value intervals, and half are in the low-value interval. Among these SEZs, industrial and commercial SEZs are in high- and medium-value intervals. The information entropy of the land-use structure in the three large-scale SEZs indicates an upward trend. Due to the positioning of the Vientiane Industrial and Trade Area as a small-scale professional industrial park, the newly increased land-use area largely includes industrial land, and the information entropy of the land-use structure continues to decrease.

The entropy information of the land-use structure in the logistics trade SEZs is quite different. Only the Boten SEZ, which is at the initial stage of development, remains in the medium-value interval. Due to its large-scale preliminary infrastructure construction, the information entropy of the land-use structure in the Boten SEZ continues to decline. The other two logistics trade SEZs are in the low-value interval.

Among the urban central SEZs, the land structures in the SEZs are highly different in terms of their orderliness. Upon diversification of industrial development and land use in the Golden Triangle SEZ, the information entropy of the land-use structure is in the high-value interval. Because its land use has entered an adjustment period, the entropy value fluctuates little. The land-use structure information entropy values of the Thatluang Lake SEZ and the Vientiane Longthanh SEZ are similar, with that of the Thatluang Lake SEZ fluctuating in the medium-value interval and that of the Vientiane Longthanh SEZ stably occurring in the low-value interval after 2016.

3.3. Land-Use Efficiency and Its Influencing Factors

Calculated with the traditional DEA model, the average TE value of each SEZ in 2018 was 0.644, and the overall efficiency was not high. Among them, SEZs with efficiency values above and below the average level each accounted for 50% of all SEZs. The SEZs with effective DEA (TE = 1.000) in 2018 included the Savan-Seno SEZ, Vientiane Industrial and Trade Area, Dongphosy SEZ, and Golden Triangle SEZ, indicating that these four SEZs attained a relatively optimal land-use efficiency (Table 3). The TE values of both the Phoukhyo and Thatluang Lake SEZs in Laos were lower than 0.1, and the land-use efficiency was low. To further compare the land-use efficiency between the four relatively optimal SEZs, this study applied the super-efficiency DEA model in the analysis and determine that the STE value in 2018 in descending order was that of the Savan-Seno SEZ, Vientiane Industrial and Trade Area, Dongphosy SEZ, and Golden Triangle SEZ. The relative non-DEA effective comprehensive efficiency values of the remaining SEZs remain unchanged (Table 4).

Table 3. Evaluation results of the land-use efficiency in Laos' SEZs in 2018.

SEZ	TE	PTE	SE ¹	RTS ²
Savan-Seno SEZ	1.000	1.000	1.000	-
Vientiane Industrial and Trade Area	1.000	1.000	1.000	-
Saysettha Development Zone	0.408	0.441	0.925	irs
Phoukhyo SEZ	0.058	1.000	0.058	irs
Boten SEZ	0.623	0.782	0.797	drs
Dongphosy SEZ	1.000	1.000	1.000	-
Thakhek SEZ	0.895	0.915	0.978	irs
Golden Triangle SEZ	1.000	1.000	1.000	-
Thatluang Lake SEZ	0.066	0.147	0.448	irs
Vientiane Longthanh SEZ	0.389	0.454	0.857	irs
Mean	0.644	0.774	0.806	-

¹ SE = TE/PTE. ² Drs, irs and “-” denote diminishing returns to scale, increasing returns to scale and constant returns to scale, respectively.

Table 4. Comparison of the TE and STE results of the land use in Laos' SEZs.

SEZ	TE	Ranking	STE	Ranking
Savan-Seno SEZ	1.000	1	15.757	1
Vientiane Industrial and Trade Area	1.000	1	1.480	2
Saysettha Development Zone	0.408	7	0.408	7
Phoukhyo SEZ	0.058	10	0.058	10
Boten SEZ	0.623	6	0.623	6
Dongphosy SEZ	1.000	1	1.308	3
Thakhek SEZ	0.895	5	0.895	5
Golden Triangle SEZ	1.000	1	1.252	4
Thatluang Lake SEZ	0.066	9	0.066	9
Vientiane Longthanh SEZ	0.389	8	0.389	8

The average PTE value of the SEZs in Laos is 0.774, and the overall PTE value is high (Table 3). Similar to the TE, the Savan-Seno SEZ, Vientiane Industrial and Trade Area, Dongphosy SEZ, and Golden Triangle SEZ attained the highest PTE values, indicating that these four SEZs are the most efficient in terms of resource utilization against the Lao economic and social background. The PTE value is higher than the average level in the Boten and Thakhek SEZs, while the PTE value of the Thatluang Lake SEZ is lower than 0.2. In terms of SE, the average SE value of the SEZs in Laos is 0.806, and the overall level is relatively high. Among them, the SE value of the Savan-Seno SEZ, Vientiane Industrial and Trade Area, Dongphosy SEZ, and Golden Triangle SEZ is 1 with constant returns to scale, indicating that these four SEZs have high land intensity and moderate development scale at present. The increasing returns to scale in the Phoukhyo and Thatluang Lake SEZs indicate that the low TE value is affected by the scale of development and investment, so it is necessary to fully manifest the benefits of scale in future development and construction.

This study applies GRA to quantitatively measure the influencing factors of the land-use efficiency in Laos' SEZs in 2018. Considering the availability of data, this study selects eight factors that reflect the basic attributes of the industrial space and the attributes of international cooperation of Laos' SEZs for discussion. In this study, the gray relational degree between each factor and the land-use efficiency in Laos' SEZs was found to be higher than 0.6, indicating a significant correlation [54]. According to the results (Table 5), the factors are ranked as follows: age of the SEZ > local actual aggregate expenditure > information entropy of the land-use structure > country of the development subject > foreign equity ratio of the development subject > distance to the nearest city center > building density within a 200 m buffer zone > border SEZ status.

Table 5. Gray relational degree between the land-use efficiency and various factors in Laos' SEZs in 2018.

Attribute	Influencing Factor	Gray Relational Degree	Ranking
Attributes of the industrial space	Local actual aggregate expenditure	0.809110	2
	Age of the SEZ	0.818071	1
	Border SEZ status	0.745616	8
	Distance to the nearest city center	0.796122	6
	Building density within a 200 m buffer zone	0.793097	7
	Information entropy of the land-use structure	0.806645	3
Attributes of international cooperation	Foreign equity ratio of the development subject	0.799730	5
	Country of the development subject	0.803279	4

The age of the SEZs and land-use efficiency attain the highest gray correlation, indicating that the development stages of the SEZs in Laos are obviously different. The initial investment costs of the SEZs are high, it is difficult for the development subjects to achieve a payment balance, and economic and social benefits have not yet been manifested. After entering the mature period, the SEZs can maintain relatively stable income and high tax contribution levels to the host country. In addition, the actual local aggregate expenditure,

information entropy of the land-use structure, country of the development subject and foreign equity ratio of the development subject each attain a high relational degree with the land-use efficiency. This indicates that the land-use efficiency in Laos' SEZs is affected by the support level of the local infrastructure and its own land-use structure. This also suggests that Laos possesses immature SEZ development experience. Moreover, the level of domestic investment is not high [18,55], and the enterprises settling in the SEZs are mainly foreign-funded enterprises. Because of the cultural similarity and policy encouragement of the investing country, the settled enterprises and the development subjects in the SEZs often establish a strong geographic relationship. Therefore, the openness of the international market and the strength and internationalization experience of the development subjects are all important factors influencing the land-use efficiency. The factors related to the location of the SEZs and the surrounding environment also achieve a certain correlation with the land-use efficiency in Laos' SEZs. This occurs because the location conditions of the SEZs and the surrounding environment determine the levels of supporting facilities and the development environment that can be relied on during SEZ construction. For example, due to the relatively low basic conditions and the severe social security situation in the border areas, the land-use efficiency in SEZs is restricted to a certain extent. This also demonstrates whether there are potential problems such as social conflicts and land disputes that can affect the land-use efficiency in SEZs.

4. Discussion

This study found that the total land-use area in Laos' SEZs continuously increased during the study period, and the land use in most SEZs maintained medium-intensity changes. As a result of tax incentives and infrastructure improvement, the attractiveness of Laos' SEZs to foreign investment has been increasing year by year [56], especially among foreign enterprises from China, Thailand, Vietnam and Japan, which has effectively contributed to the growth of land development area within the SEZs. In nearly 20 years of exploring the construction of SEZs in Laos, to promote the standardized construction and sustainable development of SEZs, Laos passed laws on SEZs and specific economic zones in 2010. Laos has also established the Lao National Committee for SEZs (NCSEZ) [57] as a specialized agency for the overall management of the development and construction of Laos' SEZs and has improved business convenience through measures such as providing one-stop services [58] for SEZs. In 2016, the revised Law on Investment Promotion abolished the strict registered capital requirements for starting companies and further liberalized Laos' domestic and foreign investment. The upgrading of the relevant management system and legal framework of the SEZ has ensured the stable development and sustainable land development of Laos' SEZs.

The construction of SEZs is a process of continuous exploration [59]. This study found that the information entropy of the land-use structure in Laos' SEZs revealed an initial downward and then an upward trend. This shows that the land-use structure in Laos' SEZs has undergone an orderly-disorderly-stable evolution process. During the preparatory and exploratory period, the construction of the Laos' SEZs faced problems, such as the lack of a national-level strategic route, a weak legal framework [60] and a poor management system. Although the number of SEZs has grown rapidly, the development progress often remains in the areas of land clearing and infrastructure construction. Laos provided insufficient support for the introduction of foreign manufacturing enterprises during this period [57], and some SEZs were even approved to give priority to entertainment industry development [61], causing an imbalance in the land-use structure of Laos' SEZs. After entering the development period, most of the SEZs put into operation passed the stage of investing heavily in infrastructure construction and began to continuously introduce enterprises and promote industrial land development; in addition, a small number of SEZs had difficulty breaking through the bottleneck of insufficient funds or difficulty attracting foreign investment, resulting in stagnant development. Overall, the land-use structure of Laos' SEZs tended to stabilize.

From the perspective of land-use efficiency in SEZs, this study found that the land-use efficiency in the Savan-Seno SEZ, Vientiane Industrial and Trade Area, Dongphosy SEZ, and Golden Triangle SEZ was relatively optimal. This is related to the fact that the four SEZs are all at a mature stage of development. The Savan-Seno SEZ was established the earliest and has maintained a stable tax contribution to the government. The FTZs and offshore financial centers in the SEZ have greatly promoted import and export trade. The high efficiency of the Vientiane Industrial and Trade Area benefited from the mature international experience of the development subjects. The construction of the SEZ and the progress of the enterprise introduction are closely matched, and its economic and social benefits are outstanding. The Dongphosy SEZ has a small area, and the output value per unit of land and capital cost is relatively high. The Golden Triangle SEZ takes service and tourism as its leading industries; this SEZ not only contributes a large amount of tax revenue to the local area but also provides a large number of jobs with high overall efficiency. The study of Alay et al. [62] supports some of the results of this study. They pointed out that the investment in Laos' SEZs is unevenly distributed, and that the Savan-Seno SEZ, Vientiane Industrial and Trade Area, and Golden Triangle SEZ are the three SEZs with high investment density in Laos. Additionally, we also found that the land-use efficiency in Laos's SEZs is impacted by the general factors of the industrial space and specific factors, such as the internationalization of the development subjects (Figure 7). Existing studies [63,64] have confirmed that location, type and development stage are important factors affecting land use in SEZs. Combined with the actual situation in Laos' SEZs, frequent social conflicts and land conflicts [65] also affect land-use efficiency. As Laos lacks SEZ development experience and the government's financial resources are limited, the most common investment and development model is the joint venture model between the Lao government and foreign companies at the expense of funds or land. The proportion of SEZs wholly owned by foreign companies is also relatively high. Only a few SEZs are developed by Lao companies or private individuals. The international experience, financial strength and investment capacity differences between the development subjects can affect the land-use efficiency.

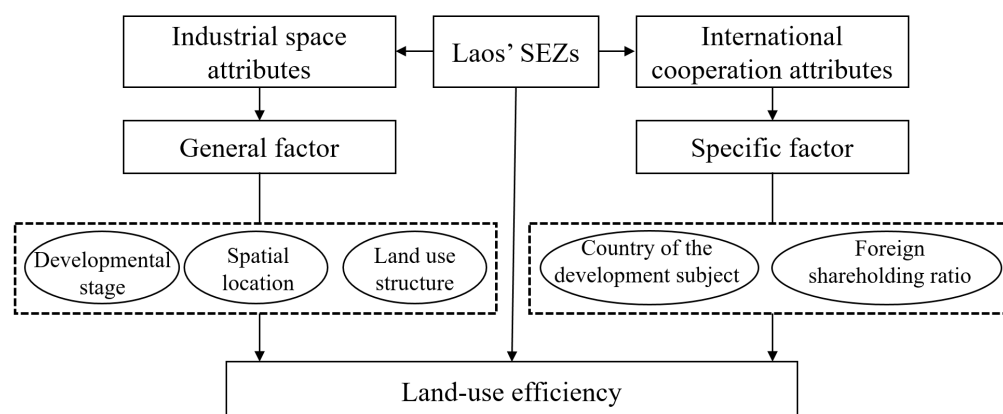


Figure 7. Land-use impact mechanism of Laos' SEZs.

Currently, many countries have established SEZs, and SEZs have been proven to be effective means to promote economic development in many developing countries. As one of the world's least developed countries (LDCs), Laos entered the global SEZ market later than other Mekong countries [66], such as Thailand. The development of SEZs in Laos is greatly dependent on foreign capital. Our study emphasizes the impact of international cooperation on land use in Laos' SEZs, which will help in understanding the development stage of Laos' SEZs. Additionally, our research also provides a case from an LDC for studying land-use in SEZs. With Laos' strategy of turning a land-locked country into a land-unified country and the upcoming operation of the China-Laos railway, the construction of SEZs and industrialization of Laos will usher in new development. This study can also

provide a reference for the formulation of policies and plans for the new round of SEZ construction in Laos. However, this study suffers from several limitations. First, due to the limitations of publicly available data, this study did not reveal the characteristics of changes in land-use efficiency in Laos' SEZs. Second, the factors affecting the efficiency of land development in the SEZs where land clearing is taking place in Laos have not been analyzed. Future studies are needed to conduct comprehensive field surveys in various SEZs in Laos and to interview relevant personnel to further reveal and verify the influencing factors and mechanism of land-use efficiency.

5. Conclusions

This study applies methods such as the land-use dynamic degree, information entropy, the super-efficiency DEA model and GRA to analyze the intensity and structural evolution of land use in Laos' SEZs, as well as the land-use efficiency. The study reveals that the total land-use area in Laos' SEZs has continuously increased from 2014 to 2020, at an average annual growth rate of 29.45%. The changes in the land-use intensity in the SEZs can be divided into three types, i.e., high intensity, medium intensity and low intensity, and most SEZs belong to the medium-intensity type. From 2014 to 2020, the proportion of land used in production systems, such as industrial land and warehouse land, in Laos' SEZs increased the most, and the proportion of land used for infrastructure, such as transportation land and municipal facilities land, declined notably. The overall information entropy of the land-use structure exhibited an initial downward and then an upward trend. In 2018, the Savan-Seno SEZ, Vientiane Industrial and Trade Area, Dongphosy SEZ, and Golden Triangle SEZ had relatively optimal the land-use efficiency. The basic factors of the industrial space and the factors reflecting the attributes of international cooperation were closely related to the land-use efficiency in the SEZs.

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