Assessment of Industrial Areas in Terms of Plan Sustainability through GIS and AHP Integration: The Case of Trabzon

Fatih Terzi [1], Bura Adem Atasoy [2], Bayram Uzun [2], Volkan Yıldırım [2,3], Furkan Aslan [2], Semih Uzun [1]

[1] Graduate School of Natural and Applied Sciences, Karadeniz Technical University, Trabzon, Türkiye
– fatihterzi@ktu.edu.tr; semihuzun8@gmail.com
[2] Karadeniz Technical University, Faculty of Engineering, Department of Geomatics Engineering, 61080 Ortahisar/Trabzon, Türkiye
–bugratasoy@ktu.edu.tr; buzun@ktu.edu.tr; yvolkan@ktu.edu.tr; furkanaslan126@gmail.com
[3] GISLAND Informatics Trade Limited Company, Trabzon Technology Development Zone, Trabzon 61080, Türkiye
–yvolkan@ktu.edu.tr

Abstract

This study aims to identify the most suitable locations for large-scale industrial facilities in the districts of Yomra, Arsin, Araklı, Sürmene, and Köprübaşı in Trabzon Province. Eight physical, infrastructural, and environmental criteria, determined through a literature review and consultations with local experts, were weighted using the Analytical Hierarchy Process (AHP) method. The criteria were selected based on their frequency of use in previous studies and the availability of data. The obtained weights were integrated into a raster analysis process within the Geographic Information Systems (GIS) environment. The data were converted into raster format with a 10-meter resolution in the TUREF/TM33 coordinate system, reclassified, and analyzed through a weighted overlay method. As a result of the analysis, areas classified as "high" and "very high" suitability were identified as potential industrial zones, and these areas were compared with existing zoning plan decisions to evaluate the sustainability of the plans. The resulting suitability map provides an original output that can serve as a decision-support tool in the industrial area planning of Trabzon.

Keywords: Geographic Information Systems (GIS), Analytical Hierarchy Process (AHP), Site Selection, Industrial Facilities.

1. Introduction

In the manufacturing or service sector, site selection is among the foremost strategic priorities during the establishment process. Correctly determining the initial location plays a major role in preventing potential problems that may arise in the later stages of the facility's operation (Kayadelen, 2021). Selecting an appropriate site is one of the most fundamental and indispensable issues for a new enterprise to initiate its activities and sustain them with maximum efficiency (Terme et al., 2022). Location decisions directly affect the costs and revenues of the facility; an incorrect choice may lead to increased transportation expenses, difficulties in workforce supply, loss of competitive advantage, and disruptions in the supply chain (Nacar and Erdebilli, 2021). Therefore, site selection is not only an economic issue but also a long-term planning process with spatial, environmental, and socio-economic dimensions (Kanbak, 2013).

The positioning of industrial areas is likewise of critical importance in terms of urban and regional planning. Appropriate site selection ensures a balance among the social, economic, and environmental impacts of industrialization. The literature emphasizes that topography, protected areas, transportation infrastructure, settlements, natural resources, and environmental constraints must be evaluated together; otherwise, unplanned development may lead to environmental pollution, efficiency loss, and sustainability problems (Fataei et al., 2015; Khavarian-Garmsir and Rezaei, 2015). In this context, the proper siting of industrial zones is considered essential for reducing land-use pressures, protecting agricultural areas and natural ecosystems, and simultaneously supporting economic growth (Hadipour and Kishani, 2014).

Since industrial site selection requires the evaluation of numerous, often conflicting criteria, multi-criteria decision-making methods integrated with Geographic Information Systems (GIS) are widely used. Studies emphasize that methods such as the Analytical Hierarchy Process (AHP), fuzzy logic, index overlay, and genetic algorithms are effective in processing spatial data and determining criterion weights; moreover, by overlaying different data layers within the GIS environment, these techniques provide powerful decision-support tools for identifying the most suitable areas (Ebadi et al., 2004; Khavarian-Garmsir and Rezaei, 2015; Hadipour and Kishani, 2014).

In the literature, numerous studies have applied GIS-based multi-criteria decision-making methods for industrial site selection in different geographic regions. The criteria used in these studies and their frequencies of occurrence were compiled through a systematic literature review, standardized, and presented in Table 1. By indicating which criteria were included in the reviewed studies and their frequencies, the table directly provides a basis for the selection of the criterion set to be used in the methodology section of this research.

However, in the case of Trabzon Province, no suitability analysis has been conducted that utilizes available spatial data and a comprehensive set of criteria to serve as a basis for zoning plans and to be comparatively evaluated with existing planning decisions. Although the need for new industrial areas in Trabzon is recognized, a definitive decision regarding their location has not yet been made. This situation creates a critical planning requirement in terms of balancing economic development with environmental and social sustainability.

In this study, a GIS-based multi-criteria suitability analysis was conducted for Trabzon Province. The analysis results were compared with existing zoning plans to assess the extent to which the designated areas aligned with the determined suitability levels. In this way, a scientific basis was provided for regional planning processes, and the effectiveness of zoning plans in terms of spatial suitability was revealed.

Criterion	Al-Rawabdeh et al., 2021	Kamali et al., 2017	Rikalovic et al., 2017	Rikalovic et al., 2015	Khavarian-Garmsir and Rezaei, 2015	Alzamili et al., 2015	Fataei et al., 2015	Hadipour and Kishani, 2014	Sahnoun et al., 2012	Reisi et al., 2011	Ebadi et al., 2004
Transportation	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Land use	–	✓	–	–	✓	✓	✓	✓	✓	✓	✓
Water resources / supply	–	✓	–	✓	✓	✓	✓	✓	✓	✓	✓
Urban centers / settlements	✓	–	–	✓	✓	✓	✓	✓	✓	✓	✓
Slope	✓	✓	–	–	✓	✓	✓	✓	–	✓	✓
Environment / protected areas	✓	–	✓	✓	✓	✓	–	✓	✓	✓	–
Energy supply	✓	✓	✓	✓	–	–	–	✓	✓	–	✓
Rivers / surface water	✓	–	–	–	✓	✓	✓	✓	✓	✓	✓
Fault distance	–	✓	–	–	✓	–	✓	–	–	✓	–
Education	–	✓	✓	✓	–	–	–	–	–	–	✓
Raw materials	–	✓	✓	✓	–	✓	–	–	✓	–	–
Local labor force	–	✓	✓	✓	–	–	–	–	–	–	–
Healthcare services	✓	–	–	✓	–	–	–	–	–	–	✓
Railway station	✓	–	✓	✓	✓	✓	–	–	–	✓	✓
Land cost	–	–	✓	✓	–	–	–	–	✓	–	–
Land availability / vacant land	✓	–	✓	✓	–	–	–	–	✓	–	–
Distance to other industries	–	–	–	✓	–	–	–	✓	✓	✓	–
Gas supply	–	✓	–	–	–	✓	–	–	–	–	✓
Geology	–	✓	–	–	–	–	–	–	✓	–	–
Soil characteristics	–	✓	–	–	–	–	–	–	–	–	–
Landfill / waste disposal	–	–	–	–	✓	✓	–	–	✓	–	–
Police security	–	✓	–	–	–	–	–	–	–	–	–
Village proximity	–	✓	–	–	–	–	–	–	–	–	✓
Forest	–	✓	–	–	–	–	–	–	–	–	✓
Green area	–	✓	–	–	–	–	–	–	–	–	✓
Wind direction	–	✓	–	–	–	–	–	–	–	–	✓
Elevation	–	✓	–	–	–	–	–	–	–	–	–
Average temperature	–	–	–	–	–	–	✓	–	–	–	–
Landslide risk	–	–	–	–	–	–	–	✓	–	–	–
Geological permeability	–	–	–	–	–	–	–	–	✓	–	–
Bare soil	–	–	–	–	–	–	–	–	✓	–	–
Olive fields proximity	–	–	–	–	–	–	–	–	✓	–	–

Table 1. Criteria Used in Industrial Site Selection in the Literature and Frequency Analysis

2. Study Area

In this study, the districts of Yomra, Arsin, Araklı, Sürmene, and Köprübaşı in Trabzon Province were selected as the study area. Trabzon has a surface area of 4,628 km^2 and, according to 2022 data from TSI (2023), a population of approximately 818,023. A significant portion of the population is concentrated in coastal districts such as Yomra, Araklı, and Arsin.

In Trabzon, existing industrial zones are scattered, particularly around the Değirmendere Valley, and they suffer from deficiencies in terms of modern industrial infrastructure. The Trabzon Metropolitan Municipality (2023) announced that efforts are underway to relocate small industrial sites and to identify new areas, aiming to improve both logistics and working conditions. Similarly, the New Trabzon Industrial Site Construction Cooperative (2023) stated that its project aims to relocate tradesmen to more modern, organized, and logistically advantageous locations. In addition, the establishment of the 5th Organized Industrial Zone in Arsin is highlighted as a significant investment intended to enhance the region's industrial capacity (Fasonara, 2023).

In this context, our research aims to identify potential industrial areas in Trabzon by conducting a GIS-based suitability analysis grounded in literature-based criteria and to evaluate the extent to which these areas align with existing zoning plan decisions. In this way, a scientific assessment of spatial needs will be provided, and the effectiveness of zoning plans in terms of industrial area suitability will be demonstrated.

Figure 1. Study area

3. Material and Methods

This study is based on the integration of AHP with GIS to develop a multi-criteria site selection model for large-scale industrial facilities. The methodological flow begins with the identification of physical, infrastructural, and environmental criteria through literature review and expert opinions. Each criterion is generated as a spatial layer, converted into raster format, and standardized. Using the AHP method, pairwise comparisons are conducted among the criteria, weight coefficients are calculated, and the consistency of the comparison matrix is evaluated. Within the GIS environment, raster layers are reclassified, a weighted overlay analysis is applied, and a general suitability map is produced. In the final stage, potential industrial areas are identified and compared with existing zoning plan decisions.

3.1 Selection of Criteria

The criteria used in industrial site selection studies were identified through a literature review and summarized in Table 1. Among these, only the criteria for which data were available in the study area and which had a high frequency of use in the literature were considered. This approach was adopted both to enhance the reliability of the analysis and to ensure data consistency at the application scale. However, since criteria for which data could not be obtained were excluded, this constitutes one of the limitations of the study. The selected criteria were grouped under three main categories:

Physical Criteria

- **Slope -** Land slope directly affects construction costs and infrastructure applications (Fataei et al., 2015; Ebadi et al., 2004; Khavarian-Garmsir and Rezaei, 2015).

- **Geology** - Suitability was assessed in terms of soil strength and earthquake risk (Hadipour and Kishani, 2014; Ebadi et al., 2004).

- **Elevation** - Elevation above sea level influences transportation costs and climatic conditions (Khavarian-Garmsir and Rezaei, 2015).

Infrastructure Criteria

- **Proximity to Main Roads -** Reduces transportation costs (Ebadi et al., 2004).

- **Proximity to Power Transmission Lines -** Critical for the economical supply of energy (Ebadi et al., 2004).

- **Proximity to Natural Gas Transmission Lines -** Important for the reliable and cost-effective supply of natural gas in industrial operations.

Environmental Criteria

- **Land Use –** Settlement, agricultural, and forest areas were considered (Hadipour and Kishani, 2014; Fataei et al., 2015).

- **Proximity to Streams –** Important in terms of flood risk and the protection of water resources (Khavarian-Garmsir and Rezaei, 2015; Fataei et al., 2015).

3.2 Data Sources and Database Development

The spatial data used in this study were obtained from various national and local institutions and evaluated in both vector and raster formats. The main datasets used in the analyses are as follows:

- Hydrology, Digital Elevation Model (DEM), and Land Use data were derived from 1:25,000-scale topographic maps provided by the General Directorate of Mapping.

- Geology data were supplied by the General Directorate of Mineral Research and Exploration (MTA).

- Transportation network data were obtained through the Spatial Address Registration System (MAKS) from the Trabzon Metropolitan Municipality.

- Energy infrastructure data (electric transmission lines and natural gas pipelines) were obtained from the Trabzon Metropolitan Municipality.

- Protected areas data were acquired from the open data services of the Ministry of Agriculture and Forestry and were used as exclusion zones (hard constraints) in the analysis rather than as weighted criteria.

All acquired data were transferred into GIS environment, with adjustments made to ensure consistency in format, coordinate system, and scale. During this process, missing data were completed, duplicate records were removed, and a spatial database specific to the study area was created for analysis purposes. To ensure consistency throughout the analysis, all datasets were projected using the TUREF / TM33 coordinate system (EPSG: 5255).

3.3 Analytical Hierarchy Process (AHP)

AHP, developed by Thomas L. Saaty (1980), is a widely used method for solving multi-criteria decision-making problems. In this study, AHP was applied to determine the relative importance of the criteria for industrial site selection. First, a hierarchical structure was established; at the top level, the objective of “identifying the most suitable areas for large-scale industrial facilities” was defined, while at the lower levels, the groups of criteria and sub-criteria presented in Section 3.1 were included.

The criteria were subjected to pairwise comparisons using Saaty’s 1–9 scale. On this scale, “1” indicates that two criteria are equally important, whereas “9” signifies that one criterion is extremely more important than the other. The pairwise comparison judgments obtained from decision-makers were processed through the eigenvector method to calculate the weight coefficient of each criterion.

To test the reliability of the weights, the Consistency Ratio (CR) was calculated. The CR value is compared with the Random Index (RI), as determined by Saaty based on the number of criteria, and if it is less than 0.10, the comparisons are considered consistent. In this study, the RI value for eight criteria was taken as 1.41, the CR value was found to be 0.07, and thus the comparison matrix was accepted as consistent. The derived criterion weights were applied to each layer during the raster analysis process in the GIS environment.

3.4 GIS-based Multi-Criteria Decision-Making Integration

The criterion weights determined by AHP were integrated into the spatial analysis process within the GIS environment. To ensure consistency in the analyses, all spatial data were converted into raster format with a 10 m cell size and clipped to the study area boundaries using the TUREF / TM33 coordinate system.

Preprocessing and Raster Conversion
Vector data (road network, power transmission lines, streams, etc.) were converted into raster format, and consistency in format and coordinate system was ensured.

Reclassification
Each criterion was reclassified on a scale from 1 (very low suitability) to 5 (very high suitability) to align with the suitability analysis. A high suitability score indicated locations advantageous for industrial facilities, while a low score represented disadvantageous areas.

Application of Weights
The weight coefficients obtained through AHP were applied to the corresponding criterion raster layers as multipliers. Thus, each raster layer was multiplied by its criterion weight, so that the cell values reflected both the standardized suitability score and its relative importance.

Weighted Overlay Analysis

All weighted raster layers were overlaid using a cell-based weighted sum method. The resulting raster was classified into five categories (very low, low, moderate, high, very high suitability) to generate the land suitability map.

Identification and Comparison of Potential Areas

Areas classified as "high" and "very high" suitability were identified as potential sites for industrial facilities. These areas were then compared with existing zoning plan decisions to evaluate the sustainability of planning decisions. The final suitability map produced in this process represents the primary decision-support output of the study.

4. Results

4.1 Criteria Maps

For each criterion identified in the study, separate suitability maps were produced within the GIS environment, thereby visualizing the spatial distribution of the criteria. These maps constitute the primary inputs of the suitability analysis and support the spatial decision-making process for industrial site selection.

Slope Map – A large part of the study area has steep topography, characteristic of the Eastern Black Sea region. Therefore, low-slope areas are limited and are generally concentrated along the coastal zones or valley floors.

Elevation Map – Areas close to sea level provide advantages in terms of transportation and logistics, while high-altitude regions received low suitability scores due to climatic conditions and transportation difficulties.

Geology Map – Based on geological formation characteristics, areas with low ground strength or unsuitable for construction were assigned low suitability scores, whereas areas with solid and buildable ground conditions were considered advantageous.

Land Use Map – The extensive presence of forests, agricultural land, and pastures constitutes one of the main constraints on industrial development. These areas were generally classified under low suitability, reflecting legal and environmental restrictions on their conversion.

Proximity to Road Networks Map – Areas near major transportation arteries received high suitability scores, with most of these zones concentrated along the Black Sea Coastal Highway.

Proximity to Power Transmission Lines Map – Locations close to electricity transmission lines were found advantageous, as they reduce energy access costs.

Proximity to Natural Gas Transmission Lines Map – Areas located close to natural gas pipelines were considered advantageous due to reduced energy supply costs and easier infrastructure integration.

Proximity to Streams Map – Riverbanks were given low suitability scores due to flood risk and the necessity of protecting water resources.

These criterion maps are presented in Figures 2 and 3, each clearly illustrating the impact of spatial criteria on the suitability analysis.

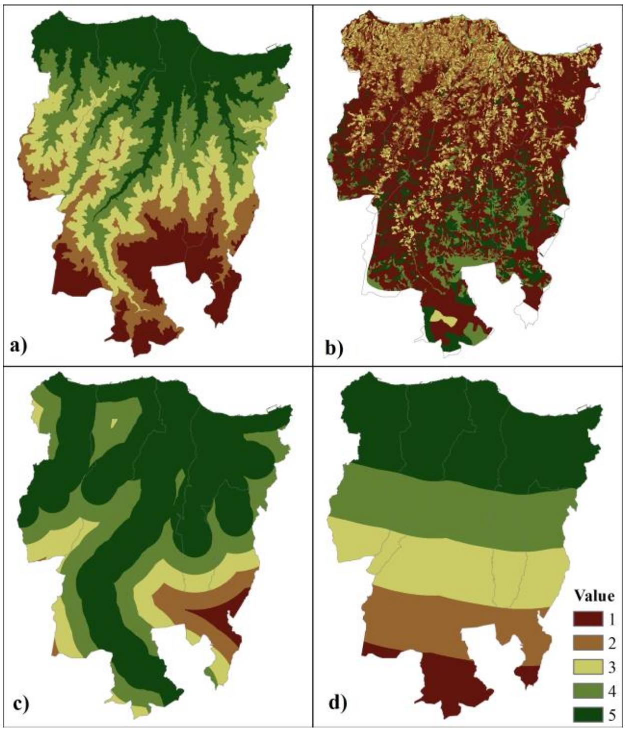

Figure 2. Criteria Maps: a) Elevation, b) Land Use, c) Roads, d) Power Transmission Lines

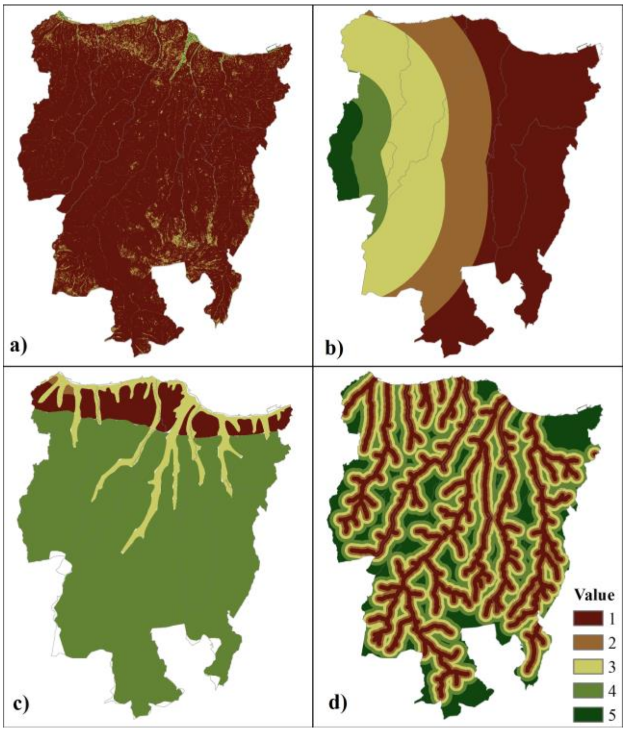

Figure 3. Criteria Maps: a) Slope, b) Natural Gas Transmission Lines, c) Geology, d) Streams

4.2 Suitability Map and Classification

The criterion weights determined through AHP were combined in the GIS environment using a weighted overlay analysis, resulting in the creation of a suitability map (Figure 4). This surface was classified into five categories based on suitability values: *very low suitability, low suitability, moderate suitability, high suitability, and very high suitability*. The area and percentage distribution statistics for these classes were calculated and are presented in Table 2.

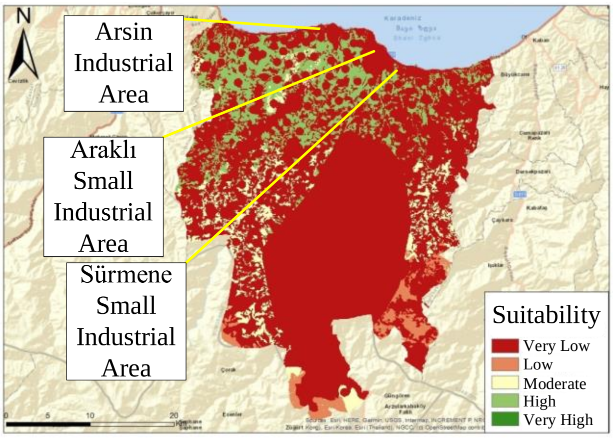

Figure 4. Suitability map

Evaluation Scale	Area (ha)	Percentage (%)
Very Low Suitability	86,384	77.07
Low Suitability	2,879	2.57
Moderate Suitability	7,570	6.75
High Suitability	15,253	13.61
Very High Suitability	2	0.00
Total	**112,089**	**100**

Table 2. Suitability Classes, Area, and Percentage Distribution

According to the results presented in Table 2:

- 77.07% of the study area (86,384 ha) falls into the very low suitability category for industrial development. The main reasons for this are the extensive presence of forests and pastures, as well as the prevalence of disaster-prone areas.
- 9.32% of the area (10,449 ha) is classified under low and moderate suitability, where steep slopes and high elevations are the primary limiting factors.
- 13.61% of the area (15,253 ha) is classified as high suitability and holds potential for industrial investments.
- Areas classified as very high suitability are almost non-existent (only 2 ha).

These results indicate that potential sites for industrial location within the study area are highly limited and that environmental and topographic constraints play a decisive role in the planning process.

5. Discussion

This study identified suitable areas for large-scale industrial facilities in the eastern districts of Trabzon through a method based on the integration of AHP with GIS. The set of criteria used included both physical and environmental factors such as slope, elevation, geology, land use, proximity to transportation and energy infrastructure, and proximity to streams. In addition, protected areas were considered as exclusion zones (constraints) rather than weighted criteria. Similar studies in the literature (Fataei et al., 2015; Hadipour and Kishani, 2014) also emphasize that infrastructure accessibility, topographic suitability, land use type, and environmental constraints play a decisive role in industrial site selection, and our findings are consistent with these results.

According to the analysis results, only 13.61% of the study area falls within the "high suitability" category, while areas classified as "very high suitability" are nearly non-existent. The steep topography of the Eastern Black Sea region, the high proportion of forests and pastures, and existing environmental restrictions largely limit the options for industrial investments. Areas in the "high suitability" category generally offer logistical advantages due to their proximity to transportation and energy infrastructure, but they also require careful planning in terms of resource conservation and land-use balance.

As shown in Figure 4, when the suitability map was compared with the industrial areas designated in existing zoning plans, it was found that some of the current industrial zones fall into low or very low suitability categories. This indicates that spatial constraints and multi-criteria analysis results were not sufficiently considered in the planning process. Integrating zoning plans with such spatial analyses can enable the reassessment of existing industrial areas as well as a more rational determination of future investment sites.

In conclusion, AHP–GIS-based multi-criteria analyses provide a decision-support tool applicable not only to Trabzon but also to other regions with similar topographic and environmental constraints. This approach goes beyond the mere availability of vacant land in industrial investments, allowing for a holistic evaluation of infrastructure accessibility, environmental sensitivity, and spatial constraints. Especially in coastal regions, where flat land is limited, the integration of such models into the planning process is crucial for ensuring long-term sustainability.

6. Conclusion and Recommendations

In this study, site selection for large-scale industrial facilities in the eastern coastal districts of Trabzon was evaluated through the integration of AHP and GIS. According to the analysis results, 77.07% of the study area is classified as very low suitability for industrial development. The main reasons for this are the extensive presence of forests and pastures, steep slopes, high elevations, and environmental constraints. The proportion of areas classified as high suitability is 13.61%, while areas falling into the very high suitability category are almost non-existent. Although the high suitability areas offer advantages in terms of infrastructure accessibility and location, they must be carefully planned to ensure the protection of natural resources.

The study revealed that industrial area planning requires not only the availability of vacant land but also a holistic evaluation of topography, infrastructure, and environmental constraints. However, the criteria used in the analysis were limited to the data available. Future studies are recommended to incorporate a broader set of factors, including land prices, socio-economic indicators, and market demands. In addition, integrating artificial intelligence and machine learning–based decision-support systems could enhance the accuracy and predictive capacity of the model. Revising existing zoning plans through comparison with such analyses is of critical importance for sustainable and data-driven industrial area planning.

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