Research on New Site Selection and Waste Sand Regeneration Coated Sand Production Strategy Based on Tianjin Casting Industry Pattern and LCA

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Abstract: Aiming at the problems of low resource utilization rate of waste sand in the foundry industry in the Beijing-Tianjin-Hebei region, unstable supply of coated sand raw materials, and lack of scientific basis for integrated project site selection, this study takes Tianjin as the research area. Through field investigation, life cycle assessment (LCA), analytic hierarchy process (AHP), and fuzzy comprehensive evaluation, the spatial distribution of foundry enterprises, waste sand generation characteristics, and coated sand market demand are analyzed. A four-dimensional multi-objective site optimization model considering environment, resources, economy, and society is constructed. Combined with typical enterprise engineering practice, the technical feasibility and economic rationality of the integrated layout of waste sand regeneration and coated sand production are verified. The results show that: the annual generation of foundry waste sand in Tianjin is about 367,600 tons, with annual coated sand demand of 150,000 to 200,000 tons; Site B is optimal in terms of full life cycle environmental load, operating cost, and industrial synergy; the integrated layout adjacent to foundry clusters can significantly reduce logistics costs, stabilize regenerated sand quality, and improve resource recycling efficiency. This study provides engineering references for green transformation of the foundry industry, resource-based project site selection, and production strategy formulation.

Keywords: Foundry Waste Sand; Recycling Utilization; Coated Sand; Life Cycle Assessment; Site Selection; Circular Economy; Tianjin.

1. Introduction

1.1 Research Background and Significance

Against the backdrop of worldwide green and low-carbon transition, the foundry sector is restricted by limited resources and increasingly strict environmental rules. China produced 50.75 million tons of castings in 2024, holding the world's top output spot for 24 straight years. Yet every ton of cast goods creates around 1.2 tons of waste sand, pushing yearly waste sand output above 10 million tons. The domestic recycling rate for such waste sand stands under 30%, lagging far behind developed economies, which points to severe resource loss and heavy pressure to complete low-carbon upgrades [1].

As a core foundry hub in North China, Tianjin turned out 1.1 million tons of cast products in 2022, alongside an annual waste sand yield of 350,000 to 370,000 tons. Boosted by the integrated development of Beijing, Tianjin and Hebei, plus local zero-waste city initiatives, reusing waste sand and manufacturing eco-friendly coated sand have become key tasks for industrial transformation [2]. Where a production plant is built exerts direct impacts on project profitability, environmental compliance and steady operation. It therefore carries practical engineering significance to adopt LCA methods for site selection for Tianjin's foundry enterprises [3,4].

1.2 Research Status at Home and Abroad

1.2.1 Casting Waste Sand Recycling Field

Countries such as the United States and Japan have built well-developed technical routes for recycling waste foundry sand, covering thermal, mechanical and chemical regeneration processes. Thermal regeneration relies on high-temperature calcination to burn off residual binders and recover the sand’s original performance, and most current studies on this technology center on energy saving and flue gas purification [5]. Domestic researchers have achieved certain breakthroughs via joint industry-university-research efforts. Even so, unstable equipment operation and inconsistent reclaimed sand quality prevent local products from competing in high-end casting manufacturing.

1.2.2 Resin-Coated Sand Production

Leading global manufacturers prioritize the research and developmentof low-carbon, high-performance resin raw materials and auxiliary agents. By enhancing their production technologies, they improve the strength of coated sand and the efficiency of shakeout processes, thereby securing a competitive advantage in the premium casting market. Key domestic manufacturers, such as Changjiang Materials have expanded their productioncapacities and elevated product standards by importing adcanced equipment and technical from abroad. In contrast, many small and medium-sized foundry material firms face challenges due to insufficient technical support and limited capital investment. Their outdated production lines result in inconsistent product quality, making it difficult for them to meet the demands of high-end casting production [6]

1.2.3 Production Site Location Research

Foreign countries topically employ the Analytic Hierarchy Process (AHP) and fuzzy comprehensive evaluation methods to develop multi-dimensional site selection evaluation systems; that consider factors such as location, cost, and environmental impact. In contrast, domestic scholars have created multi-objective planning models focused on industrial agglomeration and resource supply. However, research on the intergrated lauout of waste sand regeneration and coated sand production remains underdeveloped lacking systematic decision-marking frameworks that effectively balance environmental considerations with economic costs.

1.3 Research Content and Technical Route

Field investigation and data analysis: Conduct research in the foundry enterprise cluster areas of Tianjin, gathering data on enterprise distribution, production capacity, waste sand generation, and coated sand demand, followed by a quantitative analysis.

Life Cycle Assessment (LCA): Quantitatively analyze resource consumption and environmental impacts for waste sand regeneration routes and coated sand production.

Multi-objective decision model: Integrate AHP and fuzzy comprehensive evaluation to establish a four-dimensional site selection model for comparing and optimizing alternatives.

Field investigation → Statistical data analysis → LCA model construction → Index system and weight determination → Comprehensive site comparison → Case verification → Conclusions and recommendations

2. Investigation of Tianjin Foundry Industry Status

2.1 Enterprise Distribution and Production Capacity Pattern

Tianjin's foundry industry is mainly concentrated in Binhai New Area, Jinghai District, Ninghe District, Beichen District, Wuqing District, and Jinnan District. There are 93 foundry enterprises in the city with an output value exceeding 30 million yuan, of which 30 have an output value of over 100 million yuan; the main processes are die casting and clay sand casting, with products covering automobiles, engineering machinery, rail transit, and petroleum equipment.[7]

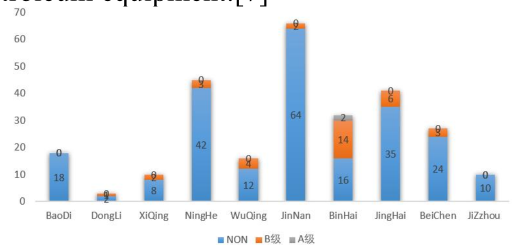

Figure 1. Spatial Distribution Map of Performance Grades for Foundry Enterprises under Heavy Pollution Weather in All Districts and Counties of Tianjin

A survey of 181 enterprises shows that: enterprises in Ninghe and Jinghai account for 43% of the total, mainly small-scale green sand enterprises with prominent environmental pressure; Binhai New Area features high-end precision casting, with 50% of enterprises reaching environmental performance grade B or above; Wuqing, Beichen, and Baodi districts develop collaboratively, with Wuqing District having established an integrated demonstration project for waste sand regeneration and coated sand production, forming a regional resource recycling model, as shown in the Figure1 and Figure 2.

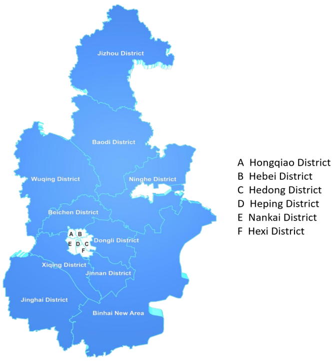

Figure 2. Spatial Distribution Map of Foundry Enterprises in Tianjin

2.2 Waste Sand Generation and Disposal Characteristics

According to estimates, Tianjin's foundry industry generates approximately 367,600 tons of waste sand annually, with 165,800 tons requiring compliant disposal, showing an overall pattern of "large enterprises self-recycling, small and medium enterprises scattered discharge." Large enterprises have built their own regeneration systems with utilization rates exceeding 90%; small and medium enterprises are constrained by funding and technology, with insufficient compliant disposal capacity, as shown in Table 1.

Table 1. Comparison of Waste Sand Characteristics among Different Casting Processes

Process Type	Main Components	Treatment Challenges	Regeneration Technologies
Clay-bonded wet sand	High clay content	Degradation of bonding performance	Mechanical reclamation, Scrubbing reclamation
Resin sand	Organic residues	High contamination risk	Thermal reclamationSodium silicate sand
Sodium silicate sand	alkalinity	Prone to efflorescence	Chemical modification + Mechanical reclamation

2.3 Regional Coated Sand Demand Analysis

Based on an analysis of process characteristics, downstream industries, and casting materials, the annual demand for coated sand in Tianjin is estimated to range between 150,000 and 200,000 tons. Multi-method calculations produce a demand estimate of 157,900 to 217,300 tons, which aligns closely with the field survey value of 176,000 tons and the pollution discharge permit statistics of 134,800 tons. Furthermore, the annual sales volume of leading suppliers in Tianjin surpasses 160,000 tons, confirming that reliability of the demand range, as shown in Table 2.

Table 2. Comparison of Estimation Results for Resin-Coated Sand Demand

Project	Field Research	Industry Category	Process Category	Material Category	Pollution Discharge Permit	Typical Suppliers
Demand/$(10^4 t\cdot a^{-1})$	17.6	21.73	17.79	15.79	13.48	10.8

3. Site Selection Optimization Model and Quantitative Analysis Based on LCA-AHP

3.1 LCA Method Framework and System Boundary

Life Cycle Assessment (LCA), asper the ISO 14040 standard, focuses on quantifying resource use and environmental impacts throughout the entire life cycle. It comprises four consecutive phases: defining goals and scope, analyzing inventory, assessing impacts, and interpreting results, facilitating a methodical assessment of the system under study. This research employs a cradle-to-gate boundary, encompassing raw material extraction, material transport, waste sand regeneration, preparation of coated sand, and delivery of the final product. The stages involving product utilization and end-of-life disposal are omitted to maintain clear evaluation boundaries and ensure comparability of outcomes.

3.2 Life Cycle Inventory Analysis

Field measurement results, corporate energy audit reports, equipment technical parameters, and authoritative LCA databases including Ecoinvent and CLCD are adopted as data sources to quantify all input and output substances within the defined system boundary, which are further sorted to form a standardized life cycle inventory, as shown in Table 3.

Table 3. Life Cycle Inventory Analysis Data Requirements

Category	Main Inputs	Main Outputs
Resources & Energy	Waste sand, Raw sand, Resin, Electricity, Natural gas	Reclaimed sand, Resin-coated sand
Air Emissions	–	CO_2, SO_2, NO_x, Particulate Matter
Water Discharge	–	Industrial water, COD, Ammonia Nitrogen, Wastewater
Solid Waste	_	Slag, Dust

3.3 Identification of Site Selection Impact Factors

Site selection optimization necessitates a systematic analysis of trade-offs among four critical factors: raw material security, logistics efficiency, environmental compliance, and market adaptability. Raw material security ensures the stability of waste sand supply; whole logistics efficiency has a direct impact on overall operational costs; Research indicates that optimizing regional transportation conditions can reduce these costs by 18%–25%; Environmental compliance serves as a crucial prerequisite for project feasibility; Furthermore, market adaptability significantly influences the supply-demand matching; for every 50-kilometer reduction in marker radius, corporate profitability may increase by 5%–8% .Thus site selection optimization should focus on a comprehensive trade-off analysis that centers on these four core factors: the stability of raw material supply, logistics efficiency, environmental compliance, and market adaptability.

3.4 Multi-Objective Site Evaluation Model Construction

3.4.1 Evaluation Index System

An evaluation indicator system for site selection is established based on the principles of scientific rigor, systematic approach, quantifiability and engineering implementability. This system encompasses four dimensions: environmental impacts, resource consumption, economic input and social benefits, as shown in Table 4.

Table 4. Waste Sand Recycling Project Site Evaluation Index System and Weights

Goal	Criterion	Weight	Index	Unit
Site comprehensive evaluation	Environmental impact	0.35	Greenhouse Gas	tCO_2/a
			Air Pollutants	kg/a
			Water Discharge Pollutants	kg/a
			Solid waste generation	kg/a
	Resource consumption	0.2	Comprehensive energy consumption	tce/a
			Fresh water consumption	m^3/a
	Economic cost	0.3	Annual operating cost	ten thousand yuan /a
	social benefit	0.15		unit

3.4.2 AHP-Based Index Weight Determination

The Analytic Hierarchy Process (AHP) is employed in this study to ascertain the weights of indicators. Ten experts from various disciplines, including environmental engineering, circular economy, foundry industry and regional planning contributed to the development of the judgment matrices. After carrying out normalization, eigenvector calculation and consistency check (CR < 0.1), the weight values of each dimension are presented as follows: environmental impact 0.35, economic cost 0.30, resource consumption 0.20, and social benefit 0.15, as shown in Table 5.

Table 5 Composition of Expert Review Panel

Expert Field	Number	Main Contribution
Environmental Science / Engineering	3	Weight assessment for environmental impact indicators
Circular Economy / Resource Management	2	Weight assessment for resource consumption indicators
Foundry Industry / Enterprise Management	3	Trade-off for economic and technical feasibility
Regional Economy / Public Policy	2	Assessment of social benefits and policy alignment

3.4.3 Standardization Processing and Comprehensive Evaluation Model

To eliminate dimensional differences, the range standardization method was adopted to normalize the raw data, and a multi-objective weighted comprehensive evaluation model was constructed:

$$S=\sum i=1n(Wi*Ri) \qquad (1)$$

Where: S is the comprehensive score of the site; Wi is the weight of the i-th indicator; Ri is the standardized score of the i-th indicator.

3.4.4 Analysis of Candidate Site Locations and Comparison Results

To guarantee the scientificity of comparative screening and engineering implementability, three typical candidate zones are selected for quantitative evaluation by integrating the spatial pattern of Tianjin's foundry industry, transportation conditions, environmental control requirements and land resource endowments. The specific locations and characteristics of each site are summarized as follows, as shown in Table 6, the specific locations and characteristics of each site are as follows:

Table 6. Comparison of Environmental-Resource-Economic-Social Indicators for Candidate Sites

Evaluation metrics	A	B	C
Greenhouse Gas(tCO_2/a)	1000	800	900

Air Pollutants(kg/a)	500	400	450
Water Discharge Pollutants(kg/a)	300	250	280
Solid waste generation(kg/a)	200	150	180
energy consumption(tce/a)	800	700	750
water consumption(m^3/a)	5000	4000	4500
Annual operating cost	300	280	290
employment positions	50	60	55

Site A: General Industrial Plot in Zhongwang Town, Jinghai District, Tianjin

This candidate site is situated in Zhongwang Town, Jinghai District, Tianjin, adjacent to the Tianjin Bingang High-tech Foundry Industrial Park. According to information from the China Investment Promotion Network, this area constitutes an agglomeration zone for the traditional foundry industry. It offers low local land costs and a robust industrial foundation, however, its distance from the core demand market, results in a wide waste sand collection radius and relatively high transportation expenses. Furthermore, environmental regulations in this region have become increasingly stringent, while supporting facilities remain inadequate, reflecting deficiencies in industrial synergy and logistics efficiency.

SiteB: Located in the Automotive Industrial Park of Wuqing District, Tianjin

The second candidate site is located in the Wuqing Automobile Industrial Park (Jingqing Automobile Industrial Park) within Wuqing District, Tianjin, this area is home to numerous precision foundry and auto parts enterprises, as well as the People's Government of Wuqing District, Tianjin. The industrial park offers comprehensive supporting facilities and adheres to standardized environmental control criteria. It benefits from a concentrated and stable supply of waste sand, minimal transportation distances and conducive conditions for industrial collaboration, rendering it the optimal location for an integrated project that combines waste sand regeneration with coated sand production [8].

Site C: Xiao Zhan Industrial Park, Jinnan District, Tianjin

Candidate Site C is located in Xiaozhan Industrial Zone, Jinnan District of Tianjin. This municipal-level demonstration industrial park is designated as Class II industrial land and is equipped with relatively comprehensive supporting infrastructure. The park emphasizes the development of ancillary industries related to high-end equipment manufacturing, new materials and precision casting. Currently, it is progressing with the construction of a valve casting base, thereby establishing a robust foundation for industrial synergy. It boasts convenient location and transportation as well as a sound logistics network, which facilitates waste sand collection and coated sand product distribution. Nevertheless, this zone is far from the core foundry agglomeration area in the northern part of Tianjin, resulting in a larger transportation radius for waste sand. Its comprehensive performance ranks between Candidate Site A and Candidate Site B.

A multi-objective weighted comprehensive evaluation model integrating LCA and AHP was adopted to conduct quantitative scoring for Candidate Sites A, B and C. The calculated scores are as follows: S_a=0.20, S_β=0.80, S^c=0.42, indicating that Candidate Site B achieves the highest comprehensive score, as shown in Table 7.

Table 7. Standardized Scores and Weighted Calculation Results for Each Site

Index	A	B	C	Weight
Environment	0.15	0.85	0.45	0.35
Resource	0.20	0.90	0.50	0.20
Economy	0.25	0.80	0.40	0.30
Society	0.22	0.75	0.48	0.15
Composite	0.20	0.80	0.42	-

3.5 Chapter Summary

A multi-objective site evaluation model integrating LCA and AHP is constructed to achieve the transformation from qualitative site selection to quantitative, scientific, and traceable decision-making. Through systematic calculation and comprehensive comparison, Site B demonstrates the optimal performance in terms of full-life-cycle resource and environmental performance as well as economic and social benefits, providing a scientific basis for the layout of the integrated waste sand regeneration and coated sand production project.

4. Engineering Case Analysis

4.1 Enterprise Waste Sand Regeneration and Coated Sand Production Example

Taking Tianjin Xinweixiang Industrial Co., Ltd. in Wuqing District, Tianjin as an engineering example, this enterprise is a large-scale foundry in the region, generating approximately 180,000 tons of foundry waste sand annually, mainly consisting of clay green sand and resin sand waste. Initially, the enterprise adopted mechanical regeneration process, with waste sand utilization rate of only 40% and limited regenerated sand quality. After technical upgrading, thermal regeneration process (treatment temperature 700–800°C) was adopted, increasing the waste sand resource utilization rate to 92%, and the regenerated sand performance can meet the requirements of high-end precision castings. Meanwhile, an automated coated sand production line was installed, achieving high-quality and stable coated sand production through stable control of key parameters such as preheating temperature, resin addition amount, and curing rate. This case confirms that the integrated production of waste sand regeneration and coated sand possesses technical feasibility and economic rationality [9].

4.2 Site Selection Decision Logic and Engineering Verification

The site selection model in this study concludes that Site B is optimal, which is highly consistent with Xinweixiang' s practice: lower environmental load: Site B is close to the industrial cluster, which can significantly reduce transportation emissions and solid waste discharge, achieving source reduction; more efficient resource utilization: recycled sand can be substituted for virgin sand through nearby recycling, reducing energy and resource consumption; better economic performance: shortened logistics distances lead to significantly lower operating costs and more stable investment returns; stronger industrial synergy: the material flow, technology flow, and supply chain in the agglomeration area are highly matched, conforming to the principles of circular economy layout.

4.3 Case Insights

Our experience in several foundry parks suggests that integrated production projects combining waste sand regeneration and coated sand manufacturing are preferably constructed adjacent to foundry industrial agglomerations. Such layout forms a closed-loop operation mode featuring on-site collection, regeneration and reuse of waste sand, which improves resource recovery efficiency, cuts comprehensive costs and stabilizes product quality. The research conclusions can provide engineering references for the site selection and construction of similar projects.

5. Conclusions and Recommendations

5.1 Conclusions

The foundry industry in Tianjin presents a high degree of industrial agglomeration, generating 367,600 tons of waste sand annually, with the annual demand for coated sand ranging from 150,000 to 200,000 tons. There is ample market potential for the resource utilization of waste sand. The four-dimensional site selection model integrating LCA and AHP can quantitatively assess four categories of benefits including environmental, economic, resource and social benefits in a scientific manner, among which Candidate Site B delivers the best overall performance. Integrated projects that arrange waste sand regeneration and coated sand production adjacent to foundry clusters can achieve solid waste reduction, cost control and stable product quality, possessing promotional value for popularization in similar regional industrial zones.

5.2 Engineering Recommendations

Enterprise side: Enterprises shall prioritize the adoption of resin sand raw materials compatible with thermal regeneration for waste sand treatment, construct automatic coated sand production lines, and promote closed-loop recycling within factories.

Government side: Local governments shall attract relevant enterprises to settle in designated industrial parks, build centralized sand regeneration centers with complete supporting infrastructure, and increase policy and financial support.

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