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Optimization analysis of water resources value transfer in iron and steel enterprises

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ABSTRACT

Water resources are an indispensable resource in the many industrial production processes. Iron and steel enterprises, which are typical of industries that produce serious water resource consumption and pollution emissions, have received much attention in terms of green development and sustainable development. The optimization of water resources value transfer has become a key topic of scholars' exploration. This paper introduces a theory of resource value transfer. Taking Shanghai Baosteel as an example, our work identifies the company's internal resource loss and external environmental damage costs, integrates circular economy indicators with the enterprise's water resource value transfer cost accounting results, and comprehensively diagnoses the design of different key improvement nodes. This paper adopts the gray situation decision-making approach to construct a water resources value circulation optimization model and selects the optimal optimization scheme. The optimization model of water resources transfer based on the analysis of the value of resources can provide effective guidance for the comprehensive optimization of water resources management, environmental benefits and the sustainable development of iron and steel enterprises in China.

Keywords: Resource value transfer; Water resources; Grey situation decision; Shanghai Baosteel

1. Introduction

Iron and steel enterprises are consumers households of large amounts of water and wastewater. They are important foundations of the Chinese national economy. Since the 1990s, China's steel industry has developed swiftly, and China's steel output ranks among the highest in the world. However, the problem of environmental pollution and water consumption caused by the high production volume is very serious, and the negative impacts of unreasonable use of water resources and unsatisfactory treatment of water pollution cannot be underestimated [1]. "The 13th Five-Year Plan for Circular Economy Development" clearly states that the steel, paper-printing and dyeing industries are key to the layout of China's industrial landscape. As typical representatives of traditional industries and high energy-consuming industries in China, iron and steel enterprises develop a recycling economy. The implementation of clean production and water conservation are of great significance to the transformation and upgrading of the steel industry and of the overall sustainable development of the country.

Analysis of resource value transfers has been widely used in relation to process manufacturing companies and is increasingly becoming an important tool for environmental management [2]. Resource value transfer analysis examines the entire process of inputting, consuming, recycling, exporting, recycling and reusing of enterprise resources. Resource value transfer is based on material transfer, and it dynamically monitors enterprise environmental costs, saves resources, and achieves win-win results in terms of both economic and environmental benefits [3]. The value transfer of iron and steel companies has long been the focus

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of scholars at home and abroad. However, the current literature focuses on the study of water resources from the macroeconomic level-how to reduce pollutant emissions from the technological process or technical level, and how to improve the efficiency of steel companies. Value transfer rarely involves the transfer of the water resources value of iron and steel enterprises. Based on the theory of value transfer, this paper studies the optimal model of water resources value transfer in steel enterprises in order to optimize the internal resource value circulation path and realize the sustainable development of iron and steel enterprises.

2. Literature review

2.1. Resource value transfer analysis

The analysis of resource value transfer refers to tracking the value changes of enterprises' internal resources from the perspective of a circular economy, based on resource transfer, and it is a new type of environmental management tool that has been extended to benefit evaluation, decision optimization, and cost control. In recent years, scholars at home and abroad have used MFCA (Material Transfer Cost Accounting) as one of the important tools of environmental management accounting methods [4] to calculate energy costs—such as electricity, gas, and water usage—of manufacturing companies in the coal, power generation and textile industries in different countries from the perspective of energy transfer. They have studied combined material transfer cost accounting as it relates to corporate ERP systems to promote the interaction of data and information [5,6]. A number of case studies have been conducted on process manufacturing [7–9] and Industrial Parks [10–13].However, most studies do not specify resources as a specific type, but rather simply analyze the transfer of resource values across the entire enterprise or park. For example, Xiao et al. [14] constructed an analysis model of the value of papermaking enterprises' resource value transfer, and this study put forward a management paradigm for the resource value transfer of papermaking companies based on the PDCA cycle. This study also evaluated and compared the internal resource loss assessment and the external environmental damage improvement plans of papermaking enterprises. Based on the characteristics of the company, the impact of the transfer of certain types of specific resources on the value of the enterprise was also discussed, but it was more focused on the papermaking industry and the coal power generation industry. Zhou et al. [15] took papermaking enterprises as its research object, and this study used an analytic hierarchy process and grey situation decision-making to construct an optimization model of circular economic value circulation. Other studies have optimized research on the environmental protection investment decisions of thermal power companies under the transfer of resource value model [16]. Ultimately, studies on the optimization of the value of water resources in iron and steel companies are still rare.

2.2. Water accounting

Water is essential to daily human life and to all businesses. In recent years, due to population growth, accelerated urbanization, and increased pollution, the pressure on water resources in countries around the world has increased dramatically [17]. Water accounting has become the focus of scholars at home and abroad. At present, research on water resources mainly focuses on the establishment of a theoretical framework for water resources management as it relates to a country's macroeconomic benefits and corporate water accounting, or as it relates to basic water resources cost accounting. China's water resources management starts with the theory of harmony between people and water, and advocates the application of the most stringent water resources management system [18]. While the water resources management models adopted by the United States, Australia, and Japan share similarities with China in the assessment cycle, they still need to learn from their management experience [19,20]. Enterprise Water Management Accounting is a recently proposed environmental management extension program designed to support business management decisions and improve water-related environmental performance [21]. In terms of the cost calculation of water resources, it proposes to include monetization in water accounting, increase the water accounting framework, and adopt interdisciplinary research to solve the complex problems of water accounting [22]. Satellite surveys have been shown to have high accuracy. Karimi and Bastiaanssen et al. [23] propose to use satellite technology to measure land and water resources. Also, cost analysis tools have been used to estimate costs to calculate energy efficiency and relative functions [24], and basic formulas have been used to calculate water price differences and perform basic cost control [25].

3. Resource value transfer optimization model construction

The content of this section is based on the unique attributes of iron and steel enterprises; it focuses on analyzing the law of water resources transfer and value transfer, and it constructs a water resource value stream analysis model that identifies alternative options for water resources value transfers and uses the grey situation decision model to screen and sort alternatives in order to select the optimal project.

3.1. Fundamental principles of water resources value transfer

The water resources technological process of iron and steel enterprises includes four processes: the sinter water system, the molten iron water system, the steel making water system, and the rolling steel system process transfer for equipment. In the iron and steel enterprises, there is a corresponding logical relationship between the circulation of water resources and the value cycle. After the initial resources enter the company, their material forms will transfer along with the transfer of production processes. Some of the resource transfers will be recycled and reused within the enterprise. Some resources will be restored, and the remaining resource transfers will be output in the form of new resources. The research model of the value stream is established by calculating the corresponding water resource costs from different item volume centers, and by then counting the value changes that accompany the inflow and outflow of water resources. Based on the internal water resources transfer of steel companies, the resource value transfer analysis adopts the economic-environmental dual cost accounting method to depict the value change of water resources in the process of the chain, ring, and net movement [26], as shown in Fig. 1. In the production process, water resources transfer along with the process transfer and go through a series of other processes, including coking, sintering, steelmaking, and continuous casting. Along with the continuous addition of energy and other raw materials, water resources take the form of raw water to new water. Water is then turned into wastewater, and part of the wastewater is treated and recycled. The calculation and evaluation of resource transfer costs reveals the costs to the iron and steel enterprises of the distribution of water resources; this analysis also considers whether there is any over-expenditure, and it taps key points for reducing costs and optimizes the process of water resources value transfer.

3.2. Water resources value stream analysis model

The analysis of resource value transfer is based on material transfer analysis. The production and operation processes of iron and steel enterprises include not only the input and output of a single resource, but also the intermediate input of resources, the transfer of processes before and after, and the counter-current and internal circulation of resources. The value transfer of water resources in iron and steel enterprises is based on water consumption, and the accounting requirements for the value transfer of circular economy are introduced in this work. Different materials departments are responsible for the process of sintering and continuous production. According to the interactive law of water resource material transfer and value transfer, the basic equation of the water resource value transfer model for steel companies is constructed as follows:

$$RC_m = RUC_m + WLC_m + WEIC_m \tag{1}$$

RC_m is the water resource value transfer cost of a certain production department; RUC_m is the actual water use cost transfer cost of a certain production department m; WLC_m is a water contaminant loss circulation cost of a production department m; $WEIC_m$ is certain The external environmental damage caused by the discharge of water pollutants from the production department is represented by m.

When $RC_m = RUC_m$, the maximum benefit of the formula can be achieved, and the cost of water pollutants can be converted into the actual use of water resources, so that the cost of the external environmental damage caused by water pollutant emissions is zero, this maximizes green economic efficiency.

The essence of water resources value circulation analysis in iron and steel enterprises is based on the analysis of the value of water resources in enterprises, which is deployed in order to achieve the objectives of economic efficiency and environmental benefits, and to seek improved environmental benefits nodes and value-added economic benefits. Project investment is used to optimize the transfer of water resources and to select the best optimization plan. Drawing on existing research results, the optimal transfer of water resources value for the iron and steel industries is as follows:

(1) According to the "material transfer-value transfer" cost circulation situation of the steel industry's circular economy, we calculate the cost of internal resources loss and external damage costs, and we carry out a horizontal comparison of various volume centers and tap the key nodes that can be improved.
(2) We prepare two-dimensional cost summary tables for the internal and external costs of the iron and steel enterprises, in order to make comprehensive diagnoses using circular economy indicator systems; we then formulate and implement targeted improvement plans and propose alternatives for optimizing models.
(3) The comprehensive diagnosis of the value calculation of the water resources value transfer of steel enterprises through circular economic indicators is used as the data basis for optimizing decision-making.

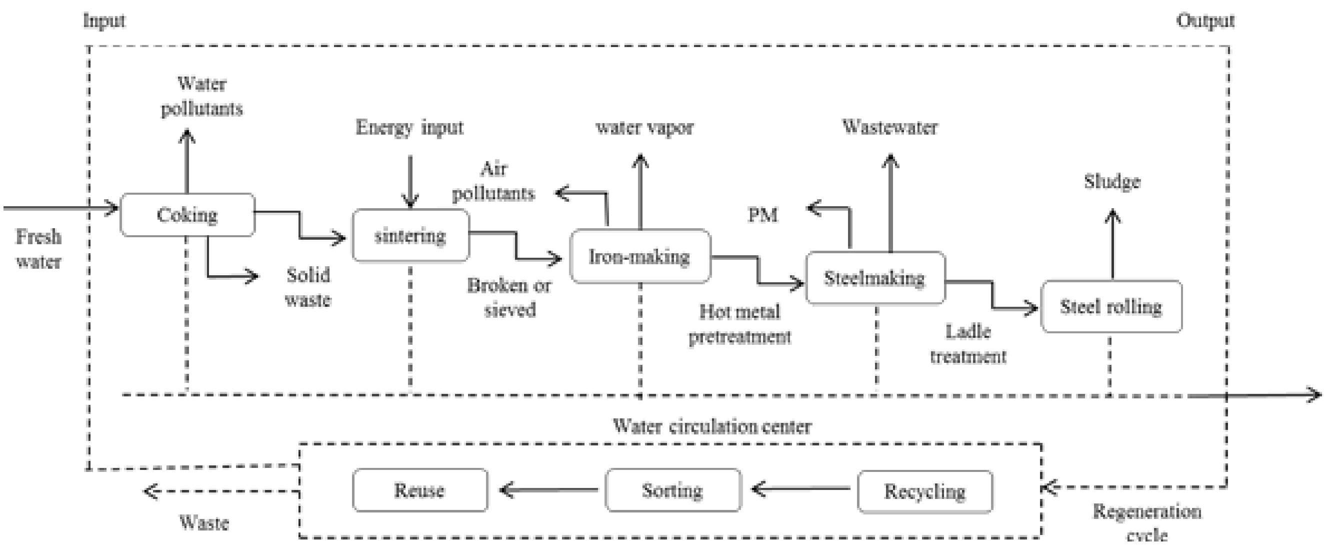

Fig. 1. Water resources value flow of iron and steel enterprises.

(4) We utilize the grey situation decision analysis method to bring various investment alternatives into account, to calculate the effect values and comprehensive effect values under different situations,and to rank the investment alternatives and select the best optimization plan.

3.3. Grey situation decision

The grey situation method refers to the decision-making method that, under the multiple dimensions, based on the grey system theory, assigns weights to different research angles or analysis indicators, converts the effect measurement values of the various indicators into comprehensive effects, and measures the merits of the projects. Over the course of implementing this concrete process, we must first identify the research object, and then combine the research object and the corresponding strategy to constitute the research situation. Then according to the research objectives and the standard framework, the project is divided into three different measurement values: maximum, minimum, and moderate.

The measure of the effectiveness of the "maximum" goal: $R^y{}_{\mathrm{mn}} = \frac{E^y{}_{mn}}{\max E^y{}_{mn}} (0 \le R^y{}_{mn} \le 1)$

The measure of effectiveness of the "minimum" goal:

$$R^y{}_{\mathrm{mn}} = \frac{\min E^y{}_{mn}}{E^y{}_{mn}} \left(0 \le R^y{}_{mn} \le 1\right)$$

The measure of effectiveness of "moderate" goal:

$$R^y{}_{\mathrm{mn}} = \frac{\min E^y{}_{mn}}{\max E^y{}_{mn}} \left(0 \le R^y{}_{mn} \le 1\right)$$

Finally, according to the formula $R^{\Sigma}{}_{mn} = \sum_{y-1}^{k} W_y \times R^y{}_{mn}$ we find the best decision.

According to the theory of circular economy water resources value transfer, this paper first obtains raw data from iron and steel enterprises, and it then processes the raw data into the categories of required water resources data. We then calculate the internal water loss costs and external environmental damage costs, prepare a cost accounting table, select the volume centers that need to be improved, and propose a number of water resources value transfer improvement programs. Through our matrix and related tests, improved schemes are compared to obtain the optimal project with the lowest input cost and the best optimization effect. In the iron and steel enterprise effect system, three types of indicators—economic effect indicators, ecological effect indicators, and value stream indicators—are usually selected. At the same time, matrix weights are given to the three levels of indicators. The weight matrix can be calculated as follows:

$$C = \begin{bmatrix} 0.0893\,0.0954\,0.0659\,0.0686\,0.0995\,0.0680 \\ 0.0955\,0.1246\,0.1182\,0.0304\,0.0593\,0.0752 \end{bmatrix}$$

Find the largest eigenvalue of the judgment matrix:

$$\lambda_{\max} = 12.8854 CI = \frac{(\lambda_{\max} - n)}{(n-1)} =$$

$$\frac{12.8854 - 12}{12} = 0.07$$

When n=12, RI=1.54, then $CR = \frac{CI}{RI} = \frac{0.07}{1.54} = 0.0455 <$ 0.1, Therefore, the satisfaction of the matrix is reliable and the distribution of weights is reasonable.

4. Case analysis

4.1. Case background

Shanghai Baosteel Group is the largest and most innovative steel enterprise in China, with the ability to compete with the world's leading iron and steel enterprises. It is critical to China's economic construction industry and it is also a leader in the development of China's industrial landscape. However, there is still a large gap between the value of water resources of the Baosteel Group and that of the steel companies of Europe and the United States.

4.2. The cost accounting of water resources in Baosteel

The cost accounting for the water resources of the Baosteel Group mainly adopts the following steps: first, we determine the volume distribution center and statistics data of the water resources; then, we collect the input and output and cost processing data of the water resources of each volume center; and finally, we determine the distribution standards of water resources costs in each volume center. According to the company's production characteristics and basic principles of cost allocation, Baosteel Group is divided according to the following six functions: sintering, continuous casting, iron making, steelmaking, hot rolling, and cold rolling. Subsequently, the cost allocation for water resources centers will be carried out and summarized. The summary table is shown in Table 1:

Because the transfer direction of water resources is diverse—that is, the water resources in each quantity center may come from new water or from the effluent from a previous process—water resources are divided into positive products and negative products according to the subsequent production needs, and the cost of water resources is allocated according to the proportion of the products produced.

4.3. Water resources cost optimization analysis of Baosteel

Through matrix mode analysis, we compare the damage cost of different sectors and the cost of normal production as shown in Table 2.

The costs of waste loss and external damages in Baosteel Group's production process are relatively high, and there is room for improvement in the value path of the water resources. In 2016, Baosteel Group's internal water resource costs in the cost center of the hot rolling process totaled 3714712.77 Yuan, and the total external damage cost was 741639.6 Yuan. This was the cost center with the largest amount of waste loss and external environmental damage, and it should be at the center of any efforts to optimize the value transfer of the water resources. The costs of cold-rolling and continuous-casting wastes and external environmental damage are relatively large. They should be regarded as the focus of Baosteel Group's low-carbon recy-

Table 1
Baosteel Group's water resources input and output table

Volume center	Input or output	Name	Number of inputs (in tons/year)	Loss (in: tons/year)	Cost amount (Yuan)
Sinter	Input	Fresh water	417011.624		
	Output	Fresh water	417011.624		
					417011.624
Iron making	Input	Fresh water	14419.08		
		Wastewater	61892.4475		
	Output	Treated water	12168		
		Reclaimed water	61892.4475		
					76311.5275
Steel making	Input	New water	3371.9556		
		Rain water	5492.5		
		Reclaimed water	81120.169		
	Output	Wastewater	28392	11880.7	
					89984.6246
Continuous casting	Input	New water	23114.7553		
		Reclaimed water	98243.08		
		Evaporation and backwater	321517.43		
	Output	Steam (hot rolling)	19889.61	10543.91	
		Wastewater (hot rolling)	5840.64		
		Flushing water from ash (to cold rolling)	3185.65		
					359044.759
Hot rolling	Input	New water	19717.399		
		Reclaimed water	569868		
		Wastewater	5840.6738		
		Steam	104389.61		
		Domestic sewage	2072.278		
		Backwater	127383.75		
		Rain water	20150.2587		
	Output	Evaporated backwater (to continuous casting)	12548.25		
		Reclaimed water (to continuous casting)	3574.35		
		Water attached (to cold rolling)	5788.25	50110.19	
					925904.056
Cold rolling	Input	Water attached (from hot rolling)	90288.588		
		Ash wastewater	53885.8359		
		Rain water	21993.8966		
	Output	Wastewater	9044.75	2056.73	
					166168.32

cling economic transformation; also, while the steelmaking, iron making and sintering cost center waste losses and external environmental damage costs are relatively small, in the scope of optimization, they should still be included.

4.4. Optimization model of alternative investment scheme

According to the analysis of the internal losses and environmental damages involved in the resource value transfer at Baosteel Group, the grey situation analysis method is selected to optimize the specific production process of Baosteel. According to the red heart link of different cost centers, the corresponding improvement methods are formulated and three alternative investment schemes are put forward.

4.4.1. Calculation of the scheme

Project1: The centralized concentration thick mud bucket in the sintering center is upgraded to a centralized zipper concentrate treatment. Because of the zipper treatment of the sludge, the continuity of the sewage discharge is ensured, the amount of environmental pollutants is reduced, and the production efficiency of the enterprise

Table 2
Summary of two-dimensional accounting of internal and external costs of Baosteel Group's water resources

Department center		Sinter (Yuan)	Iron making (Yuan)	Steel making (Yuan)	Continuous casting (Yuan)	Hot rolling (Yuan)	Cold rolling (Yuan)
Cost of internal water resources	Positive cost	747237.218	490625.59	1276543.14	3431722.55	3639991.37	2843412.72
	Negative cost	22808.578	11504.0159	25137.4487	88468.627	74721.3896	52508.4521
	Account	770045.796	502129.589	1301680.59	3520191.18	3714712.77	2895921.17
	Numeric rankings	5	6	4	2	1	3
Cost of external damage	Cost	240723.6	292555.9	21209.5	293992.4	741639.6	336546.6
	Numeric rankings	5	4	6	3	1	2
Positive product rate		0.971	0.978	0.981	0.975	0.98	0.982

Table 3
Comprehensive benefit calculation table for concentrated concentration zipper

Project cost	Object	Initial value (Yuan)	Change (Yuan)	Final value (Yuan)
initial water cost	Clean water	442000000	470600	442470600
other energy costs	Energy consumption	2605118.555	–243681.048	2361437.507
equipment and labor cost	New equipment depreciation	11698849.773	533000	12199298.007
	Labor and Other costs		–32551.766	
Internal loss cost	Integrated cost	455913968.341	598667.186	456512635.514
External loss cost	Discharge wastewater	1204748.649	–1023821.331 895334.947	1076262.265
Internal improvement effect = Other income – Variable cost – Initial input cost = 3900000 – 598667.186 = 3301332.814				
External improvement effect = External loss cost reduction = 1023821.331 – 895334.947 = 128486.384				

is improved. Baosteel needs to invest 5,980,000 Yuan to upgrade their facilities to include concentrated zippers. At the same time, the total amount of wastewater used in sintering the same quality of crude iron ore would be increased by 7,800,000 tons. Calculated according to the unit price of water resources of 1 Yuan/ton, the reduced cost loss (or the resulting benefit) would be 3,900,000 Yuan. Based on the above changes in costs and changes in returns, a benefit calculation table is prepared, as shown in Table 3 below.

Project 2: The water supply and washing workshop invested in the iron-making center will be introduced into the washing tower and the Venturi parallel water supply washing process. The wastewater would be transported from the tower to the circulatory system. An acid port would be provided at the pipeline, and the waste sulfuric acid in the waste acid pool would be evenly distributed. The precipitate would be dehydrated and then introduced into the water and used for sintering.

Investment in the water supply and washing workshop would cost an estimated 83,200,000 Yuan, but there would be depreciation in the water supply and washing plant, and the depreciation period would be 20 years. However, the additional benefit generated from the recovery of wastewater would be 3,988,660 Yuan. According to the calculation principle of project 1, the internal improvement effect would be 65,443,720.017 Yuan, and the external improvement effect would be 200,635,899.373 Yuan. The specific calculation process is not listed.

Project 3: The continuous casting center will be transformed, and the main object of the transformation is to upgrade the indirect cooling water system of the equipment to obtain more water utilization efficiency, thereby reducing the water consumption of the enterprise. The upgrade of the inter-equipment cooling system would cost 31,200,000Yuan, with the depreciation time set to 20 years. Depreciation statistics and amortization would be performed during the useful life. According to the calculation principle of project 1, the internal improvement effect would be 17,319,884.712 Yuan, and the external improvement effect would be 4,353,552.073 Yuan. The specific calculation process is not listed.

4.4.2. Give the target and the polarity

If we integrate the existing literature and industry characteristics, we may construct a comprehensive diagnosis index of a circular economy, and use the analytic hierarchy process to determine the weight of each indicator. According to the establishment of an iron and steel enterprise water resource value transfer optimization model, each target value and polarity can be determined, and the effectiveness of the above-mentioned program can be analyzed accordingly.

4.4.3. Standards for setting up plans

In the previous calculations, the relevant cost data and performance data of the Shanghai Baosteel Group were

Table 4
The target effect of different optimization projects of the Baosteel Group

Index	Project	Project 1	Project 2	Project 3
Economic comprehensive utility index	Total investment (ten thousand Yuan)	598	8320	3120
	Economic benefits (%)	93.71	78.99	96.76
	Annual operating cost (ten thousand Yuan)	54.6	709.8	172.9
	Added value output efficiency (%)	0	4.888	0
Resource recycling index	Material cost utilization ratio (%)	59.449	60.034	62.816
	Energy cost utilization ratio (%)	72.748	71.526	71.513
	Reuse rate of industrial water (%)	94.978	94.757	97.825
	Rate of change in cost of value transfer of internal resources (%)	0.221	–36.257	–32.578
Social environmental utility index	External damage rate of environmental cost (%)	–16.848	–64.74	–35.061
	Rate of change in value of exhaust gas damage (%)	–11.31	17.004	–7.956
	The rate of change in the value of the emission of solid pollutants (%)	10.413	–39.364	–16.289
	Change rate of wastewater discharge value (%)	85.839	–42.38	–10.816

obtained, and the final values of various evaluation factors were subdivided under different effect systems. Finally, a suitable project was selected, as shown in Table 4.

4.4.4. Calculating the value of the effect in different situations

With the objective P1 total investment as a maximization goal, the effect measure is $R^{P}{}_{1n} = \{0.377, 0.026, 0.13, 0.156, 0.078, 1\}$; With the objective P2 total investment as a minimization goal, the effect measure is $R^{P}{}_{2n} = \{0.429, 0.364, 0.39, 1, 0.273, 0.338\}$; With the objective P3 total investment as a moderate goal, the effect measure is $R^{P}{}_{1j} = \{0.377, 0.026, 0.143, 0.156, 0.078, 1\}$.

4.4.5. Calculating the comprehensive effect measure and making the optimal decision

According to the measured values of each target, we can use the formula $R\sum_{\text{mn}} = \sum_{P=1}^{k} W_{P=1} \times R_{mn}^{P}$ to get the comprehensive effect of each investment project. The comprehensive validity of Projects 1, 2, and 3 is 0.64012, 0.75504, and 0.62829 respectively.

From the comprehensive measurement value of each investment project, the project (project 2) of the investment water supply workshop if found to have the best effect. First, the scheme effectively controls the internal resources consumption and external environment damage of Shanghai Baosteel, such that the comprehensive utility is effectively improved. The effect value of project one is 0.64012, the effect value of project two is0.75504, and the effect value of project three is 0.62829. According to the calculation results, the arrangement of item effect value from small to large is: item two, item three and item one. The actual connotation of the project effect value is under the environment factor, the social development factor, the resource change cost factor and so on, and at a certain weight proportion, the weight comprehensive result is the most effective. Project two is the most economical project plan, because it can combine the cost-related environmental income with the benefit income of the enterprise.

5. Conclusion

This paper takes Shanghai Baosteel Group as an example to analyze the value transfer of water resources, and uses the grey situation analysis method to construct the optimization model and find the best optimization scheme, so as to achieve the goal of improving economic efficiency and reducing environmental cost. This work has a distinct theoretical and practical significance. The contribution of this study is reflected in the following aspects: 1) the water resources are taken as the research object and the construction of the optimization model of the water resources value circulation is considered. The previous research is limited to general research on industry resources and does not involve a single specific element; 2) through the study of the model of the value circulation optimization of a typical steel enterprise in China—Shanghai Baosteel water resources—our work can provide theoretical and practical guidance for the circulation of water resources in China's iron and steel enterprises.

This paper has certain shortcomings. The division of departmental centers is biased. The production of iron and steel enterprises is not limited to sintering, hot rolling, continuous casting and other sectors. Because the index system of water resources accounting is not uniform, a measurement method is adopted that is unique to this paper. Future research can be further refined on the basis of this paper. It can compare the water resources value circulation of different iron and steel enterprises, or expand research on the model of water resource value transfer to industrial park fields. It can also discuss the similarities and differences of the optimization model of water resources value transfer between Chinese and foreign enterprises. In summary, research about the resource value transfer optimization system needs further improvement.

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