Research on Low-Carbon Operation Mechanism and Environmental Value Transformation of Waste Feed Resource Utilization Equipment under a Dual-Carbon Background

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ABSTRACT Under the dual-carbon situation, the carbon emission intensity of the equipment for recovering resources from waste feed is high and it is difficult to obtain environmental value. Firstly, an equipment-level carbon flow traceability model is established to find the carbon hotspots; then, a time-varying load-following control method based on moisture content is proposed to realize the on-demand heating; secondly, a multi-machine energy efficiency redistribution strategy under time-of-use electricity pricing and carbon factor constraint is established; finally, a life-cycle value conversion path is constructed to convert the carbon reduction contribution into carbon asset. The experimental results show that the power consumption per ton under follow-up control is reduced from 42.4 kW·h·t-1 to 33.9 kW·h·t-1, representing a 20.0% energy reduction, while the integrated operational carbon intensity (including heat and power) is reduced by 19. 4%; the peak power and daily cost are reduced by 81.0% and 31.0% respectively after the implementation of energy efficiency redistribution strategy; the present value of implied environmental value is 12,800 yuan, which accounts for 6 .5% of the investment. The conclusion shows that carbon reduction can be accumulated into carbon asset by opening up the conversion path; and dual-carbon synergy of equipment is improved. The near-infrared moisture measurement and load-following control provide an optical sensing basis for low-carbon equipment operation.

INDEX TERMS waste feed resource recovery,low-carbon operation,load-response control,carbon asset,near-infrared moisture sensing

I. INTRODUCTION

IN the current context of gradually implementing dual carbon strategy, carbon emission control of carbon emission in feed industry and breeding process is no longer limited in front-end energy consumption, but also in the whole process of waste disposal. Waste feed is a mixed body of processing by-products and breeding residues. It is a important link between agricultural cycle and carbon reduction target [1-2]. However, the current waste feed resources utilization equipment still adhere to the traditional high energy consumption operation mode. Meanwhile, the carbon emission constraint has no dynamic response ability of drying, crushing, conveying unit, and the carbon intensity of whole process remains in a high level. The more notice able problem exists in the fact that carbon emission reduction benefit brought by the equipment running in low carbon mode has long been beyond the current carbon trading and green finance accounting system, there is no link between “physically saving energy” and “value representation” [3]. Both of two situations seriously weakened the intrinsic motivation of relevant parties to actively promote low carbon technological transformation, and need to break through in two dimensions of operating mechanism design and path of value transformation.

Regarding the carbon emission problem in the field of waste feed treatment, domestic and foreign scholars have conducted a series of preliminary explorations. Rao and Sivalingam systematically analyzed the energy efficiency and environmental load of the drying process based on the energy-exertion-environment triple evaluation framework [4]; Singh et al. further quantitatively characterized the energy consumption structure and carbon emission pathway in the drying process of agricultural products from the perspective of exertion and environmental coupling [5]; Hollas et al. assessed the energy recovery and carbon emission reduction potential in the process of resource utilization of livestock waste through life cycle assessment [6]; at the same time, Deymi-Dashtebayaz et al. reviewed waste drying equipment and its energy supply methods from the equipment level, pointing out that the energy structure and operation mode have a significant impact on the carbon intensity of the system [7]. However, existing studies mostly focus on the energy efficiency improvement of single equipment or single link, lacking research on carbon flow tracing and coordinated control of the entire equipment group.

In response to the above-mentioned needs for carbon hotspot identification and coordinated optimization of equipment groups, the carbon flow tracing and dynamic coupling method of operating parameters has received attention in the field of carbon reduction in industrial processes in recent years. For example, Alsaleh and Aleisa constructed a triple bottom-line assessment system for the process of converting waste into animal feed based on life cycle assessment, incorporating environmental benefits into a comprehensive decision-making framework [8]; Liu et al. proposed a regionalized life cycle monetization method to transform environmental benefits such as carbon emission reduction into quantifiable economic value [9]; Wei S et al. systematically reviewed various process routes for converting waste into feed from the perspective of technical paths and environmental benefits, emphasizing the emission reduction potential and sustainable value in the process of resource utilization [10]. However, the integrated application of the above methods in the scenario of waste feed resource utilization is still lacking. To this end, this paper proposes a low-carbon operation mechanism that integrates equipment-level carbon flow traceability, load response and energy efficiency redistribution, and combines it with an improved ecological life cycle value transformation path, aiming to open up the key links from process carbon reduction to carbon asset accumulation.

The main research achievements of this paper are summarized in the following three aspects: First, an equipment level carbon flow traceability model of waste feed resource utilization process was established, and the accurate identification of dynamic carbon hotspots of drying, crushing and conveying unit were achieved, and the data basis of subsequent precise regulation was provided; Second, a coupled regulation strategy of "load response-energy efficiency redistribution" and real-time feedback of material characteristics and time-of-use electricity price signal were proposed, which could reduce the operating carbon intensity and energy cost at process optimization level and scheduling optimization level, respectively; Third, a whole life cycle transformation model from total physical energy saving and carbon reduction to the present value of external environmental value was established, and the present carbon asset gain effect of low-carbon operation measure over a long period and its sensitivity to key parameters were quantitatively revealed.

II. HOLOGRAPHIC MAPPING OF MULTI-SOURCE CARBON FLOW AND THERMODYNAMIC STATE IN THE PROCESSING PROCESS

To achieve refined source tracing and thermodynamic state visualization of carbon emissions throughout the entire waste feed resource recovery process, this section constructs an equipment-level carbon flow accounting and state mapping model covering three units: drying, crushing, and pneumatic conveying. In the drying unit, carbon flow mainly consists of direct emissions from fuel combustion in the hot air furnace and indirect emissions from induced draft and drive motors. This study uses a paddle-type pre-dryer as the object, establishing a heat balance equation based on inlet and outlet air temperatures, material inlet and outlet moisture content, and residence time. The effective heat consumption required for evaporation per unit mass of moisture is calculated, and fuel consumption is inferred from the combustion equipment's thermal efficiency. Direct carbon emissions are calculated based on the lower heating value of the fuel and the default emission factor, while indirect emissions are obtained by integrating the operating power of the dryer's main and auxiliary motors. Furthermore, the specific enthalpy change is introduced to characterize the thermody namic state. While moisture is detected at the outlet, a virtual sensing model based on the axial heat-and-mass transfer gradient is employed. This model uses the outlet moisture and inlet/outlet temperature differences to back-calculate the internal drying rate curve, identifying the critical inflection point to provide an indirect yet comprehensive mapping of the non-uniform state inside the paddle-type dryer.

Carbon emissions from crushing unit are indirect carbon emissions from electricity. The power consumption of hammer mill shows a nonlinear change with moisture content of materials, feeding rate and aperture of screen. This study establishes a corrected model of power consumption per unit mass of materials in milling process referring to Bond's milling work theory. The specific power consumption is online monitored by main unit current and instantaneous output. To achieve dynamic traceability, this value is coupled with the realtime marginal carbon emission factor of the local power grid (updated via the regional energy management system), rather than a static annual average, to calculate the instantaneous carbon intensity of the electricity being physically consumed. For thermodynamic state mapping method, the change of particle size distribution of materials before and after milling and temperature rise of materials after milling are selected as state variables, and then the increase of ineffective energy consumption due to over-milling is evaluated. Carbon emissions from pneumatic conveying unit are indirect carbon emissions from electricity. Conveying pressure loss is affected by pipeline resistance characteristic, airflow velocity and solid-gas ratio. This study establishes the functional relationship between shaft power of fan and material conveying volume based on the pressure-flow characteristic curve under design conditions of conveying system, and then calculate hourly power consumption and corresponding carbon flow by combining with the operating frequency of inverter. The thermodynamic state during conveying process is characterized by pressure drop of pipeline and gas temperature rise, and then used to evaluate the distortion of unit carbon intensity under low-load conveying conditions.

III. EQUIPMENT LOAD RESPONSE MECHANISM BASED ON TIME-VARYING CHARACTERISTICS OF MATERIAL MOISTURE CONTENT

When the waste feed is in the drying process, the moisture content of the waste feed shows a nonlinear decreasing characteristic with the degree of heat and mass transfer. In this section, an equipment load followup control mechanism based on the feedback of material moisture content is proposed. In the detection stage, a near-infrared online moisture meter is arranged at the discharge outlet of paddle type pre-dryer to continuously collect the surface moisture content signal of the material, and the sampling period is 2 s. To align with the long residence time and high thermal inertia of the industrial paddle dryer, the control system employs a time-average integration strategy over a 5-minute sliding window. This high-frequency raw data is used to calculate a stable trend, which then informs the gas valve adjustment via a PID controller with a large derivative time constant, effectively preventing system oscillations or chattering. At the same time, based on the target moisture content threshold (usually 13%–14% is the lower limit of material storage safety), the current moisture content deviation is calculated in real time as the basis of load adjustment.

At the control strategy level, a segmented variable structure load response rule is constructed. In the initial drying stage, the material has a high moisture content, and the evaporation rate is controlled by surface vapor ization. At this time, the hot air temperature is set to the upper limit of the process allowable temperature (140°C), and the dryer spindle speed is maintained at the rated value to quickly remove free moisture. When the moisture content drops to the critical transition point of approximately 18%, the drying enters a deceler ation phase. Moisture migration is controlled by internal diffusion; continuing to maintain a high temperature would cause the surface of the material to overheat while internal moisture is difficult to escape. At this point, the control system dynamically adjusts the opening of the hot air furnace gas regulating valve according to the moisture content decay gradient, so that the hot air temperature smoothly decreases along the preset temperature-moisture content reference trajectory, eventually stabilizing at the lower limit of 100°C when approaching the target moisture content. Simultaneously, the dryer spindle speed is synchronously adjusted downwards to extend the residence time of the material in the drying chamber, completing the removal of remaining moisture with lower heat intensity and avoiding energy waste and material quality deterioration caused by short-term high-temperature shocks.

The mathematical description of the above control logic is as follows: Let the detected moisture content of the material at time t be $M(t)$, and the target moisture content be M_{target}. Then, the hot air temperature setpoint is given by

$$T_{\text{set}}(t) = T_{\min} + (T_{\max} - T_{\min}) \cdot \frac{M(t) - M_{\text{target}}}{M_0 - M_{\text{target}}} \cdot \alpha \quad (1)$$

Where, $T_{\max}$ and $T_{\min}$ are the upper and lower limits of temperature adjustment, respectively, M_0 is the initial moisture content, and α is the decay rate correction factor, which is dynamically adjusted according to the real-time drying rate to prevent temperature fluctuations. Furthermore, to enhance the system's adaptability in discontinuous operation scenarios, this response mechanism further couples the equipment start-up and shutdown status with the feedforward compensation of the amount of material to be processed.

IV. MULTI-MACHINE COLLABORATIVE ENERGY EFFICIENCY REDISTRIBUTION STRATEGY UNDER DISCONTINUOUS OPERATION CONDITIONS

This strategy is restricted by both time-of-use pricing signal and grid carbon emission factor. It adopts a multi-machine coordinated energy efficiency redistribution strategy to realize orderly shifting of energy consumption process to low carbon emission period by adjusting the start-up and shutdown sequence and operating power of each unit. The core idea of this strategy is to design a scheduling model to minimize the cumulative energy cost of each day and total carbon emission. The decision variables are start time and expected running duration of all batches of drying, crushing and conveying process. The constraints are maximum value of rated power of equipment, logic of process before and after, capacity of buffer silo and order delivery deadline, as shown in Table 1.

TABLE 1. Key Parameters and Constraints of the Multi-Equipment Collaborative Scheduling Model

Category	Item	Setting/Description
Decision variable	Start time and duration of each process	Discrete encoding with 15 min time slot
Optimization objective	Daily electricity cost + carbon penalty term	Penalty factor $\lambda = 0.3$
Equipment power	Dryer / Grinder / Blower capacity	7.5 kW / 22 kW / 5.5 kW (Total 35 kW)
Flexible adjustment	Frequency conversion range	60%–100% of rated power
Buffer silo constraint	Capacity of pre-grinding buffer silo	$\leq$1000 kg (2 batches)
Time constraint	Maximum completion time per batch	$\leq$4 h
Solution algorithm	Improved Particle Swarm Optimization (PSO)	Population size 30, max iterations 100

The objective function is composed of two weighted terms: first, the time-of-use electricity cost based on time-of-use pricing; and secondly, the indirect carbon emission penalty based on the regional power grid's dynamic carbon emission factor. With the introduction of penalty factor λ, the carbon constraint is converted into an equivalent economic cost. When a conflict arises between 'low-cost/high-carbon' valley power and 'high-cost/low-carbon' periods, the penalty factor λ acts as a weighting mechanism. By adjusting λ based on the enterprise's priority (e.g., carbon-neutral mandates vs. immediate OpEx), the model achieves a Pareto optimal solution that balances economic savings with carbon reduction targets.

Due to the randomness of the arrival of materials and equipment failures existing in the actual production, the above strategy is implemented in the rolling time-domain interval. That is, the scheduler implements a 4-hour rolling window and solves the optimal start-stop sequence in the future window area according to the current level of silos and batches and the latest electricity price information and carbon emission factor. The solution algorithm uses improved particle swarm optimization method. Discrete encoding is used to represent the start time slot of each batch and process, and population iteration approximates the global optimal solution. To achieve the real-time performance, the maximum number of iterations and the convergence tolerance are restricted. And heuristic rules are implemented as backup schemes in the optimization interval.

At the process-level power allocation level, the above strategy further fine-grained the flexible range of operating power for each unit. For the crusher, variable frequency drive is implemented and the speed can be continuously adjusted in the range of 60% - 100% of the rated power. When the optimal start-stop sequence in the scheduling model decides to reduce the total load in a certain period of time, it is preferred to reduce the frequency of the conveyor fan to reduce the pneumatic conveying pressure loss and power consumption. While the speed of the crusher is adjusted according to the filling level of the downstream silo to prevent blockage of silos due to too much frequency reduction. The gas flow rate of the hot air furnace of the dryer's dryer can also be coordinated with the power reduction within the certain range, so that the heat and electricity load change over time in sync.

V. CONSTRUCTION OF THE OPERATIONAL LIFE-CYCLE VALUE TRANSFORMATION PATH FOR IMPLICIT ENVIRONMENTAL GAINS

The construction of the value transformation path follows a four-step progressive logic focusing on the usephase impact within the equipment's service life: "boundary definition—benefit aggregation—present value conversion—sensitivity verification." First, the system boundary is set as the operational life cycle (use-phase) of a single treatment unit from commissioning to scrapping, focusing on the annual carbon emission reduction contribution during the operation and use phase. Given the small proportion of carbon emissions during equipment manufacturing and waste disposal and their high data uncertainty, these are treated as background values and not included in the incremental benefit aggregation. In the benefit aggregation stage, implicit environmental gains consist of three components. The first is direct carbon emission reduction benefit, which is the reduction in carbon dioxide emissions during the equipment operation phase compared to the traditional baseline model multiplied by the current carbon market trading price. The annual emission reduction is calculated based on the electricity and heat savings data obtained from Experiments 1 and 2, combined with the grid carbon emission factor and the default fuel emission factor. The second is the by-product substitution benefit; the dried and pulverized waste feed can be used to replace a portion of conventional feed raw materials, thereby avoiding carbon emissions during the corresponding proportion of raw material production. This study calculates the indirect emission reduction contribution based on the substitution ratio, while applying a quality-correction coefficient ($\eta = 0.85$) to account for potential nutritional degradation and the energy consumption required for specialized sterilization and microbial load control of the waste feed, ensuring the substitution benefit is not overestimated, and converts it into monetary benefits at the carbon price equivalent. Thirdly, there is the potential benefit of carbon inclusion. Referring to the verification rules for energy-saving technological transformation projects in local carbon inclusion methodologies, the annual emission reduction is converted into tradable carbon inclusion certified emission reductions at a certain issuance ratio and included in the long-term benefit expectation.

In the present value conversion stage, considering the intertemporal distribution characteristics of environ mental benefits, a dynamic discounting method is used to uniformly convert the environmental gains generated in each year into the present value on the assessment benchmark date. The calculation formula is as follows

$$V_{\text{env}} = \sum_{t=1}^{n} \frac{R_{\text{carbon},t} + R_{\text{byprod},t} + R_{\text{ph},t}}{(1+r)^t} \tag{2}$$

Where V_{env} is the present value of the implicit environmental value, n is the evaluation period (taking the equipment depreciation period of 5 years), $R_{\text{carbon},t}$, $R_{\text{byprod},t}$, and $R_{\text{ph},t}$ are the direct carbon emission reduction benefit, by-product substitution benefit, and expected carbon inclusion benefit in year t, respec tively, and r is the discount rate (taking the industry benchmark of 5%). In the sensitivity verification phase, given that carbon trading prices and the actual service life of equipment are two key uncertainties affecting the conversion results, this study sets up a multi-scenario analysis scheme with carbon prices fluctuating within

a range of ±30% of the benchmark value and the depreciation period extended to 8 years, in order to assess the robustness of the value conversion results to changes in different parameters.

VI. VERIFICATION OF LOW-CARBON OPERATION MECHANISM AND ENVIRONMENTAL CONVERSION EFFICIENCY OF PROCESSING EQUIPMENT

A. EXPERIMENTAL SETUP AND PREPARATION

The experiment was conducted with a pilot-scale waste feed resource utilization line with a capacity of 500 kg/ h. The equipment includes paddle pre-dryer (JYG-1.5, installed power 7.5 kW), hammer mill unit (SFSP56×40, installed power 22 kW), pneumatic negative pressure conveying closed-loop system (fan power 5.5 kW), which were connected in series.The raw material was waste compound feed from a large-scale egg-laying chicken farm. The moisture content of the raw material was 18.2 ~23.5%, and the average lower calorific value was 15.8 MJ/kg.The process parameter monitoring terminal includes online near-infrared moisture analyzer (MCT460, detection interval 2 s), three-phase intelligent electrical parameter acquisition module (voltage/ current accuracy class 0.5), flue gas analysis unit (Testo 350, CO2 range 0~50% Vol). The operating data will be uploaded to the database of industrial control computer at 1Hz through PLC control cabinet online.In addition, the carbon accounting boundary uniformly takes the carbon emission factor of regional power grid in 2023 published by Ministry of Ecology and Environment (0.5703 tCO2/MWh) as the benchmark value of indirect power emission.

B. COMPARATIVE EXPERIMENT OF OPERATING CARBON INTENSITY UNDER DIFFERENT LOAD RESPONSE STRATEGIES

In order to explore the carbon intensity characteristics of waste feed treatment process under different operating strategies, taking 50 consecutive batches as the research object, a comparative experiment was carried out in the pilot production line with processing capacity of 500 kg·h^{-1}. Two operating modes were designed as follows: traditional constant temperature and constant speed mode and follow-up control mode. Mode 1 maintained the drying temperature at 120°C and constant speed of equipment. Mode 2 regulated the temperature of hot air and crushing and conveying speed of equipment in real time according to the signal feedback from online near-infrared moisture meter. In the process, the electricity consumption per ton was recorded for each batch. Then, based on the regional power grid carbon emission factor, the operational carbon intensity was calculated in turn for each batch to reflect the carbon emission characteristic differences under the two modes.

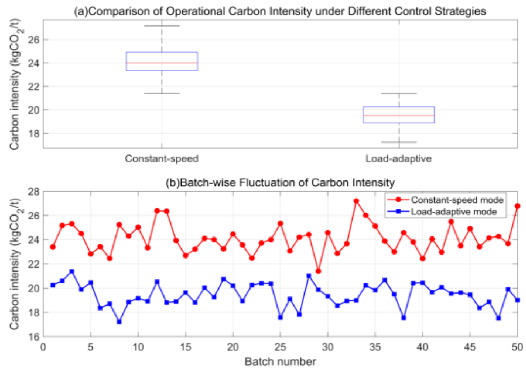

FIGURE 1. Evaluation of Operational Carbon Intensity under Different Load Response Strategies

Figures 1 (a-b) show the distribution comparison and batch-by-batch fluctuation characteristics of operational carbon intensity under the two control strategies, respectively. The experimental results show that the pro posed follow-up control strategy exhibits significant low-carbon operation advantages throughout the entire waste feed drying-crushing-conveying process. Data from 50 consecutive batches of processing showed that, compared to the traditional constant-temperature, constant-speed mode, the average power consumption per ton of waste feed processed by the servo-controlled mode decreased from 42.4 kWh·t^{-1} to 33.9 kWh·t^{-1}, a reduction of 20.0%; the corresponding operating carbon intensity decreased from 24.12 kgCO2·t^{-1} to 19.45 kgCO2·t^{-1}, a reduction of 19.4%. Simultaneously, the batch-to-batch standard deviation of carbon intensity decreased from 1.20 to 0.97, indicating that this strategy not only effectively reduced the absolute amount of energy consumption and carbon emissions but also improved the robustness of the process to fluctuations in material properties.

C. SIMULATION AND EXPERIMENTAL STUDY ON ENERGY EFFICIENCY REDISTRIBUTION OF EQUIPMENT GROUPS UNDER MULTIPLE OPERATING CONDITIONS

In order to explore the energy consumption performance of coordinated scheduling of equipment groups in the case of time-of-use pricing, multi-condition combined experiments of dryers, crushers and conveyor fans were carried out on the waste feed resource recovery pilot production line with 4 tons of daily processing capacity. The experiment took two ways of operation scheduling, traditional sequential start-stop and energy efficiency redistribution based on electricity price signal as objects. The former starts and stops all equipment connectedly according to the arrival time sequence, and the later aims to reduce the daily electricity cost by adjusting the start time of high power consumption process to off-peak period. During the experiment, the hourly power of each device was recorded continuously, and the average power and cumulative daily electricity cost of on-peak, flat and off-peak period were calculated.

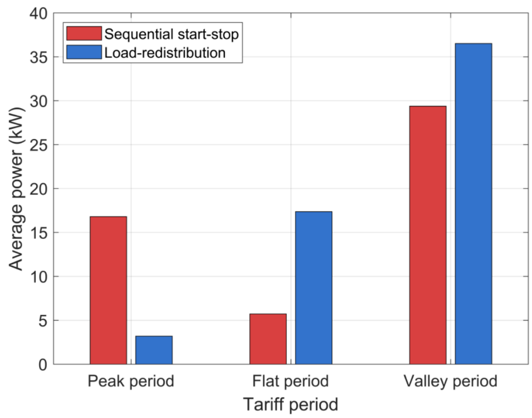

FIGURE 2. Energy Efficiency Redistribution Evaluation of Equipment Groups under Multiple Operating

As shown in Figure 2, the energy efficiency redistribution strategy effectively reshaped the power temporal distribution of the equipment group. Compared with the traditional sequential start-stop mode, this strategy reduced the average operating power during peak hours from 16.8 kW to 3.2 kW, a reduction of 81.0%, significantly alleviating the pressure of peak load on the power grid. Simultaneously, by shifting high-power processes such as crushing to off-peak hours, the daily electricity cost decreased from 287.5 yuan to 198.4 yuan, a reduction of 31.0%. These data confirm that the proposed scheduling algorithm possesses both excellent peak-shaving and valley-filling capabilities and operational economy in time-of-use pricing scenarios.

D. QUANTIFICATION AND SENSITIVITY ANALYSIS OF IMPLICIT ENVIRONMENTAL VALUE THROUGHOUT THE LIFE CYCLE

To evaluate the external environmental value contained in the low-carbon operation of waste feed resource recovery equipment, this study establishes an improved ecological life cycle value assessment framework to integrate the energy saving and carbon emission reduction data acquired in Experiment 1 and 2 into a common accounting boundary. The time period of the evaluation is 5 years after the equipment commissioning. The discount rate is set as 5%. The carbon emission factor of grid is 0.5703 $kgCO2{\cdot}kW^{-1}{\cdot}h^{-1}$. The benchmark price of carbon trading is established according to the average price of national carbon market in the past year, which is 58.6 $yuan{\cdot}t^{-1}$. In addition, the two-factor sensitivity test of carbon price fluctuation range (±30%) and the depreciation period of equipment (5–8 years) on the environmental value transformation results are conducted for sensitivity test.

TABLE 2. Life Cycle Quantification and Sensitivity Analysis of Implicit Environmental Value

Parameter	Baseline value	Fluctuation range (sensitivity analysis)
Carbon trading price ($CNY{\cdot}t^{-1}$)	58.6	41.0–76.2
Discount rate (%)	5	—
Equipment depreciation period (year)	5	5–8
Annual carbon emission reduction ($tCO2{\cdot}a^{-1}$)	30.2	—
Present value of embodied environmental benefit (10^4 CNY)	1.28	0.94–1.63
Proportion of initial equipment investment (%)	6.5	4.8–8.3

Table 2 shows that, under a 5-year operating cycle and a carbon price benchmark of RMB 58.6 per t-1, the present value of the implicit environmental value generated by the waste feed resource recovery equipment through low-carbon operation is RMB 12,800, accounting for approximately 6.5% of the initial investment in a single set of equipment. Sensitivity analysis shows that when the carbon trading price fluctuates within ±30%, this proportion varies between 4.8% and 8.3%; if the depreciation period is extended to 8 years, the value proportion can increase to 7.9%. These quantitative results confirm that the constructed value trans formation path can effectively convert energy-saving and carbon-reduction behaviors at the operational level into measurable carbon asset gains. Although the current proportion is limited, its economic attractiveness will gradually emerge as the expectation of rising carbon prices strengthens.

VII. CONCLUSION

To solve the problems of high energy consumption and difficulty in realizing the environmental value of waste feed resource recovery equipment under the dual-carbon background, this paper constructs a carbon flow traceability and "load response-energy efficiency redistribution" synergistic control mechanism, and establishes a full life-cycle environmental value transformation path. The experimental results show that the mechanism proposed in this paper can effectively reduce the operational carbon intensity and peak load of the treatment process, and improve energy efficiency significantly. It is also proved that low-carbon operating behavior can be quantified as implicit carbon assets with clear economic significance, providing the green equipment upgrade value anchor. The limitations of this research are the pilot-scale and single-material-type limitations. Subsequent research will further expand the adaptability verification of multi-source waste feed and explore the dynamic value accounting method under the carbon inclusive mechanism.

AUTHOR CONTRIBUTIONS

Conceptualization –Rui Zhao, Yanjiao Zhang, Jie Cao, Xiaohan Pang, Xiaohe Zhang and Pingchuan Jin; method

ology – Rui Zhao, Yanjiao Zhang, Jie Cao, Xiaohan Pang, Xiaohe Zhang and Pingchuan Jin; investigation – Rui Zhao, Yanjiao Zhang, Jie Cao, Xiaohan Pang, Xiaohe Zhang and Pingchuan Jin; writing-original draft preparation – Rui Zhao, Yanjiao Zhang, Jie Cao, Xiaohan Pang, Xiaohe Zhang and Pingchuan Jin. All authors have read and agreed to the published version of the manuscript.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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