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Article

Optimizing environmental costs and economic benefits in new energy vehicle production: A case study of FAW Hongqi in China

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Abstract: This study focuses on the environmental cost accounting and economic benefit optimization of China's FAW Hongqi New Energy Vehicle manufacturing enterprise under uncertain conditions, within the context of the emission permit system This study calculates the pollution situation throughout the manufacturing and production process of FAW Hongqi new energy vehicles, and constructs a multi-level environmental cost evaluation system for FAW Hongqi new energy vehicle manufacturing projects. Through the interval fuzzy model of FAW Hongqi new energy vehicle manufacturing projects, the maximum economic benefits of the enterprise are simulated. The research results indicate that the pollution emissions of enterprises are mainly concentrated in the three processes of welding, painting, and final assembly. Enterprises use their own exhaust gas and wastewater treatment devices to meet the standards for pollution emissions. At the same time, solid waste generated during the automobile manufacturing process is handed over to third-party companies for treatment. Secondly, based on the accounting results of enterprise pollution source intensity and a multi-layer environmental cost evaluation system, the environmental costs of enterprises are accounted for, and the environmental costs are represented in interval form to reduce uncertainty in the accounting process. According to the accounting results of enterprise environmental costs, the main environmental costs of enterprises are environmental remediation costs caused by normal pollution discharge and purchase costs of environmental protection facilities. Pollutant emission taxes and routine environmental monitoring costs are relatively low. Enterprises can adopt more scientific solutions from the aspects of environmental remediation and environmental protection facilities to reduce environmental costs. After optimization by the fuzzy interval uncertainty optimization model, the economic benefits of the FAW Hongqi new energy vehicle manufacturing project were [101,254.71, 6278.5413] million yuan. Compared with the interval uncertainty optimization model, the lower bound of economic benefits increased by 57.68%, and the upper bound decreased by 12.08%, shortening the results of the economic benefits interval. Clarify the current environmental pollution situation of FAW Hongqi's new energy vehicle manufacturing enterprise, provide data support for sustainable development of the enterprise, and provide reasonable decision-making space for enterprise decision-makers.

Keywords: environmental cost; economic benefit; new energy vehicles; sustainable manufacturing

1. Introduction

Since the economic reform in 1978, China, as the largest developing country, has been globally recognized as one of the largest economies in the world. After four decades of rapid economic development, China's GDP exceeded 90 trillion yuan in

2018, accounting for 15.9% of the world economy (Xu et al., 2023a). In the context of steady economic growth, China has gradually intensified its efforts to promote environmental protection, and prioritized the management and treatment of pollutant discharge as the focus of environmental protection (Zhou, 2021). In order to enhance the standardization of pollutant discharge control by enterprises and improve the effectiveness of their environmental management, China has gradually introduced a pollutant discharge permit system (Wang and Yang, 2016). The emission permit system is a key component of the current version of the basic system of international environmental management, a system of existing laws and regulations, and a concrete guiding standard and regulatory intervention measures advocated and proposed around the discharge practice process of fixed pollution sources (Bi et al., 2011; Guo et al, 2021). Take the United States as an example, when determining the pollutant emission limits stipulated in the fixed pollution source license, it is necessary to consider both the allowable limits of technical pollutants, so that the current pollutant treatment level can meet the requirements, and the allowable limits of pollutants based on water quality, so as to ensure that the receiving water body can maintain its specific use. Compared with the discharge permit system adopted worldwide, China has drawbacks in improving water quality. First, the current total emission limits based on the capacity of water functional zones are allocated and controlled by administrative regions, while emission limits specified in discharge permits are measured at the enterprise level rather than the regional level (Hu et al, 2018; Zhao et al, 2022). Therefore, it is necessary to explore a scientific environmental cost calculation method based on the pollutant discharge permit system to further promote the sustainable development of enterprises.

With the continuous development of the automobile manufacturing industry, modern automobile manufacturing will generate a large amount of waste and emissions of pollutants. For example, in the production process of automobile parts, a large amount of production dust and noise such as aluminum powder and welding dust will be generated. In the stamping, welding, painting, and final assembly processes of automobile manufacturing, heavy polluting gases such as butanone, benzene, toluene, xylene, styrene, tin dioxide, copper smoke, nitric oxide, nitrogen dioxide, ozone, and carbon monoxide are produced (Al-Shami and Rashid, 2021; Ghandehariun et al, 2016; Kultan et al., 2022). Therefore, for the future development of the automobile manufacturing industry, it is of certain practical significance to study the scientific environmental cost calculation method and select the appropriate automobile manufacturing process to solve the environmental pollution treatment problem of the auto parts industry.

In the production process of automobile enterprises, the uncertainty and variability of influencing factors such as employees' environmental quality, enterprise production scale and production technology make plan formulation more complicated and difficult (Xu et al., 2023b). Aiming at various uncertainties in the research process, there are two main optimization methods: interval programming and fuzzy programming (Robers and Ben-Israel, 1969; Arjmandzadeh and Safi, 2017; Shih et al, 2009). Chang (2006) derived a new interval goal programming method by studying the mixed binary preference decision problem related to the penalty function used in goal programming, and at the same time added binary variables constrained by environment to enhance the usability of the model. Li et al. (2022) proposed a solution method based on the approximation of the nearest interval based on the fuzzy number with all parameters as trapezoid intervals, obtained bytes with different specific meanings by decomposition, and verified the rationality and practical significance of the method through the algorithm. The interval model usually adopts the two-step method for the optimal solution. Wan et al. (2011) Proposed a two-step solution method to find the interval solution of the original model through the developed two-step sampling method, and the numerical results show that the model is helpful to solve the triangular belt drive system. In this study, the two-step method will be used to solve the constructed interval optimization model, and the reliability of the decision scheme will be ensured by a variety of constraints. Li et al. (2002) introduced a new type of fuzzy game matrix, which combined fuzzy linear programming solution method and multi-objective programming solution method to solve fuzzy linear programming, and demonstrated the effectiveness of the model through the numerical results. Veeramani and Sumathi (2014) proposed a fuzzy linear programming problem in which the objective function cost, resources and technical coefficients are triangular fuzzy numbers, and transformed the fuzzy linear programming problem with triangular fuzzy numbers into a deterministic multi-objective linear programming problem, reducing the single-objective linear programming problem and making the model more efficient. Wang et al. (2020) constructed a consensus framework for environmental information, environmental costs, and corporate value, and found that environmental costs are negatively correlated with corporate value. Environmental information can effectively alleviate the negative correlation between environmental costs and corporate value. From the perspective of environmental cost management, Shang and Chen (2021) established an environmental cost management model and found that the environmental cost of the research enterprise increased from 17.03% to 17.86%, providing suggestions for the company's environmental cost accounting. However, few existing studies have focused on the automotive industry, and there is a gap in the environmental cost statistics of the automotive industry.

Based on China's emission permit system, this study fully considers the requirements of China's emission permit system on the automobile industry, starts from the whole process of production and manufacturing of FAW Hongqi new energy vehicles, and accounts the environmental cost of the whole process of production and manufacturing of FAW Hongqi new energy vehicles based on various environmental cost inputs of FAW Hongqi new energy vehicles manufacturing enterprises. Clarify the size of the internal environmental cost of FAW Hongqi new energy automobile enterprise, and introduce interval planning and fuzzy programming methods to establish the economic benefit optimization model of the whole process of FAW Hongqi new energy automobile manufacturing, take the economic benefit maximization of FAW Hongqi new energy automobile enterprise as the objective function, fully consider the actual uncertain factors to enhance the stability of the model. To provide flexible, feasible and scientific and reasonable environmental cost allocation scheme for leading departments of enterprises.

2. Materials and methods

2.1. Introduction of FAW Hongqi new energy vehicle project

China FAW Co., LTD. (FAW for short) has always been committed to the development and production of self-branded automobile products. The “Red Flag” brand is a household name in China and the core value brand of FAW. In 2018, it has achieved a total sales volume of 33,028 vehicles. The future development goal of the new Red Flag is to strive for 200,000 vehicles in 2020, exceed 400,000 vehicles in 2022, strive to exceed 600,000 vehicles in 2025, and strive to hit 800,000 to 1 million vehicles in 2030. Changchun Changfa New Energy Industry Investment and Construction Co., Ltd. is responsible for the construction of Changchun Qi Kai District Prosperity Intelligent Manufacturing Industrial Park project. After the project is completed, FAW Company uses the plant and production equipment of Prosperity Industrial Park by lease. Prosperity Intelligent Manufacturing Industrial Park can meet the supporting demand of 200,000 Hongqi cars per year of the settled enterprises. Faw’s “China FAW Hongqi New Energy Vehicle Factory E111 Model Project” is located in the factory area of Prosperity Intelligent Manufacturing Industrial Park, Changchun. It covers an industrial land, covering an area of 755,485 m^2. The buildings include the main workshop such as welding joint workshop, painting workshop, assembly workshop, battery electric driving room, joint power station building, logistics distribution center, oil chemical storage, dangerous chemical storage, guard and other public auxiliary buildings, with a total construction area of 434,983.3 m^2. The design annual output of new energy models (E111) is 80,000, double shift system, annual operation of 250 days. It is expected to be put into operation by the end of 2021.

2.2. FAW Hongqi new energy vehicle environmental cost accounting

Enterprise environmental cost, through the establishment of indicators, changes the performance of various aspects of the organization’s environmental protection work into the content that is easy to evaluate, aiming to evaluate the impact of enterprise activities, products and services in the construction planning and projects on the environment, and maintain good environmental quality (Roos and Kliemann Neto, 2017). As an enterprise’s environmental cost accounting is a process of self-evaluation, the scope of implementation depends on its own will. But in order to make a correct evaluation, the extension and connotation of the scope must be carefully designed in order to play the role of environmental cost accounting (Gschösser and Wallbaum, 2013; Wattage and Soussan, 2003). The contents of environmental cost accounting mainly include two aspects: one is to select appropriate indicators according to different environmental problems arising in different industries; the other is to collect relevant data and select reasonable statistical analysis techniques (Yang et al., 2021). Given the general situation of the automobile manufacturing industry and the characteristics of continuous pollution, it is necessary for enterprises in the automobile manufacturing industry to introduce the application of the environmental cost accounting index system of automobile manufacturing (Helman et al., 2023).

When evaluating the environmental cost of enterprises in the automobile manufacturing industry, since the automobile manufacturing industry itself is a complex industrial chain, the impact of each process in its production on the environment should be taken into account, and we need to consider not only the environmental impact of its own production. But also include indicators such as enterprise environmental management, environmental finance and external impact (Liang and Yao, 2022; Zhang et al, 2022). The evaluation system of environmental cost is also characterized by complexity, which cannot be listed with simple indicators, nor can it be blindly added without considering its reflected effects. It should be analyzed layer by layer, and different indicators at different levels should be fully taken into account to build a multi-level index system with hierarchical structure. It can reflect all aspects related to environmental costs and help evaluate the level of environmental costs of automobile manufacturing enterprises (Zhang et al., 2023; Motschman et al., 2020; Wei et al., 2017; Jane et al., 2009; Choi and Ahn, 2015). Therefore, in view of the incompleteness of the current environmental performance evaluation index system of automobile manufacturing enterprises, it is the best optimization idea to build a multi-level evaluation index system, so as to better reflect the real environmental cost of enterprises. In this study, 4 first-level standards and 12 second-level standards are established as the environmental cost accounting system of FAW Red Flag enterprise, and the environmental cost of FAW Red Flag new energy automobile enterprise is accurately calculated through the multi-level index system, as shown in **Figure 1**.

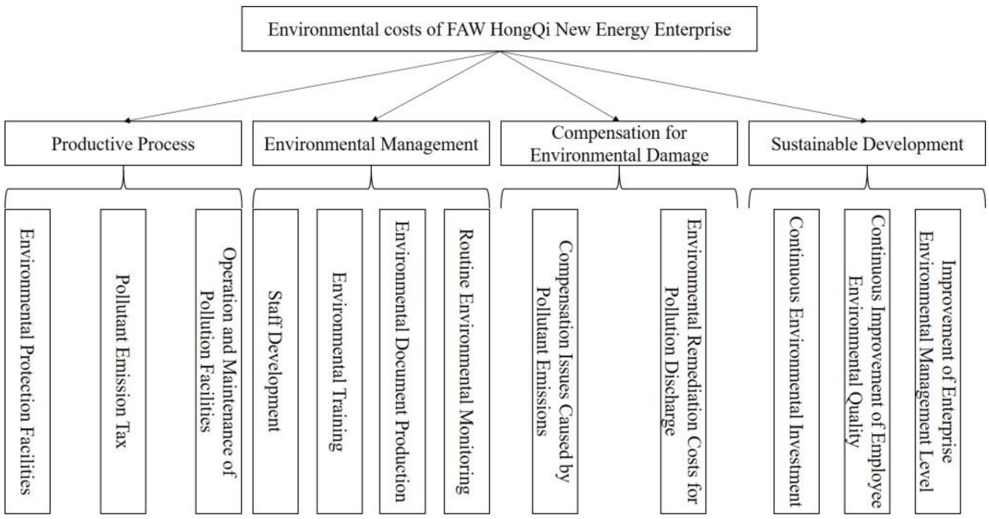

Figure 1. Multi-level accounting system of environmental cost of FAW Red Flag new energy vehicles.

2.3. FAW Hongqi new energy vehicle manufacturing project economic benefit fuzzy-interval uncertainty optimization model

This study systematically analyzed the economic benefit production process of FAW Hongqi new energy vehicle manufacturing project (fixed environmental protection facilities, pollutant emission tax and operation and maintenance investment of environmental protection facilities), environmental management (personnel expenses, environmental training, environmental document production and routine environmental monitoring), environmental damage compensation (damage caused by pollutant emission and its recovery cost) and enterprise environmental sustainability Development input (environmental sustainable development input, continuous improvement of environmental personnel literacy and improvement of the overall environmental management level of enterprises) and other parameters are uncertain between regions. Based on the "Ecological Protection Red Line, Environmental Quality bottom Line, Resource Utilization Ceiling and Ecological Environment Access List Preparation Technical Guide" and China's emission permit system, The interval linear programming method was used to construct the optimization model of economic benefit interval uncertainty of FAW Hongqi new energy vehicle manufacturing project, and a geographical relationship between environmental cost and economic benefit was established. However, the interval optimization model lacks the fuzziness of various environmental costs in the economic benefit process of FAW Hongqi new energy automobile manufacturing project under complex realistic environment. Some parameters, variables and objective functions have fuzziness consistent with the reality. For example, the automobile sales price is very fuzzy when it is affected by market factors. The automobile manufacturing cost also presents strong fuzzy uncertainty due to the change of raw materials (Peidro et al., 2009; Peidro et al., 2010). In addition, it is difficult for the interval optimization model to deal with the fuzzy uncertainty caused by the above fuzzy uncertainty parameters, resulting in certain defects in the fuzzy optimization of the model output (Figueroa-García et al., 2012; Li et al., 2009). The fuzzy-interval uncertainty optimization method combines the theory of interval mathematics with the theory of fuzzy mathematics, and applies it to the traditional interval uncertainty optimization model to solve the interval uncertainty problem in the process of environmental cost accounting of FAW Hongqi Enterprise by representing the model parameters in the form of interval number, so as to obtain a more reasonable and scientific optimal solution. This article couple's interval planning and fuzzy programming to apply to the environmental cost accounting model of automotive enterprises, establishes a scientific and standardized environmental cost accounting method, and improves the stability of model application. The model is as follows:

Objective function:

$$max = \lambda^{\pm} \tag{1}$$

Constraints:

(1) Constraints on economic benefits:

$$f_1^{\pm} - f_2^{\pm} - f_3^{\pm} - f_4^{\pm} - f_5^{\pm} \geq f^{+} - (1 - \lambda^{\pm}) \times (f^{+} - f^{-}) \tag{2}$$

$$f_1^{\pm} = N^{\pm} \times (VUP^{\pm} - APC^{\pm}) \tag{3}$$

$$f_2^{\pm} = \sum_{i=1}^{3} FAS^{\pm} + \sum_{i=1}^{3} PET^{\pm} + \sum_{j=1}^{9} SWT^{\pm} + \sum_{i=1}^{3} EFO^{\pm} \tag{4}$$

$$f_3^{\pm} = \sum_{m=1}^{3} PES^{\pm} + \sum_{n=1}^{4} ETS^{\pm} + \sum_{n=1}^{4} EDP^{\pm} + \sum_{k=1}^{4} REM^{\pm} \tag{5}$$

$$f_4^{\pm} = \sum_{l=1}^{3} PDC^{\pm} + PRC^{\pm} \quad (6)$$

$$f_5^{\pm} = CEI^{\pm} + EMT^{\pm} + EEM^{\pm} \quad (7)$$

(2) The cost of enterprise environmental facilities (fixed assets) shall not exceed 10% of the total cost of equipment and installation.

$$\sum_{i=1}^{3} FAS^{\pm} \leq 0.1 \times (EI^{-} + (1 - \lambda^{\pm}) \times (EI^{+} - EI^{-})), \forall i \quad (8)$$

(3) The annual operation and maintenance investment of the enterprise environmental facilities shall not exceed 0.1% of the annual profit of the enterprise.

$$\sum_{i=1}^{3} EFO^{\pm} \leq 0.001 \times f^{\pm} \quad (9)$$

(4) Enterprise personnel expenses and related environmental training costs should not exceed 0.2% of the annual profit of the enterprise.

$$\sum_{m=1}^{3} PES^{\pm} + \sum_{n=1}^{4} ETS^{\pm} \leq 0.002 \times f^{\pm} \quad (10)$$

(5) The total cost of making environmental documents and routine environmental monitoring shall not exceed 0.5% of the annual profit of the enterprise.

$$\sum_{n=1}^{4} EDP^{\pm} + \sum_{k=1}^{4} REM^{\pm} \leq 0.005 \times (f^{-} + (1 - \lambda^{\pm}) \times (f^{+} - f^{-})) \quad (11)$$

(6) The allowance for pollutant discharge compensation and pollution remediation shall not be less than 0.3% of the annual profit of the enterprise.

$$\sum_{l=1}^{3} PDC^{\pm} + PRC^{\pm} \geq 0.003 \times f^{\pm} \quad (12)$$

(7) The cost input of the enterprise's environmentally sustainable development exceeds 0.4% of the enterprise's annual profit.

$$CEI^{\pm} + EMT^{\pm} + EEM^{\pm} \leq 0.004 \times f^{\pm} \quad (13)$$

(8) The environmental cost input should not exceed 3% of the annual profit of the enterprise.

$$f_2^{\pm} + f_3^{\pm} + f_4^{\pm} + f_5^{\pm} \leq 0.03 \times f^{\pm} \quad (14)$$

(9) Non-negative constraint: all variables in the entire optimization model are greater than 0.

The membership degree function represents the upper bound of the total economic benefit of the project (yuan), the lower bound of the total economic benefit of the project (yuan), the profit of automobile sales (yuan), the environmental cost of the automobile production process (yuan), the environmental management cost of the enterprise (yuan), the compensation cost of the enterprise's environmental damage (yuan), and the input cost of the enterprise's sustainable development (yuan). $\lambda f^{+} f^{-} f_1^{\pm} f_2^{\pm} f_3^{\pm} f_4^{\pm} f_5^{\pm} N^{\pm}$ represents the annual sales volume of automobiles (units), the unit price of automobile sales (yuan), and the production cost of automobiles (yuan). $VUP^{\pm}$ (Value unit price), $APC^{\pm}$ (Automobile production cost) *i* stands for pollutant category (i = 1, exhaust gas; i = 2, wastewater; i = 3, solid waste), represents the enterprise environmental protection fixed assets (yuan), represents the enterprise pollutant discharge tax (yuan), $FAS^{\pm}$ (Fixed asset statement), $PET^{\pm}$ (Pollutant emission tax) j represents the type of solid waste, represents the enterprise solid cost treatment cost, represents the enterprise environmental protection facilities operation and maintenance investment (yuan). $SWT^{\pm}$ (Solid waste treatment), $EFO^{\pm}$ (Environmental facilities operation) m represents the category of environmental practitioners within the enterprise (m = 1, environmental monitoring; m = 2, environmental engineer; m = 3, environmental supervisor), represents the salary cost of enterprise environmental employees (yuan), $PES^{\pm}$ (Personnel environment salary) n represents the type, represents the cost of enterprise environmental training (yuan), represents the cost of environment-related documents (yuan), represents the cost of enterprise routine environmental monitoring (yuan), $ETS^{\pm}$ (Environmental training spend), $EDP^{\pm}$ (Environmental document production), $REM^{\pm}$(Routine environmental monitoring) k represents the category of enterprise routine monitoring (k = 1, environmental air monitoring; k = 2, enterprise waste water monitoring; k = 3, noise monitoring; k = 4, ambient quality monitoring). $PDC^{\pm}$ (Pollutant discharge compensation) represents the potential cost of enterprise pollutant discharge compensation (yuan), l represents the type of pollution compensation cost (l = 1, personal injury compensation cost; l = 2, property damage compensation; l = 3, compensation for mental damage), which represents the potential repair cost (yuan) of the enterprise after the environment deteriorates due to the discharge of pollutants. $PRC^{\pm}$ (Potential remediation costs), $CEI^{\pm}$ (Continuous environmental investment) represents the cost of continuous environmental investment of the enterprise (yuan), the cost of training of environmental management personnel of the enterprise (yuan), and the cost of improving the level of environmental management of the enterprise (yuan). $EMT^{\pm}$ (Environmental management training), $EEM^{\pm}$ (Enterprise environmental management), $EI^{\pm}$ (Equipment installation) represents the total cost of equipment and installation of the enterprise (yuan).

2.4. FAW Hongqi new energy vehicle manufacturing project economic benefit fuzzy-interval uncertainty optimization model based on the two-step method

Firstly, the fuzzy interval upper bound sub-model can be solved using Lingo11 software, which can be represented as:

Objective function:

$$\max = \lambda^{+} \tag{15}$$

Constraints:

$$f_1^{+} - f_2^{-} - f_3^{-} - f_4^{-} - f_5^{-} \geq f^{+} - (1 - \lambda^{\pm}) \times (f^{+} - f^{-}) \tag{16}$$

$$f_1^{+} = N^{+} \times (VUP^{+} - APC^{-}) \tag{17}$$

$$f_2^{-} = \sum_{i=1}^{3} FAS^{-} + \sum_{i=1}^{3} PET^{-} + \sum_{j=1}^{9} SWT^{-} + \sum_{i=1}^{3} EFO^{-} \tag{18}$$

$$f_3^- = \sum_{m=1}^{3} PES^- + \sum_{n=1}^{4} ETS^- + \sum_{n=1}^{4} EDP^- + \sum_{k=1}^{4} REM^- \tag{19}$$

$$f_4^- = \sum_{l=1}^{3} PDC^- + PRC^- \tag{20}$$

$$f_5^- = CEI^- + EMT^- + EEM^- \tag{21}$$

$$\sum_{i=1}^{3} FAS^- \leq 0.1 \times (EI^- + (1-\lambda^{\pm}) * (EI^+ - EI^-)), \forall i \tag{22}$$

$$\sum_{i=1}^{3} EFO^- \leq 0.001 \times f^+ \tag{23}$$

$$\sum_{m=1}^{3} PES^- + \sum_{n=1}^{4} ETS^- \leq 0.002 \times f^+ \tag{24}$$

$$\sum_{n=1}^{4} EDP^- + \sum_{k=1}^{4} REM^- \leq 0.005 \times (f^- + (1-\lambda^{\pm}) \times (f^+ - f^-)) \tag{25}$$

$$\sum_{l=1}^{3} PDC^- + PRC^- \geq 0.003 \times f^+ \tag{26}$$

$$CEI^- + EMT^- + EEM^- \leq 0.004 \times f^+ \tag{27}$$

$$f_2^- + f_3^- + f_4^- + f_5^- \leq 0.03 \times f^+ \tag{28}$$

The upper bound of membership function is obtained by solving the upper bound sub-model, and the lower bound sub-model of fuzzy-interval is solved by interactive algorithm, which can be expressed as: λ^+

Objective function:

$$\max = \lambda^- \tag{29}$$

Constraints:

$$f_1^+ - f_2^- - f_3^- - f_4^- - f_5^- \geq f^+ - (1-\lambda^{\pm}) \times (f^+ - f^-) \tag{30}$$

$$f_1^+ = N^+ \times (VUP^+ - APC^-) \tag{31}$$

$$f_2^- = \sum_{i=1}^{3} FAS^- + \sum_{i=1}^{3} PET^- + \sum_{j=1}^{9} SWT^- + \sum_{i=1}^{3} EFO^- \tag{32}$$

$$f_3^- = \sum_{m=1}^{3} PES^- + \sum_{n=1}^{4} ETS^- + \sum_{n=1}^{4} EDP^- + \sum_{k=1}^{4} REM^- \tag{33}$$

$$f_4^- = \sum_{l=1}^{3} PDC^- + PRC^- \tag{34}$$

$$f_5^- = CEI^- + EMT^- + EEM^- \tag{35}$$

$$\sum_{i=1}^{3} FAS^- \leq 0.1 \times (EI^- + (1-\lambda^{\pm}) \times (EI^+ - EI^-)), \forall i \tag{36}$$

$$\sum_{i=1}^{3} EFO^- \leq 0.001 \times f^+ \tag{37}$$

$$\sum_{m=1}^{3} PES^{-} + \sum_{n=1}^{4} ETS^{-} \leq 0.002 \times f^{+} \tag{38}$$

$$\sum_{n=1}^{4} EDP^{-} + \sum_{k=1}^{4} REM^{-} \leq 0.005 \times (f^{-} + (1-\lambda^{\pm}) \times (f^{+} - f^{-})) \tag{39}$$

$$\sum_{l=1}^{3} PDC^{-} + PRC^{-} \geq 0.003 \times f^{+} \tag{40}$$

$$CEI^{-} + EMT^{-} + EEM^{-} \leq 0.004 \times f^{+} \tag{41}$$

$$f_2^{-} + f_3^{-} + f_4^{-} + f_5^{-} \leq 0.03 \times f^{+} \tag{42}$$

3. Results and discussion

3.1. FAW Red Flag new energy vehicle manufacturing project pollution strong analysis

FAW Hongqi new energy vehicle manufacturing production process is mainly for the whole vehicle manufacturing, including stamping, welding, painting and final assembly of these four processes. Among them, welding, painting and final assembly process is the main link of pollutant discharge. Welding workshop undertakes the tasks of welding, testing, adjusting, grinding and other tasks of the body in white assembly and some of its sub-assemblies for passenger cars, as well as the storage of some of the body in white assembly before painting. Spot welding is the main welding process, supplemented by arc welding. The workshop undertakes the tasks of welding, testing, adjusting, grinding and other tasks of the body in white assembly and some of its sub-assemblies for passenger cars, as well as the storage of some of the body in white assembly before painting. The welding process is mainly spot welding, supplemented by arc welding. The painting workshop is mainly engaged in the production tasks of Hongqi series welding body in white before surface treatment, cathode electrophoresis, PVC spraying, weld seal, surface coating and wax injection.

3.1.1. Source strength analysis of industrial exhaust gas of FAW Hongqi new energy automobile manufacturing project

The exhaust gas generation of FAW Hongqi New energy Automobile Manufacturing project is shown in **Table 1**. Among them, the welding workshop of FAW new energy automobile manufacturing project has a total of 15 CO_2 gas shielded welding, the welding wire consumption is 18 t/a, and the exhaust gas collection measures are set for each welding machine, the filter cartridge filter is used for dust removal treatment, the capture efficiency is 95%, and the final exhaust gas is discharged through 8 15 m high exhaust cylinders. Coating workshop electrophoresis, painting and drying processes produce organic waste gas, the main pollutants in the waste gas for particulate matter, xylene and VOCs. The fuel of electrophoresis drying, color coating flash drying and varnish drying furnace is natural gas. The amount of natural gas is 2,489,400 m^3/a, and the exhaust gas is directly discharged through 32 high exhaust cylinders of 28.6 m respectively. The amount of paint in the final assembly workshop is about 0.22 t/a, the main pollutants are particulate matter, xylene and VOCs, the waste gas passes through the “fiber cotton filter device + activated carbon adsorption device", the purification efficiency is 90%, and the treated waste gas is discharged from 3 15 m high exhaust cylinders through the closed pipeline. Faw Red flag new energy vehicle production plant at the same time there are other exhaust gases, such as canteen fume, canteen 1 fume emission concentration of 0.12 t/a; The fume emission concentration of canteen 2 is 0.19 mg/m^3, and the emission is 0.02 t/a; The odor of the sewage station mainly comes from the wastewater regulation tank, biochemical treatment tank and sludge dewatering area, and the foul-smelling pollutants produced are mainly ammonia and hydrogen sulfide. The foul-smelling gas produced by the comprehensive sewage biochemical treatment system adopts the "chemical adsorption + biological treatment" process and is discharged through a 15 m exhaust cylinder.

Table 1. Calculation results of economic benefits of FAW Hongqi new energy automobile manufacturing project exhaust gas pollution stream strength.

Process	Source of Pollution	Pollutants	Before treatment			After processing			
						Organized emissions			Unorganized emissions
			Waste gas production (m^3/h)	Mass concentration produced (mg/m^3)	Yield (kg/h)	Exhaust emissions (m^3/h)	Emission mass concentration (mg/m^3)	Emissions (kg/h)	Emissions (kg/h)
Welding	CO_2 Shielded Welding	Particulate matter	165,960	-	0.122	165,960	-	0.006	0.006
coating	Electrophoresis tank	VOCs	27,000	241.33	6.52	27,000	21.72	0.59	0.65
	Electrophoretic drying	VOCs	22,000	550.50	12.10	606,200	1. Particulate Matter Emission concentration: 0.15 mg/m Emission rate: 0.09 kg/h Emission: 0.14 t/a. 2. Xylene Emission concentration: 3.15 mg/m Emission rate: 1.91 kg/h Emission: 2.87 t/a. 3.VOCs Emission concentration: 28.97 mg/m Emission rate: 17.56 kg/h Emission: 26.4 t/a		0.06
	Color paint spray	Particulate matter	168,000	142.48	23.94				0.12
		VOCs		278.62	46.81				0.23
	Varnish spray	Particulate matter	168,000	170.97	28.72				0.144
		VOCs		625.32	105.05				0.53
		xylene		107.65	18.09				0.09
	Color paint drying	VOCs	80,000	279.26	22.34				0.11
	Varnish drying	VOCs	80,000	408.91	32.71				0.032
		xylene		79.79	6.38				0.03
	Sealant for drying	VOCs	80,000	797.87	63.83				0.32
	Touch up Paint	Particulate matter	175,200	0.085	0.015				0.00007
		VOCs		0.34	0.06				0.0003
		xylene		0.08	0.013				0.00007
	Color paint mixing room	VOCs	7500	42.55	0.32				0.0016
	Varnish mixing room	VOCs	7500	63.83	0.48				0.0024
		xylene		14.18	0.11				0.0005

Table 1. (*Continued*).

Process	Source of Pollution	Pollutants	Before treatment			After processing			
						Organized emissions			Unorganized emissions
			Waste gas production (m^3/h)	Mass concentration produced (mg/m^3)	Yield (kg/h)	Exhaust emissions (m^3/h)	Emission mass concentration (mg/m^3)	Emissions (kg/h)	Emissions (kg/h)
coating	RTO natural gas combustion-assisted	SO_2	606,200	0.02	0.012		0.02	0.012	-
		NO_x		0.46	0.281		0.46	0.281	-
		Soot		0.14	0.086		0.14	0.086	-
	Wax injection exhaust	VOCs	58,400 × 2	3.07	0.36	58,400 × 2	0.31	0.04	0.0018
	Electrophoresis drying oven Burner	SO_2	514 × 6	7.35	0.024	514 × 6	7.35	0.024	-
		NO_x		172.06	0.528		172.06	0.528	-
		Soot		52.57	0.162		52.57	0.162	-
	Color paint flash dry oven Burner	SO_2	195 × 6	7.35	0.006	195 × 6	7.35	0.06	-
		NO_x		172.06	0.204		172.06	0.204	-
		Soot		52.57	0.06		52.57	0.06	-
	Varnish drying oven Burner	SO_2	166 × 14	7.35	0.014	166 × 14	7.35	0.014	-
		NO_x		172.06	0.406		172.06	0.406	-
		Soot		52.57	0.126		52.57	0.126	-
	Multi-purpose flash drying Burner	SO_2	186 × 2	7.35	0.002	186 × 2	7.35	0.006	-
		NO_x		172.06	0.064		172.06	0.12	-
		Soot		52.57	0.02		52.57	0.036	-
	Multi-purpose drying Burner	SO_2	234 × 3	7.35	0.006	234 × 3	7.35	0.006	-
		NO_x		172.06	0.12		172.06	0.12	-
		Soot		52.57	0.036		52.57	0.036	-
	Glue drying oven	SO_2	1341	7.35	0.01	1341	7.35	0.01	-
		NO_x		172.06	0.231		172.06	0.231	-
		Soot		52.57	0.071		52.57	0.071	-
Final assembly	Patching Room Touch up paint exhaust	Particulate matter	70,000 × 3	0.233	0.016	70,000 × 3	0.023	0.0016	0.00008
		VOCs		0.31	0.065		0.093	0.006	0.0003
		xylene		0.07	0.014		0.021	0.001	0.00007

3.1.2. FAW Red Flag new energy vehicle manufacturing project industrial waste water source strength analysis

At present, the waste water discharged by the economic benefits of FAW Hongqi new energy automobile manufacturing project can be divided into two categories: production waste water and domestic sewage. Degreasing waste water and degreasing cleaning wastewater: degreasing waste water is discharged intermittently, replaced once every three months, with a maximum of 150 m^3/time. The waste liquid in the degreasing waste liquid pool is lifted to the degreasing waste liquid batch treatment tank. The designed processing capacity of degreasing pretreatment measures is 30 m^3/d. Phosphating cleaning tank waste liquid, phosphating washing wastewater: surface adjustment, passivation, phosphating cleaning tank waste liquid batch limited to join the phosphating wastewater regulation tank, and phosphating, passivation after washing wastewater treatment together, phosphating wastewater pretreatment facility design treatment capacity of 35 m^3/h. Electrophoretic waste and electrophoretic cleaning wastewater: intermittent discharge of electrophoretic waste, 25 t/year. Grinding wastewater: The grinding wastewater is continuously discharged, and the grinding wastewater is directly discharged into the comprehensive wastewater regulation tank. Rain line wastewater: The wastewater generated by the rain line of the assembly workshop is directly discharged into the municipal pipe network, and the advanced treatment wastewater for production and reuse is discharged into the discharge tank, overflow to the municipal pipe network and discharged into the western sewage treatment plant of Changchun City. Equipment backwashing wastewater: equipment backwashing water is directly discharged into the sewage treatment station. Domestic sewage: Domestic sewage mainly comes from bath shower, canteen, toilet flushing and other living places of workers. The specific production of waste water is shown in **Table 2**. At the same time, in order to reduce the impact of enterprise wastewater, FAW new energy automobile manufacturing enterprise adopts the process as shown in **Figure 2** for wastewater disposal. The surface adjustment waste liquid, phosphating waste liquid and passivation waste liquid are added to the phosphating wastewater regulation tank in batches and limited amounts, and are treated together with the washing wastewater after phosphating and passivation and the wastewater from the phosphating cleaning tank. The process of "pH adjustment + coagulation + precipitation" is adopted.

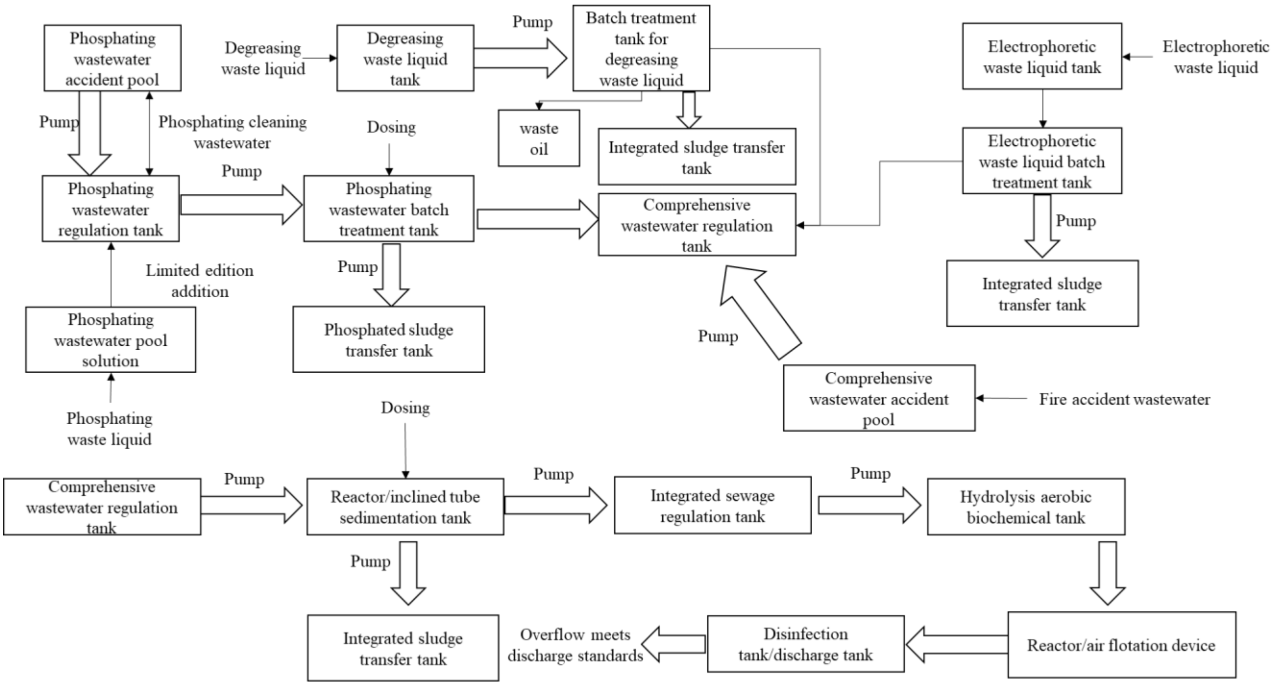

Figure 2. Wastewater treatment process of FAW Hongqi new energy vehicle manufacturing project.

Table 2. Economic benefit wastewater generation of FAW Hongqi new energy automobile manufacturing project.

Workshop	Wastewater source	Water quantity	Contaminants							
		m^3/a	COD (t/a)	SS (t/a)	Oil category (t/a)	Total phosphorus (t/a)	Total zinc (t/a)	Total nickel (t/a)	BOD_5 (t/a)	NH_3-N (t/a)
Painting shop	Degreasing waste liquid	880.00	14.96	3.52	1.14	-	-	-	-	-
	Electrophoretic waste	25.00	0.63	0.31	-	-	-	-	-	-
	Phosphating waste liquid	600.00	0.36	0.48	-	1.80	0.06	0.15	-	-
	Table mixing waste liquid	248.80	0.12	-	-	0.08	0.0025	-	-	-
	Phosphating wastewater	24,000.00	12.12	-	-	9.70	0.72	0.12	-	-
	Chromium-free passivation wastewater	1488.00	0.15	-	-	-	-	-	-	-
	Degreasing cleaning water	16,184.00	19.42	2.43	0.97	-	-	-	-	-
	Electrophoresis cleaning water	36,792.00	55.19	-	-	-	-	-	-	-
	Sanding wastewater	2200.00	0.77	1.32	-	-	-	-	-	-
	Other wastewater	6650.00	0.27	-	-	-	-	-	-	-
Final assembly workshop	Rain line drain	2720.00	0.14	0.04	0.04	-	-	-	0.05	0.00
United Power Station	Circulatory system drainage	16,625.00	0.83	0.33	0.08	-	-	-	0.17	0.12
Other	Flushing wastewater	21,120.00	10.56	8.45	-	-	-	-	4.22	0.42
	Domestic sewage	96,000.00	33.60	14.40	-	0.82	-	-	14.40	3.36
	Strong water	10,817.50	3.35	1.30	0.05	0.02	0.0107	0.00	0.70	0.15

3.1.3. Source strength analysis of solid waste for FAW Hongqi new energy vehicle manufacturing project

According to the source, solid waste can be roughly divided into three kinds: domestic waste, general industrial solid waste and hazardous waste. Domestic waste refers to the waste generated in People's Daily life, including food residues, paper scraps, gray soil, packaging, waste products, etc. (Quispe et al., 2023). General industrial solid waste includes fly ash, smelting waste slag, furnace slag, tailings, industrial water treatment sludge, coal gangue and industrial dust. Hazardous waste refers to flammable, explosive, corrosive, infectious, radioactive and other toxic and harmful wastes. In addition to solid wastes, semi-solid and liquid hazardous wastes are usually classified as hazardous wastes in environmental management (Gu et al., 2023; Owojori et al, 2020). Solid waste has a duality, that is to say, at a certain time and place, some items are no longer useful or temporarily unnecessary to users and are discarded and become waste; But for some users or under certain specific conditions, waste may become useful or even necessary raw materials (Bowan et al., 2020; Ge et al, 2022). Solid waste generation is shown in **Table 3**.

Table 3. Solid waste generation of FAW Hongqi new energy vehicle manufacturing project.

Category	Name	Solid Waste Properties	Quantity produced (t/a)	Final destination
Hazardous waste	Waste lime powder (solvent-based)	HW12 (900-252-12)	43.2	The hazardous waste shall be stored in the temporary storage room, the seepage prevention treatment shall be done in the temporary storage room, and then the hazardous waste treatment unit shall be disposed of.
	Phosphating sludge	HW17 (336-064-17)	9.5	
	Phosphating slag	HW17 (336-064-17)	31.2	
	Scrap glue stock	HW13 (900-014-13)	2.4	
	Waste oil	HW08 (900-249-08)	4	
	Waste activated charcoal	HW49 (900-041-49)	0.8	
	Waste filter fiber	HW49 (900-041-49)	0.8	
	Waste zeolite	HW49 (900-041-49)	Replace every 3–5 years	
	Waste cleaning agent (solvent-based)	HW12 (900-256-12)	192	
	Waste ultrafiltration membrane	HW49 (900-041-49)	0.36	
	Waste RO reverse osmosis membrane	HW49 (900-041-49)	0.44	
	Used battery	HW49 (900-044-49)	5/100,000 units	Factory recycling
	Waste bucket	HW49 (900-041-49)	16	
General Solid waste	Waste colored paint cleaning solvent	-	384	Factory Recycling
	Waste bucket (water-based paint)	-	16	
	Scrap scraps	-	1450	Take-out comprehensive utilization
	Waste plastic, paper	-	8	
	Waste welding wire and waste welding slag	-	0.48	
	Waste lime powder (water-based)	-	36	Disposal by Department of Sanitation

3.2. Uncertainty optimization analysis of FAW Hongqi new energy vehicle manufacturing project

3.2.1. Environmental cost analysis of FAW Hongqi new energy vehicle manufacturing project

Based on the strong and small pollution stream of FAW Red Flag new energy vehicle manufacturing project and the pollution treatment method, the environmental cost of the enterprise is calculated, and the results are shown in **Figure 3**. The annual output of vehicles is [45,305, 58,630], and the estimated sales price of each vehicle is [212,500, 275,000] CNY. The price of waste gas treatment equipment in the environmental protection fixed assets of the project is [435,965, 564,190] CNY. The price of waste water treatment equipment is CNY [1,038,190, 1,343,540], and there is no fixed environmental protection facility for solid waste. The cost of pollutant discharge tax is CNY [6013.07, 7781.62] for waste gas, CNY [74,684.01, 96,649.90] for pollutants in wastewater. No pollution discharge tax is levied on solid waste because it is treated outside the enterprise. As enterprises entrust other companies to deal with solid waste, they need to pay the cost of solid waste treatment. The total price of solid waste treatment is CNY [646,303.11, 836,392.26] (solid waste code 900-041-49: [147,851.21, 191,336.86] CNY; 900-014-13: [54,989.48, 71,162.85] CNY; 900-403-06: [7676.86, 9934.76] CNY; 336-064-17: [40,525.28, 52,444.48] CNY; 900-252-12: [142,101.30, 183,895.80] CNY; 900-399-35: [932.03, 1206.15] CNY; 900-249-08: [30,128.25, 38,989.50] CNY; 900-219-08: [65,287.48, 84,489.68] CNY; General industrial solid waste: [156,811.23, 202,932.18] CNY).

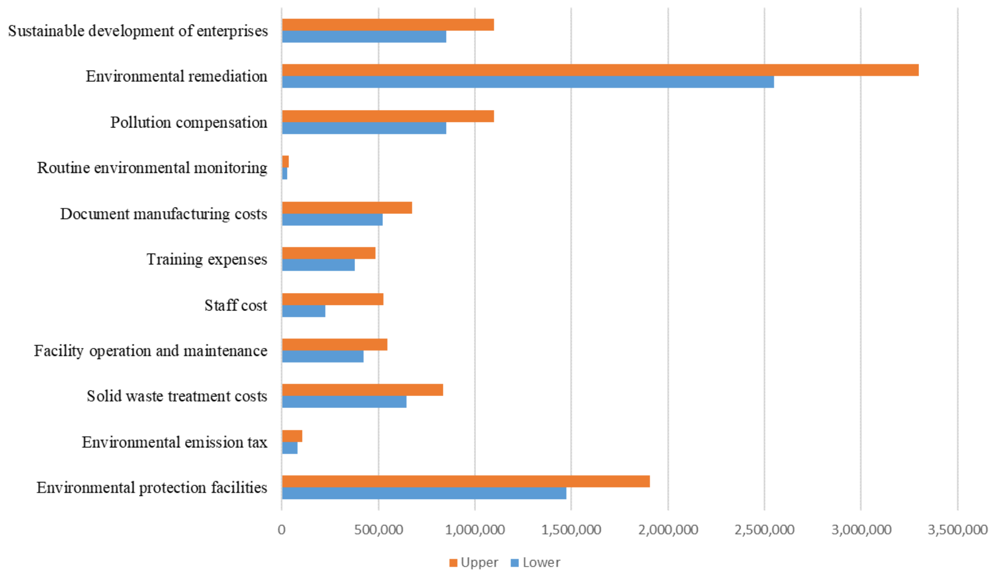

Figure 3. Environmental cost of FAW Hongqi new energy vehicle manufacturing project.

The environmental cost of operation and maintenance of environmental protection facilities is [297,840.00, 385,440.00] CNY in waste gas and [124,473.35, 161,083.16] CNY in waste water. The staff of the environmental department of FAW Hongqi Enterprise is divided into different positions and levels, so there are three different wage costs, the sum of which is [136,000.00, 176,000.00] CNY, [68,000.00, 88,000.00] CNY, [20,400.00, 26,400.00] CNY. Faw Red Flag enterprises carry out four regular environmental training times a year, the price of each time is [98,974.00, 128,084.00] CNY, [89,076.60, 115,275.60] CNY, [98,974.00, 128,084.00] CNY, [89,076.60, 115,275.60] CNY. Companies produce various environmental documents in-house, such as Project environmental assessment report, environmental monitoring plan, environmental emergency plan and emission permit application and other environment-related documents, their prices are [425,000.00, 550,000.00] CNY, [21,250.00, 27,500.00] CNY, [34,000.00, 44,000.00] CNY and [42,500.00, 55,000.00] CNY. For routine monitoring of enterprises, the cost of ambient air monitoring is [7021.60, 9086.77] CNY, the cost of wastewater monitoring is [8838.30, 11,437.8] CNY, and the cost of noise monitoring is [3570.00, 4620.00] CNY, The surrounding environmental quality monitoring cost is [8103.90, 10,487.40] CNY, the compensation for environmental problems caused by pollutant discharge is [850,000.00] CNY, property damage compensation and mental damage compensation are [850,000.00] CNY, The amount set aside for environmental restoration problems caused by environmental pollution is [2,550,000.00, 3,300,000.00] CNY. In terms of the enterprise's environmentally sustainable development, the cost of [850,000.00, 1,100,000.00] CNY is set aside for the enterprise's sustainable investment in environmental protection, the continuous improvement of environmental management personnel and the improvement of the enterprise's overall environmental management level. From the environmental cost details of FAW Red Flag new energy automobile manufacturing project, in addition to the waste water, waste gas and solid waste disposal costs generated by the production process, environmental costs such as staff environmental quality training, routine environmental monitoring and enterprise environmental impact assessment documents cannot be ignored. At the same time, for automobile manufacturing enterprises, enterprises themselves should set aside pollution compensation costs. In order to cope with sudden environmental problems. The environmental cost interval of FAW Red Flag new energy vehicle manufacturing project provides a reference for the enterprise environmental management department, and the environmental cost interval reduces the uncertainty in the process of environmental cost accounting and gives decision makers a certain decision-making space.

3.2.2. Economic benefit analysis of FAW Hongqi new energy automobile manufacturing project

After the optimization of fuzzy-interval uncertainty optimization model, the economic benefit of FAW Hongqi New energy automobile manufacturing project is [101,254.71, 627,854.13] million yuan. Compared with the interval uncertainty optimization model, the lower limit of economic benefit is increased by 57.68%, and the upper limit is reduced by 12.08%, shortening the result of economic benefit interval. At the same time, the membership λ value interval obtained according to the fuzzy membership function is [0.2, 0.95], which indicates that the decision maker has the probability of 20% to obtain the lower bound of economic benefit, while the risk is low, but also has the probability of 95% to obtain the upper bound of economic benefit, but the risk is high. Through the combination of fuzzy programming and interval programming, the interval range of a single interval programming result can be shortened, the accuracy of the optimal solution can be improved, and the influence of uncertainty on decision-making can be reduced. The larger the interval range of the interval planning result, the higher the uncertainty of the optimal solution, and the decision maker is difficult to make an effective choice. By introducing fuzzy programming, membership function can be used to describe the fuzzy properties of uncertain parameters, so as to narrow the range of intervals and improve the reliability of the optimal solution. Increase the feasibility of the optimal solution and avoid the situation of infeasible solution or no solution. Interval programming may have unbounded or no row solutions, this is because the interval function may have singular points or discontinuities, resulting in the objective function or constraints cannot be satisfied. By introducing fuzzy programming, membership function can be used to describe the fuzzy properties of objective functions and constraints, so as to relax the solution conditions and increase the existence of optimal solutions. The applicability of the optimal solution can be expanded to adapt to more practical problems. Interval programming can only deal with interval uncertainty, while there may be other types of uncertainty in practical problems, such as probabilistic uncertainty, fuzzy uncertainty, mixed uncertainty, etc. By introducing fuzzy programming, membership function can be used to describe various types of uncertainty, so as to make the model more flexible and general. In summary, by combining fuzzy programming and interval programming, the interval range of a single interval programming result can be shortened, which is of great significance for improving the accuracy, feasibility and applicability of the optimal solution.

Environmental protection facilities, environmental emission tax, solid waste treatment costs, and facility operation and maintenance have a certain correlation with the economic benefits of Hongqi automobile manufacturing enterprises. Firstly, the more advanced environmental protection facilities are, the higher the cost of purchasing them, and the higher the operation and maintenance costs of the facilities. Secondly, when advanced environmental protection facilities are adopted, the emissions of environmental pollutants caused by this are relatively low, and the purification of pollutants can be achieved in automobile manufacturing plants, resulting in a reduction in pollutant emission taxes and a reduction in the cost of solid waste treatment. Routine environmental monitoring, pollution compensation, environmental remediation, and sustainable development of enterprises are correlated. Daily monitoring can effectively reduce the risk of severe environmental pollution, reduce environmental remediation and pollution compensation costs, and promote the sustainable development of enterprises. The above environmental cost parameters have a negative or no impact on the economic benefits of the enterprise. For example, when the enterprise has no sudden environmental problems, pollution compensation expenses are generally less and not a fixed annual expenditure of the enterprise. Environmental monitoring, pollutant emission tax, and environmental protection facility operation and maintenance are the daily environmental costs of enterprises; therefore, these parameters have a significant impact on the economic benefits of enterprises.

4. Conclusion

By constructing a multi-layer environmental cost evaluation system for FAW Hongqi New energy automobile manufacturing project, this study accounted for a number of internal environmental costs of the enterprise, clarified the exhaust gas intensity of welding, painting and final assembly workshops, clarified the wastewater discharge situation and treatment technology in the process of automobile production, and determined the types and treatment methods of solid waste generated in the process of automobile production project. Through the accounting of enterprise pollution sources, it is clear that the existing pollution problems of enterprises. Secondly, based on the accounting results of the strong source of enterprise pollution and the multi-layer environmental cost evaluation system, the enterprise environmental cost is calculated, and the environmental cost is expressed in the form of interval to reduce the uncertainty in the accounting process. According to the results of enterprise environmental cost accounting, the enterprise environmental cost is mainly the environmental restoration cost and the purchase cost of environmental protection facilities caused by normal pollution discharge. The cost of pollutant emission tax and routine environmental monitoring is low. Enterprises can adopt more scientific programs from the aspects of environmental restoration and environmental protection facilities to reduce environmental costs. After the optimization of fuzzy-interval uncertainty optimization model, the economic benefit of FAW Hongqi new energy vehicle manufacturing project is [101,254.71, 627,854.13] million yuan. Compared with the interval uncertainty optimization model, the lower limit of economic benefit is increased by 57.68%, the upper limit is reduced by 12.08%, and the result of economic benefit interval is shortened. It provides more accurate decision-making space for decision makers, and provides a reference basis for realizing the maximum economic benefit of enterprises. However, this article also has certain shortcomings, as it did not fully consider the random uncertainty of parameters. Subsequent research should demonstrate this perspective.

Authors contributions: Conceptualization, GW; methodology, GW; validation, GW, YW and ML; formal analysis, GW, YW and ML; investigation, GW, YW and ML; data curation, YW and ML; writing—original draft preparation, GW; writing—review and editing, GW; visualization, YW; supervision, GW; project administration, GW; funding acquisition, GW. All authors have read and agreed to the published version of the manuscript.

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