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Benefit sharing model of hydropower development based on input perspective: a case study of Xiluodu project in China

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Hydropower provides important support for achieving dual-carbon goal, but problems such as reservoir resettlement conflicts are common in developing countries, which have become a bottleneck of sustainable hydropower development. Fair distribution of benefits is the key to solve this dilemma. While the concept of benefit sharing as the fundamental guarantee for the sustainable livelihood of landless resettlers is gradually reaching consensus, the amount of benefit distribution has always been an outstanding issue. In order to quantify the amount of benefit sharing scientifically and reasonably, this paper constructs a benefit sharing model of hydropower development from the perspective of stakeholder input, and carries out a case analysis. The results indicate that the main stakeholders of hydropower projects include governments, development enterprises and reservoir resettlers. Their inputs are water or environmental resources, capital, and land resources, which produce hydropower resources. The net present value method can be used to construct the benefit sharing model. In this model, sharing amount of resettlers and other major stakeholders is the product of the sum of the present value of the net cash flow of hydropower projects and the proportion of their respective input. In view of many uncertainties, the grey prediction method and Monte Carlo simulation method are used to solve the model. The case of the Xiluodu hydropower station in China proves the rationality and operability of the model. The study also shows with reference to the model's calculation results, a shared development fund can be established by drawing money from electricity generation income to ensure long-term benefits for resettlers, while considering the reasonable benefit of other stakeholders. The two are connected. It is expected to achieve a new pattern of mutual benefit and multi-win outcome, which are characterized by stable power station revenue, prosperity and stability of the reservoir area, and increased benefit and common wealth of resettlers. This paper may provide a convenient and novel analysis tool for benefit sharing systems.

KEYWORDS

hydropower project, benefit sharing, quantitative model, uncertainty, resettlement

1. Introduction

Hydropower is a clean and renewable energy source with mature technology and flexible operation, providing strong support for achieving carbon peak and carbon neutral goals. The economic, social, and ecological benefits of hydropower projects are significant, but the flooding of land or houses and the resulting a large number of involuntary resettlers are inevitable. Due to disparities in politics, economy, law, culture, and other aspects, countries around the world have established their own distinctive involuntary resettlement policies. Nevertheless, they agree on the general principle of minimizing the number of resettlers, reducing the impact of resettlement, and keeping their living standards from falling below the original level. The involuntary resettlement policies of developed countries are mainly based on the equivalent exchange of market economy, but the resettlement policies of most developing countries cannot meet the needs of involuntary resettlement practices (Duan, 2011). The World Commission on Dams (2000) conducted a survey of more than 300 large hydropower stations worldwide, and found that the global dam construction had caused the resettlement of 40–80 million individuals, with most of the resettler communities in relative poverty. Reservoir resettlement has long been recognized as a global issue.

The rich water resources in China have expedited the development of hydropower projects. By 2021, China's total installed hydropower capacity had reached 0.39 billion kilowatts. However, the sustainable development of hydropower in China is increasingly facing two major challenges: resettlement and environmental protection, similar to other developing countries (Chen et al., 2017; Shi and Shang, 2021). China currently has the largest number of reservoir dams and the reservoir resettlers in the world. In 2006, the number of resettlers reached 25 million (Yao, 2020). China may add more than 3 million resettlers by 2026 due to low-carbon energy development and water conservancy construction (Zhang, 2007). Reservoir resettlement in China has shifted from simple compensation to development resettlement, and has innovated some resettlement methods, such as long-term compensation instead of one-time compensation (Hu, 2015). Reservoir resettlers are, however, a vulnerable group full of uncertainties. Problems such as low land compensation, job loss, and social marginalization easily cause conflicts and disputes, and may even lead to mass incidents. The essence of the resettlement problem is the distribution of benefits (Chen et al., 2017). Involuntary resettlers leave their homes for the public good, resulting in significant changes in their livelihoods. The poverty or lack of a sense of gain of experienced by some resettlers is in sharp contrast to the remarkable economic and social benefits of hydropower projects. In the process of reflecting on the traditional resource development model and the problems associated with it, the concept of benefit sharing has gradually attracted the attention of the international community and has become an important way to alleviate conflicts and contradictions in resource development (Yang and Meng, 2017). Hydropower development should take more responsibility and play a more significant role in the process of poverty alleviation and livelihood reconstruction for resettlers.

Theoretical research on benefit sharing of hydropower development can be summarized into three levels: sharing basis, sharing mechanism and optimization path. First in terms of sharing basis, Zhang et al. (2017) regarded benefit sharing as the compensation given to the affected groups to restore their living standards before relocation. The motivation hehind benefit sharing was rooted in concerns about social justice, human rights, participation and empowerment (Suhardiman et al., 2014). Benefit sharing could transform the zero-sum game of relevant subjects into a positive-sum game (Ilkhom et al., 2015). Cernea (2000) advocated for the sustainable livelihood of resettlers by sharing the benefits of hydropower projects that had made contributions. Li and He (2010) believed that land development rights should be shared by the state and resettlers, and resettlers should share the potential value of resources fairly. Chen et al. (2017) argued that governments and project owners had their own financial sources and foundation for resettlers to share the operating benefits of power stations, given that resettlers were the losers in all spheres of economy, culture, and psychology.

Second, in terms of sharing mechanisms, Dai (2013) proposed sharing the costs and benefits fairly according to the principle of "who is responsible for who invests, who inputs who benefits." Equitable sharing of benefits was not only an idea, but also a component of sustainable development, and benefit sharing in water resources development covered three aspects: fair sharing of project services, non-monetary compensation, and gain sharing (Skinner et al., 2009). Lebel et al. (2014) categorized resettler benefit sharing models into four types: compensation for resettlement, community development funds, corporate social responsibility, and payments for ecosystem services. The specific methods for resettlers to share the benefits of hydropower include land resource utility value sharing, long-term land compensation, investment in shares, social security, direct tax sharing, preferential electricity prices, etc. (Kong et al., 2008; Fan, 2010). Zhang and Han (2018) conducted a SWOT analysis on different ways of benefit sharing.

Third, in terms of the optimization path, Men et al. (2014) concluded through specific case analysis that there may be a large gap between the actual implementation of benefit sharing and the written commitment. Based on the analysis of the practical difficulties and their causes of resettler benefit sharing, Wu and Shi (2018) proposed improvement measures such as improving the benefit sharing management mechanism, giving priority to helping poor resettlers out of poverty, and encouraging enterprises to fulfill their social responsibilities. In order to provide solutions for restoring the squeezed benefit space of resettlers, Singer and Watanabe (2014) called for rebuilding the mode and mechanism of benefit sharing for hydropower resources development by improving the compensation price of reservoir resettlement and the formation mechanism of hydropower on-grid price. Based on the input–output analysis, Xia et al. (2018) pointed out that the income of reservoir resettlers was significantly low. They suggested that the benefits of all parties should be promoted to a more reasonable and fair level by raising the compensation standard for resettlement and fine-tuning the power generation price. Singer et al. (2014) highlighted the roles of international financial institutions and civil society organizations in deepening the benefit sharing of hydropower development.

At the policy level, the World Bank (2001) identified the ability of resettlers to share the benefits of the project as one of the policy targets of involuntary resettlement. The World Commission on Dams (2000) included public acceptance, recognition of rights, and sharing of benefits as strategic priorities for hydropower development. Although some developing countries have adopted practices of resettlers sharing benefits in World Bank loan projects, these practices are arbitrary. Few countries have incorporated the sharing of project benefits into their resettlement policy systems. Moreover, project owners often have no desire to share benefits with resettlers, which leads to the marginalization of resettlers in the resettlement process and only limited compensation. Thus, it is difficult to restore and rebuild the livelihoods of resettlers (Van Wicklin III, 1999).

Since China's reform and opening up in 1978, the evolution of resettlement policy can be divided into three stages: the initial stage (1978–1990), the development stage (1991–2005), and the deepening stage (2006–present) (Yao, 2020). In the initial stage, the regulations and norms for resettlement were preliminarily formed. In the development stage, the resettlement work not only had uniform national laws and regulations, but also presented strong project characteristics, such as Regulations on Residents-Resettlement for the Yangtze River Three Gorges Project Construction. During the deepening period, in 2006 China promulgated the Regulations on Land Acquisition Compensation and Resettlement for Large and Medium-sized Water Conservancy and Hydropower Project Construction, the Opinions of the State Council on Improving the Later Support Policy for Large and Medium-sized Reservoir Resettlement, and made a reasonable revision in 2017. All of these reflected the idea of benefit sharing. The resettlement of over 300 thousand people in the Middle Route of South-to-North Water Transfer Project was completed within three years (2009–2012), attracting worldwide attention. In 2019, China issued guidelines on Benefit Sharing in Hydropower Development, many of which focused on the issue of resettlement, and required the establishment and improvement of a long-term mechanism for enterprises, local governments and resettlers to share the benefits of hydropower. It provides a direct basis for the healthy and orderly development of the benefit sharing work and the promotion of common prosperity. However, it is unfortunate that there are no operating rules. Under the guidance and support of relevant policies, countries around the world have carried out a lot of exploration and practice on benefit sharing of hydropower resettlers and achieved positive results (Egre, 2007; Cernea, 2008; Sun and Wang, 2021).

To sum up, the concept of benefit sharing has been integrated into the research and practice of hydropower resources development. The rationale for benefit sharing of resettlers is sufficient, and the policy support is increasing. However, it needs to be further strengthened and perfected at the operational level. Although many theoretical studies emphasize that the amount of sharing is the focus of balanced benefit distribution, its reasonable determination still lacks empirical analysis, and most practical cases do not have specific quantitative data. As stakeholders of reservoir land acquisition, they naturally pursue the maximization of their own interests. Due to the lack of calculation models and quantitative basis, it is difficult to accurately define deserved benefits of resettlers. Resettlers tend to believe that they have yet to receive reasonable compensation and expect to seek more benefits through disturbances. However, the subject of land acquisition often regards providing development opportunities for resettlers as a boon. No matter how much they pay, they hold that they are generous enough, which will ultimately affect the agreement of all parties. This is also one of the reasons why compensation and resettlement of resettlers in developing countries are prone to questions, disputes, and dissatisfaction. Based on clarifying the main stakeholders of hydropower projects and their current benefits, this paper establishes a quantitative model and carries out a case analysis to try to solve the problem of the benefit distribution amount available for resettlers and explore more equitable and reasonable systems of benefit sharing. This paper is organized as follows. Section 2 narrates the conceptual framework. Section 3 presents the methods, which introduces the calculation model in detail and basic data. Section 4 takes the Xiluodu project in China as an example to demonstrate the feasibility and effectiveness of the model and puts forward the idea of optimizing benefit distribution. Section 5 is the discussion, and the conclusion is summarized in Section 6.

2. Conceptual framework

2.1. Identification of main stakeholders of hydropower project

Benefit sharing has long been proposed as a post-relocation support tool, which is that some on-going revenues from the project that induced the resettlement is somehow shared with project-affected-people or stakeholders (Downing et al., 2021). Stakeholders of hydropower projects refer to individuals and groups who have invested in specific investments that can bring benefits or value to the project. They also actively or passively undertake the risks and returns brought by the project (Shi and Kong, 2008). The development of resource projects depends on the support of all stakeholders. However, due to limited financial resources and conflicting interests, it is difficult to meet the needs of all stakeholders at once (Fan, 2010). Core stakeholders refer to those grouped as high interest and high influence (Rosso et al., 2014; Xia et al., 2018). To simplify further quantitative analysis, this paper focuses on the main stakeholders of China's hydropower resources projects. These stakeholders include the central government, hydropower development enterprises (representing shareholders, creditors, management, and employees), local governments (provincial, municipal, and county governments), and reservoir resettlers (individual and village collectives, including residents in resettlement areas). Water resources belong to the state, and the central government has the ownership and income acquisition right of the power station by virtue of these inputs. Development enterprises (project owners) are responsible for raising funds for the development and construction of the power station and carrying out operational management. Under the strict restriction of compensation and resettlement policy, local governments undertake the tasks of relocating and reconstructing inundated cities and towns, relocating resettlers and protecting the ecological environment of the reservoir area. Resettlers resign land, houses and other assets for reservoir construction. In summary, the main input factors of the central government, local governments, development enterprises, and resettlers are water resources, environmental resources, capital, and land resources. Together, they produce hydroenergy resources. Their investment and impact on the project qualify them to participate in the benefit sharing of the projects.

2.2. Benefit distribution among main stakeholders

In general, the hydropower station has multiple functions such as power generation, flood control, shipping, water supply, and ecology. Public benefits generated by the hydropower station can be shared freely by relevant subjects (flood control area, power receiving area, water receiving area, etc.). However, the economic benefits are mostly shared by the central government and development enterprises, while local governments especially reservoir resettlers receive less in China (Dai, 2013; Xia et al., 2018). Resettlers usually have to accept simple compensatory resettlement without marketization passively and are excluded from the substantial economic and social benefits of hydropower projects (Kong and Shi, 2008). They also bear the impoverishment risks associated with livelihood transformation, such as landlessness, joblessness, food insecurity, social disarticulation, etc. (Cernea, 1997). In particular, expropriated farmland is generally compensated based on the loss of original function, which results in low compensation standards and has been criticized by various sectors of society. Resettlers are yet to participate fully in the benefit distribution process and enjoy the value-added benefits after their farmland is converted into a reservoir (Shanahan, 2012; Chen et al., 2017). Consensus has been reached on the unfair distribution of benefits among stakeholders in hydropower projects (Egre, 2007; Skinner et al., 2009). The unfair distribution has caused an imbalance between cost sharing and benefit sharing, which may lead to social conflicts and environmental risks, and is not conducive to the sustainable development of the economic society. According to Mitchell's three-dimensional scoring method, hydropower development enterprises and governments are determined stakeholders, while resettlers are expected stakeholders. Although resettlers enjoy legitimacy and urgency, they do not have power. To address this issue, the benefits of hydropower projects should be reasonably shared between investors and contributors to highlight social equity (Dai, 2013). Resettlers deserve to share part of the ownership of the project and claim its benefits, while hydropower companies should be more responsible (Fan et al., 2015). It is widely agreed that reservoir resettlers should share more in hydropower benefits to ensure their long-term livelihoods on the basis of compensations and grants (Cernea, 2000; Duan and Zhang, 2013; Zhang et al., 2017; Shi and Shang, 2021). Benefit sharing in hydropower development has received policy support in China. Table 1 summarizes the details of the main stakeholders of hydropower projects.

2.3. The mechanism of shared benefits

To achieve interest competition balance, it is necessary to establish a scientific benefit sharing mechanism. This paper comprehensively absorbs the previous research results and combines the characteristics of hydropower projects to construct a framework for benefit sharing mechanism, as shown in Figure 1.

Based on the above analysis, Sharing subjects (who will share) mainly refer to governments, hydropower enterprises, and resettlers, etc. Sharing objects (what to share) consist of financial benefits such as power generation benefit and non-financial benefits such as flood control benefit. Reasonable sharing standards (how much to share) are the key for the sharing mechanism to work well and achieve the expected goal, and this paper focuses on this issue. Sharing means (how to share) can be divided into two types: monetary and non-monetary. Strong support systems required by the sharing mechanism include policy and implementation supports, such as public participation mechanism and feedback mechanism.

3. Methods

3.1. Model construction

After projects construction, the utility value of the reservoir formed by the land resources is significantly higher than the original agricultural use value based on the resource value transfer theory. In other words, the use value of the expropriated land resources has been appreciated. The operational benefits of hydropower projects include the added value of land resources after expropriation, and their sharing should appropriately consider resettlers (Fan et al., 2015). Equitable sharing of project benefits can be based on the financial output of the project and calculated according to the proportion of quantifiable input (Zhu and Shi, 1995; Zhang et al., 2017). Referring to the research on investment in equity sharing (Fan, 2010; Duan and Zhang, 2013), from the perspective of input this paper attempts to use the net present value method to estimate the reasonable sharing of hydropower benefits among stakeholders, particularly resettlers. The specific steps are as follows. Firstly, discount the net cash flow of the hydropower station in each year to the beginning of the construction period based on a specific discount rate, and add up all present values. This is the present value of net income, depreciation and residual value of the power station minus the original investment. Secondly, the share proportion of related parties is calculated according to the degree of investment contribution. Finally, the product of the net present value of the project and the proportion of input is used as the sharing amount. The quantitative model formula is:

TABLE 1 Status of core stakeholders of hydropower projects in China.

The main stakeholders	Main input factors	Current benefits return	Current risk-taking	Further interest demands
Central government	Water resource	Social, economic, ecological benefits	Environmental and social risks	Maximization of comprehensive benefits
Local governments	Environmental resource	Statutory taxes, development support	Social and ecological risk	The prosperity and stability of the reservoir area
Hydropower development enterprises	Capital	Operating profit	Investment risk	Steady gains of power station
Reservoir resettlers	Land resources	Compensation, subsidy	Poverty risk	Increased income and affluence

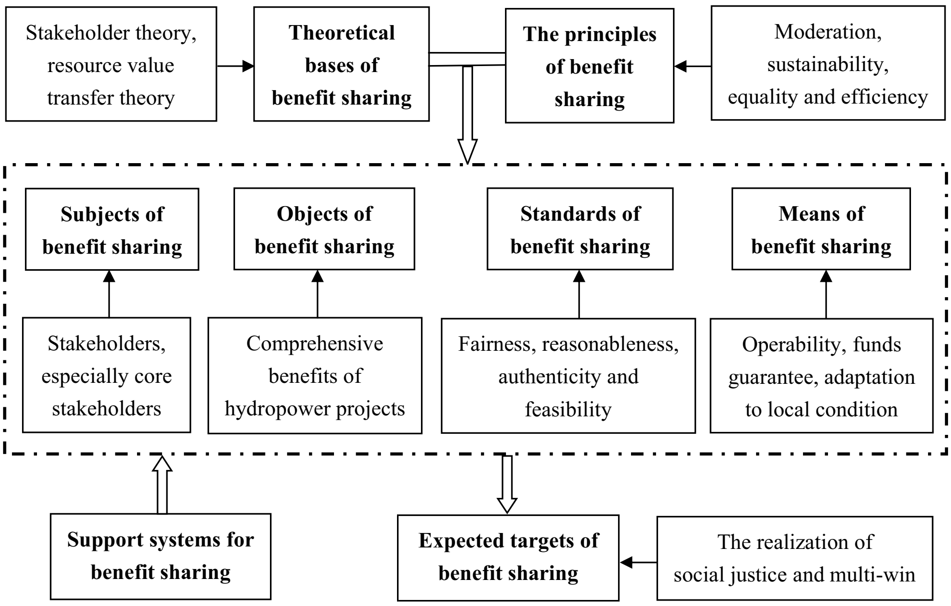

FIGURE 1
Theoretical framework for the mechanism of shared benefits in hydropower projects.

$$V=\left[\frac{\sum_{i=1}^{n}\frac{Ri}{(1+r)^{i}}+\sum_{i=1}^{n}\frac{P\times(1+r)^{t}\times(1-s)}{n\times(1+r)^{i}}+\frac{P\times(1+r)^{t}\times s}{(1+r)^{n}}}{(1+r)^{t}}-P\right]\times\frac{T}{P}. \quad (1)$$

Where V is the income that stakeholders should share in the initial stage of construction of a hydropower station, R_i is the net income in the year i during the project operation period, r is the discount rate, i is the serial number of the year, t is the construction period, n is the operation period which is equal to the income period, s is the residual value rate, and the depreciation of the power station is calculated according to the average life method. T is the inputs of all parties in the initial stage of project construction, while P is the total project inputs, which is calculated using the static investment at the beginning of the project construction. To simplify the analysis, input factors such as water resources (difficult to quantify) are not considered, nor are taxes and fees. In addition, the input factors involved in the benefit distribution for resettlers must be the losses that have made positive contributions to the project and have not been reasonably compensated in the project construction. Losses such as houses and crops cannot be included as they generally have received full compensation (Zhu and Shi, 1995; Fan, 2010; Xia et al., 2018). Farmland compensation belongs to incomplete compensation in China. If it is difficult to obtain the agricultural land appraisal price, the compensation and subsidy for all or part of the cultivated land and garden plot can generally be used as the inputs of resettlers in the projects (Kong and Shi, 2008; Sun and Liang, 2022).

The influencing factors of the share amount in the model can be divided into two categories: deterministic and uncertain factors. The former includes the discount rate, construction period, operation period, the residual value rate, static investment and inputs of all parties, among others. The latter refers to the net operating income of the power station. Even though non-financial benefits such as flood control are high but difficult to measure, resettlers usually can only participate in the distribution of power generation benefits. The main elements that determine the net revenue of generation (R_i) are operating income and operating cost. The operating income can be obtained by multiplying the on-grid electricity price (P_i) and the annual electricity sales (S_i). The calculation of operating costs is complex, but the data of net profit margin on sales (N_i) for hydropower companies is relatively easy to obtain. Therefore, the calculation formula of net income for the year i is $R_i = P_i \times S_i \times N_i$. Affected by the national macro-policy, economic development demand, market competition, the size of incoming water, and the level of operation and management, there is great uncertainty in electricity sales, electricity price, operating cost or net profit margin on sales. Previous studies have shown that the grey system is suitable for analyzing the problem with "small sample, poor information, uncertainty." The Monte Carlo method is a stochastic simulation method and can solve the uncertainty problem well. Therefore, the grey prediction method and Monte Carlo simulation method are used to predict the uncertainty factors respectively, and then the value of sharing benefits for resettlers is estimated.

3.2. Basic data

In this paper, a case study of the Xiluodu hydropower station on the Jinsha River in China is carried out to test the applicability of the model. After the completion of major projects such as the Three Gorges Project, southwest China has become the main location for hydropower development. The Xiluodu hydropower station is the backbone project of west-to-east power transmission, and is representative of this trend. The project was initiated in 2005, and all units were put into operation in 2014, with completion in 2015. It is a large-scale hydropower station mainly for power generation and has comprehensive benefits such as sediment retention, flood control, and improvement of downstream navigation. It is also the third-largest hydropower station in China and the fourth-largest in the world. The designed average annual power generation for many years is 57.12–64.06 billion kWh. In 2005, the total static investment of the power station was 50.342 billion yuan, and 4,650.8 hm^2 of cultivated land was expropriated. The compensation cost was 1.981 billion yuan, equivalent to 16 times of the annual output value, involving 52,690 resettlers (Fan, 2010). Nine counties (districts) in the reservoir area are multi-ethnic communities, and all of which are impoverished counties (districts). It is expected to gradually narrow the regional disparity by transforming the advantages of green energy into the advantages of economic development. Since 2004, resettlers have moved, and their demands for sharing the benefits of hydropower have become higher and higher (Chen and Zhao, 2017). However, for various reasons, hydropower development has performed poorly in driving the local economy and improving the livelihoods of resettlers (Fan et al., 2013). Therefore, scientifically determining and realizing the amount of benefit sharing can help stakeholders form reasonable expectations, promote local governments, especially resettlers to share the benefits of hydropower development better, eliminate conflicts, and ensure sustainable economic and social development.

Among the deterministic factors of the model, 2005 is the first year of the construction period, 2015 is the initial year of the operation period, the construction period is 10 years, the operation period is taken as 50 years, the residual value rate of fixed assets is determined as 5%, and the discount rate is calculated using the safe interest rate plus the risk adjustment value. This paper takes the 50-year treasury rate of 3.99% in 2015 as the safe interest rate, the risk adjustment value is taken as 1% with reference to similar studies, and the discount rate is set at 4.99%. In this paper, compensation funds for all cultivated land and garden land are regarded as the investment of resettlers, so the proportion of investment of resettlers is 3.94%.

China Yangtze Power Co., Ltd. owns the generation assets of Xiluodu hydropower station. Among the uncertain factors, this paper obtains the data of electricity sales, electricity price, and net profit margin on sales over the years from the power station purchase and sales contracts and the enterprises financial statements.

4. Results

4.1. Calculation of benefit sharing

4.1.1. Calculation of grey prediction method

The core models of grey prediction include the GM (1,1) model and the grey verhulst model. The former is suitable for time series with an exponential variation rule, while the latter is applicable to non-monotonous swing development sequences (Liu, 2021). The change trend of electricity price and net profit margin on sales of Xiluodu hydropower station is not monotonous, but the overall trend of electricity sales is monotonous. Through statistical analysis of the electricity sales of other hydropower stations, it is found that electricity sales will not increase or decrease year by year, and there are large fluctuations. From 2015 to 2020, electricity sales of Xiluodu hydropower station increased continuously, which may be caused by the short operation period and is not sustainable. The decrease in electricity sales in 2021 can also verify this. Therefore, in this paper, the grey verhulst model is constructed. To improve the accuracy of simulation and prediction, the model is improved by using the technique of dynamic forecasting with recursive compensation by grey numbers of identical dimensions. With the help of MATLAB software, the above model is used to predict electricity sales, electricity price, and net profit margin on sales of the hydropower station, respectively. The accuracy test shows that the precisions of the improved models are not enough. Therefore, the data sequence is processed by weakening buffer operator, which makes the development trend of data more practical. The relative errors of the final three models are less than 0.01, the variance ratios are less than 0.35, the correlation degrees are greater than 0.9, and the probabilities of small errors are greater than 0.95. The accuracy grades of all models are determined to be Grade 1 (good). The prediction performances are excellent, and the prediction results have high reliability. The fitting results of the model are shown in Tables 2, 3, 4.

Using the verhulst model with good accuracy, the relevant data for 2022–2064 can be predicted from the known data, and then the sum of the discounted value of net income of the hydropower station is 77.93 billion yuan (discounted to 2005). The specific calculation process is shown in Table 5.

It is not difficult to calculate that the discount value of depreciation is 17.489 billion yuan and the discount value of residual value is 221 million yuan. After deducting the initial investment, the total benefit sharing amount of Xiluodu hydropower station is 45.298 billion yuan and the average income shared by resettlers is 1.783 billion yuan. China's late-stage support policy for reservoir resettlers reflects the idea of sharing. Since 2006, Xiluodu resettlers have enjoyed the government's direct cash subsidies of 600 yuan per person per year for 20 consecutive years. The calculation formula of the discount value is:

$$B = 600 \times H \times \left(P/A,\, r,\, n\right). \tag{2}$$

Where B is the present value of subsidies for resettlers, H is the total number of resettlers, and $(P\ /\ A,\ r,\ n)$ is the present value coefficient of annuity. Since the direct subsidy for resettlers has stable financial security, without considering the risk premium, r is set at 3.70% with reference to the 20-year treasury rate in 2015, n is taken as 20, and the measured result is 441 million yuan. If other assistance funds are not considered and late-stage support subsidies are deducted, the benefit sharing amount of Xiluodu resettlers is 1.342 billion yuan (2005 price). This figure represents the benefits of hydropower development that should be fairly shared by resettlers in addition to compensations and subsidies in the resettlement policy.

4.1.2. Calculation of Monte Carlo simulation method

This paper uses Crystal Ball (an external plug-in of Excel) to predict and automatically fit the above historical data to obtain their respective probability distributions. Among them, electricity sales follows a lognormal distribution, with an average value of 554.42 and a standard deviation of 46.24. Electricity price follows a logical distribution with an average value of 0.27 and a scale of 0.01. Net profit margin on sales follows a logical distribution with an average value of 0.45 and a scale of 0.01. The value of deterministic factors and the formula of benefit sharing are then entered to define and predict the

TABLE 2 Forecast results of electricity sales.

Year	Actual electricity sales	Improved verhulst model					Electricity sales after weakening	Improved verhulst model after weakening				
		Predicted value	Relative error (%)	Variance ratio	Correlation degree	Small error probability		Predicted value	Relative error (%)	Variance ratio	Correlation degree	Small error probability
2015	523.65	-	-	0.35	0.98	1.00	534.73	-	-	0.17	1.00	1.00
2016	526.10	534.34	1.57				557.73	554.30	−0.61			
2017	538.00	558.60	3.83				563.41	565.07	0.29			
2018	589.60	572.42	−2.91				568.58	570.85	0.40			
2019	589.60	587.56	−0.35				570.87	573.90	0.53			
2020	602.42	604.21	0.30				575.58	575.50	−0.01			
2021	534.73	545.95	2.10				579.09	576.34	−0.47			

Unit: billion kWh.

amount of benefit sharing. The simulation is run with 100,000 times, and the software provides a probability distribution histogram and statistical value of the benefit sharing amount for resettlers, as shown in Figure 2 (Unit: 100 million yuan).

Figure 2 shows that the average share of resettlers is 1.723 billion yuan, with a standard deviation of 33 million yuan. To make the simulation results more reliable, experts were consulted and related research was combined (Zheng et al., 2016). This paper directly defines the assumption that electricity sales obeys a uniform distribution (523.65, 608.57), where 608.57 is obtained by multiplying the maximum power generation capacity of 640.6 and the consumption utilization rate of 95%. The electricity price obeys a uniform distribution (0.26, 0.29), and the net profit margin on sales follows a uniform distribution (0.42, 0.48). The above operation is carried out again, and the predicted average value is 1.787 billion yuan. The difference between the two results is small. After comprehensive consideration, this paper takes 1.723 billion yuan as a conservative estimate of the shared benefits of resettlers. Similarly, if other assistance funds are not considered, and late-stage support subsidies are deducted, the benefit sharing of resettlers should be 1.282 billion yuan (2005 price).

4.2. New ideas of benefit sharing

Based on the above analysis, and with reference to relevant research results and practical experiences, new ideas of benefit sharing and win-win in hydropower development are proposed to protect the interests of resettlers, power stations, and local governments fairly. Firstly, establish a shared development fund to realize long-term benefits for resettlers. Referring to the estimated amount of benefit sharing by the model, each hydropower station can draw funds from the generation income to establish the development fund according to its own actual situation. It is dedicated to supporting the improvement of livelihoods and the stable development of the resettlers and ensuring the continuous improvement of their sense of gain and happiness. Long-term sharing rather than one-off sharing is recommended. The benefit sharing schemes for hydropower resettlers in the Xiluodu project are detailed in Table 6, and the specific implementation rules can be discussed and determined by main stakeholders. The implementation of annual sharing during the service life of the power station can ensure that resettlers have stable incomes every year, and at least food security is guaranteed, which can reduce the livelihood dilemma of resettlers and social risks after irrational consumption in a short period of time, and also alleviate the financing pressure of hydropower enterprises. The application scope of the shared development fund is relief and social security for resettlers in difficulties, capacity building and employment promotion, livable environment and cultural life, etc. Secondly, increase the policy support to ensure stable incomes for the power station. In view of many uncertainties in the operation of the power station, governments should undertake the guarantee responsibility for reservoir resettlers to participate in and enjoy the development benefits. To reduce the uncertain risk of power stations and confirm the source of benefit sharing funds, policies such as giving priority to hydropower generation and ensuring its consumption, improving the mechanism of electricity price, tax preference or return should be adopted. Thirdly, integrate all kinds of resources to promote the sustainable

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TABLE 3 Forecast results of electricity price.

Year	Actual electricity price	Improved verhulst model					Electricity price after weakening	Improved verhulst model after weakening				
		Predicted value	Relative error (%)	Variance ratio	Correlation degree	Small error probability		Predicted value	Relative error (%)	Variance ratio	Correlation degree	Small error probability
2015	0.284	-	-				0.280	-	-			
2016	0.270	0.271	0.37				0.273	0.274	0.37			
2017	0.263	0.268	1.90				0.273	0.272	−0.37			
2018	0.271	0.266	−1.85	0.40	0.99	1.00	0.272	0.272	0.00	0.27	1.00	1.00
2019	0.273	0.274	0.37				0.270	0.271	0.37			
2020	0.265	0.265	0.00				0.272	0.271	−0.37			
2021	0.280	0.278	−0.71				0.270	0.271	0.37			

Unit: yuan/kWh.

development of the reservoir area. Reservoirs resources, placement and allocation of resources, and related policy items are utilized sufficiently to boost rural revitalization, promote industrial upgrading and ecological environment optimization in the reservoir area, and the transformation from a relatively poor and backward reservoir area to a new rich, beautiful and harmonious one is realized.

5. Discussion

Although the concept and mode of benefit sharing have their advantages, there are many difficulties in the practical application (Yang and Meng, 2017). One of the main reasons is the difficulty in quantifying the amount of benefit sharing. In this paper, grey prediction method and Monte Carlo simulation method are used to calculate the benefit sharing amount of resettlers, which are 1.342 billion yuan and 1.282 billion yuan respectively, with little difference. To reduce the deviation, the average value of the benefits allocated by resettlers is 1.312 billion yuan, which is about 2.61% of project investment and 11 times the annual output value of land. The amount of benefit sharing mentioned above is within the acceptable range of development enterprises. In fact, hydropower enterprises are also increasing supports for resettlers to make peace (Hu, 2013). A clear sharing amount can effectively avoid enterprises falling into the mud of unlimited responsibilities, making it highly operable. The profit distribution model of hydropower development based on dynamic income was established to adjust the rate of return of all parties, and the total amount of additional compensation for Xiluodu project resettlers was 1.198 billion yuan (Xia et al., 2018). The estimated results in this paper do not differ much from the above results, which further proves the rationality of the calculation model. Moreover, the calculation method in this paper is more simpler and more convenient. Once the parameters for model calculation are determined, the corresponding benefit distribution results under hydropower revenue can be easily calculated.

If the benefit sharing plan is implemented, resettlers will change from expected stakeholders to determined stakeholders, which is conducive to obtaining support from resettlers for hydropower development. In 2021, the *per capita* disposable income of Chinese reservoir resettlers was 18,016 yuan, which is 95.2% of that of rural residents, with a difference of 909 yuan between the two. If production and living subsidies are directly distributed, the *per capita* income of Xiluodu resettlers will increase by at least 2,230 yuan per year (calculated based on a 40-year long-term sharing approach), which is expected to exceed that of rural residents. The effect is quite apparent, but it may encourage the dependence of some resettlers. Project assistance can also be implemented, such as education and training, industrial support, public services, etc., to gradually improve the sustainable livelihood ability of resettlers. However, there may be problems such as slow project effectiveness and difficulties in subsequent management and maintenance. Taking into account both immediate and long-term interests, it is better to adopt a combination of the two. According to the current regulations on land acquisition compensation in China, the distribution ratio between individual resettlers and village collectives can be set at 80 and 20%. Chinese society has always had the concept of "inequality rather than want is the cause of trouble." The proposal in the benefit sharing program for resettlers to adopt uniform sharing standards is mainly based on the

TABLE 4 Forecast results of net profit margin on sales.

Year	Actual net profit margin on sales (%)	Improved verhulst model					Net profit margin on sales after weakening (%)	Improved verhulst model after weakening				
		Predicted value (%)	Relative error (%)	Variance ratio	Correlation degree	Small error probability		Predicted value (%)	Relative error (%)	Variance ratio	Correlation degree	Small error probability
2015	47.53	–	–				47.60	–	–			
2016	42.78	44.39	3.76				46.74	46.53	−0.45			
2017	44.42	43.76	−1.49				45.57	45.86	0.64			
2018	44.21	45.07	1.95	0.45	0.97	0.86	45.09	45.44	0.75	0.23	0.99	1.00
2019	43.24	43.18	−0.14				45.23	45.16	−0.15			
2020	45.87	45.82	−0.11				44.69	44.99	0.67			
2021	47.60	46.64	−2.02				45.07	44.88	−0.42			

consideration that the inconsistent sharing standards are likely to cause comparison and contradiction among resettlers, with potential factors of instability. This is also one of the reasons why China's late-stage support policies have continuously supported reservoir resettlers for 20 years, with the standard of 600 yuan per person per year remaining unchanged. Of course, detailed allocation may also be made based on the amount of land loss, but the large number of resettlers makes it challenging to calculate separately. The central government of China supports resettlers in sharing the achievements of hydropower development and has formulated guiding opinions. The realization of the benefit sharing scheme is expected. To promote benefit sharing in other hydropower stations, the case study of Xiluodu project can be referred to. It may be necessary to follow principles such as moderation, sustainability, and balance between fairness and efficiency.

However, uncertainties exist in the operation of the hydropower station. When basic data is scare, using grey prediction or Monte Carlo simulation to calculate the expected income of the power station is appropriate. If no historical data is available, referring to the development data of other power stations in similar areas can be helpful. Due to space limitation, this paper only provides a rough quantitative analysis of the benefit sharing of resettlers, and the results may have some deviations. The distribution of other stakeholders is also worth considering. The input factors such as water resources, and non-financial benefits such as flood control and shipping have not been quantified, which may require in-depth research. The model can be developed further by considering the fluid capital of projects. Other estimation methods can also be used for comparative studies.

6. Conclusion

This paper identifies the main stakeholders participating in the benefit distribution of hydropower development, establishes a quantitative model for the benefit sharing amount from the perspective of stakeholders inputs and carries out a case study. The results indicate that the main stakeholders of hydropower projects include governments, hydropower enterprises, and resettlers. The input of resources is the basis for sharing project benefits, and stakeholders share the benefits of the project according to the proportion of input. Resettlers participate in the distribution of project benefits by taking land compensation as the capital of hydropower projects. The net present value method can be used to establish a benefit sharing model, in which the main stakeholders such as resettlers take the product of the cumulative discounted value of net cash flow in the hydropower projects and their proportion of investment as the sharing amount. In this model, influencing factors are divided into two categories: certainty and uncertainty. The latter is innovatively solved by the grey prediction method and Monte Carlo method, and the amount of benefit sharing can be calculated. The case of Xiluodu hydropower station proves the feasibility and rationality of the model.

In this paper, reservoir resettlers are regarded as the investors in hydropower projects rather than the passive compensation recipients. This paper also takes the time value and risk of funds into full consideration, provides a measuring tool for the reasonable amount of benefit sharing, and opens up a new idea of benefit sharing, which gives a quantitative basis for reference and offers strong support for further promoting benefit sharing in hydropower development.

TABLE 5 Net income and its discounted value of hydropower generation from 2015 to 2064.

Year	Electricity sales (billion kWh)	Electricity price (yuan/kWh)	Net profit margin on sales (%)	Net income of power generation (billion yuan)	Discounted value (billion yuan)
2015	52.365	0.284	47.53	7.068	4.137
2016	52.610	0.270	42.78	6.077	3.388
2017	53.800	0.263	44.42	6.285	3.337
2018	58.960	0.271	44.21	7.064	3.573
2019	58.960	0.273	43.24	6.960	3.353
2020	60.242	0.265	45.87	7.323	3.360
2021	53.473	0.280	47.60	7.127	3.114
Forecast annual average value of 2022–2064	57.724	0.271	44.68	6.989	53.669
Total					77.930

53.669 in the table is the sum of the present value of expected net income from 2022 to 2064.

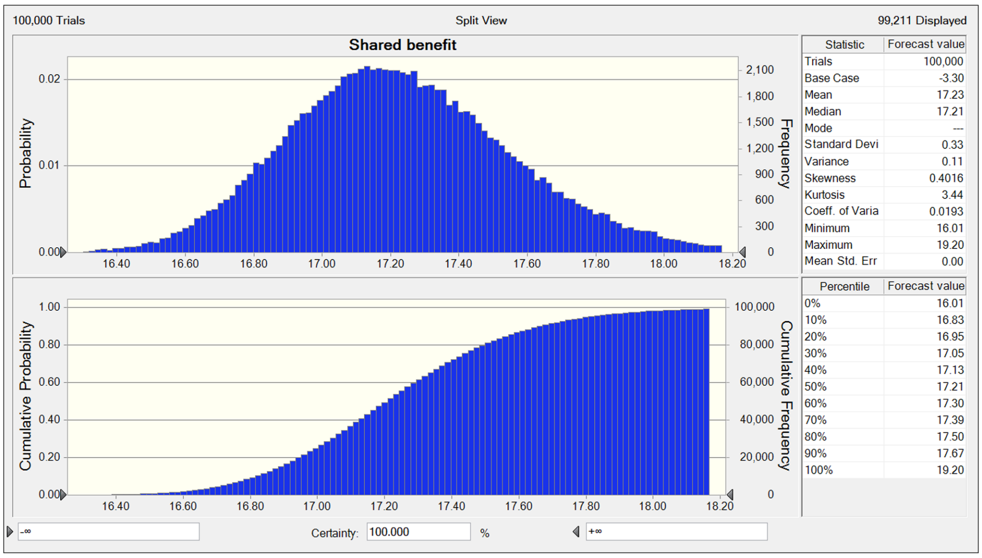

FIGURE 2
Probability distribution and statistical value of benefit sharing amount for Xiluodu resettlers.

TABLE 6 Benefit sharing selectable schemes for Xiluodu project resettlers.

The mode of long-term sharing	Sharing standards (equal every year)	Source of funds (electricity extraction per kWh per year)
2022–2031, last 10 years	5,609 yuan per person per year	5.12×10^{-3} yuan
2022–2041, last 20 years	3,308 yuan per person per year	3.02×10^{-3} yuan
2022–2051, last 30 years	2,574 yuan per person per year	2.35×10^{-3} yuan
2022–2061, last 40 years	2,230 yuan per person per year	2.04×10^{-3} yuan

The sharing amount is taken as the average of two forecasting methods and is calculated based on the discount rate of 3.70%, the average annual electricity sales of 57.724 billion kWh and 52,690 resettlers who enjoy late-stage support in 2021 as the base year.

Driven by the goal of achieving carbon peak and carbon neutrality, hydropower development has a new historical opportunity. Benefit sharing emphasizes the sustainable use of resources and fair distribution of benefits. The ideal goal of hydropower development is to build a power station that drives the local economic growth, improves the environment, and benefits a group of resettlers.

However, resettlement is often the most significant social problem in hydropower development, and it also restricts the process of hydropower development in developing countries. Reconciling the benefit conflicts of all parties and establishing a fair benefit sharing mechanism are fundamental measures to solve the dilemma of land acquisition and resettlement work in hydropower projects, as well as the basic guarantee for realizing sustainable hydropower development and driving regional economic growth. However, benefit sharing is not simply dividing hydropower profits but taking into account the interests and demands of all parties concerned. Governments, resettler groups and development enterprises can obtain reasonable benefits from the hydropower development legally and compliantly to reach a consensus. Based on the estimation results of the benefit sharing model in this paper, it is reflected that base on China's current resettlement compensation and subsidy policies, there is still much room for improvement in the benefits that resettlers are entitled to. According to the model's prediction, hydropower stations in developing countries can withdraw money from power generation benefits to establish a shared development fund for resettlers. Through various forms of support, development gains can continue to benefit the poor areas and resettlers, ensuring that resettlers effectively avoid uncertainty risks, achieve sustainable livelihoods and common prosperity, and become the real beneficiaries and supporters of the project. Benefit sharing will create a new situation of co-construction, sharing and multi-win in hydropower projects, promoting green, low-carbon and sustainable development.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

HS and YD conceptualized and designed the work. HS wrote the first draft of manuscript. XL, YD, and NZ reviewed and edited the manuscript. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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