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Benefit Sharing in Hydropower Development: A Model Using Game Theory and Cost–Benefit Analysis

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Abstract: Globally, hydropower is one of the most important energy sources, but its development often entails population displacement. Traditional economics cannot fundamentally resolve disputes over relocation compensation. In the present study, we use the game theory to model the relationship between stakeholders. The main issue is the distribution of benefits between hydropower developers and the affected population. To distribute benefits more fairly and rationally, we model the benefits and costs for the developers and the affected people over the full life cycle of the project, consider the affected people as project investors, adjust benefit distribution based on the internal rate of return, and assess the rationality of the resulting plan. Under this benefit-sharing model, hydropower developers and affected people can share benefits and risks, effectively eliminate conflicts, and ensure project success. The model provides guidance for the formulation of compensation for affected people, and a new paradigm for the study of benefit-sharing mechanisms for hydropower development.

Keywords: benefit sharing; reservoir-displaced people; hydropower developers; game theory; internal rate of return; full life cycle

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1. Introduction

In the preamble of *Transforming Our World: The 2030 Agenda for Sustainable Development*, the United Nations (2015) recognized that "eradicating poverty in all its forms and dimensions, including extreme poverty, is the greatest global challenge". The World Bank mentioned in Operational Manual 4.12, "Involuntary Resettlement," that if involuntary resettlement caused by project development is not effectively managed, it can have serious economic, social, and environmental consequences. Around the world, about 10 to 15 million people are displaced every year due to development projects [1]. Through the demolition of their production systems, the alienation of their skills, fierce competition for resources, and weakened social networks, reservoir-displaced people (RDP) are threatened by poverty.

Hydropower development serves national interests and has significant economic, social, and ecological benefits, but it has been criticized for its ecological damage [2]. There is no evidence of a causal relationship between hydropower development and the ecological footprint, but it is clear that it will inundate large amounts of built-up land, grazing land, and cropland, causing involuntary resettlement to occur [3]. Countries that wish to accelerate hydropower development are being hampered by resettlement issues [4]. How to protect the legal rights and interests of RDP, so that they can relocate smoothly and improve their livelihoods, is the key problem [5].

In practice, in many resettlement cases, resettlement models are gradually improving. Early on, RDP received little compensation. Due to poor compensation standards and their constrained survival skills, they could not adapt well to their new environment, which caused great poverty [6]. To ensure social stability, resettlement is now considered a core project task, and all such costs are included in project budgets [7]. In 1980, the World Bank drafted the first requirements around involuntary resettlement, attracting more attention to the human rights of RDP [8]. To reduce the risk of poverty, successive scholars proposed ideas meant to help RDP recover their original living standards; these include helping them restructure their livelihoods, negotiating for their individual needs, and offering long-term compensation. In 1999, the World Bank revised its involuntary resettlement policy, adding emphasis to the development rights of RDP. However, although compensation standards are gradually improving, much of the unmeasured cost of resettlement work is still externalized, and hydropower developers continue to try to minimize their resettlement expenditure as much as possible, within the legal limits [9]. Cernea (2008) believes that the total of material and non-material poverty, risks, and losses experienced by RDP far exceeds the capacity of the narrow compensation-centered solution provided by traditional economics. He advocates a shift from compensation economics to resettlement economics integrated with development; that is, benefit sharing [10].

Benefit sharing is a new and important supplement to the resettlement model. Literally understood, benefit sharing means that the benefits of a project are shared by the people it affects. This redistribution of benefits is prone to being misunderstood as reducing the vested interests of developers. However, benefit sharing in hydropower development should be considered from the perspective of all stakeholders. Ideally, it is a win–win strategy: the optimal solution that meets the interests of everyone and maximizes overall benefit.

However, research on benefit sharing mainly considers the perspective of RDP, aiming to protect their welfare and reduce the threat of poverty. Roughly, its recommendations are of two kinds. One is to give part of the project's profits to the RDP, for example, through preferential water and electricity tariffs. The other is to treat RDP as project investors and let them share in the project benefits according to their contributions. However, such studies focus on the gains and losses of RDP, apart from other stakeholders, and thus cannot point the way to a win–win solution. This paper introduces game analysis; through the comparison of the benefit levels of both parties, the benefit sharing can be made more fair and reasonable.

This article analyzes the economic relationship between RDP and hydropower developers, considers how to achieve a win–win situation, builds a benefit-sharing model, and verifies its feasibility and effectiveness. Section 2 summarizes the previous research, sorting out research methods and current problems. Section 3 builds a game-theoretic model to analyze the stakes among RDP, hydropower developers, and the government. Section 4 builds a cost–benefit model, measures the actual benefits for RDP and hydropower developers, adjusts the distribution of benefits based on the internal rate of return, and assesses the rationality of the resulting plan. Section 5 uses a case study to assess the reliability and validity of the model.

2. Literature Review

The concept of benefit sharing arises in response to the unfair distribution of resources in the process of social development [11]. For de Ortuzar, benefit sharing is a universal distribution; that is, to anyone who needs it [12]. In the case of overcapacity, surplus resources are allocated to those in need. This definition has certain limitations. Extended to other fields, it sounds similar to an excuse for free riding. For Schroeder, benefit sharing refers to presenting some advantage or profit to a provider of resources to achieve fair exchange [13]. This explains who can share the benefits, but it does not mention specific benefit-sharing methods, and it cannot ensure that the outcome is fair and reasonable for all parties. In this article, benefit sharing means that the core participants share the net profit of the project, according to their contribution, as well as sharing its risks. This definition narrows the scope of benefit sharing to the core participants of the project, eliminating compensation for external stakeholders and project costs, and sharing the overall net profit of the project. Net profit is distributed and benefits are shared, along with risks, according to the contributions of the core participants, to maximize the smooth development of the project.

Academic proposals for models of benefit sharing for RDP can be roughly divided into two types. The first approach is based on Schroeder's definition of benefit sharing, where part of the project's benefits is presented to the RDP, to improve their welfare. Joseph Milewski (1999) proposed a model providing preferential water and electricity tariffs and establishing a development fund [14]. Dominique Égré (2002) argued that it is possible to negotiate with hydropower developers to reduce or exempt energy prices in the reservoir and resettlement areas, and promote their economic development, to benefit the RDP [15]. Siqin (2008) emphasized the cultivation of talent and provision of appropriate jobs [16]. Zhang Yumin (2010) proposed a long-term compensation installment system [17]. Fan Qixiang (2010) modeled annual income based on the different ways of using resettlement compensation, and proposed a formula of "long-term compensation + share dividend + basic social security" [18]. Fan Jie (2013) used specific factor models to measure changes in RDP's income, arguing that long-term compensation should gradually increase with basic living and production prices [19]. Zheng Tengfei (2015) argued that the current hydropower benefit-sharing mechanism is unreasonable, with many external costs and benefits not yet internalized and resettlement losses not fully compensated [20]. Liu Weiwen (2019) proposed that the compensation standard for resettlers should be improved, based on the economic rent from hydropower [21]. Sun Haibing (2019) argued that the government or project representatives can increase the income of RDP through a combination of higher compensation and better survival skills, achieving a relatively balanced allocation of benefits, and a win–win situation for multiple parties [22].

The second approach is to treat RDP as project investors, who share the project's benefits and risks. In the 1970s, the Canadian Hydropower Corporation allocated 17.5% of its investment share to Quebec's indigenous people. The indigenous people made loans to the bank for investment. Once they were shareholders, they no longer opposed the project, and ultimately contributed to a win–win situation [23]. Zhu Wenlong (1995) argued that the land resources lost by RDP are invested capital, which suggests benefit sharing through land equity dividends [24]. A report from the World Commission on Dams (2000) put forward 26 guidelines, one of which is to make RDP project shareholders who are entitled to a share of project benefits [25]. Shi (2002) proposed the securitization of land assets and verified the feasibility of introducing market mechanisms to the transfer of land use rights [26]. Duan Yuefang (2004) argued that current methods of benefit sharing are a kind of poverty relief, a short-term act, and that RDP should participate as investors [27,28]. Li Xunhua (2010) argued that benefit sharing should follow market-oriented principles and solicit opinions from all parties [29]. Yu Qingnian (2014) proposed that the responsibilities, rights, and benefits of the government departments, hydropower developers, and RDP should be improved in the benefit-sharing mechanism [30]. Meng Beibei (2021) believes that benefit sharing should allow immigrants to participate more in decision making [31]. Sun Haibing (2021) believes that benefit sharing lacks effective legal protection, and it is easy to cause disputes during the implementation process [32].

The first type of research performs an analysis, mainly from the perspective of RDP, emphasizing how to increase their compensation, and does not consider the cost to hydropower developers, so it is not a win–win solution. Additionally, although the second type of research promises benefit sharing and risk sharing through economic shares, how to calculate these shares, and the relative responsibilities and powers of the government, enterprises, and RDP in the project have yet to be determined.

3. Game-Theoretic Analysis

Game theory is a decision analysis method, which mainly resolves the conflict between the two parties in the game and studies a reasonable action plan that is beneficial to all parties [33]. The research on the game of benefit distribution can be roughly divided into two categories. One is to use the Shapley value method to adjust the benefit distribution according to the marginal contributions of the participants, and the other is to find the Nash-Harsanyi solution based on the objective function and constraints, which is an optimal strategy for either party. Zavalloni et al. propose that the Nash–Harsanyi solution is more beneficial to small players than the Shapley value method [34]. Reservoir resettlement involves many individuals, and its goal is to produce more RDP benefits. Therefore, this paper chooses the second method to analyze the interest game of stakeholders in hydropower development.

The Nash equilibrium solution is to list all possible decision sets according to the relationship between the game participants, and then find the optimal strategy. Ding et al. found the utility functions of different decision groups and constructed a dynamic game decision model [35]. Hachol et al. list the set of possible solutions and finds the best decision through matrix analysis [36]. Liu et al. found all possible weight combinations, and then screened out the optimal weight vector [37,38]. Xiao et al. constrain both decision-making parties by replicating dynamic equations and finds an evolutionary stable strategy [39]. Lv et al. constructed a cooperative decision-making set of three sub-regions to explore the possibility of multi-regional sustainable and coordinated development [40]. Orduna Alegria et al. introduce the board game rule Mahiz for the dynamic decision analysis of agricultural cooperation [41]. Bai et al. list the differences in pollution control under different strategies and find the best pollution control cooperation scheme [42]. This paper constructs a game model among hydropower developers, RDP, and government departments; analyzes their interest relationships; and lays the foundation for the following benefit distribution.

3.1. Definition of the Beneficiaries of Benefit Sharing

Stakeholders are groups that have a stake in the construction and operation of a project. The idea was first applied to water conservancy and hydropower projects by the World Commission on Dams [43]. Shi Guoqing (2008) defined the stakeholders in hydropower development to include shareholders (investors), banks and other creditors, management, company employees, government industry authorities, local governments in the reservoir area, local governments in the resettlement area, displaced people, and indigenous residents in the resettlement area [44]. Xu Junxin (2008) listed the central government, local governments and relevant departments, project representatives and authorities, displaced people, non-immigrants in resettlement areas, planning and design units, resettlement supervision units, resettlement monitoring and evaluation units, non-governmental organizations, and construction firms [45]. Some stakeholders only conduct fair transactions according to market mechanisms and do not need to adjust their interests. Therefore, we put them aside and used the concept of core stakeholders; that is, the core participants in benefit sharing. The economic benefits of hydropower projects are limited, but many groups are involved. The more core stakeholders, the lower the rate of return. If the rate of return of a project is too low, the project will be terminated. For the smooth development of the project and optimal benefit distribution, core stakeholders should be selected from the project stakeholders.

We argue that core stakeholders should have the following characteristics. First, they are indispensable participants. Their withdrawal will terminate the project. Second, they should make a certain contribution to the project, such as human capital, physical capital, or other resources. Third, their participation can be active or passive. Fourth, they assume certain risks regarding the project, for example financial risks, political risks, or poverty risks.

Based on these criteria, for this article, the core stakeholders are government departments, hydropower developers, and RDP (Table 1). Since the government's main purpose is public service, not profit, in this article, we define RDP and the hydropower developers as the main targets of benefit sharing in hydropower development.

Table 1. The core stakeholders in hydropower development.

Core Stakeholders	Nature	Behavior	Resources Invested	Main Risk
Hydropower developer	Active	Investment, construction	Financial resources, human resources	Financial
Government department	Active	Administrative management	Administrative resources	Political
RDP	Passive	Relocation	Land resources, socio-economic relations, etc.	Poverty

3.2. Definition of the Beneficiaries of Benefit Sharing

Determination of the amount of compensation can be analyzed as a game between the resettled people and the hydropower developers. For a more intuitive treatment of this relationship, we use PC, the amount developers are prepared to offer for compensation, as the independent variable, and WP, the willingness to participate in the project, as the dependent variable.

Participation willingness is negatively correlated with participation costs, and positively correlated with participation revenue. The model assumes that the RDP's participation willingness is:

$$\mathrm{WP}_1 = k \times \mathrm{PC} + b \ \ (k > 0, b > 0), \quad (1)$$

The hydropower developers' participation willingness is:

$$\mathrm{WP}_2 = -h \times \mathrm{PC} + d \ \ (h > 0, d > 0), \quad (2)$$

WP_1 and PC are positively correlated, k is the expected rate of return of the RDP to the project, and b is the loss suffered by the RDP in the project. WP_2 and PC are negatively correlated, h is the developer's expected rate of return, and d is the developer's profit from the project.

The hydropower developers lead the project. Within the scope of the resettlement policy, according to their wishes, the actual compensation investment level is in the point $\mathrm{C}_1(\mathrm{pc}, \mathrm{wp}_1)$, as shown in Figure 1. Due to the incomplete in-kind compensation index, the participation willingness of RDP is often lower than that of hydropower developers.

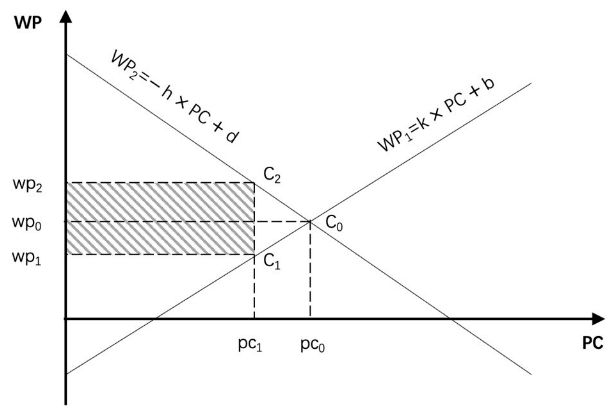

Figure 1. Game-theoretic analysis of the interest relationship.

The participation willingness of RDP is directly proportional to the progress of resettlement towards completion. If the former is low, the latter will be delayed, project income will decrease accordingly, and the interests of the hydropower developer will be damaged. The completion time for relocation and resettlement is:

$$T = \begin{cases} T_0 + F(\mathrm{WP}) & \mathrm{WP} < r_0 \\ T_0 & \mathrm{WP} \geq r_0 \end{cases}, \tag{3}$$

where T_0 is the planned completion time, $F(\mathrm{WP})$ is the delay caused by the low participation willingness of RDP, and r_0 is the participation willingness when the RDP and hydropower developers reach a consensus.

After the project is put into use, the annual economic benefits of hydropower are:

$$E(t) = P(t) \times W \tag{4}$$

where W is the multi-year average power generation and $P(t)$ is the price of one year's generated electricity.

The loss caused by the delay in relocation and resettlement is:

$$D = F(R)\ E(t), \tag{5}$$

Combining (1) and (2) and solving, we find that when both parties have an equal willingness to participate, compensation investment is $\mathrm{pc}_0 = \frac{d-b}{l+h}$ and participation willingness is $\mathrm{wp}_0 = \frac{dl+bh}{l+h}$. Therefore, hydropower developers need to adjust the compensation investment level by $N = \mathrm{pc}_0 - \mathrm{pc}$. When $N < D$, the adjustment can reduce the developer's losses and the RDP can obtain more benefits—a win–win situation.

3.3. Game Analysis: Government Departments and RDP

The relationship of the government departments to RDP should be one of protection and restraint, to alleviate conflicts over land expropriation and achieve some measure of social justice (Table 2).

Table 2. The game between government departments and RDP.

RDP \ Government Department	Deal With	Not Deal With
Reasonable demands	Satisfy	Pressure from public opinion
Unreasonable demands	Comparison psychology, other social issues	Resolve through policy explanation

When formulating a policy, government departments try to protect disadvantaged farmers, meet their reasonable demands, and improve government credibility. However, due to their psychological dependence, RDP may also make unreasonable demands. Government departments may ignore these for their own interests. When such demands cannot be met, RDP may resort to petitioning high-level authorities or to collective disturbance, which may put pressure on government departments through public opinion.

If the unreasonable demands of some RDP are met, other RDP may want the same benefits and cause greater social problems.

3.4. Game Analysis: Hydropower Developers and Government Departments

The relationship between hydropower developers and government departments is mutually beneficial. Hydropower developers spend money to develop local resources and pay corresponding taxes, which promotes local economic development. Government departments assist in resettlement and protect the legal rights and interests of RDP. To maintain their reputation, government departments strive to protect the rights and interests of RDP, within the acceptable range of hydropower developers, to promote the stable development of the local area.

Since 2018, in the Opinions on Establishing and Improving the Benefit Sharing Mechanism of Hydropower Development (Draft for Comment), the Guiding Opinions on Doing a Good Job in the Benefit Sharing of Hydropower Development (Development and Reform Energy Regulations (2019) No. 439), and other documents, the National Development and Reform Commission of China developed a plan describing a mechanism for RDP, government departments, and hydropower developers to share the benefits of hydropower development over the long term.

4. Cost–Benefit Model Construction

In addition to generating revenue, hydropower projects also have social benefits, such as flood control. Its social benefits cannot directly produce economic benefits, but indirectly produce benefits by reducing flood disasters in downstream areas. The performance of government departments is related to local economic development. Therefore, the social benefit beneficiaries of hydropower development are classified as government departments. This paper mainly explores how RDP shares the benefits of hydropower development, so it does not involve the analysis of the level of benefits of government departments.

The analyses in the previous section showed that the main dispute lies in the determination of compensation; that is, the distribution of benefits between hydropower developers and RDP. Therefore, our model does not consider the income of government departments.

To better measure the income of the benefit-sharing subjects and ensure that it is reasonable, we need to quantify and compare their input and output factors [46]. Displaced people face complex livelihood changes, which produce economic, social, and psychological pressures. The research on non-economic input-output factors is still immature. The evaluation method for many factors is unclear, and which factors should be included in the analysis is still under discussion [47].

Here, we study the economic changes of RDP and hydropower developers, use cash flow analysis to construct cost–benefit models, and use internal rate of return (IRR) as an indicator for comparative analysis. IRR is the discount rate that makes the present value of the cash inflow of the project equal to the present value of the cash outflow. It represents the profitability and risk tolerance of the stakeholders in the project. For each project benefit-sharing subject, the higher the IRR, the better the feasibility of the project investment and the stronger the ability to bear risks. Net present value is defined as:

$$\mathrm{NPV} = \sum\nolimits_{t=1}^{T_c} \frac{I_t - S_t}{(1 + \mathrm{IRR})^t} = 0, \quad (6)$$

where T_c is the project concession period, IRR is the internal rate of return, I_t is the income in year t, and S_t is the expenditure in year t.

4.1. Cost–Benefit Analysis for RDP

4.1.1. Selection of Index System

In the classification standard of the National Bureau of Statistics, farmers' income sources are of four types: household operating income, wage income, transferred income, and property income [48]. We selected the economic evaluation indicators according to the economic impacts of water conservancy and hydropower project construction on RDP (Table 3). Household operating income includes agriculture, aquaculture, and the secondary and tertiary industries. Agricultural income is reduced by a decrease in area of arable land. The income from the second and third industries depends on the local economic development. Breeding conditions are usually not significantly changed by the relocation, so income from aquaculture is not included in the indicator system. With the smaller area of arable land, the lifestyle of the agricultural population changes from farming to working, and the change in wage income is directly proportional to the growth rate of the local economy and the movement of the working population. Changes in transfer income are mainly based on relevant policies. After their relocation, RDP receive post-support funds and transitional resettlement subsidies. The change in property income is mainly that RDP will receive land in compensation for their relocation.

Table 3. RDP income and expenditure indicators.

	Disposable Income	Category	Annotation
Income	Household operating income	Agriculture I_1	Change in arable land area
		Second and third industries I_2	Affected by regional economic development
	Wages	Wages from enterprises I_3	Relatively stable income
		Part − time income I_4	Young farmers who have lost their land mainly become migrant workers
	Transferred income	Post − support funds I_5	CNY 600 per person per year
		Transitional resettlement subsidies I_6	Determined by the length of the transition period
	Property income	Compensation I_7	One-time and long-term compensation
Expenditure	Resettlement cost	Resettlement cost S_1	Rental costs, decoration costs, etc.
	Living cost	Living cost S_2	Differences in regional consumption levels

The expenditures affected by relocation are mainly resettlement costs and living costs. The main resettlement costs are rent during the transition and decoration of the new house in the resettlement area. The original houses were old and in rural areas, so the new houses are usually worth more. Therefore, there is usually no surplus of house compensation after the replacement of the house itself, and the RDP bear the cost of renovation after they move in. Changes in the cost of living are mainly reflected in the regional economic differences, depending on the local economic growth rate.

4.1.2. RDP Income and Expenditure Forecast

In accordance with State Council Order No. 679, China implements a developmental immigration policy. A combination of early stage compensation, subsidies, and later-stage support are required to bring the living standards of RDP up to or above their previous level. Due to the RDPid increase in expenditures during resettlement and the lag of income recovery, the per capita annual net income of RDP will experience a short-term decline (Figure 2) [49]. This would be hard to recover from without adequate compensation [50].

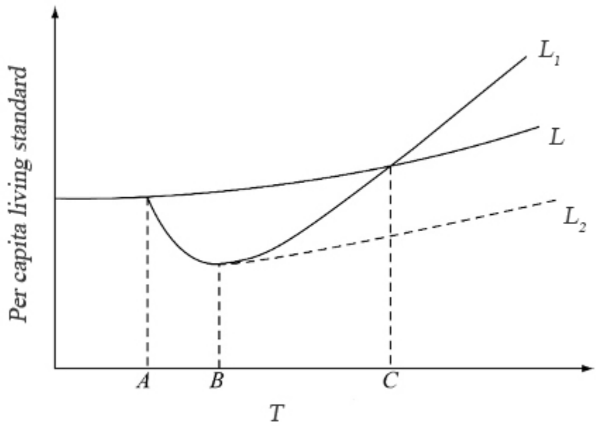

Figure 2. Changes in migrants' living standards.

In the figure, L represents the situation in which, without relocation, the living standards of RDP can be regarded as a time series with a certain growth rate. L_1 represents the situation in which, with relocation, the living standards of RDP may recover or exceed their original level through compensation, subsidies, and subsequent support. Section AB represents the relocation process, when their livelihood has been destroyed, and their living standards decline. Section BC represents the implementation of resettlement policies, when RDP gradually adapt to their new life and their living standards recover. L_2 represents the case in which resettlement measures have failed, and RDP are threatened by poverty.

The difference in RDP's economic benefits between relocation and non-relocation is:

$$G(t) = \int_0^t g_i(t) - g_j(t)\, dt, \tag{7}$$

where $g_i(t)$ is the RDP's actual income function each year under the condition of relocation, and $g_j(t)$ is their actual income function each year without relocation.

1. Prediction of change trend of income and expenditure without relocation:

Call the per capita annual income and per capita annual expenditure in year t without relocation $I_j(t)$ and $S_j(t)$, respectively. Income can be calculated with reference to the initial income, the local national economic development plan, and the annual growth rate. Expenditure is calculated according to the growth rate of the consumption costs for rural households. Then, we obtain:

$$g_j(t) = I_j(t) - S_j(t), \tag{8}$$

$$I_j(t) = I_{j0}\,\left(1 + r_j\right)^t, \tag{9}$$

$$S_j(t) = S_{j0}\,\left(1 + r_j{}'\right)^t, \tag{10}$$

where I_{j0} and S_{j0} are the per capita annual income and per capita annual expenditure before relocation, r_j is the growth rate of the economic development plan of the original residence area, and $r_j{}'$ is the growth rate of consumption costs for rural households in the original residence area.

2. Prediction of change trend of income and expenditure under relocation:

The income changes can be divided into three categories. The first category is the income increase according to the growth rate of the local national economic development plan, including agricultural income, second and third industry income, enterprise wages, and part-time income. The second category includes land compensation, subsidies, and post-support funds. The third category is income differences caused by changes in livelihood capital.

Call the per capita annual income and per capita annual expenditure in year t under the relocation situation $I_i(t)$ and $S_i(t)$, respectively. Then:

$$g_i(t) = I_i(t) - S_i(t), \tag{11}$$

$$I_i(t) = I_{i0}(1 + r_i)^t + Q(t) + \Delta A, \tag{12}$$

$$S_i(t) = S_{i0}\left(1 + r_i{}'\right)^t + \mathrm{RC}_t, \tag{13}$$

where I_{i0} and S_{i0} represent the per capita annual income and per capita annual expenditure before relocation; r_i is the growth rate of the local economic development plan in the resettlement area; $Q(t)$ is the post-support funds, transitional resettlement fee, and compensation received in year t; ΔA is the income change caused by the change in the amount of livelihood capital; $r_i{}'$ is the growth rate of the consumer price of rural households in the resettlement area; and RC_t is the cost of relocation and resettlement.

4.2. Cost–Benefit Analysis for Hydropower Developers

The investment of hydropower developers in water conservancy and hydropower projects is intended for the purpose of profitability, and is generally repaid through the significant economic benefits brought by hydropower. The hydropower developer coordinates and promotes the entire project, including fundraising, schedule control, construction management, and subsequent operation and maintenance.

1. Benefit Calculation

Along with power generation, water conservancy and hydropower projects provide flood control, irrigation, water supply, and other benefits, but only power generation provides monetary income. There is no authoritative standard for evaluating the value of the other social benefits, and it is difficult to charge beneficiaries for them. Therefore, we consider only income from power generation.

2. Project Cost Calculation

The outflow of funds mainly includes project planning investment, operating costs, tax expenses, and loan principal and interest. The first category, V_1, includes project construction costs and resettlement compensation fees. Once the project is running, there will be a certain annual operating cost, V_2, which includes labor, depreciation, repair, and insurance. There will also be value-added tax, V_3, and supplementary sales tax, V_4. The loan principal and interest, V_5, depend on the loan amount and the time and method of repayment. Hydropower developers have a variety of options here.

The developer's revenue will thus be:

$$H(t) = \int_0^t \mathrm{E}(t) - \sum_{i=1}^{5} V_i(t)\, dt, \tag{14}$$

where $\mathrm{E}(t)$ is the power generation revenue in year t.

4.3. Project Income Adjustment

The income distribution should be adjusted to meet the actual needs of the benefit-sharing subjects. To ensure the fair and reasonable distribution of funds, we divided the project into an investment-recovery period and a benefit-sharing period. Adjusting the income distribution share of the investment payback period can change the length of the investment payback period for RDP and hydropower developers, so we sought a plan that makes the two periods the same. We then adjust the income distribution during the benefit-sharing period to make the IRR of the two stakeholders the same.

The adjusted incomes of RDP and hydropower developers, $\overline{H}(t)$ and $\overline{G}(t)$, respectively, are:

$$\overline{H}(t) = H(t) - N(t), \tag{15}$$

$$\overline{G}(t) = G(t) + N(t), \tag{16}$$

where $N(t)$ is the adjustment to the project income in year t.

4.4. Verification of the Rationality of Benefit Adjustment

Consider the game between RDP and hydropower developers. If the two parties do not cooperate, the time to benefits will be delayed. However, bank loans need to be paid on time, and money has a time value. The relationship between the hydropower developer's IRR and the delay time $F(R)$ caused by the low participation willingness of RDP can be calculated.

According to Section 3.2, if the capital adjustment share is less than the loss caused by non-cooperation ($N < D$), it means that through capital adjustment, RDP and the developer have achieved a win–win situation; RDP receive more compensation and the developer avoids losses due to non-cooperation.

5. Case Study

The GB Water Conservancy Project takes flood control and water supply as its main tasks, but also provides benefits in power generation and shipping. This is a public–private partnership (PPP) pilot project jointly funded by government departments and private investments. The construction period is 66 months. The total project investment is CNY 5918.66 million, of which the government's budgeted investment is CNY 3962.66 million, the developers' investment is CNY 1005 million, and loans are CNY 951 million. The loans are financed by the developers. The fixed assets created by the project belong to the government and its designated agencies, and the power generation income belongs to the developers. The concession period is 35 years.

We used the project's start date of 2015 as the starting point for the cash flow calculations, and the end of the franchise period (2055) as the cut-off point. An income-and-expenditure model was used to measure the changes in the economic indicators of the benefit-sharing subject, obtain cash flow diagrams for the RDP and the developers, and calculate their actual benefits from the project.

1. Government Departments

Government departments have public service functions, and their primary task is to ensure the stable development of society. The GB Water Conservancy Project is a public welfare project focusing on flood control and water supply to meet local development needs. The government department completed the project with help from private investment. According to the report on the PPP pilot model of the GB Water Conservancy Project, the government department retains ownership of the project, and during the concession period, it can also raise fiscal revenue through taxes on electricity fees [51]. The government's principal concern is for flood control and water supply in the region, and less for economic benefits. To ensure the economic feasibility for other core stakeholders, during the franchise period, government departments will levy taxes in accordance with relevant policies, and no other benefit distribution adjustments will be made.

2. RDP

The project puts RDP in a complex situation, and they will face the problem of livelihood reconstruction after relocation. In addition to the loss of land resources, they face many hidden losses. However, the current compensation indicators are limited, and it is difficult to achieve full coverage. Here, we evaluate the income of RDP by calculating the difference in predicted income between the two situations (relocation or not).

According to the planning report, 4178 people were resettled, and the resettlement subsidy is CNY 18.9889 million, to be distributed over 5 years. The compensation for arable land is based on the average annual output value of the paddy field in the 3 years before the expropriation, multiplied by 30 (for a total outlay of CNY 360.329 million). Of these 30 parts, 14 are provided as a one-time payment, followed by 16 cases of long-term compensation. Long-term compensation is the investment of the RDP in the project, and a certain amount of funds will be issued for compensation every year.

The original calculation parameters can be obtained from the monitoring and evaluation data collected before relocation. Changes in the income and expenditure growth rate from before to after relocation are not significant, because the relocation distance was not very large.

Most of the RDP in this project chose to resettle in a centralized manner. The original houses were demolished, new houses were allocated, and the house compensation covered only this replacement cost. Rentals during the transition, and decoration of the new house, had to be paid by the RDP themselves. The relocation times varied by household, so we calculated costs based on the average.

The original data on RDP's income and expenditure were obtained from the 2015 monitoring and evaluation survey (Table 4). A cash flow diagram is shown in Figure 3.

The RDP had relatively large expenditures during the relocation. Agricultural income accounts for a small proportion of household income, and compensation for the corresponding output value is obtained every year. Land-lost farmers do not need to farm, and gradually start doing odd jobs to increase their family income. The RDP had higher incomes (on average) after the relocation than before. We calculated that the dynamic payback period of reservoir resettlement is 23 years, with an IRR of 5.22%.

Table 4. Reservoir resettlement income and expenditure calculation parameters.

	Original Data (Yuan)	Calculation Method	Relocation Situation	No Relocation Situation	Original Data (Yuan)
Income	Agricultural income	1176	Arable land area × output value per mu	Output value per mu is adjusted year by year at an annual growth rate of 2%	Output value per mu is adjusted year by year at an annual growth rate of 2%
	Income from second and third industries	2506	Increases year by year according to the initial per capita income level	Growth rate is based on the local development plan growth rate of 8%	Growth rate is based on the local development plan growth rate of 8%
	Enterprise wages	1558			
	Part-time income	6150	Number of part-time workers × per capita part-time income	Number of workers = initial number + labor transfer Per capita part-time income is adjusted year by year in accordance with the local development plan growth rate of 8%	Per capita part-time income is adjusted year by year in accordance with the local development plan growth rate of 8%
	Post-support funds	600	–	According to national policy standards	-
	Transitional resettlement subsidies	–	Total transition subsidy/relocation number	According to planning reporting standards	-
	Compensation	–	Total compensation/number of people to be relocated	One-time plus long-term compensation	-
Expenditure	Resettlement cost	–	Rental + house decoration	According to local price standards	-
	Living cost	7005	Increases year by year according to the initial cost of living	Growth rate is taken as 8% of the consumption growth rate of local rural residents	Growth rate is taken as 8% of the consumption growth rate of local rural residents

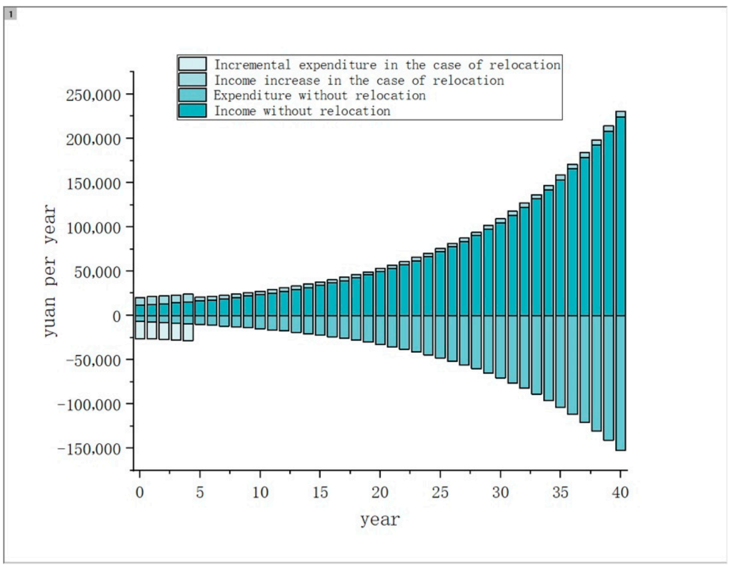

Figure 3. Cash flow of RDP.

3. Hydropower Developers

Hydropower developers are responsible for the implementation of investment and financing funds; project construction quality, safety, and schedule management; the operation of the entire hub project during the project operation period (concession period); and the maintenance, renewal, and daily management of facilities according to the project schedule. According to the planning report, the GB Water Conservancy Project generates on average 401 million kWh per year. The electricity price for the first 5 years was 0.47 CNY/kWh, and from the 6th year, 0.52 CNY/kWh.

The developers invested CNY 1005 million. To facilitate the calculations, we averaged the investment over the construction period. Salary costs are based on 100 employees with an average salary of CNY 0.15 million each, for a total of CNY 15 million per year. Depreciation, repair, and insurance costs are estimated at 4%, 1%, and 0.25% of the power generation revenue, respectively [52]. The value-added tax rate is 17% (the supplementary sales tax includes urban maintenance and construction tax and supplementary education tax, which account for 5% and 3% of the total value-added tax, respectively) [53]. The total loan is CNY 951 million, which is estimated according to the equal principal and interest repayment method, with repayment to be completed by the end of the franchise period. A cash flow diagram for the hydropower developers is shown in Figure 4.

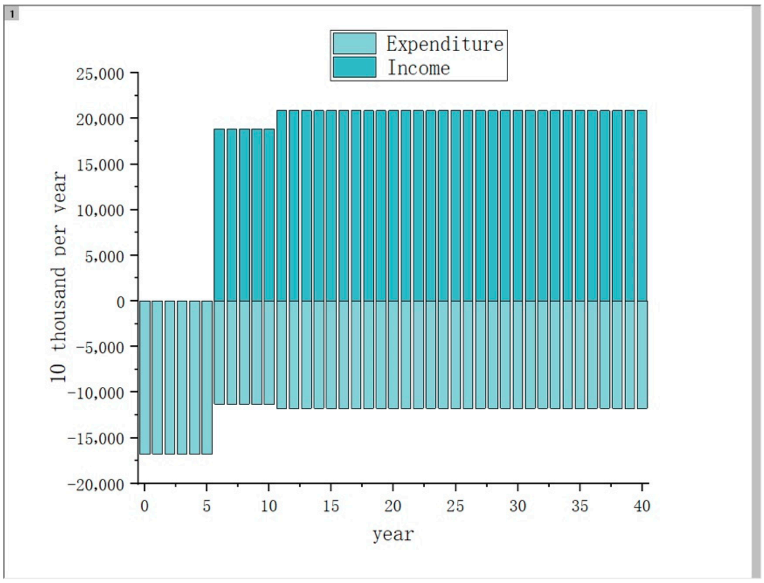

Figure 4. Cash flow for hydropower developers.

The developers invested a large amount of funds during the project construction period (the first six years). After the project started the operation, the funds were gradually recovered, and the static fund payback period was 16 years. Thus, we estimated the IRR of hydropower developers at 6.49%.

4. Adjustment of Income Distribution

Since the IRR of RDP is lower than that of hydropower developers, the income distribution needs to be adjusted in accordance with the principle of fairness. The adjustment could look like this:

$$N(t) = \begin{cases} \text{1200 yuan per person per year} & t \le 17 \\ \text{670 yuan per person per year} & t > 17 \end{cases},$$

Increasing the long-term compensation for reservoir resettlement by CNY 1200 per person per year can make the static investment payback period of hydropower developers and reservoir resettlement equal, at 17 years. Starting in the 18th year, this is reduced to CNY 670 per person per year. The IRR for RDP and developer is now equal, at 6.12%.

5. Verification of the Rationality of Benefit Adjustments

According to the contract signed for the project, the concession period will remain unchanged for 35 years. If the project is delayed by one year, the capital gains will be delayed by one year. Operating costs, business income tax, and value-added tax will also be delayed by one year, but bank loans and interest still need to be repaid according to the original repayment method. The IRR for the developers can be calculated according to the corresponding cash flow diagram. Similarly, the relationship between developers' IRR and project delay time, $F(R)$, can be obtained (Figure 5). The IRR is roughly proportional to the delay time, with a linear fitting equation

$$\text{IRR} = -0.00575F(R) + 0.06325,$$

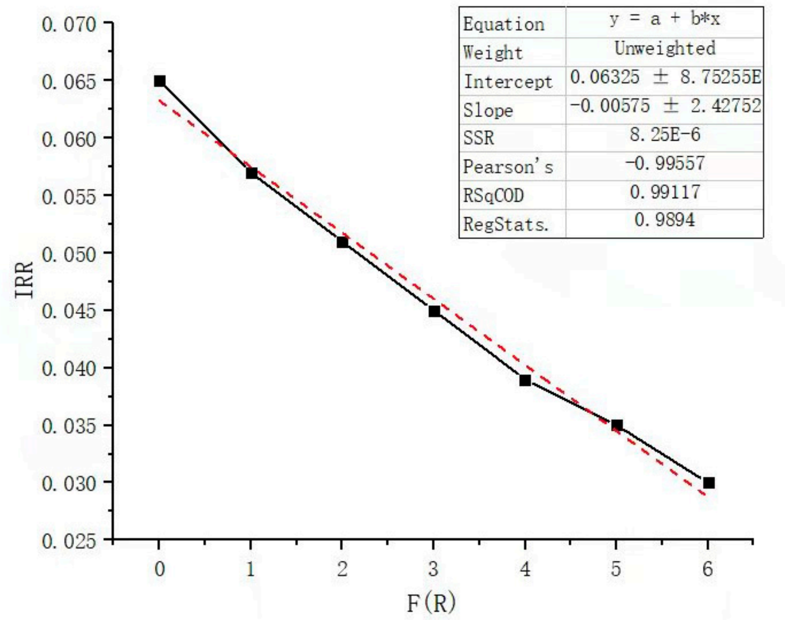

Figure 5. Relationship between IRR for hydropower developers and project delay time.

Taking IRR = 0.0612, we find that $F(R)$ = 0.36 years, or 4.3 months. If the non-cooperation of RDP causes the developer less than 4.3 months of delay, it is better to choose non-cooperation. On the other hand, increasing the compensation provides a win–win situation.

6. Discussion

The case study of the GB Water Conservancy Project verifies the feasibility and effectiveness of the benefit-sharing model presented in this paper. Once all the parameters required for cash flow calculation are determined, the corresponding revenue distribution results for hydropower development can be obtained. The cash flow diagram shows the input and output for the benefit-sharing subjects in the hydropower development process. Calculating the IRR shows the benefits the two have obtained from the hydropower project. Considering the goals of the different benefit-sharing subjects, we proposed a benefit distribution adjustment scheme based on achieving the same IRR, verified the rationality of the scheme, and calculated feasible boundary conditions.

In this project, both the RDP and the hydropower developer invested a lot of resources in the early stage, which were repaid after the project was put into use. At the end of the concession period, the IRR of the benefit-sharing subjects was greater than zero. However, the IRR of hydropower developers was higher than that of the RDP. By adjusting the income distribution, the IRR for the RDP and the developers can be made the same, at 6.12%. Since this adjustment gives part of the developer's income to the RDP, the feasibility of the plan is verified from the developer's perspective. We calculated that, if the project delay caused by RDP exceeds 4.3 months, the sharing scheme is feasible; otherwise, there is no need to adjust the income distribution. Here, are a few thoughts about the calculation process.

1. To build new houses for RDP requires a large investment, which would be difficult for them to raise. The cash flow diagram shows that they have large expenditures during the relocation process. With the necessary improvement of house quality, the compensation fund is not enough to offset the costs of house construction and decoration. Successful resettlement would then depend on whether RDP can raise their own funds as scheduled. Therefore, benefit sharing should give priority to meeting the economic needs of the RDP during the relocation process.

2. The IRR of the RDP is greater than zero, indicating that it exceeds the original standard of living. We found that RDP have relatively high expenditures in the early stage of relocation, and their income decreased due to the loss of arable land resources. Long-term compensation can support the follow-up basic living needs of RDP. With the help of the resettlement policy, the land-lost farmers can gradually realize labor transfer, and their income gradually increases.

3. The IRR of RDP is lower than that of hydropower developers. The resettlement program is based on compensation, aiming to ensure living standards not lower than before their relocation. They are not regarded as participants in the project, and their benefits are not compared to the benefits of hydropower developers. If the income distribution is not adjusted, the IRR for RDP is 5.22%, and for the developers it is 6.49%. This unequal income can easily trigger comparison psychology and thus collective disturbances.

4. Benefit sharing can effectively eliminate this conflict. In this benefit-sharing model, the adjusted benefits of the RDP and the developers are closely related to the economic benefits of the project. Losses caused by RDP non-cooperation will affect all benefit-sharing subjects. Through risk sharing and benefit sharing, the conflict can be resolved, and the smooth progress of the project can be ensured.

5. The social benefits of water conservancy and hydropower projects should gradually realize the internalization of external effects. Our case study and calculations show that the economic benefits of water conservancy and hydropower projects are mainly from power generation; the social costs and benefits are not considered. Some people enjoy the benefits of the project without any cost. The power-generation benefit of the project is limited. For projects with a small installed capacity, the IRR of the benefit-sharing subjects is small, and the internalization of external effects can be achieved through government measures, such as taxation and subsidies.

7. Conclusions

With the increasing demand for green energy and renewable energy, hydropower has become an important part of China's energy development strategy. However, the unfair distribution of benefits may lead to resettlement conflicts and other issues, which seriously hinder the development of hydropower. For a better resolution of disputes over resettlement compensation standards, scholars have begun to explore scientific and reasonable benefit-sharing mechanisms and policies. However, due to the lack of appropriate quantitative analysis tools, the principle of compensation based on resettlement losses is generally adopted.

In this paper, we treat the displaced population as an investor in the project, choose IRR as an evaluation criterion, and construct a hydropower development benefit-sharing plan based on a cost–benefit model. We consider the relationship between core stakeholders using game theory, estimate the actual income of the RDP and the developers (who have the most disputes over the distribution of benefits), and calculate the IRR. We then adjust the income distribution based on these results and verify the rationality of the adjustment plan.

The case study presents two conclusions. First, in the long run, the RDP's standard of living is improved, but in the short term it is reduced, and the rate of return is lower than that of hydropower developers. A fair distribution method promotes cooperation. Having the RDP share both the benefits and the risks is the best way to resolve reservoir resettlement issues. Second, the income from water conservancy and hydropower projects is presently only derived from power generation, and their social benefits have not yet been measured by a good standard, nor have they been transformed into economic benefits. The IRR is low for both developers and RDP. For water conservancy and hydropower projects with social benefits as the main goal, the internalization of the external effects can be achieved through government measures, such as taxation and subsidies.

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