Water and Hydroelectric Power Sharing

Chengxin Ye [1, #], Zhaopeng Ning [2, #], Jinshi Liu [3, #], Chuxun Yu [2, *], Yaying Su [4]

[1] College of Traffic and Transportation Engineering, Dalian Maritime University, Dalian, Liaoning

[2] College of Information Science and Technology, Dalian Maritime University, Dalian, Liaoning

[3] School of Electronic Science and Engineering, University of Electronic Science and Technology of China Chengdu, Sichuan

[4] School of Shipping Economics and Management, Dalian Maritime University, Dalian, Liaoning

* Corresponding Author Email: 2179168701@qq.com

[#]These authors contributed equally.

Abstract. A rational, defensible water allocation plan for current and future water supply conditions is critically important. According to the request and suggestion of State natural resources negotiators, our team developed a water allocation plan for five states (AZ, CA, WY, NM, and CO) Since general industrial water and power generation water are very important, we comprehensively analyze and establish a multi-objective optimal allocation model, which involves social benefits, economic benefits and water environmental benefits. Using the foal attain function in MATLAB to solve the model, we get Satisfaction of water demand for electricity generation and general industry in each state.

Keywords: objective programming method, analytic hierarchy process, cluster analysis, sensitivity analysis, water resources allocationert.

1. Introduction

Dams is important to managing water supplies and Hydroelectric power. With climate change, the volume of water from sources feeding dams and reservoirs is decreasing in many areas. Consequently, dams may not be able to meet the demands for water in these areas and hydroelectric power generation may stop. [1-3].

If drought conditions continue in the Colorado River basin, the water volume at some point will be insufficient to meet the basic water and generated electricity needs [4-6]. Consequently, a rational, defensible water allocation plan for current and future water supply conditions is critically important [7].

2. Statement of our Model

2.1. Water allocation model for balanced development

The water allocation model needs to take into account the water and electricity needs of each state's industry, agriculture, and residence, as well as the development level of each region, so as to achieve a balanced and sustainable development of each region now and in the future.

By calculating $Z_{i,j,t}$(Water allocation benefit measure factor), we get different priorities for water allocation in each state.

$$Z_{t,i,j} = \max \sum_{j} R_j \times g_j^t \left[\left(c_i + a_i \right) \times X_{j,t} \right] \tag{1}$$

Where g_j^t is calculated based on the agricultural, industrial and residential water and electricity consumption and their population in each region, and R_j is determined according to the development status of different regions.

$$g_j^t = \alpha(c_{\text{Agr}} + a_{\text{Agr}})X_{j,t} + \beta(c_{\text{Ind}} + a_{\text{Ind}})X_{j,t} + \gamma(c_{\text{Res}} + a_{\text{Res}})X_{j,t} \tag{2}$$

Among them, the more the less developed area is, the larger the R is, which means that the policy of water allocation is inclined to the less developed area.

2.2. Hydropower generation model

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3. Prepare Your Paper Before Styling

The water flow interacts with the runner of the hydropower station to generate electricity. According to the knowledge in this field, the relevant calculation formula is deduced as follows.

$$\mathrm{N_e}=\mathrm{M}\overline{\omega}=\frac{\mathrm{rQ_e}}{\mathrm{g}}(\mathrm{V_{u_{in}}}\bullet\mathrm{r}_{in}-\mathrm{V_{u_{out}}}\bullet\mathrm{r}_{out})\times\overline{\omega}=\frac{\mathrm{rQ_e}}{\mathrm{g}}(\mathrm{V_{u_{in}}}\bullet\mathrm{U}_{in}-\mathrm{V_{u_{out}}}\bullet\mathrm{U}_{out}) \tag{3}$$

Where:
- M is torque of water flow to runner;
- V_u is velocity torque of water flowing in and out;
- r is generator turbine radius;
- U is generator turbine voltage;

$$M=\frac{\mathrm{rQ_e}}{\mathrm{g}}(\mathrm{V_{u_{in}}}\bullet\mathrm{r}_{in}-\mathrm{V_{u_{out}}}\bullet\mathrm{r}_{out}) \tag{4}$$

$$\mathrm{N_e}=\mathrm{rQ_eH}\eta_S \tag{5}$$

Simultaneous formula (3) and (5), and reasonably deform the formula, we obtain formula (6).

$$E=\mathrm{H}\eta_S\bullet g=Q\bullet U \tag{6}$$

$$\eta_S=\eta_H\bullet\eta_v\bullet\eta_m \tag{7}$$

Where η_H is used to calculate the energy lost by the collision of water flow, which is called hydraulic efficiency; η_v mainly considers the situation that the water flow cannot be fully utilized, which is called flow efficiency; η_m is used to measure the energy loss of converting mechanical energy into electrical energy, called mechanical efficiency, η_s is the total efficiency.

$$\eta_H=\frac{H-\sum\Delta H}{H}\times 100\% \tag{8}$$

$$\eta_v=\frac{Q-\sum q}{Q}=\frac{Q_e}{Q} \tag{9}$$

$$\eta_m = \frac{N_e - \Delta N_m}{N_e} \tag{10}$$

The constraints in the model are inequalities (11) and (12).

$$\sum c_i X_{j,t} < \frac{E}{U} \tag{11}$$

$$\sum a_i X_{j,t} < F \tag{12}$$

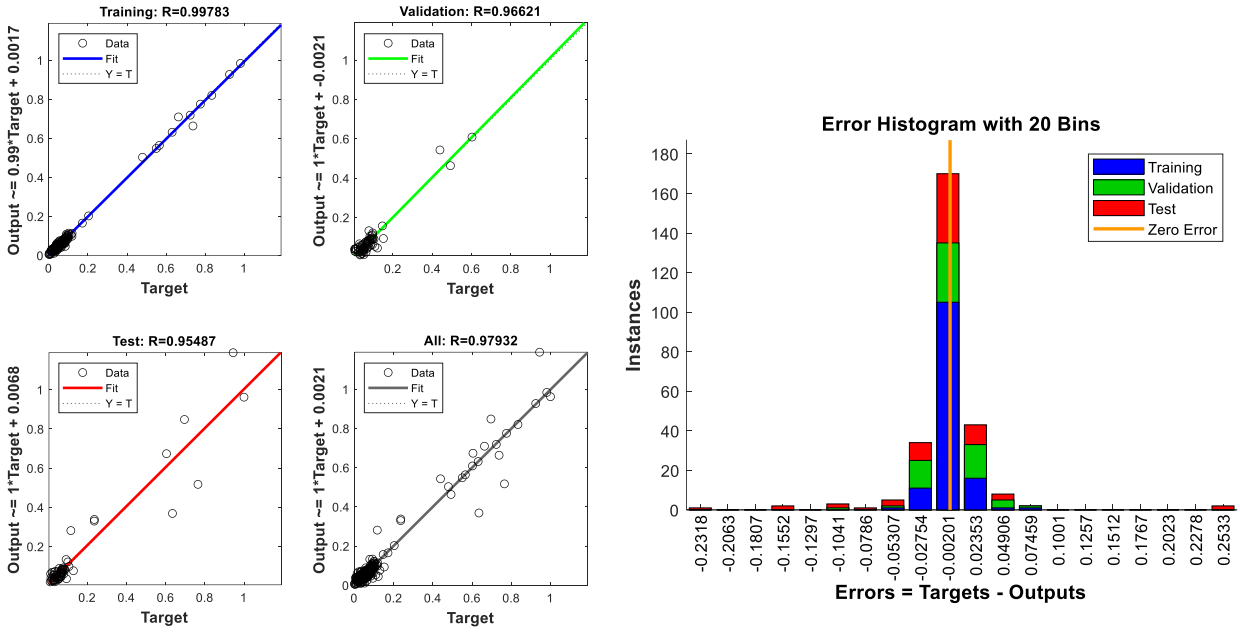


Figure 1. Data Neural Network Prediction Fitting for Water Level and Power Generation

As shown in the figure 1, the neural network fitting effect is very high, and the error is symmetrically distributed at the 0 point and is even and small, which also confirms that the power generation and water level are closely related.

3.1. Multi-objective optimization and demand forecasting model

By establishing a multi-objective optimization model to achieve the overall optimization of multiple objectives, supplemented by a water demand forecast model, related problems can be solved scientifically and reasonably.

Establish a multi-objective collaborative optimization model, and set economic goals, social goals and water environment goals; where f1(x) is the economic goal, aiming at maximizing the net benefit brought by the utilization of water resources; f2(x) is the social goal , taking the demand for water resources (water scarcity) of each state as a reference, and pursuing balanced development between regions; f3(x) is the water environment goal, and strictly abides by the total amount of sewage to achieve sustainable development.

$$optF(x) = \{ f_1(x), f_2(x), f_3(x)..., f_n(x) \}^T \tag{13}$$

$$\max f_1(x) = \max \sum_j (B_{i,j} - C_{i,j}) \times x_{i,j} \tag{14}$$

$$\min f_2(x) = \min \sum \sum (D_{i,j} - X_{i,j}) \tag{15}$$

$$\min f_3(x) = \sum_{j=1}^{5} 0.01 \times d_{j,i} \times p_{j,i} \times \sum x_{j,i} \tag{16}$$

Among them, i is used to represent agriculture, industry and residents, j is used to represent five states; B is water use efficiency, C is water cost, x is water supply, D is water demand, and d is pollutant content per unit of wastewater, p is the amount of wastewater discharge.

It is generally difficult to quantify the benefits of domestic water use, and the proportion of benefits produced is small, so this paper selects the benefits of agriculture and industry for calculation. Among them, the industrial benefit is determined by the output value apportionment method. The fee is determined according to the water tariffs of the five states in the United States.

When forecasting water resources demand, it is calculated according to agricultural water, industrial water and residential water (considering water consumption for power generation), in which agricultural water is subdivided into farmland irrigation water, fish pond replenishment water, and livestock breeding water.

$$x_{j1} = LW_n^t + w_o + w_i \tag{17}$$

$$LW_n^t = PQ_i^t \times LQ_i^t \times 365 \div 1000 \tag{18}$$

Where wo is the demand for agricultural water, wi is the demand for industrial water, LW is the total population with water in year t, and LQ is the quota for domestic water use in year t.

$$w_o = w_g + w_F + w_c \tag{19}$$

$$w_g = A \times Q_g \tag{20}$$

$$w_F = A_F \times Q_F \tag{21}$$

$$w_c = A_c \times Q_c \tag{22}$$

$$w_i = M \times Q_i \tag{23}$$

$$w_e = M_e \times Q_e \tag{24}$$

$$x_{j2} = w_e \tag{25}$$

Where w is the water demand for farmland irrigation, fish pond replenishment, animal husbandry, industry, and power generation; A is the irrigation area, fish pond area, and the number of livestock; Q is the net water quota for each category; M is the industrial added value.

The constraints of the model are as follows:

Water supply constraints

$$\sum_{j=1}^{5} x_{i,j} \le F \tag{26}$$

Water demand constraints

$$\sum_{j=1}^{5} x_{i,j} \le \sum D_{i,j} \tag{27}$$

Water quality constraints

$$\begin{cases} c_j \le c_0 \\ \sum_{j=1}^{5} 0.01 \times d_{j,i} \times p_{j,i} \times \sum x_{j,i} \le w_0 \end{cases} \tag{28}$$

3.2. Water allocation strategy based on AHP

By constructing an index system and using AHP to deal with the problem of water allocation, the most suitable option can be scientifically and reasonably selected from several water allocation options according to the actual local conditions.

Option 1: Prioritize the allocation of water to agriculture, then to industry, and then to residential;

Option 2: Prioritize the allocation of water to residential, then to industry, and then to agriculture;

Option 3: Prioritize the allocation of water to industry, then to agriculture, and then to residential;

Option 4: Prioritize the allocation of water to residential, then to agriculture, and then to industry;

Use the Analytic hierarchy process to analyze and select the option that are suitable for each state, and then calculate the water demand according to the content of the option. Then, the priority of water use is determined according to the economic and social development ($\boldsymbol{R_j}$) of each state, and the policy is preferentially inclined to the backward areas. Based on this, macro-control of water resources is carried out until the water supply reaches a relative balance. The results are shown in the figure 2.

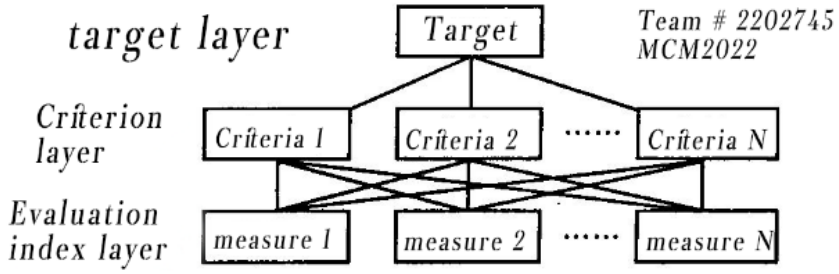


Figure 2. Schematic diagram of the analytic hierarchy process

4. Model Implementation and Results

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4.1. Lake water levels and information for dam operations s

According to the background of the topic, in order to get the best solution, the relevant data is substituted into mathematical models such as Water allocation model for balanced development and Hydropower generation model for simulation operations (the reference unit of water level is Feet above sea level). The results are shown in the figure 3.



Figure 3. Schematic diagram of the results

After relevant data analysis and calculation, the results are as follows:

M= 1086.3 feet = 331.1 meters, 38,890,715 cubic meters of water need to be drawn from Lake Mead;

p = 3654.27 feet = 1113.82 meters, 152,124,608 cubic meters of water need to be drawn from Lake Powell.

The average flow of the river is 620 square meters per second; if additional water resources are provided, 98,556,608 square meters of water can be provided every day to ensure that the demand can be met; the above water level must be maintained to meet the electricity demand. If there are no additional water resources, the corresponding water resources will be consumed on that day. After that, it will take an additional 1.8398 days to meet the electricity demand again.

Based on 3.10Ghz CPU and Windows10 platform, it takes about 31.592 seconds to run this simulation.

4.2. The competing interests of water availability for general usage and electricity production

Use multi-objective optimal allocation model to recommend the best means to resolve the competing interests of water availability for general (agricultural, industrial, residential) usage and electricity production, and based on MATLAB platform for data calculation and simulation.

4.3. Water is not enough

Use your model to address what should be done if there is not enough water to meet all water and electricity demands.

Build an indicator structure

Select indicators such as output value, economic benefit, Gini coefficient, resident satisfaction, and pollution discharge, and calculate the comprehensive weight of each indicator.

Suppose the importance of each index C1, C2, ..., Cn to be compared to the target.

$$C_{\mathrm{i}} : C_j \Rightarrow a_{ij} \quad \mathrm{A}=(a_{ij})_{\mathrm{n}\times\mathrm{n}},\ a_{ij} > 0,\ a_{ji} = \frac{1}{a_{ij}} \tag{29}$$

- Construct judgment matrix
- Calculate the weight vector and check the consistency
- Calculate the maximum eigenvalue of each judgment matrix and its corresponding weight vector.

The consistency of the matrix can be judged according to the maximum eigenvalue; the influence weight of each factor is represented by the corresponding eigenvector, and the weight vector can be obtained by normalization. The relevant calculations are as follows:

Maximum eigenvalue λ_{max} = 5.073; Weight vector (feature vector) w = (0.263, 0.475, 0.055, 0.090, 0.110)^T; Consistency indicator $CI = \frac{5.073-5}{5-1} = 0.01825$; Random consistency index RI=1.12 (check the table to know) ;Consistency ratio $CR = \frac{0.01825}{1.12} = 0.0162946 < 0.10$; Through the above operations, it can be proved that the consistency check is passed.

- Calculate composite weights

Based on the above data, the scheme comparison weight matrix of each option can be obtained, and the local scheme weights of the four schemes can be further calculated, and the comprehensive weight can be calculated based on Table1.

Table 1. Single-level AHP weights based on each indicator

Output value	Option1	Option2	Option3	Option4
Option1	1.00	3.00	0.20	2.00
Option2	0.33	1.00	0.17	3.00
Option3	5.00	6.00	1.00	7.00
Option4	0.50	0.33	0.14	1.00
Economic benefit	Option1	Option2	Option3	Option4
Option1	1.00	3.00	0.33	2.00
Option2	0.33	1.00	0.17	3.00
Option3	3.00	6.00	1.00	7.00
Option4	0.50	0.33	0.14	1.00
Gini coefficient	Option1	Option2	Option3	Option4
Option1	1.00	3.00	0.33	2.00
Option2	0.33	1.00	0.20	3.00
Option3	3.00	5.00	1.00	6.00
Option4	0.50	0.33	0.17	1.00
Resident satisfaction	Option1	Option2	Option3	Option4
Option1	1.00	3.00	0.33	2.00
Option2	0.33	1.00	0.17	3.00
Option3	3.00	6.00	1.00	6.00
Option4	0.50	0.33	0.17	1.00
Pollution discharge	Option1	Option2	Option3	Option4
Option1	1.00	2.00	0.33	2.00
Option2	0.50	1.00	0.20	3.00
Option3	3.00	5.00	1.00	6.00
Option4	0.50	0.33	0.17	1.00

4.4. Model checking in special cases & Sensitivity Analysis

Case 1: Changes in water and electricity demand, growth or decline in agriculture, industry, and population

The demands for water and electricity in the communities of interest change over time. Related curves when population, agriculture, and industry grow or shrink in AZ, CA, WY, NM, CO are as follows:

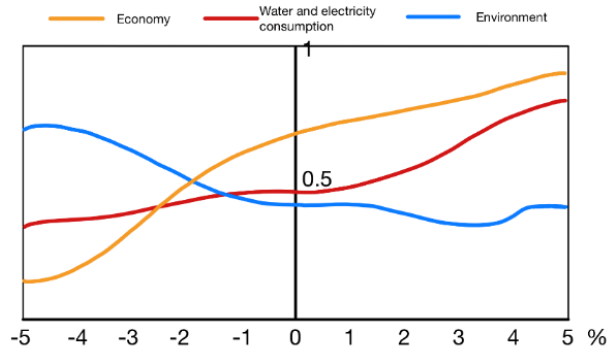


Figure 4. The population of CA changes

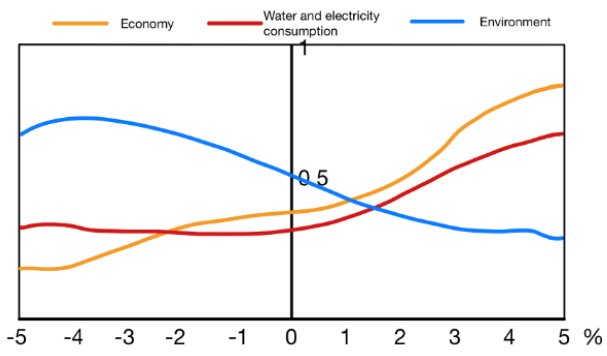


Figure 5. The industry of CA changes

As shown in Figure 4 and Figure 5, the blue curve is opposite to the yellow curve and the red curve, indicating that economic goals are positively related to water and electricity consumption, but negatively related to environmental protection.

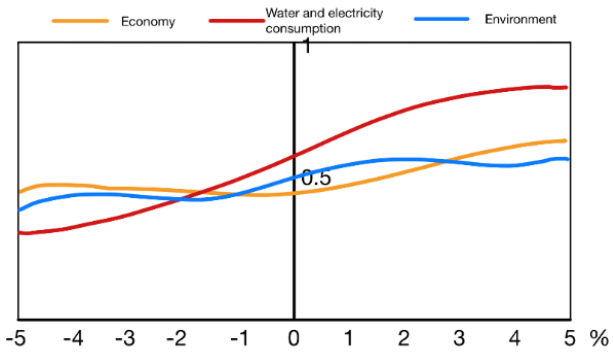


Figure 6. The agriculture of CA changes

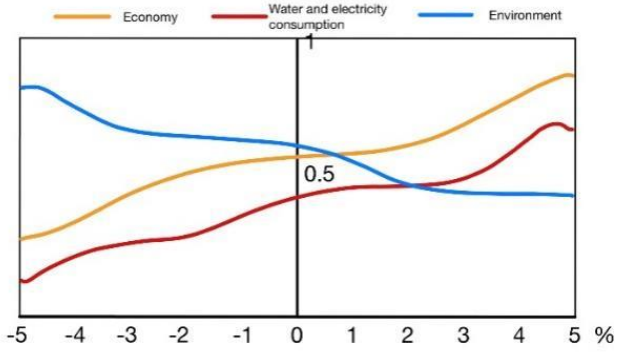


Figure 7. The population of CO changes

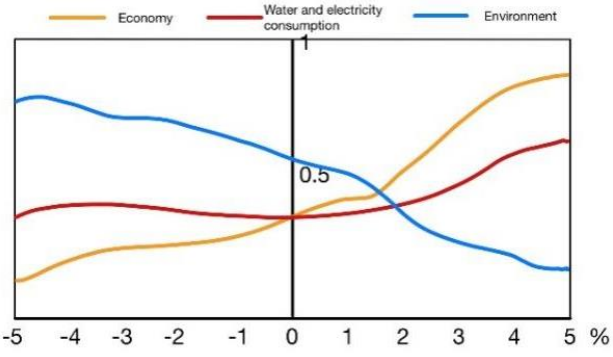


Figure 8. The industry of CO changes

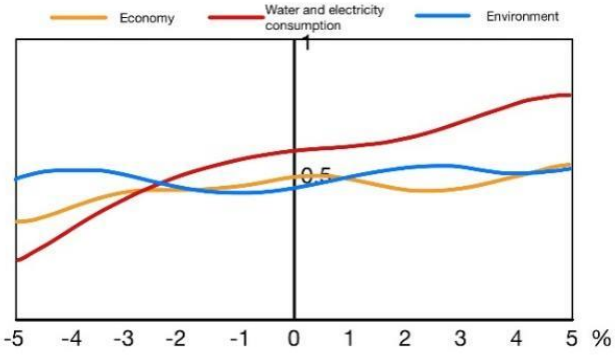


Figure 9. The agriculture of CO changes

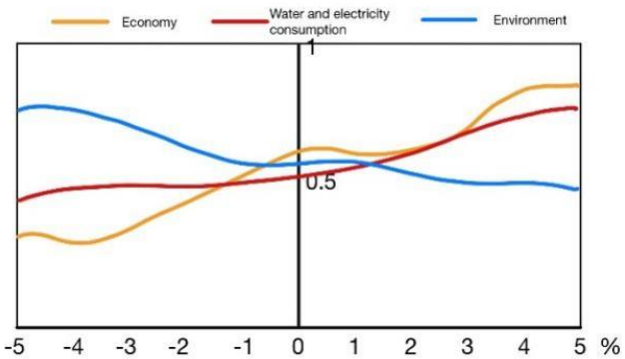


Figure 10. The population of AZ changes

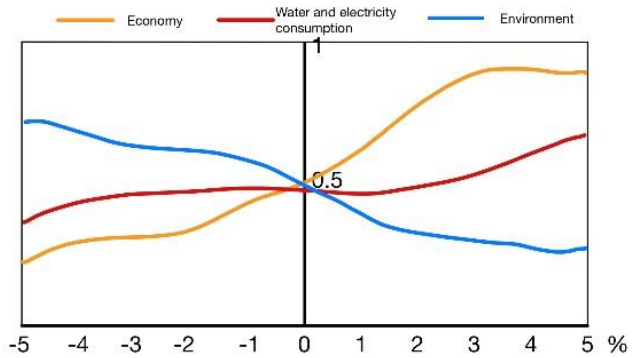


Figure 11. The industry of AZ changes

As shown in Figure 5 to Figure 8, when the development of industrial activities shrinks, the environmental changes are larger; as shown in Figures 4 to 7, when the development of agricultural activities shrinks, the environmental changes are small.

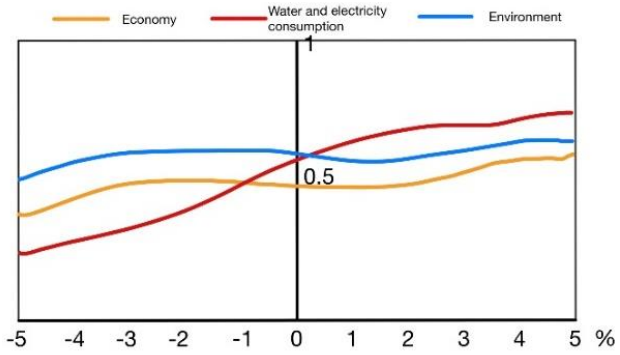


Figure 12. The agriculture of AZ changes

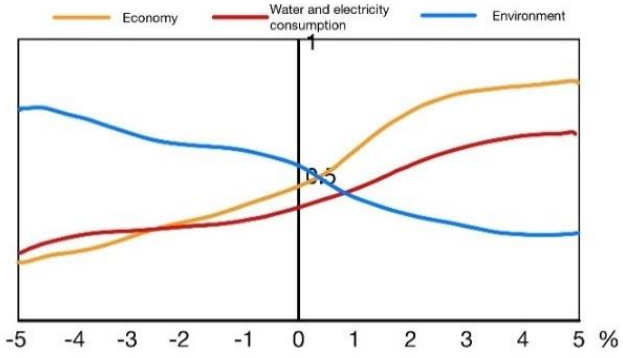


Figure 13. The population of NM changes

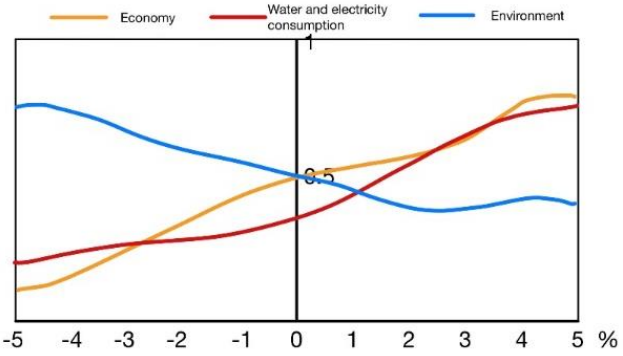


Figure14. The industry of NM changes

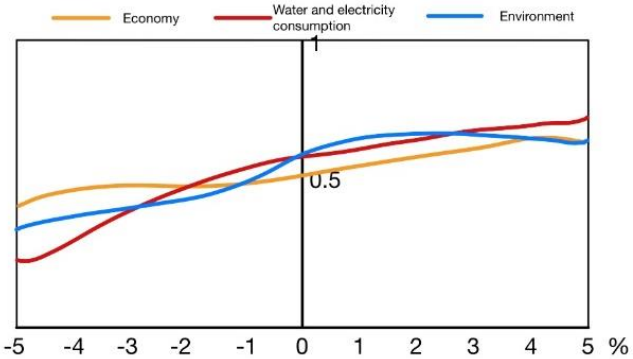


Figure15. The agriculture of NM changes

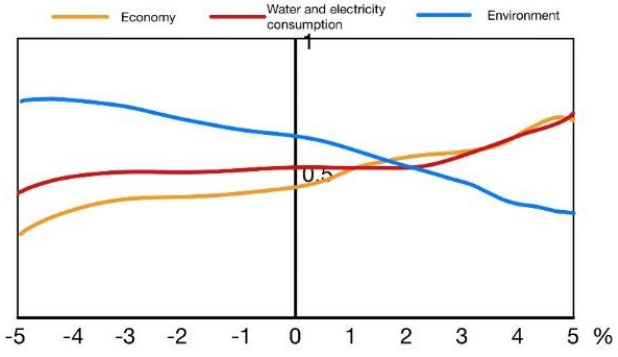


Figure 16. The population of WY changes

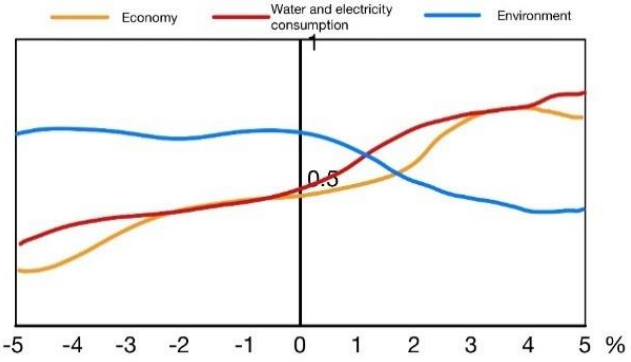


Figure 17. The industry of WY changes

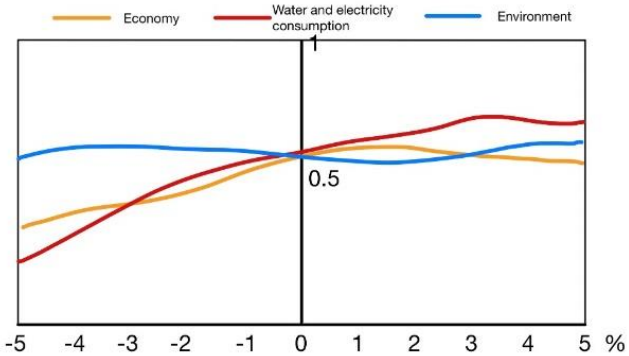


Figure 18. The agriculture of WY changes

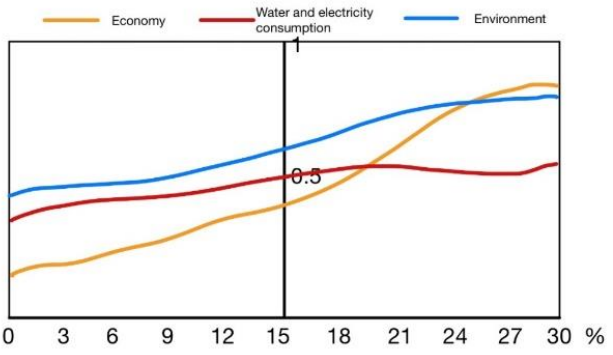


Figure 19. use more renewable energy

Case 2: The proportion of renewable energy technologies increases over the initial value used in analysis

When the renewable energy technology is gradually mature and put into use, the relevant changes are shown in figure20

As shown in Figure 20, when clean energy and renewable energy continue to develop, the economy, water and electricity consumption and environmental protection all continue to develop, and all three are positively correlated.

Case 3: Additional water and electricity conservation measures are implemented

When more water and electricity conservation measures are implemented, the relevant changes are shown in the following figure:

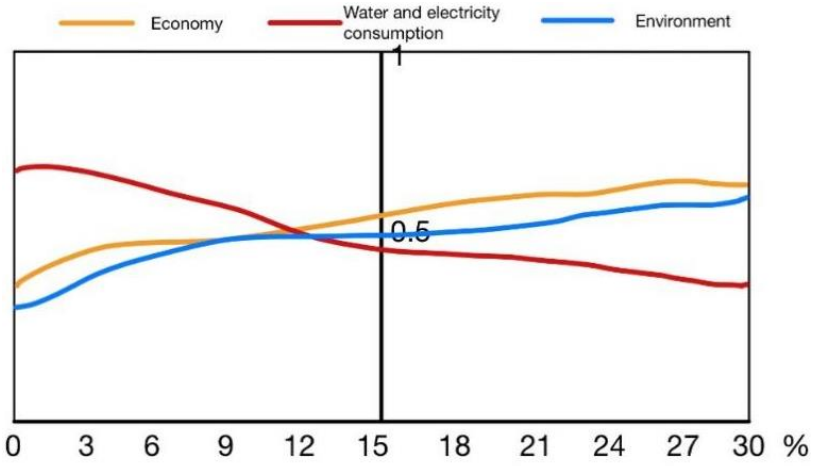


Figure 20. Implemented more water and electricity saving measures

As shown in Figure 9 to 20, when more water and electricity saving measures are implemented, the consumption of water and electricity will naturally decrease. At this time, the economy and environmental protection have both developed slightly. It can be seen that saving water and electricity is also a possibility. way of continuous development.

5. Conclusion

Paper has explored best mathematical solution for the allocation of water in five U.S. states, to determine the best way to manage water usage and electricity production at dams and to address some competing interests. In this process, the model we built played an important role.

The predecessors have proposed the method of initial water rights allocation, but due to the lack of consideration of objectives, the analysis of factors will be insufficient, the effect of maximizing benefits will not be achieved, and the distribution will be uneven. Therefore, we often build a multi-objective water resource allocation model to carry out configuration.

We first set up social benefit indicators: such as Gini coefficient, Engel coefficient, resident satisfaction; economic benefit indicators: output value, economic benefits, unit cost; environmental benefit indicators: environmental pollutant concentration in unit discharge, BOD (biochemical oxygen demand), COD (Chemical Oxygen Demand), these indicators are used to estimate the total benefit of water supply in a region, not only to pursue sustainable development, water conservation and energy conservation, but also to pursue economic growth and balance of payments; in addition, in arid environment, we are more We should pay attention to poor and backward areas, and give priority to water resources to make the allocation of resources fair.

From the results of multiple analyses and fittings, it can be concluded that the best solution is to give priority to water supply to industry, then to agriculture, and finally to residents, so as to achieve the best water resource allocation under drought conditions.

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