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Study on the multi-level evaluation method of small hydropower sustainable development

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Abstract: Currently, there is a lack of a comprehensive evaluation method for assessing the sustainability of small hydropower at different levels. This deficiency hinders the rational planning of small hydropower development and utilization, as well as the delicate balance between safeguarding and harnessing small hydropower resources. To address this gap, this study primarily focuses on establishing a comprehensive evaluation system for the sustainability of small hydropower at the international, national, and individual power station levels. On the international stage, an evaluation index system is formulated, and a national quantitative assessment model for small hydropower sustainability is developed using the Analytic Hierarchy Process (AHP) combined with fuzzy evaluation techniques. The research is exemplified by investigating countries within the Belt and Road Initiative. At the national level, models for assessing the overall development status and spatial distribution patterns of small hydropower are created. The study thoroughly examines the temporal and spatial evolution patterns and trends in the sustainable development of small hydropower in various provinces and states, with China serving as a case study. At the individual power station level, a green evaluation model is established to comprehensively assess small hydropower stations. This model considers ecological, social, managerial, and economic dimensions to evaluate the environmental sustainability of each small hydropower station.

1. Introduction

At present, the researches related to the evaluation of small hydropower sustainability are mainly focus on the international level, the national level and the single power station level.

At the international level, researches have mainly used quantitative and qualitative methods[1-5], for example, AHP-fuzzy comprehensive evaluation, from the perspectives of climate change, hydro-energy resources, electrification rate, technology, cost, bidding, employment, investment and financing, etc. At the national level, researches have evaluated the sustainability of small hydropower from both qualitative and quantitative perspectives. Firstly, from the point of view of society, economy, resources, ecological environment and safe operation, some researches have carried out sustainability evaluation of small hydropower in China, the United States and Spain by using quantitative methods, such as AHP-fuzzy evaluation model, entropy weight TOPSIS method, coupling coordination degree theory, β convergence analysis theory, cluster analysis and center of gravity analysis theory. They discovered that the development of water energy resources in different countries is inadequate, and small hydropower still has a large potential for growth. At the level of a single power station, developed countries have carried out studies on the sustainability assessment of small hydropower stations for over three decades. Related researches evaluate the sustainability of small hydropower stations mainly from the aspects of nature, ecology, society, economy, management, by using AHP-fuzzy comprehensive evaluation model, multi-regional general equilibrium model, DPSIR (Drivers-Pressures-States-Impacts-Responses) model, remote sensing data analysis, multi-standard scoring tools, PROMETHE and other methods [6-10].The more representative evaluation systems mainly include: Swiss green hydropower certification (Low Impact Hydropower Institution, 2004), US low impact hydropower certification[11], International Hydropower Association (IHA) (IHA, 2010) and hydropower sustainability/green assessment of IHA (China Ministry of Water Resources, 2017).

As a whole, many achievements have been made, but there is still a long way to go. Mainly from the following aspects: first, most of the current researches evaluate small hydropower just from a single aspect, however, there is still a shortage of an international, national, and single power

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station system, leading to less comprehensiveness and systematization in the global small hydropower industry sustainability comprehensive evaluation standards. Secondly, the current small hydropower sustainability evaluation index system both at home and abroad has encompassed economic, social, ecological environment, management and other types of the indexes. Due to the lack of international, national and single power station systems, most of the current studies only evaluate small hydropower from a single perspective, resulting in poor comprehensiveness and systematism of the global small hydropower industry sustainability evaluation standards. The majority of the current small hydropower sustainability evaluation indicators both in China and abroad are of qualitative description and there is a scarcity of quantitative research. Therefore, this study constructs a scientific small hydropower comprehensive evaluation method system from three levels: international, domestic and single power station. The sustainability of global small hydropower is evaluated scientifically and rationally.

2. Methodologies

2.1. General framework

From the perspective of research idea, this study includes: raising the problems, setting the goals, defining key tasks, establishing index system, constructing the models and so on. From the perspective of research objects, this study evaluates indexes at the international, the national and the single power station levels. The overall study framework is formed through the intersection of research areas and research objects.

From the point of view of research idea, each step is linked with one another. From the perspective of the research objects, the evaluation results of the previous level help to make key evaluation objects and key evaluation indexes clear for the next level. Evaluation results of the next level help to deepen the objective understanding of small hydropower (Fig. 1).

2.2. Comprehensive assessment model for the sustainability of small hydropower in the countries along the Belt and Road

(1) Countries along the belt and road

The "Belt and Road" initiative connects ASEAN, the Arab League, the African Union and the European Union. The easternmost part connects with the Asia-Pacific economic circle, and the westernmost part radiates the European economic circle. Moreover, the middle part traverses Africa. It not only connects Europe to Asia but also radiates Latin America. Up to December 2020, the total 140 countries have been connected because of The "Belt and Road" initiative, most of which are developing countries.

(2) Evaluation index system

Upon analyzing the literature and data of the countries along the Belt and Road, the authors discover that the majority of studies center on the qualitative analysis of the evaluation index system for small hydropower sustainability, encompassing aspects such as economy, society, ecological environment, management, and so forth. Quantitative studies on the sustainability evaluation index system are relatively scarce. The qualitative index systems in the related researches consist of 11 to 28 indexes, with an average of 21. Meanwhile, the quantitative index systems include 14 to 16 indexes, with an average of 15. Hence, the foundation of this research lies in the principles of sustainability, systematization, and pragmatism, along with the literature investigation and data collection of the countries along the Belt and Road. In combination with the basic traits of the sustainable development of small hydropower, this study selects 17 indexes (Table 1) in five aspects of economy, politics, society, ecological environment, and resources, and builds a comprehensive evaluation index system for the sustainability of small hydropower in the countries along the Belt and Road.

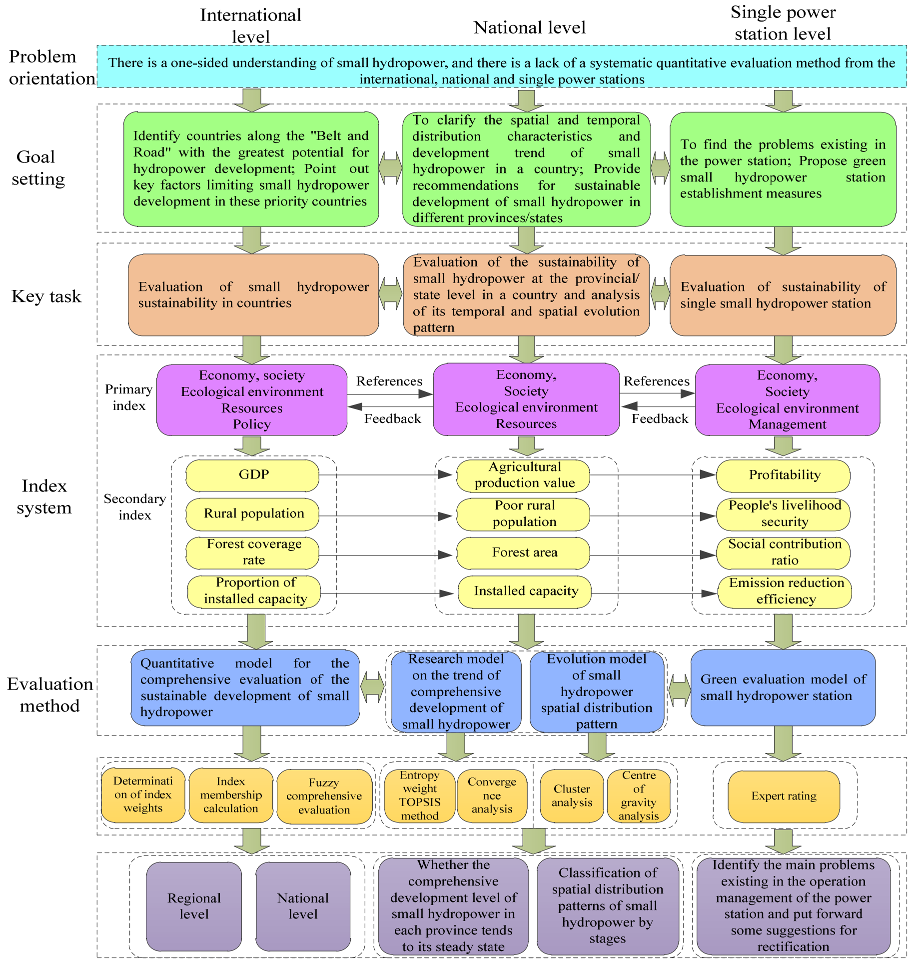

Figure 1. Framework of methodologies for integrated assessment of the sustainability of small hydropower at multiple levels.

2.3. Quantitative Evaluation Model of the Sustainability Level of Small Hydropower in China

At the national level, by relying on the long series of panel data of each province in our country China, the key factors influencing the sustainability level of small hydropower are determined, and the quantitative evaluation model and spatial-temporal distribution pattern analysis model of the sustainability level of small hydropower are established. This article examines the temporal and spatial evolution rule of the sustainability level of small hydropower in each province of China, comprehensively investigates the evolution trend of the sustainability level, clarifies the future development layout of small hydropower in China, and offers support for the classification of regional hydropower.

Table 1. The index system for evaluating the sustainability of small hydropower

Primary index	Serial Number	Secondary index	Definition
(A) Economy	A1	The average GDP per person	The proportion of the gross domestic product (GDP) attained within a country's accounting period (typically one year) to the resident population of the country.
	A2	National economic index	The comprehensive index calculated by some methods, according to factors such as the import and export of natural resources, the economic rent of natural resources, the degree of host country's absorption of FDI, the fluctuation of exchange rate and the total amount of bilateral imports and exports
	A3	Agricultural value-added in proportion to GDP	The proportion of agricultural value added, encompassing forestry, hunting and fisheries, as well as crop cultivation and livestock production of a country, to the national GDP.
(B) Politics	B1	Political stability	A country's political regime changes, national contradictions and other factors on the political stability of the comprehensive impact
	B2	National political openness	The extent and degree of political openness that a country or region demonstrates towards other countries and regions
	B3	National integrity index	Businesspeople, risk analyzers, and the common public are frequently selected as the targets to evaluate the honesty and bribery of government officials in a nation
(C)	C1	Rural population proportion	The proportion of the rural population to the entire population in a nation

Society	C2	Electricity consumption per capita	The proportion of electricity consumption to the entire population in a nation
	C3	Human development index	A comprehensive indicator that takes into account life expectancy, educational attainment, and quality of life, in accordance with certain calculation methods
	C4	Rural electrification ratio	The proportion of the population having access to power supply to the total population in a nation
(D) Ecological environment	D1	CO_2 emission per capita	The proportion of total carbon emissions to the entire population in a nation
	D2	Global Environment Facility (GEF) benefits index for biodiversity	A comprehensive indicator of the relative biodiversity potential among countries taking into account the variety of national representative species, threatened status, and habitat species
	D3	Forest coverage rate	The proportion of forestland to the total landmass in a nation
(E) Resources	E1	Waterpower utilization rate of small hydropower	The proportion of installed capacity to potential capacity of small hydropower in a nation
	E2	Renewable freshwater resources per capita	The quantity of freshwater resources per person in a region/basin at a specific time
	E3	Installed capacity proportion of small hydropower	The ratio of the installed capacity of small hydropower in a country to the total installed capacity
	E4	Fossil fuel energy consumption proportion	The ratio of fossil fuel consumption to the total energy consumption in a nation

Remarks: Considering the data availability at the country level, the index system has the drawback of time consistency.

Currently, the evaluation of the development status of small hydropower in China mainly consists of five aspects regarding the sustainability of a single hydropower station: concept, development strategy, evaluation system, standard formulation and empirical analysis. It mainly incorporates qualitative analysis from the aspects of economy, society, ecological environment, management, and others. This study abides by the principles of sustainability, operability and yearbooks and annual reports. It also obtains 20 indicators from four aspects of economy, society, ecological environment and resources in 31 provinces of China. Utilizing the 20 indicators screened by the entropy weight TOPSIS method, the study acquires 15 indicators (seen in Table 2) from the trial operation until the cumulative variance reaches 90%, and builds the evaluation index system of the development level of small hydropower in China.

Table 2. Evaluation index system of development level of small hydropower.

Primary index	No.	Secondary index	Effect	Proportion of variance%	Proportion of cumulative variance%
Economy (A)	A1	Power generation in rural areas (Unit: 10,000 kWh)	positive	9.67	9.67
	A2	Rural fixed asset investment (Unit:100 million yuan)	positive	5.56	15.23
	A3	Effective irrigated area (Unit: 1000 hm^2)	positive	3.21	18.44
	A4	Total agricultural output value (Unit: 100 million yuan)	positive	2.85	21.29
	A5	Diesel engine power for agricultural irrigation and drainage (Unit: 10,000 kWh)	negative	8.56	29.85
Society (B)	B1	Power consumption in rural areas (Unit: 100,000,000 kWh)	positive	6.6	36.45
	B2	Rural impoverished population (Unit: 10,000)	negative	3.99	40.44
	B3	Net income per capita of rural households (Unit: RMB)	positive	1.95	42.39
Ecological environment (C)	C1	Area affected by drought (Unit: 1000 hm^2)	negative	6.61	49.00
	C2	Region controlled against waterlogging (Unit: 1000 hm^2)	positive	8.19	57.19
	C3	Region affected by flooding (Unit: 1000 hm^2)	negative	7.11	64.30
	C4	Forest area (Unit: 1000 hm^2)	positive	4.11	68.41
Resources (D)	D1	Quantity of hydropower stations operated by villages	positive	9.49	77.90
	D2	Capacity installed in small hydropower stations (Unit: 10,000 kW)	positive	9.02	86.92
	D3	Total storage capability of rural reservoirs (Unit: 100,000,000 m^3))	positive	3.76	90.68

Remarks: in "Effect", "positive" means benefit index;" negative" means cost index.

Table 3. Green small hydropower evaluation index system.

Category	Element	Index
Ecological environment (A)	A1 Hydrological states	A11 Ecological water security (15points)
	A2 River morphology	A21 River shape influence (3points)
		A22 Impact of sediment transport (2points)
	A3 Water quality	A31 Water quality change (5points)
	A4 Aquatic and terrestrial ecosystems	A41 The impact of aquatic protection species (5points)
		A42 The impact of terrestrial protection species (5points)
	A5 Landscape	A51 Landscape coordination (5points)
		A52 Landscape restoration (5points)
	A6 Pollution reduction	A61 Substitution effect (5points)

Category	Element	Index
		A62 Emission reduction efficiency (5points)
Society (B)	B1 Immigration	B11 Immigration resettlement implementation (6points)
	B2 Mutual benefits	B21 Infrastructure improvements (4points)
		B22 People's livelihood security (4points)
	B3 Integrated utilization	B31 Water resources integrated utilization (4points)
Management (C)	C1 Production and operation	C11 Safety production standardization construction (6points)
	C2 Construction management	C21 Institution construction and implementation (4points)
		C22 Facilities construction and operation (4points)
	C3 Technological progress	C31 Equipment performance and degree of automation (4points)
Economy (D)	D1 Financial stability	D11 Profitability (3points)
		D12 Solvency (3points)
	D2 Regional economic distribution	D21 Social contribution rate (3points)

2.4. Comprehensive Evaluation Approach for Green Small Hydropower Stations

The development of green small hydropower stations is of urgency as it is necessary to implement the policy of "innovation, coordination, green, openness, and sharing" and the energy strategies of the central government. Green small hydropower stations have profound impacts on addressing climate change and maintaining national ecological security. The development of small hydropower is an inevitable option to adhere to the harmony between humans and water, promote the construction of water ecological civilization, accelerate the transformation of small hydropower, and enhance quality and efficiency. To develop small hydropower, it is necessary to establish more green small hydropower stations, which in turn stimulate the development of green small hydropower.

The establishment of the "Green Small Hydropower Evaluation Standard" (SL752-2017) adheres to the principles of sustainable development, the integration of international and domestic aspects, and the combination of qualitative and quantitative elements, ensuring that the evaluation index system emphasizes both balance and key points. The Evaluation Standard encompasses a total of 21 evaluation indicators (including four evaluation categories: Ecological Environment, Society, Management, and Economy) and 14 evaluation elements (Table 3).

3. Discussions

The multi-level comprehensive evaluation method for the sustainability of small hydropower proposed in this study is an evaluation idea for the sustainable development of small hydropower. It is available, feasible and effective. However, there is still room for further improvement in the index system and model construction, which are reflected as follows:

(1) Insufficient index system. For example, at the international level, in the economic field, various countries' investment and financing support for small hydropower, small hydropower feed-in tariffs, development costs and other indexes have great scientific value for measuring the economic benefit of small hydropower development. But due to unavailable data, they are not included in this study.

(2) This study evaluates the sustainability of small hydropower at three levels: international, national and single power station. Some evaluation indexes may need to be adjusted according to actual conditions. And the existing index system may not be directly applied to every country because some indexes need to be adjusted according to actual evaluation objects.

4. Conclusions

Based on the existing research results at home and abroad, this study constructs a scientific and systematic comprehensive evaluation method of small hydropower at three levels: international, national, and single power station aspects, which conduct a scientific and rational assessment of the global sustainability of small hydropower.

The study examines the spatial and temporal distribution traits, development tendencies, and crucial factors restricting the development of small hydropower at each level. Subsequently, based on the accessible panel data, it establishes a quantitative evaluation model for the sustainable development from aspects such as the ecological environment, society, management, and economy.

At the international level, the study identifies the key areas where China's small hydropower will preferentially engage in the future. It also selects the restrictive first-level indexes of the economy, society, and resources, as well as some second-level indexes that need to be taken into account.

At the national level, the temporal and spatial distribution characteristics and development trends of China's small hydropower are clarified.

Finally, a comprehensive evaluation model of green small hydropower stations is built at the level of a single power station in line with the Green Small Hydropower Evaluation Standard. It can assist us in analyzing the current situations and determining the development trend of small hydropower at critical moments.

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