Paper:

Evaluation of Diverse Values of Hydropower

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Japan is suitable for hydropower generation because of its varying topology and abundant water resources. The use of natural energy resources has recently gained importance in Japan, and as such the subject of small- and medium-scale hydropower generation has drawn much attention. However, new developments have not advanced significantly. Hydropower has various advantages over other natural energy sources; it provides stable power output, and if construction and maintenance are implemented appropriately, it can provide electricity at low costs and over long timescales. Further, hydropower is environmentally friendly, and can protect and improve the environment when implemented in harmony with natural and social factors. Moreover, it has social benefits; it contributes to aspects such as regional revitalization, local attractiveness, and disaster prevention. The possibilities of hydropower are not fully understood, and methods have not yet been established for its comprehensive practical utilization. Hydropower in Japan has not been in full-scale development for a while. Therefore, there are currently only a few experts on hydropower development. Accordingly, technologies and institutions for the development of small- and medium-scale hydropower generation while ensuring harmony with the natural and social environment are required. Further, a system is also needed to allow experts to promote and support such technologies and institutions in a cross-sectional way.

Keywords: hydropower generation, diverse values of hydropower, social value, system to support hydropower development, Hydropower Development Research Institute (HDRI)

1. Introduction

1.1. Background of Hydropower Development in Japan

Energy security, measures against global warming, and regional revitalization have all become important issues in Japan, and in the modern day all citizens should be involved in solving the energy problem. Japan has already recognized the significance of hydropower generation as a source of renewable energy, and various business entities have attempted to develop hydropower schemes.

Hydropower generation is not only an independent, nationally-produced energy source, which provides a stable and continuous power generation, but also various contributes to the environment and local communities in other ways [1]. In July 2012, a feed-in tariff (FIT) came into force, aimed at introducing renewable energy as much as possible. In FIT, the electric power selling unit price was raised by more than three times compared to its price under the Act on Special Measures Concerning New Energy Use by Operators of Electric Utilities (RPS Act), which was enacted in April 2003. However, FIT has so far failed to promote the full-scale development of hydropower generation. Research into why hydropower development has not advanced as expected revealed that hydropower projects ran into problems such as profitability and gaining consensus for building within local communities. In the context of such problems, there are weak points within Japan's comprehensive development strategies and promotions, based on the common understanding of the values of hydropower and the support to the persons involved [1].

Following the reorganization of Japan's electric power industry after the Second World War, hydropower has mainly been developed by power companies and public electric utilities. During the period of the high economic growth, power demand increased rapidly. Hydropower generation struggled to meet this demand because its scale was small, its generating cost was comparatively high, restrictions were strict, gaining consensus for building within local communities was difficult, and it took a long time for development. Accordingly, thermal power generation and nuclear power generation played the leading role in supplying power in this period, with pumped storage hydroelectric power being used in combination with them. As a result, conventional hydropower has not undergone full-scale development during in these 30 years, the fostering of human resources in the field of hydropower development has stagnated, and the number of the active experts on hydropower has decreased remarkably. Moreover, the technologies and institutions for small and medium hydropower development have not been reviewed to harmonize with the natural and social environment.

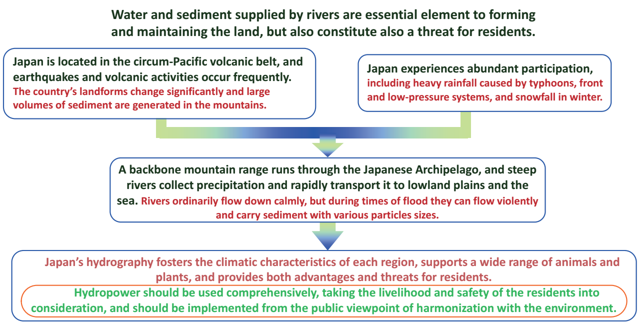

Fig. 1. Characteristics of transportation of water and sediment from mountains, through rivers, to the sea.

1.2. Blessings and Threat of Water

In Japan earthquakes and volcanic activities occur frequently, and the country is characterized by significant landform changes. Accordingly, a large volume of sediment is generated in the mountainous regions. Furthermore, there is abundant participation, such as heavy rainfall caused by typhoons, fronts and low-pressure systems, and snowfall in winter. Backbone mountain ranges run through the Japanese Archipelago, so many small tributaries collect water from small springs to form abundant streams, and steep rivers collect precipitation and rapidly transport it to plains and seashores. Ordinarily, calm and clean streams increase the livelihoods of residents, but during flooding events sediments and driftwood flow rapidly through rivers, posing a threat to residents, and these streams foster a rich eco system (**Fig. 1**). Hydropower in Japan should be implemented based on the country's natural characteristics, and should be integrated with the livelihoods of residents and the safety of the region and its environment. It should also be considered from the viewpoint of the total system, including both ordinary operation and emergencies [2].

This paper highlights diverse values provided by hydropower and recommends a system to promote and support its implementation and resolve associated problems.

2. Values of Hydropower

The values of hydropower were evaluated via comparison with solar power and wind power, based on three viewpoints: power supply, compatibility with the environment, and contribution to local communities.

2.1. Value of Power Supply

Hydropower's value as a power supply was evaluated based on its abundance, economic efficiency, and quality.

2.1.1. Abundance

(1) Survey of Hydropower Capability

Gross theoretical capability refers to the sum of the potential energy of water (excluding evapotranspiration) from precipitation falling on the earth's surface, traveling down rivers from the mountains, to flowing into the sea. According to the World Energy Council [3], Asia, North America, and Latin America have particularly large hydropower capabilities. Japan enjoys a large gross theoretical capability of 718 TWh as it is rich in precipitation and has suitable topography. Japan's gross theoretical capability is six times that of Germany (120 TWh), for example, yet Germany's small-scale hydropower operations are five times greater than Japan, despite the two countries having a similar land area.

Table 1. Hydropower capability in Japan.

	Number of sites	Power output*	Electricity production*
Undeveloped	2,698	12×10^6 kW	45 TWh
Developed and under construction	2,025	23×10^6 kW	94 TWh

*The values of power output and electricity production are rounded up to the nearest integer.

In addition to gross theoretical capability, hydropower capability refers to a country's development possibility (classified as either developed, under-construction, or undeveloped) based on the technological and economic levels at the time of calculation. This metric changes according to factors such as technological progress, economic situation, and environmental conditions. In 1986 the Agency for Natural Resources and Energy conducted its fifth survey on hydropower capability. Japan's hydropower capability was estimated in March 2016 to be 139 TWh, about 19% of the gross theoretical capability [4]. There are 2,698 untapped hydro-sites contributing to this hydropower capability, accounting for roughly half of the combined values for hydropower plants either currently operating or under construction (**Table 1**). The survey identified feasible sites from each watershed and accurately estimated the possible electricity production based on preliminary design, returning an average power output of 4,400 kW. However, since the survey excluded mountain streams that were presumed to be economically inefficient, many small-scale sites less than 1,000 kW were not covered by the survey, so it is possible that there are more undeveloped sites.

More than 30 years have passed since the fifth survey on hydropower capability was conducted. However, new hydropower projects developed or planned during this period correspond to about 4.4 TWh, only 8.9% of the undeveloped electricity production of 49.7 TWh during this time.

(2) Survey of Untapped Heads Within Existing Structures

The Energy for Natural Resources and Energy conducted a survey in March 2009 [5] on untapped heads arising from the heads of river maintenance flows from dam and check dam. The survey also considered existing structures such as irrigation constructions and water and

Table 2. Result of survey on untapped heads within existing structures [5].

Usage type		Number of sites	Power output* [$\times 10^3$kW]	Electricity production* [$\times 10^6$kWh]
Dam use	River maintenance flow	223	28	142
	Water supply and industrial water supply	227	154	742
	Irrigation water	392	111	525
	Check dam	129	17	85
	Subtotal	971	309	1,494
Channel use	Irrigation channel	151	8	60
	Water supply	178	10	78
	Industrial water supply	23	2	15
	Sewerage	66	2	14
	Subtotal	418	22	167
Total		1,389	331	1,661

*The values of power output and electricity production are rounded up to the nearest integer.

sewer services, which were not covered in the surveys described in the preceding paragraph. The survey identified 1,389 untapped sites of power generation using untapped heads, with a power output of approximately 331 MW, and electricity production of approximately 1.7 GWh, and an average power output of 238 kW (**Table 2**). Again, it is possible that candidate sites have not been extracted exhaustively in this survey, as sites were only selected based on interviews with property owners.

(3) Other Surveys on Water Abundance

Assessments of hydropower capability in Japan do not include hydropower potential from reservoirs and untapped heads at existing dams for flood-control. Therefore, estimations are made on hydropower potential on the assumption that existing dams are thoroughly used for hydropower by changing operational procedures, removing various economic, environmental, technical, and institutional constraints, and increasing dam height as necessary, as shown in **Fig. 2** [6]. These findings point to an additional electric energy generation of 34 TWh and power output of 9.32 million kW from this newly identified potential hydropower generation.

The Ministry of the Environment has tried to promote the potential for introducing small and medium scale hydropower generation in rivers and irrigation channels, and has calculated the potential electricity production for these schemes at about 9 million kW based on the existing electric national geographical information [7].

The scale of the identified untapped hydropower energy opportunities varies significantly. Problems associated with harmonizing these hydropower opportunities

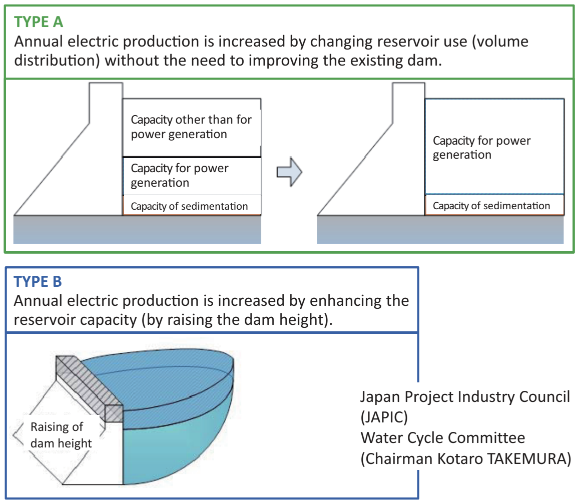

Fig. 2. Figure of maximum use of power generation at existing dams [6].

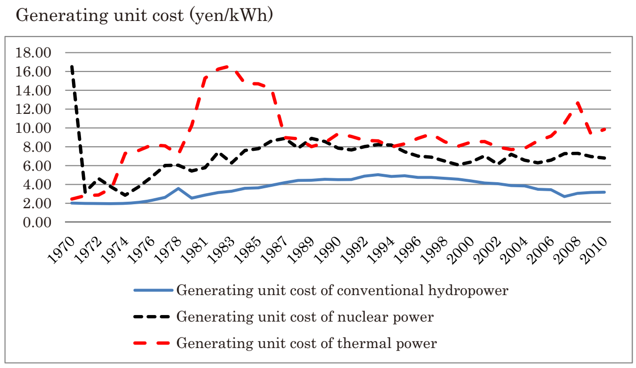

Fig. 3. Actual generating unit cost of hydropower, thermal power, and nuclear power generation.

with the natural and social environment, and with balancing costs, should be tackled in the future.

2.1.2. Economy

(1) Actual Conditions of Generating Cost

Although hydropower requires a large the initial investment compared to power output, the serviceable life of hydropower is very long. If maintenance is conducted appropriately, water wheels and generators can be used for more than 50 years, and concrete structures such as dams and channels can last for more than 100 years.

The development of the actual generating unit cost of past hydropower, thermal power, and nuclear power generation is shown in **Fig. 3**. The average generating unit cost is found by dividing the annual expense (capital cost, cost for operation and maintenance, and cost of fuel) necessary for each power source in possession of nine power companies by the annual electricity production based on the statistical data of the Federation of Electric Power Companies of Japan [8]. Hydropower is both cheaper and more stable than thermal power and nuclear power.

Table 3. Comparison and review of generating unit cost.

	Annual electricity production	Utilization factor	Maximum power output	Condition of calculation
Hydropower generation	About 35 million kWh	0.55	7,200 kW	Construction unit price of 800,000 yen/kW, Repair work is carried out after 60 years
Wind power generation	the same as above	0.20	20,000 kW	Construction unit price of 800,000 yen/kW, Serviceable life of 20 years, Cost reduction of 20% after 20 years
Solar power generation	the same as above	0.12	34,000 kW	Construction unit price of 250,000 yen/kW, Serviceable life of 20 years, Cost reduction of 20% after 20 years and 40% after 40 years, Exchange of power converter each 10 years

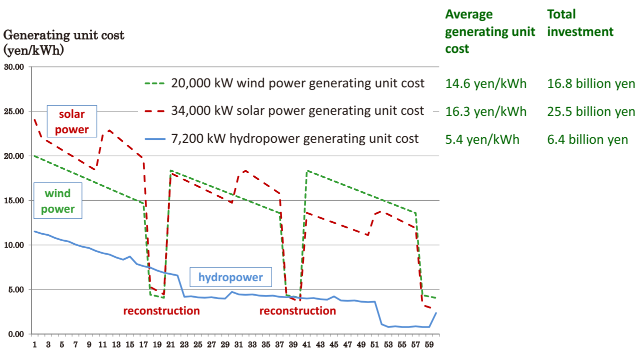

Fig. 4. Result of trial calculation of generating unit cost over 60 years.

If hydropower is operated and maintained appropriately, power generation is possible even after the full depreciation of the facility. Thus, hydropower is the cheapest power source in the long term. Effective use of aging hydropower facilities, and reduction of the construction cost of small-scale hydropower using existing infrastructures are issues that need to be tackled in the future.

(2) Comparison of Generating Unit Cost of Renewable Energy in the Long Term

Hydropower generation is characterized among renewable energy sources by a high utilization factor and a very long serviceable lifetime. Simulations were conducted to understand the change of the generating unit cost of hydropower, wind, and solar energy over 60 years, assuming that the power facility in each case had the same annual electricity output of 35 million kWh. The conditions of calculation are shown in **Table 3**. In the cases of wind and solar power generation, some degree of future cost reduction was taken in into consideration. However, the disposal cost associated with renewing the facilities of wind power and solar power generation, which is expected to occur every 20 years, was not considered.

The results of trial calculations are shown **Fig. 4**. The hydropower generating unit cost is cheapest of the three, and renewing hydropower facilities generates almost no waste during very long lifetime.

2.1.3. Quality

(1) Security of Stability of Power System

Generated power is delivered to its intended destinations via circulation facilities, including transmission, transformation, and distribution. This network, termed the power system, requires a constant frequency and voltage to supply power stably.

To stabilize the frequency of the power system, the consumption and production of electricity need to be well balanced. To this end, power companies respond to the ever-changing power demand by combining base, middle, and peak load power sources. Run-of-river type hydropower systems provide a stable base load power source, which increases the security of stability of frequency of the power system. Pond-type and reservoir-type hydropower facilities can be regulated by controlling power output, responding to power variations ranging from several minutes to several dozen minutes, and a synchronous generator can be used to respond to variation ranging from several seconds to several minutes by changing its output characteristics. It is also necessary to keep the voltage of power system constant, which requires regulation corresponding to variations of load. Synchronous generators play an important role in regulating the voltage in hydropower generation. The use of unstable power sources like solar power has recently increased, which has increased the value of hydropower, as it can provide security and stability for the power system.

(2) Future Power Demand-Supply Balance

A case study was conducted on long-term power-demand supply balance, based on the mass introduction of renewable energy in recent years, and the simultaneous extrication from dependency on fossil fuel and nuclear power. Future population decrease in Japan was also taken into consideration. An example is presented below:

The conditions of calculation are shown in **Table 4**. A simulation was performed whereby renewable energy is introduced in the early stages as much as possible, and thermal nuclear power are abandoned once their serviceable years are reached. **Figs. 5** and **6** show the relationships between population and power consumption and between population and maximum power respectively, and **Figs. 7** and **8** show the relationship between power demand and electricity production and the demand-supply balance of the maximum power output over the period from 2010 to 2110 respectively.

In this simulation, solar power generation with a low utilization factor was introduced on a large scale, but thermal and nuclear power generation was simply abandoned after the lifespan of each had been reached. In this simulation, electricity production was projected to be in deficit after about 2035, with hydropower generation playing a leading role in providing electricity by 2110, supplying 140 billion kWh.

In the case of maximum power, supply exceeds demand well. However, solar and wind power generation, which constitute a large part of the power sources, have problems associated with the stability of the power system, such as the adjustment of frequency of the system due to variations in power output, the generation of surplus electricity, and the lowering of synchronizing power. Accordingly, the practice of early-stage widespread introduction of unstable power sources should be carefully examined. Pond-

Table 4. Conditions of calculation for power long-term demand-supply balance.

Item	Conditions of calculation
Power demand	• The population in Japan in 2100 is estimated to be between 31 million (low level) and 62 million (high level). Source: National Institute of Population and Social Security Research • Power demand is assumed to be proportional to population. • The marginal supply capacity of 10% is secured.
Supposed amount of renewable energy to be introduced	• Solar power generation of 72 million kW, wind power generation of 14 million kW, geothermal power generation of 6 million kW, biomass power generation of 5 million kW, and hydropower generation of 35.3 million kW are to be introduced until 2030. The maximum amount to be introduced is estimated based on the data from the Science and Technology Agency.
Thermal and nuclear power generation	• The baseline was set to include facilities either in existence or planned in 2010 prior to the Great East Japan Earthquake. Facilities are abandoned once their serviceable lifespans of 40 years have passed. Coal-fired thermal power is gradually decreased to zero in 2110 because minable coal resources are large enough to supply coal for more than 160 years.

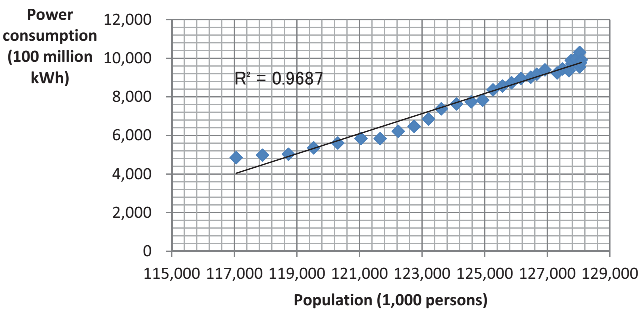

Fig. 5. Relationship between population in Japan and annual power consumption.

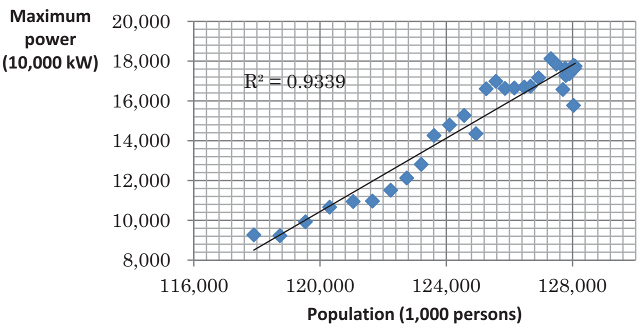

Fig. 6. Relationship between population in Japan and maximum power.

type and reservoir-type hydropower schemes, which can perform power conditioning and have high controllability and synchronizing power, are expected to play a more important role in the future.

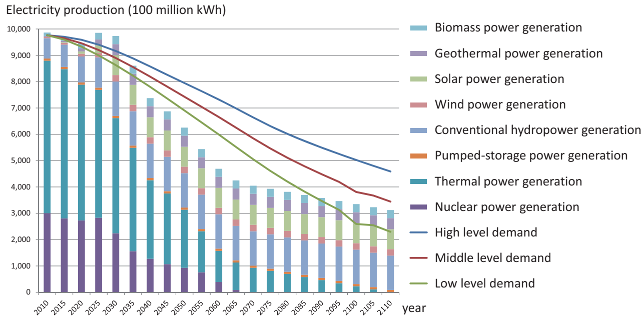

Fig. 7. Relationship between power supply and electricity production.

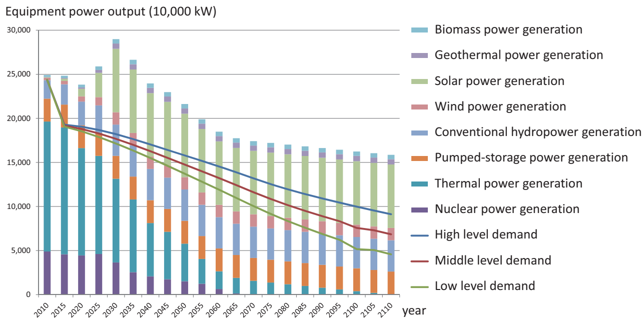

Fig. 8. Relationship between demand of maximum power and equipment power output.

2.2. Environmental Value

The environmental value of hydropower was evaluated from the viewpoints of CO_2 emission, air pollutant emission, and its effect on river environments.

2.2.1. CO_2 emission

Hydropower generation is a low-carbon power source, with very low CO_2 emissions per unit of electricity produced. Throughout its lifecycle, from manufacture and construction to operation and maintenance, it has the lowest levels of CO_2 emission among the renewable energies.

A comparison of the emission intensity of hydropower against solar, wind, and geothermal power generation is shown in **Fig. 9** [9]. The demolition and abandonment of facilities during the time of renewal were not taken into account for the cases of solar and wind energy. When considering that hydropower generation also has a long serviceable life, it becomes even more advantageous. Japan's existing hydropower generation facilities annually produce about 92 billion kWh; their annual CO_2 emissions are about 0.1 million tons (**Fig. 9**). If this hydropower generation were to be replaced by liquid natural gas (LNG) and coal-fired thermal power, CO_2 emissions would rise to about 68.1 million tons, an increase of 68 million tons of CO_2, which constitutes approximately 6% of Japan's total CO_2 emissions.

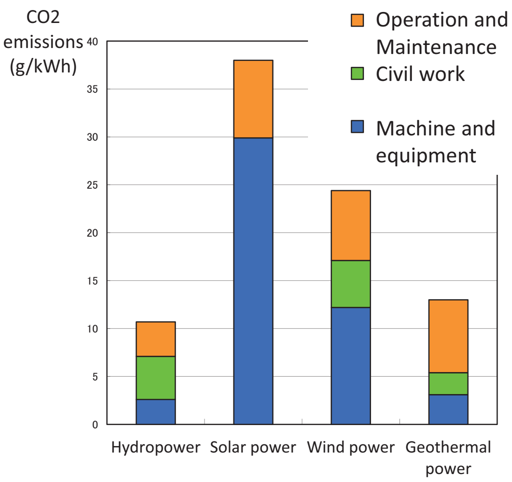

Fig. 9. CO_2 emissions of renewable energy sources [9].

Table 5. Air pollutant emission of renewable energy [10].

Power generation technology		SO_2 emissions intensity [g/kWh]	NOx emissions intensity [g/kWh]	$PM_{2.5}$ emissions intensity [g/kWh]
Renewable energy	Solar power	0〜0.3	0〜1.3	0〜0.02
	Wind power	0〜0.1	0〜0.1	0〜0.01
	Hydropower (Run-of-river type and reservoir type)	0〜0.1	0	0
	Geothermal power	0	0.3	0.04
	Biomass power	0〜2.5	1.3〜5.7	0.31〜0.54
Coal-fired thermal power (for reference)		0.3〜7.7	0.6〜4.3	0.03〜1.87
LNG- fired thermal power (for reference)		0〜0.3	0.1〜1.4	0

2.2.2. Air Pollutant Emissions

Hydropower generation is a clean power source, and produces very little in the way of air pollutant emissions during the life cycle. In fact, its air pollutant emissions are the lowest of all renewable energy sources (**Table 5**).

2.2.3. Load on River Environment

The load on river environment varies depending on the scale and form of the power plant. Dependent type hydropower plants, which utilize maintenance discharge from existing dams, or from the untapped heads of irrigation channels and water supplies, have a smaller load on river environment than traditional hydropower plants.

Conduit type hydropower plants, however, change the river regime because they take in water for power generation, influencing the habitat of aquatic animals and changing the landscape of the river.

Dam type hydropower plants cause influences such as submergence and the hindrance of migration of fish. Although the degree of the problems that arise vary depending largely on the natural characteristics of the basin and the scale, form, and operation method of the facility, the dam blocks sediment from traveling downstream, causing increased sedimentation in the reservoir, a rise in the riverbed upstream of the reservoir, the deterioration of water quality due to long-lasting turbid water and eutrophication of the reservoir, a lowering of the riverbed and coarse-grained sediment triggered by decrease of sediment downstream of the dam, a shortage of river gravel resources, and coastal erosion. Furthermore, decreases in the size and frequency of floods lead to the permanent formation of sandbanks, and permit tree growth on riverbanks, both of which can influence the habitat and social environment. It has been suggested that dam and conduit type hydropower plants could generate both of the load of conduit type and that of dam type hydropower plants combined [11].

As hydropower plants are constructed on public sites, it is necessary to take into account the relationship between hydropower and the natural environment and local communities. During Japan's development of hydropower generation, measures have been taken to address the environmental problems that have been encountered over the past 100 years and more. These measures include discharge for maintenance in reduced flow sections, equipment to permit fish migration in intake weirs, and the construction of selective water intake facilities to mitigate long-lasting turbid water in reservoirs. In order to achieve sustainable utilization of hydropower alongside the preservation and restoration of river environments, concrete measures should be taken in the future, in terms of zoning in each basin and preservation and improvement of the environment. These measured should be based on the characteristics of the environment and the facility at each site, the method for planning of utilization of hydropower generation, considering its natural dynamics, and on comprehensive sediment control [11], which can be conducted by releasing sediment from the dam.

2.3. Social Value

Renewable energy sources utilize available natural energy peculiar to their location, and so can affect local livelihoods. Therefore, renewable power generation should be introduced with due consideration for harmonization with the local communities. National and regional energy policies were surveyed on the subject of how the operation of power facilities could contribute to local communities. The survey found that a new mode of thinking, of "sustainable co-existence of power plant with local communities" to share the benefits of the project for renewable energy is now regarded to be more important than the previous thinking of "the local measures to be provided for the sake of construction of power plant."

In farming and mountain villages where hydropower plants are located, agriculture, forestry, and fisheries have fallen into decline, population has decreased, aging processes have accelerated and underemployment has become a problem for younger generations. Therefore, it has become more difficult in such regions to inherit the local cultures and traditions while also having any vision for the future. When developing hydropower plants that utilize river water, which is a resource for local communities, it is now expected that the operation of the hydropower should not conflict with the interests of local communities, but should instead contribute to them permanently.

Table 6. Factors of contribution of hydropower to local communities.

Classification		Factors of contribution
I. Revitalization of local economy	A	Revenue from tax and grand-in-aid etc.
	B	Return a portion of profits to local communities
	C	Promotion of investment and production, creation of employment and industries
II. Improvement of local infrastructures	A1	Improvement of road and park etc., utilization of land
	A2	Improvement of river, channel, and reservoir etc.
	B	Function of equipment for disaster prevention
III. Energy supply for local communities	A1	Power for business entities, public facilities, street lights, preventive measures against damage by wild animals, agricultural electrification, infrastructures for charging, and emergency power supply.
	A2	Heat utilization etc.
	B	Private power generation, power supply to local communities via local power distribution and sole power supply etc.
IV. Conservation and improvement of local environments	A	Conservation and improvement of forests and ecosystems
	B	Conservation of water environments
	C	Reduction of waste and recycling
V. Revitalization of local communities	A	increasing the attractiveness and name recognition of local communities
	B	Sightseeing, recreation, and cultural resources
	C	Education, training, and fostering of human resources, events, and interchanging
VI. Establishment in local communities	A	Low business risk and ease of introduction
	B	Sustainability of operations

2.3.1. Factors Contributing to Local Communities

Literature reviews and field surveys have been conducted on ideas and cases specific to contributions made by hydropower to local communities. These factors of contribution are classified into six categories: revitalization of economy, improvement of infrastructures, energy supply, conservation and improvement of environment, revitalization of local communities, and establishment in local communities; each of these factors is summarized in **Table 6**. The contributions vary according to the type, form, and size of the hydropower plant, its operation, and the conditions of the local environment. Japan should promote the building of hydropower plants that are based on local characteristics and local communities. These plants can benefit local communities by working with the residents, relevant local government personnel, researchers, experts, and hydropower operators.

2.3.2. Cases of Contributions to Local Communities

Three of the many cases of contributions made by hydropower to local communities are presented below.

(1) Promotion of Rural Areas by Profits from Electricity Sales

– Small scale hydropower generation by agricultural cooperatives [12] –

1) Outline (I-C, VI-B of **Table 6**)

In the Chugoku region, at times when other than power companies were not allowed to operate power generation

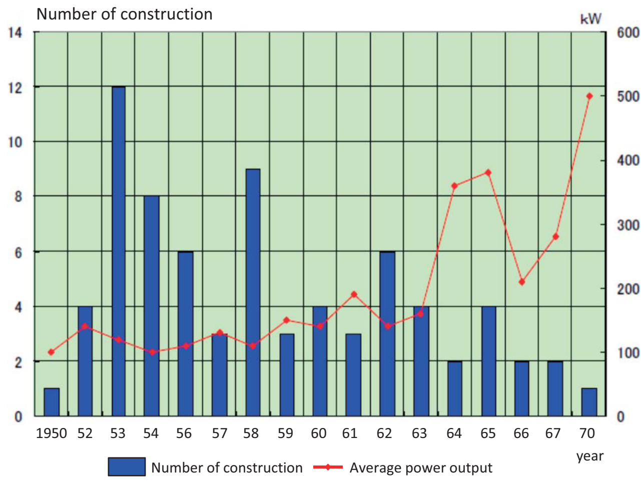

Fig. 10. Development of small-scale hydropower plant construction in the Chugoku region (Takehiro Oki, "Small scale hydropower plant in the Chugoku region") [12].

(except for private power generation) the sale of electricity generated by small-scale hydropower plants was actively managed by agricultural cooperatives and electrification agricultural cooperatives. These small-scale hydropower plants were constructed at 90 sites, and in total generated 12.2 MW of power over a period of about 20 years (**Fig. 10**). These power plants were aimed not at agricultural electrification, but were instead aimed at utilizing water energy as a local resource, returning profits from electricity sales to local communities through the activities of the agricultural cooperatives, and developing rural areas. Shiro Oda, who worked at Chugoku Electric Power Co., worked to enact "the Act on the Promotion of Introducing Electricity into Farming and Fishing Villages" (1952) and founded the EAML Engineering Co., Ltd. in 1950 to plan and design small scale hydropower generation, and to manufacture, construct, and maintain equipment in a consistent way to promote further development.

2) Contributions of hydropower operations to local communities:

- The creation of employment for some hundred persons per site during the construction process.
- Farmers work in shifts as operational staff for power plants in addition to their farm work.
- Profits from electricity sales contribute greatly to the local economy, by improvement of agricultural facilities etc.

3) Problems and future development

In many power stations, more than 50 years have passed since the start of their operation. The profitability of some of these power plants has worsened because of aging facilities, increasing maintenance costs, and reconstruction from heavy rain and sediment related disasters, and so some plants were abandoned. However, more than half

Fig. 11. Taishaku-River Reservoir (Ryujin Lake) [14].

Table 7. Planning factors of the new Taishaku-River power plant [13].

	Existing facility	After redevelopment	
Name of power plant	Taishaku-River	New Taishaku-River	Taishaku-River
Power generation method	Dam and conduit type	Dam and conduit type	Conduit type
Effective head [m]	95.2	129	95.2
Maximum flow [m^3/s]	5.7	10	3.1
Maximum power output [MW]	4.4	11	2.4
Year when operation started	1924	2006	2006

of the plants built (53 plants) are still in operation today. To operate and maintain these aged power plants for the foreseeable future, it is necessary to develop technology for low-cost maintenance and support repair and renewals both financially and technically.

(2) Utilization of Reservoir for Sightseeing, Conservation, and Improvement of the Natural Environment

– Redevelopment of hydropower generation in the quasi national park area [13] –

1) Outline (I-A, I-C and IV-B of **Table 6**)

The Taishaku-River dam and its surrounding area are operated by Chugoku Electric Power Co.; both are located within the 1st Class special area of the Hiba-Dogo-Taishaku quasi national park. A sightseeing boat operates on the reservoir, and the surrounding area represents a precious resource for sightseeing (**Fig. 11**). During its redevelopment, the Taishaku-River power plant's power output was increased from 4.4 MW to 13.4 MW (**Table 7**). In this example, construction was performed with due consideration for the preservation of the natural environment, so as not to impact sightseeing in the area. The effective depth of the reservoir under construction, for example, was determined with consideration for local utilization of reservoir surface; changes to the surrounding natural environment caused by construction were kept to a minimum; and the color and form of the structures were designed to keep them in harmony with the surrounding landscape. Over 80 years have passed since the completion of Taishaku-River Dam; during this time the safety and operability of the facility have been improved by structurally reinforcing the decrepit dam body and improving the performance of flood control. The river environment has been also improved by discharge for river maintenance flow.

2) Contributions of hydropower redevelopment to local communities:

- The water level of the reservoir, which is a precious local tourist attraction, was raised to enhance its sightseeing value, preserve the natural environment, and improve the river environment.
- Grant-in-aid for promotion of power sources in the region has been paid to the municipalities where the power plant is located, to be applied for the construction of pavement, town roads, and slope protection works etc.

3) Problems and future developments

Earlier hydropower generation plants frequently have various problems associated with aspects such as their function, safety, and environmental feasibility. In the case of the Taishaku-River Dam, the performance of power generation and the safety of the aging dam have been improved by redevelopment, the attractiveness of the reservoir has been enhanced, and the natural environment has been conserved and improved. Such efforts should be continued in the future to rebuild the existing dam to improve its performance in such a way that it remains in harmony with the surrounding environment.

(3) Flood Control by Using Hydroelectric Dam

– Use of available volume of hydroelectric dam for flood control [15] –

1) Outline (II-B of **Table 6**)

Tokyo Electric Power Co. owns five hydroelectric dams on the upper reaches of the Sai River, which is part of the Shinano River. The Takase Dam and Nanakura Dam are located on the Takase River, which is part of the Shinano Sai River water system, whereas the Nagawado Dam, Midono Dam, and Inekoki Dam are located on the Azusa River, also part of the Shinano Sai River water system. These dams were originally not obliged to provide a function of flood control. In the vicinity, only the Omachi Dam, which is located in the middle reaches of Takase River, provides a function of flood control. It is under the jurisdiction of the Ministry of Land, Infrastructure, Transport, and Tourism.

When heavy rain threatened to trigger flooding along the lower reaches of the Sai River (also part of the Shinano water system) in July 2006, Tokyo Electric Power Co. conducted exceptional flood control by request from the river administrator. They used mixed pumped storage hydropower plants to manipulate the available volumes of the above five dams, in cooperation with the Omachi Dam, to prevent flooding damage along the Sai River. Although such exceptional operation has certain limitations, this case demonstrates that hydroelectric dams can control flooding to some degree, within the range of their operation.

2) Contribution of hydropower plant operation to local communities

- At times of flooding along the Sai River, dangerous floods along the river's the lower reaches (at Rikugo) were prevented by using the available volume of the hydroelectric dams, even though these dams were not originally obliged to control floods and or operate in cooperation with a state-owned flood control dam.

3) Problems and future developments

The ability of hydroelectric dams to control flooding is an important social value, which is not provided by other renewable energy sources. The practical use hydroelectric dams for flood control is expected to increase due to increasing occurrences of large floods in the future. Reservoir capacities should be utilized in diversified ways; for example such as utilization of flood control dams could be used for power generation, improving the efficiency of use of water resources.

"Project for Reorganization of Omachi Dam etc." is now being implemented along the Takase River to secure flood regulation capacity by using existing dams [16]. It is anticipated that researchers and experts in various fields will be involved in this project, in order to sustainably and comprehensively optimize technologies and systems on topics such as flood control, water utilization, energy, environment, and contribution to local communities.

3. More Effective Utilization of Hydropower

Hydropower generation is a renewable energy source, and will play an important role in the future of Japan's power supply, and it has the potential to create the diverse values if it is developed and integrated with consideration to local livelihoods and economies, and the improvement of disaster prevention and the environment. However, these potential values are not fully understood, and the methods required to apply these values comprehensively need to be established. The steps needed to improve the effectiveness of hydropower generation are described below.

3.1. Bottlenecks on Hydropower Development

3.1.1. Survey of Bottlenecks on Development

A hearing survey was carried out from 2012 to 2014 on the theme of efforts and problems of hydropower development among the following bodies: general electricity utilities, public electricity utilities, power companies, local governments, land improvement districts, agricultural cooperatives, water and sewerage operators, equipment manufacturers, construction companies, consultants, research institutes, incorporated foundations, and the alumni of power companies and administrative organizations in Japan, all of whom are strongly interested in hydropower. Based on the findings of the above survey, an additional questionnaire was conducted to reveal the reasons behind the stagnation of hydropower development and requests for its improvement. The questionnaire's items included building a consensus on development within local communities, the economy of projects, regulations, support systems, hydropower technology, dam-type hydropower, comprehensive strategies and institutions for development, understanding the values of hydropower, FIT systems, and efforts made by water wheel manufacturers. Responses to the questionnaire were in the form of personal, confidential opinions. The questionnaire was sent to 235 people in total via post and email, most of whom had already been involved with previous discussions; 212 people (90%) answered. As a result, more than 1,300 precious opinions and requests were obtained.

These opinions and requests were roughly classified into the following four problems: "strategy and system sharing understanding on characteristics and values of hydropower in entire country," "economy of hydropower development," "permanent contribution of hydropower to local communities," and "support systems to persons involved with hydropower;" these four problems are further divided into 34 categories in total (**Table 8**).

Two-thirds of the respondents cited the failure to build a consensus with local communities as a reason for the stagnation of hydropower development. This is a large problem because river water, which is required for hydropower development, is a key resource for local communities. The main answers and requests given by the respondents are as follows:

1) Contribution to local communities

The following points are insufficiently addressed at present: local revitalization and continuous profits brought by the promotion of local industries and sightseeing; contribution to local communities from the viewpoint of disaster prevention and reduction (for example by supplying power in the time of disaster); and hydropower development coexisting in harmony with local communities.

2) Harmonization with the natural and social environment

The following points are insufficiently addressed at present: support and coordination from central and local governments; harmonization with local communities such as fishery cooperatives, irrigation management associations, and residents; technology to take measures for nature conservation; and the response capabilities of the operator.

3) Hydropower development carried out on the initiative of local communities

The following points are insufficiently addressed at present: promoting understanding of the various values of hydropower; fostering the support of local leaders in

Table 8. Categorization of causes of the stagnation of hydropower development.

Large classification	Middle classification	Small classification
Strategy and system sharing understanding on characteristics and values of hydropower across the entire country	Strategy for comprehensive development promotion	· Development policies, strategies · Local strategies
	System for comprehensive development promotion	· Cross-sectional system for promotion · Utilization of existing infrastructures
	Deregulation	· System for water utilization · River Act, Electricity Business Act, National Parks Act, Forest Act, Sand Erosion Control Act, Land Improvement Act etc. · Grid connection
	Comprehensive financial support system	· Funding, loan guarantee, grant-in-aid, tax incentives · Local contribution, support for the promotion of harmonization with the environment · FIT system
	Sharing the values of hydropower	· Valuation of hydropower · Promotion of the application of values · Transmission of information on values
Economy of hydropower development	Reduction of cost of construction, maintenance, and operation	· Expertise and appropriate use of human resources · System for construction, maintenance and operation · Effective use of the existing infrastructures
	Development and improvement of hydropower technology	· Electric machine · Civil engineering
Permanent contribution of hydropower to local communities	Contribution to local communities	· Contribution measures suitable to local communities · Hydropower development in harmony with local communities
	Harmonization with natural and social environments	· Cooperation with, and participation in, hydropower projects by municipalities and local organizations · Improvement of technology for environmental conservation · response capabilities of operators to local communities
	Support for the promotion of hydropower development carried out on the initiative of local communities	· Project scheme for comprehensive hydropower development carried out mainly by local communities · Understanding of the values of hydropower by local communities · Materialization and development of successful case
Support system for persons involved with hydropower	Support by experts	· Integration of the appropriate use of human resources · Integration of the application of hydropower technology · Support system over all development procedures
	Support for collection and utilization of information	· Collection and publication of information on-site · Education and training · Provision of information and recommendation on policies for policy makers
	Reduction of development risk	· Risk evaluation · Measures for alleviation of risk

the promotion of hydropower development; and creating a project model for hydropower development to comprehensively increase contributions to local communities.

3.1.2. Towards Solutions for Bottlenecks

The main bottlenecks identified at developing hydropower sites are economic limitations and building consensus with local communities. Examining the background causes of these bottlenecks reveals a weakness in comprehensive development strategies and promotion systems, based on the characterization of hydropower and its support system by experts, researchers, and practitioners. These groups should be encouraged to analyze the professional support given to hydropower sites and related information, and recommend their opinions to the policy makers. In order to fully realize the potential of hydropower development in the future, the following four bottlenecks should be resolved comprehensively (**Fig. 12**).

3.2. Problems of Hydropower Development

The problems preventing the realization of hydropower development are summarized as follows, based on the findings of research on the bottlenecks of hydropower development [1, 17].

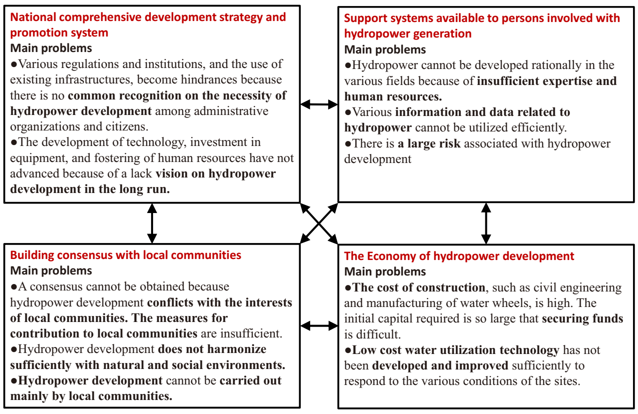

Fig. 12. Main bottlenecks of hydropower development.

3.2.1. Comprehensive Development Strategies and Promotion Systems for Hydropower Development

Hydropower development is related to various fields such as flood control, river water use, natural environment, agriculture, forestry and fisheries, power generation, and local livelihoods.

In order to develop hydropower more effectively it is necessary to share understandings on the characteristics and values of hydropower among the persons concerned, and improve the vision, promotion strategies, and systems of hydropower. The burden of initial investment is a large hindrance on development, and comprehensive financial support systems like low-interest long-term financing systems should be prepared, taking on board conditions such as local contributions, upgrading functions for environmental conservation and disaster prevention, and development of technology. Regulations should be reviewed to balance water utilization with environmental conservation and public safety and security.

3.2.2. Improving the Building of Consensus

Hydropower generation needs to coexist with local infrastructures in the long-term, because it utilizes river water and local common resources, and its serviceable life is very long. In hydropower development, full attention needs to be paid to harmonizing with the actual situation of local natural environments and livelihoods.

As mentioned above in "Section 2.3. Social value of hydropower," hydropower development should be considered as a local problem, and therefore should be carried out mainly by on the initiative of the residents and concerned municipalities. This will bring public benefits to the local communities, who should also review and decide by themselves suitable environmental conservation measures to respond to problems such as river maintenance flow in reduced flow sections and sedimentation. However, the local people concerned often lack experience, knowledge, and funds. Accordingly, the project model should be built in such a way that it fosters and supports local leaders who promote hydropower development in cooperation with experts and companies outside the region.

3.2.3. Realization of Hydropower Utilization with Appropriate Costs

Japan has not operated full-scale hydropower development in recent history, so there are currently no systems for construction, human resources, or technologies with which to tackle small and medium-scale hydropower generation for various operators.

As hydropower generation is planned and designed based on the natural and social conditions at each site, it becomes a single product, and its performance could influence the economy of the hydropower development. Accordingly, improvements are required to current practices for fostering and supporting technological human resources, and the development and systems for technological packages should be reviewed to utilize precious infrastructures such as existing dams, weirs, channels, roads, and established and abandoned hydropower plants for power generation, whilst also improving local environments. Moreover, the major companies involved in manufacturing, construction, and power maintenance ones need to foster local companies and residents from the point of view of a power generation operator, so that they can manage the manufacturing, construction, operation, and maintenance of equipment by themselves.

3.2.4. Support Systems for Hydropower Development

Steady hydropower development requires a wide range of expertise and experience on topics including hydrological characteristics; topography and geographical features of basins; ecological environment; design, construction, operation, and maintenance of electrical, mechanical, and civil engineering equipment; official approval; local social environment and contribution to local communities; consensus building; and funding.

To efficiently and comprehensively develop hydropower in harmony with local natural and social environments, support systems should be built to promote the project on site by fully utilizing the knowledge and experiences of experts. In cases where it is difficult for investors to evaluate the feasibility of hydropower development, any available support systems are needed for such investors. Furthermore, support systems are also necessary to analyze information on river regimes and power transmission and distribution systems at sites proposed for development, to effectively use of information on infrastructure equipment, to construct estimation systems based on the actual situation of the site, and to identify trends in hydropower development and operational experiences.

3.3. Building Promotion and Support Systems for Hydropower Development

3.3.1. Basic Idea

In order to resolve the above-mentioned problems associated with hydropower development and ensure harmony with the environment, a comprehensive promotion and support system for hydropower development should be built.

For example, the National Hydropower Association (NHA) is a non-profitable private organization for promoting and supporting hydropower development. Its activities include making recommendations for national policies, laws and regulations; promoting communication among members, public relations and educators; and supporting technological development. There are nine standing committees and conferences. Results have been achieved by improving the hydropower-related budgets of the institution of the Federal Government, holding forums and workshops, transmitting the information via the internet, providing publications, making management and maintenance of power plant more efficient, and conducting a survey on environmental measures. The NHA has a membership of 231 companies and organizations, including federal institutions like the US Bureau of Reclamation and the US Army Corps of Engineers, TVA, public and private utilities, IPP, equipment manufacturers, environmental and technological consultants, lawyers, and universities [18].

In Japan, where the adverse effects of a vertically-segmented administrative system have been pointed out,

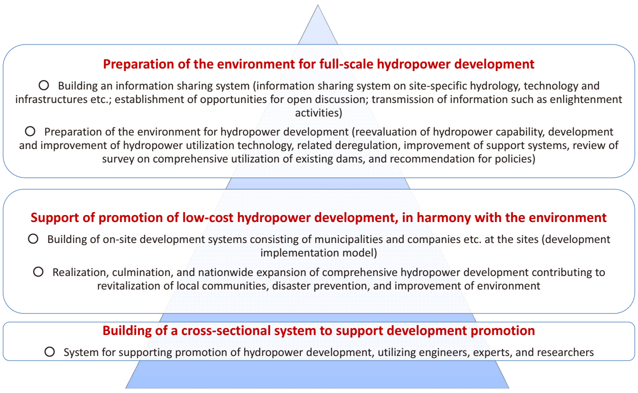

Fig. 13. Building of comprehensive promotion and support systems for hydropower development.

an organization like the NHA seems very significant; it has a wide range of members including companies and organizations, shares the values of hydropower, and coordinates opinions and requests to reflect them in comprehensive policies on water resources. However, under the current situation, in which the values of hydropower are not fully understood, it is not realistic that such national-level organization will suddenly be founded. To begin with, a specified nonprofit organization that complements functions that are lacking under the existing system needs established, and experts and researchers on hydropower are needed to support hydropower development. There also needs to be a system for development consisting of residents, municipalities, experts, and companies etc. built at the sites to realize a comprehensive hydropower development project model of in harmony with local natural and social environment, and this model needs to be expanded nationwide. Understanding of the values of hydropower needs to be shared nationwide, leading to preparation of the environment for full-scale hydropower development (**Fig. 13**).

3.3.2. Establishment of a Specified Nonprofit Organization, the Hydropower Development Research Institute [19]

(1) Objective and Organization

The Hydropower Development Research Institute (HDRI), which is a specified nonprofit organization, was founded in January 2018, for residents, and local companies and organizations. It aims to create an environmentally friendly society in harmony with nature by promoting the realization of the hydropower, which is friendly to the environment and contributes permanently to the local communities.

The original members consist of persons involved with hydropower, i.e., researchers at universities and research institutes, the alumni of administrative organizations, power companies, consultants, and organizations supporting hydropower generation and construction companies etc.

(2) Activities

The HDRI is engaged in the following activities to share and enhance the values of hydropower.

1) Project pertaining to hydropower development in harmony with the environment

- Support of hydropower development in harmony with environment
  Realizing hydropower development in harmony with environment. This comprehensively applies various benefits values of hydropower, and is carried out on the initiative of local communities. A system of support is established with experts on hydropower generation and environment etc. at each site.
- Building the project model
  The project model for hydropower development is built in harmony with the environment. It has high reliability and profitability, contributes permanently to local communities, and is implemented together with local and outside experts and investment.

2) Research project pertaining to valuation of hydropower

- Value of power
  Conduct research to enhance the value of power from the viewpoints of abundance, price, and quality (stability and controllability).
- Environmental value
  Conduct research on planning methods for hydropower generation in harmony with the environment, river maintenance flow, sediment flushing from dams, and environmental regeneration etc. to improve environmental factors.
- Social values
  Conduct research on the revitalization of local communities, the improvement of infrastructures, energy provision, the improvement of the environment and establishments in local communities etc. to improve the contribution of hydropower generation to local communities.

3) Project pertaining to the transmission of information and fostering of human resources

- Transmission of information
  Transmit information widely on sharing and applying the various values of hydropower to society, including to persons involved with hydropower at the sites and administrative organizations. Recommend policies on hydropower development as a part of such activities.
- Fostering of human resources
  Tackle the problem of fostering human resources to promote hydropower generation in harmony with environment. For this purpose, receive internships at the site for development models, hold seminars, and conduct training.

4. Conclusion

Hydropower generation in Japan has played an important role for more than 100 years in providing a stable power source. During this time, both knowledge and problems have accumulated in terms of compatibility with the natural environment and local communities.

Japan has enjoyed rich water resources since ancient times, and water has played a central role in the formation of its land, livelihoods (including agriculture), and ecosystems. Hydropower energy should be developed and utilized not only for generating electricity but also as renewable energy source that contributes permanently to local communities in harmony with local environments. Accordingly, it is necessary to consider higher viewpoints including society, environment, and resources; pursue the project model to comprehensively apply local resources in each region; develop technology for water utilization; develop a desirable system, and review the values of hydropower. Concerning the HDRI, a specified nonprofit organization that was established in 2018, it is desirable that younger generations and experienced members exchange their opinions in a multidisciplinary way. Support should be provided to persons concerned regardless of their status to achieve the objectives, and results should be obtained in a concrete manner.

It is hoped that Japan's environmentally friendly comprehensive hydropower technologies and systems will be applied across Asia, which is rich in hydropower resources. Hydropower development is expected to increase in Asia in the future, and it is hoped that Japan will make an international contribution as a developed Asian nation.

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- "The Need to Change the Concept of Water-related Disaster Prevention," Science & Technology Trends – Quarterly Review, No.44, pp. 8-25, 2012.

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