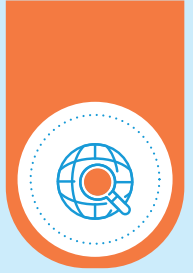




UNITED NATIONS
INDUSTRIAL DEVELOPMENT ORGANIZATION



INTERNATIONAL CENTER
ON SMALL HYDROPOWER



World Small Hydropower Development Report 2022

Case Studies

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Suggested citation:

UNIDO, ICSHP (2022). *World Small Hydropower Development Report 2022*. United Nations Industrial Development Organization, Vienna, Austria; International Center on Small Hydro Power, Hangzhou, China. Available at www.unido.org/WSHPDR2022.

ISSN: 2406-4580 (print)

ISSN: 2706-7599 (online)

The digital copy is available at www.unido.org/WSHPDR2022.

Design: red not 'n' cool

Cover Picture: depositphotos

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Acknowledgements

The World Small Hydropower Development Report 2022: Case Studies was prepared under the overall guidance of Tareq Emtairah, Director of the Division of Decarbonization and Sustainable Energy, Petra Schwager-Kederst, Chief of the Division of Climate and Technology Partnerships at the United Nations Industrial Development Organization (UNIDO) and LIU Deyou, Director General of the International Center on Small Hydropower (ICSHP).

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1. SHP for social and community development

1.1 Jatoarana: Small-scale hydropower generation in Brazilian Amazon for development of rural communities

CATEGORY:

SHP FOR SOCIAL AND COMMUNITY DEVELOPMENT

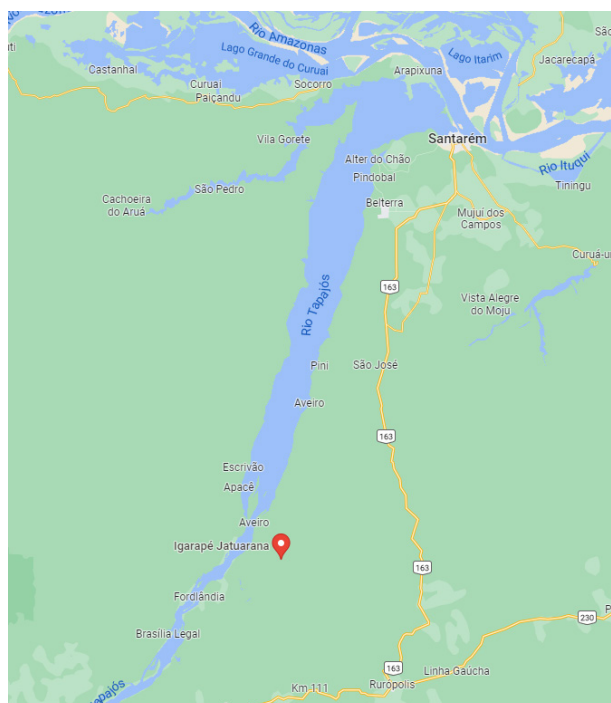
COUNTRY:

BRAZIL

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Figure 1. Location of the SHP plant



Source: Google Maps

Table 1. Project Overview

SHP plant name: Jatoarana

Location: Nova Olinda and Santa Luzia communities, Pará state, Brazil

Installed capacity: 50 kW

Water source: Jatoarana Creek

Key actors: Civil society – dwellers from the two impacted communities, including technicians; National Government – through funding programmes and incentives for electrification initiatives; designers and executors of the SHP project.

Status of the SHP project: Completed in 2008.

Benefits

Economic:

- employment opportunities for local people in civil works
- expansion of markets (e.g., home appliances, electric motors)
- development of local production processes
- reduction of the reliance on high-cost fossil fuels delivered from distant areas

Environmental:

Replacement of the few diesel generators that were used before, reducing the use of fossil fuels.

Social:

- electricity access
- new possibilities of economic activities for the dwellers.

Support schemes/incentives:

- *Luz para Todos* (Light for all) programme
- Energy Sectoral Fund (CT-Energ) for projects related to energy generation.

Potential: The Amazon rainforest is a region with communities in need of quality access to electricity and, at the same time, with a huge hydropower potential.

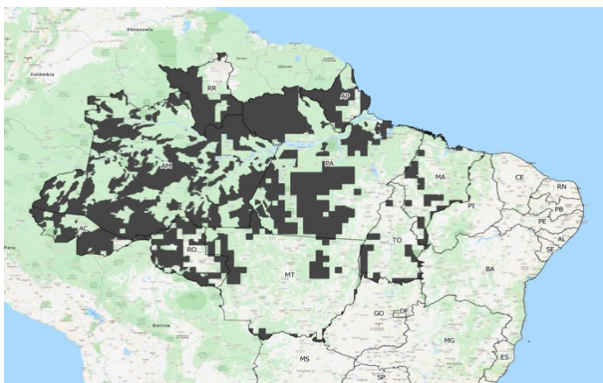
1. INTRODUCTION

Electricity access in isolated regions, mainly in the Amazon region, is still an unmet challenge in Brazil. At the same time, the Amazon region is characterized by a large amount of undeveloped hydropower potential, i.e., a potential for electricity generation using a renewable and local energy source.

In 2007, more than 3 million people in Brazil did not have access to electricity (the calculation is based on data of the World Bank – population and access to electricity), most of them being from the Amazon region, where the population is organized in small communities or in isolated and difficult to access dwellings.¹ Although this population is small, in relative terms, the area to be covered is very large, which makes it difficult to develop extension and distribution networks. One of the solutions is to provide these communities with their own generating units.

The Jatoarana SHP plant was one of the pilot projects implemented in the Amazon region. The project's results showed that local communities could operate and maintain small generating units itself, supported by the robust technology.

Figure 2. Regions in Brazil without access to electricity in 2019



Source: IEMA, 2019 (p. 27) ²

The Jatoarana plant is a 50 kW hydropower plant located in the state of Pará, 90 kilometres away from Belterra, a city in the Amazon Forest region with approximately 17,000 inhabitants, and 140 kilometres away from Santarém (300,000 inhabitants). The plant uses water from the Jatoarana (or Jaturarana) watercourse, which flows into the Tapajós River. The Jatoarana freshwater stream is an *igarapé* (creek), a specific type of tributary found in the Amazon Forest region with low depths and widths (Figures 3(a) and 3(b)). The Jatoarana Igarapé is characterized by an adequate flow rate distribution throughout the year.

Figure 3.

a. Igarapé

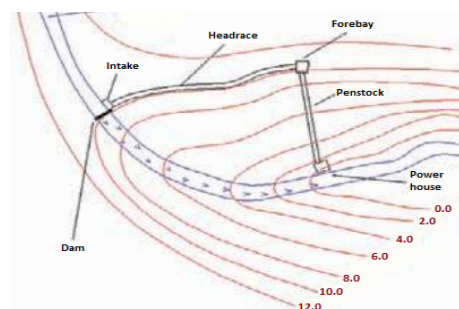


b. Jatoarana Creek



The plant was developed to generate electricity for approximately 40 families that live in two communities (Nova Olin-da and Santa Lúzia) in the rural area around Belterra city. Before the project, the only access to electricity for those families was the use of private diesel generators. The quality of electricity was very low, as the diesel was not always available and the operation costs were dependent on the fuel market. The replacement of diesel small generators by an SHP plant provided more stable and just access to electricity for people living in the communities.

Figure 4. Jatoarana SHP plant arrangement



The Jatoarana SHP plant was built with respect to the environmental regulations and environmental conditions of the Amazon region. It is a run-of-river plant that includes a

diversion dam (Figure 4). The plant operates on an isolated system as the Santa Luzia and Nova Olinda communities are located far from the electricity transmission network. The output is enough for household use.

The civil works for the construction of the hydropower plant were initiated in 2007 and the plant operation started in 2008. The Brazilian National Reference Center of Small Hydropower Plants (CERPCH) helped the Ministry of Mines and Energy to realize the project. It was completed as part of the national electrification programme called *Luz para Todos* (Light for All), which is still going in the country.

Having considered technical, social, economic and environmental aspects, this project serves as a successful example of SHP development in the Amazon region. The plant is still operational, while some other projects that were designed at the same time, faced operational, maintenance and other problems and were decommissioned. The lessons learned from the Jatoarana project could be relevant for future SHP plants, which may become a widely used alternative for electricity generation in the Brazilian Amazon outlying areas.

Table 2. Project Stakeholders

Inhabitants of the small communities of Nova Olinda and Santa Luzia.

Energy sectoral fund (CT-Energ) – financial support through the Federal Government programme Luz para Todos.

National Reference Center of Small Hydropower Plants – cooperation in project development and execution.

Turbine producers, civil engineering company and electric service provider for the distribution lines and installations in the houses.

2. TECHNICAL CHARACTERISTICS OF THE PLANT

Table 3. Technical Characteristics of the Jatoarana Plant

Item	Value
Turbine output	50 kW
Total output	50 kW
Electricity generation per year	Data not available. It is estimated that the turbine operates 95% of the time, the remaining time is for maintenance.

Item	Value
Site condition and parameters of the plant	Flow rate measured: 1.9 m ³ /s; Unevenness of the terrain: 10 m; Run-of-river plant; Diversion dam – materials: earth and rock.
Turbine	Francis, horizontal axis; Design flow rate: 1.0 m ³ /s; Net head: 9.7 m; Minimum efficiency of the turbine (in the design point): 60%; Nominal rotational speed: 720 rpm; Suction head: 2.50 m.
Type of generator	Three-phase synchronous generator, horizontal axis; Nominal speed: 1,800 rpm; Frequency: 60 Hz; Power output: 65 kVA Rated voltage: 220/127 V

Figure 5. Dam construction



3. BENEFITS

Electrification in remote areas is a complex challenge in Brazil. There is lack of information about isolated communities that do not have or have only intermittent access to electricity. Specifically, in the Amazon Forest region, there are many small communities that rely on diesel generators, while a huge hydropower potential remains untapped. That is a great opportunity for implementing SHP plants for the benefit of those populations.

The *Luz para Todos* programme aimed to stimulate the sustainable economic and social development of the communities in Santa Luzia and Nova Olinda. The Jatoarana SHP project had an objective to bring electricity to approximately 40 families living in two main communities in scattered houses along an 8-kilometres-long dirt road. Before the implementation of the SHP project, local economic activi-

ties were hampered by the lack of electricity access. A few households which had diesel generators had electricity for three hours per day. As a result, the SHP project had a huge social appeal.

Economic benefits

Access to electricity on a daily basis considerably changed the local economic activities and boosted the development of local production processes.

Social benefits

Street lighting poles made the life in the communities more secure. It also became possible to work and study in the dark hours. Women could benefit from electricity by attending night classes at schools and developing their skills. The use of house appliances made housekeeping easier and more efficient.

During the implementation of the SHP plant some local technicians received a training on the technology. The capacity building and a simple design of the plant made it possible, in spite of the geographical isolation, to ensure the continuous and autonomous operation and maintenance of the facilities by local people.

Environmental benefits

The Jatoarana SHP plant replaced the few diesel generators that were used before, reducing the use of fossil fuels.

4. BUSINESS FIGURES

Table 4. Business Figures of the Jatoarana Plant

Total investment	BRL 999,383 (USD 199,876)
Estimated generation of electricity per year	372,800 kWh/year
Expected income per year	11,140 USD/year
Break-even	No financial return; at lost bottom
Lifespan	Approx. 20 years

5. LESSONS LEARNED AND CONCLUSIONS

1. The distance and lack of communication with such isolated communities can be a threat to the sustainability of an SHP plant. For example, in this Brazilian case, the research centre CERPCH (in Itajubá, state of Minas Gerais) is more than 3 thousand kilometers away from Belterra (state of Pará) and its rural areas of Santa Luzia and Nova Olinda. The last contact and face-to-face visits to the isolated SHP was in 2012.

- 2. Local capacity building and communication are of high importance to isolated SHP plants.** For example, after the Jatoarana project implementation, the operation of the plant has been the responsibility of local technicians. In 2012, it was found that some similar plants in the Amazon region were not operating anymore (only a few years after their construction) due to technical problems that could not be solved by the local technicians. Fortunately, this did not happen in Jatoarana. It is of key significance to train local people, so that they can manage different technical issues autonomously. And it is very important to keep in touch with the communities after the project implementation phase, which can be easier, even in the case of such isolated communities as the Amazon region, due to modern communication technologies.
- 3. Different sources of funding and government incentives are needed** to expand SHP as a source of sustainable electricity generation to remote places, including the Amazon region. For example, in this particular case, the *Luz para Todos* electrification programme made it possible to realize the Jatoarana SHP project.

Replication potential

In Brazil, and mainly in the Amazon Rainforest, there are still isolated communities without satisfactory access to electricity and a huge untapped hydropower potential. This means that there are possibilities to expand SHP in Brazil, considering social, environmental and economic aspects.

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1.2. Ghana's first small hydropower plant as a centre for capacity building and tourism

CATEGORY:

SHP FOR SOCIAL AND COMMUNITY DEVELOPMENT

COUNTRY:

GHANA

Author:

Chinedum Ibegbulam, Renewable Energy and Development Practitioner

Table 1. Project Overview

SHP plant name: Tsatsadu SHP plant

Location: Alavanyo, Volta Region, Ghana

Installed capacity: 45 kW

Water source: Tsatsadu Waterfall

Key actors: Ministry of Energy, Bui Power Authority, UNIDO, IN-SHP, UNDP, the technical implementation committee

Construction cost: USD 400,000

Support schemes: Additional funding from UNDP, technical support from UNIDO and IN-SHP.

Ownership: Bui Power Authority (appointed by the Ministry of Energy)

Status of the SHP project: commissioned by the Government of Ghana on 21 November 2020

Benefits

Economic:

- Income generation for the community and local entrepreneurship development.

Environmental:

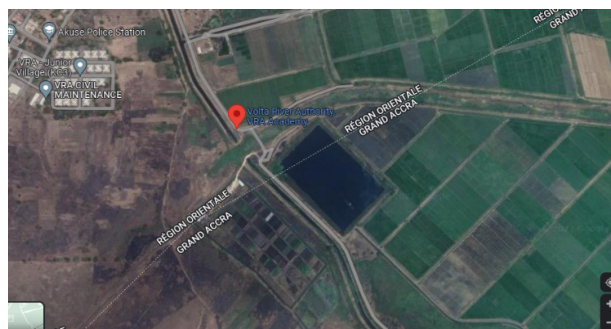
- Conservation of local river and forest ecosystems;
- Reduction of CO₂ emissions.

Social:

- Youth empowerment and capacity building;
- Learning and research opportunities for students and young engineers
- Better working and living conditions for local communities

Potential: Similar hydropower plants can be constructed on other waterfalls.

Figure 1. Approximate Geographic Location



Source: Google Maps

1. INTRODUCTION

Access to sustainable energy is of great importance in Ghana. Small hydropower (SHP) plants can contribute to the country's energy mix and provide a source of reliable power supply for local communities. If carefully planned, SHP plants can also protect the river and forest ecosystems. Furthermore, SHP plants can boost economic development and become a centre of touristic attraction and capacity building for young engineers. The example of the Tsatsadu plant, described in this case study, is a good demonstration of such important benefits for the communities and the environment.

In 2005, aiming to realize the potential of SHP in the country, the Ministry of Energy signed a Memorandum of Understanding with the United Nations Industrial Development Organization and the International Network on Small Hydro Power (IN-SHP) to undertake studies on the potential of SHP development in the country and provide technical consulting.

The Bui Power Authority (BPA) was appointed to develop the first SHP project in the country on behalf of the Government and review all project documentation, including site assessment surveys, detailed topographical surveys and engineering drawings for the project.

Figure 2. First small hydropower plant in Ghana



Based on the analysis, the experts selected the Tsatsadu Waterfall site, located at Alavanyo Abehenease in the Hohoe District of the Volta Region, as a location for a pilot project (Figure 2).

Young engineers of the BPA, who were earlier trained during the development of the 400 MW Bui hydropower plant, were empowered to further develop their skills and knowledge and undertake the entire Tsatsadu plant construction works. Capacity building and local youth skill development became an important element of this hydropower project in Ghana.

The 45 kW Tsatsadu plant was commissioned in 2020. According to the BPA, the cost of the SHP project was USD 400,000.¹ The biggest part of the funds came from the BPA, with a contribution of USD 80,000 offered by the United Nations Development Programme (UNDP), which received funding from the Government of Denmark.

At the ceremony of inauguration of the country's first SHP plant, President Nana Addo Dankwa Akufo-Addo said: *"This important project is going to assist the people of Volta Region and Ghana as a whole, and we will get the best out of it because it is wholly owned by us, the Ghanaian people. The design and engineering and its construction is all Ghanaian owned. It's been done 100 per cent by the engineers and the workers of the Bui Power Authority. For us also to get the full benefit, there is going to be a research site for those who are going to be operating it to get the necessary knowledge."*

Based on the successful finalization of this pilot project, the authorities of Ghana started looking for other waterfalls in the region that may be viable for the construction of hydropower plants. The Government expressed its commitment to build more SHP plants across the country, to increase power supply from the national grid, according to the Ghana News Agency (Hydro Review, 2019).²

Table 2. Project Stakeholders

- The Ministry of Energy — commissioned the project;
- UNIDO and IN-SHP — provided technical support and conducted studies on SHP potential;
- BPA — coordinated the project management on behalf of the Government.

Technical committee to implement the project:

- The Renewable and Alternate Energy Directorate of the Ministry of Energy;
- The Energy Commission of Ghana;
- The UNDP, Renewable Energy Technology Transfer Project Implementation Unit;
- The Electricity Company of Ghana.

Other stakeholders:

- The Alavanyo Traditional Council;
- Foyer de Charité;
- The Alavanyo Abehenease Community

Donors:

- BPA;
- UNDP (funding from the Government of Denmark);
- UNIDO (in kind, technical support).

2. TECHNICAL CHARACTERISTICS

Table 3. Key Technical Characteristics of the Tsatsadu SHP Plant

Item	Value
Turbine output	Upgraded to 45 kW
Total output	45 kW
Site condition and parameters of the plants	Run-of-river plant (no dam) ³ Landscape is intact ⁴
Type of generator	Asynchronous generator

The plant uses a run-of-river scheme, which does not require the formation of a reservoir. It consists of a concrete diversion weir, an intake structure, diversion channel, a forebay, steel penstock, a powerhouse and a transmission line to feed the electricity generated into the distribution grid. The weir diverts part of the river flow through an intake channel into the diversion channel. The diverted water goes through a penstock (30 centimetres in diameter) to the base of the hill where the powerhouse, which houses the turbines and the generator, is located. The water drives the turbines and flows out through the tailrace channel and into the downstream of the waterfall.

Following the initial studies, UNIDO donated a 30 kW generator and a Turgo Turbine with associated electromechanical equipment to the project. Then the project, which was designed as a 30 kW stand-alone system was upgraded to a 45 kW grid-connection system (with the possibility of upgrading the capacity of the turbine up to 60 kW). A new 45 kW capacity Asynchronous generator and a new load controller were procured to replace the existing 30 kW generator and load controller.⁵

The BPA estimates that the plant can generate power for seven months a year and the other five months are needed for the maintenance work.

3. BENEFITS

The Tsatsadu SHP plant delivers energy to rural areas and helps create local employment, alleviate poverty and generate income. In particular, the following benefits can be highlighted:

Economic benefits

The stable access to electricity through the SHP plant provides opportunities for better working conditions and de-

velopment of local industries and entrepreneurship. For example, the plant became a touristic attraction, generating additional income for the Hohoe Municipality and its inhabitants.

Environmental benefits

The plant was built in such a way that there is no impoundment or reservoir formation, minimizing its environmental impact. On the contrary, the SHP plant helps to protect the local ecosystem. In the absence of alternative energy sources, the local communities were relying on the wood, cutting trees around. Generation of renewable electricity by the SHP plant helps protect the local forest and reduce emissions. Furthermore, a reforestation programme implemented at the project site seeks to restore the vegetation in order to protect the river's shoreline against siltation, sedimentation, erosion, nitrogen and phosphate loading. As a result, the planted trees and the forest conservation contribute to climate change adaptation and climate resilience.

Social benefits

The SHP plant, which is the first of its kind in Ghana, is a point of interest for academia and tourists. It can be used, among other things, as a practical tutorial plant for engineering students and young energy experts across the country and the West-African region.

The plant supports the improvement of living conditions and creates employment opportunities for the local population (such as employees operating the plant, security personnel and plant maintenance staff).

4. BUSINESS FIGURES

Table 4. Business Figures of the Tsatsadu SHP Plant

Total investment	USD 400,000
Break-even	10–15 years ³

5. LESSONS LEARNED AND CONCLUSIONS

A few lessons can be highlighted:

- SHP plants can use different water sources available in rural communities.** For example, they can be successfully constructed next to the waterfalls, as presented in this case study.
- The engagement and commitment of the Government plays an important role in developing and upscaling alternative energy,** such as SHP (as part of a strategy to diversify the country's energy sources). The Government authorities can, for example, help undertake initial studies, conduct pilot projects, develop mechanisms for financing SHP plants and promote successful practices on the municipal, regional, national and international levels.
- SHP plants can be constructed and operated by the local**

experts, including young engineers. This case study from Ghana illustrates that SHP can provide a great opportunity for upgrade of skills, local employment and entrepreneurship development. And for the sustainable operation and maintenance of a plant, the involvement of local experts is very important.

- SHP plants are not only a source of energy, but can also be a touristic attraction and a centre of local capacity building.** The aforementioned example in Ghana demonstrates such an indirect but still very significant benefit from developing a power plant in rural areas.
- Areas where SHP plants are built can be used for reforestation programmes,** which contribute to climate change mitigation. In Ghana's rural areas, which heavily rely on wood as a source of energy, such programmes would be of great significance.
- A thorough feasibility study is an important element of developing a successful project.** As in the example in Ghana, the study helped to select the right characteristics of a plant and analyze the potential for upgrading its capacity later.

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1.3. Private-public partnership model for developing SHP in a remote mountainous community of Japan

CATEGORY:

SHP FOR SOCIAL AND COMMUNITY DEVELOPMENT

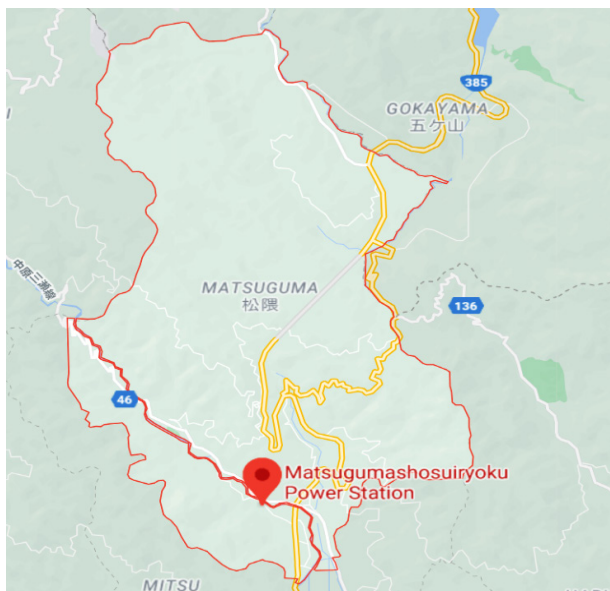
COUNTRY:

JAPAN

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Figure 1. Location of the Matsuguma SHP plant



Source: Google Maps

Table 1. Project Overview

SHP plant name: Matsugumashosuiryoku / Matsuguma SHP

Location: Matsuguma Village, Yoshinogari Town, Saga Prefecture, Japan

Installed capacity: 30 kW

Water source: Pre-existing irrigation channel for agricultural use

Developers: A public-private partnership. Key actors: Saga prefectural government and the community company, Matsuguma Community Development Co., Ltd.

Construction cost: USD 600,000 (in the form of loan, taken by the community for 20 years).

Support schemes/incentives: A cheap financial loan and high FIT prices.

Ownership: 100% by the local community.

Status of the SHP project: The construction was completed in 2020.

Benefits

Economic:

- Economic independence of the community: electricity generation for local needs and for sale.

Environmental:

- Renewable energy generation
- Reduction of 18 tons of CO₂ per year (estimation)
- Maintenance of the irrigation channel and regeneration of the land and mountain landscape

Social:

- Training and employment of local inhabitants linked to maintenance of the SHP plant for a minimum of 20 years
- Community empowerment: a joint project that unites all households of the village

Potential: This model can be further adopted in Japan and abroad in mountainous areas with available irrigation channels.

1. INTRODUCTION

The Matsuguma community is located in the northern part of Saga Prefecture. Its total area is approximately 2.7 km². In 2015, the community comprised 43 households (136 people). Almost all of them were small-scale family farmers.

In the past, the community had a 36 kW SHP plant, which was in operation from 1945 to 1967. But the plant stopped functioning due to the lack of appropriate management and maintenance.

Over the years, the community faced the growing pressure of an ageing population, emigration due to the lack of economic opportunities for the younger generation and degradation of farmlands, roads, irrigation systems and waterways. The remaining households were seeking a way to revive the life in the village and socioeconomic activities in the area and increase social welfare and sustainability.

“Matsuguma village is suffering from damage due to declining birthrate and an ageing population. Everyone in the village was worried about how to develop the community for the future, how to regenerate the agricultural fields and mountains and how to connect the community to the next generation. We will emulate our predecessors and think about what we should protect and pass on to the next generation”, said Mr Masahiro Tara, the ex-mayor of this community and the chief of Matsuguma SHP.

A good opportunity appeared in 2016, when the government of the Saga Prefecture identified the Matsuguma village and its pre-existing irrigation channel used for agricultural purposes and characterized by a rich water flow throughout the year as an appropriate location for constructing a new 30 kW SHP plant that could supply stable power to the Kyushu Electric Power grid. The local government approached the community to discuss the benefits of the project. The local community agreed to collaborate with the government and for the SHP plant to be installed “by the local community and for the local community”. This project became the first case of the public-private partnership model implementation for the construction of an SHP plant in the Saga Prefecture with the aim of community development. *“The mountainous areas with a high ageing rate should survive without relying on subsidies. As residents, we are responsible for the future of the prefecture. Our actions and ideas should lead towards sustainability of the community”* – said Governor of Saga Prefecture Mr. Yoshinori Yamaguchi.

Table 2. Project Stakeholders

1. Concept design of compact hydropower: Nakayama Iron Works Co. Ltd (Japan) and Seiko Service and Engineering Co. Ltd (Japan)
2. Civil Engineering: Masakoumuten Co. Ltd (Japan)
3. Management and consulting: River Village Co. Ltd (Japan)
4. Owner: Matsuguma community development Co. Ltd.
5. Saga Prefecture government: initial study of the project’s viability / feasibility study.

A feasibility study showed that the plant would supply enough electricity to meet the community’s needs as well as for sale, thus, generating revenues that could make the community economically independent.

In November 2020, the community of the Matsuguma Village, in Yoshinogari Town, successfully finalized the construction and inaugurated the local SHP plant.

2. TECHNICAL CHARACTERISTICS OF THE PLANT

Table 3. Key Technical Characteristics of the Matsuguma SHP

Item	Value
Turbine	Cross-flow
Total output	30 kW
Electricity generation per year	212 MWh (est.)
Site condition and parameters of the plants	Source of water – Ichinose izeki sabo dam
	Effective head – 20.4 m
	Design discharge – 0.22 m ³ /s
Turbine	Cross-flow T14 (D225, B270) from Asosiasi Hidro Bandung (Indonesia)
	Efficiency of the turbine – 76%
Type of generator	IPM generator from Yasukawa Electronics (Fukuoka, Japan)
	Generator spec – 850 rpm, 45 kW
	Generator/GD/DC efficiency = ~95/95/95%

Figure 2. 10f container-based powerhouse of the Matsuguma SHP plant



The Matsuguma SHP plant represents a compact system that uses water from a pre-existing irrigation channel. The key benefit of such a system is that it is easy to install, monitor and manage, as outlined below.

2.1 Compact SHP system

The 30 kW Matsuguma SHP uses an old (second-hand) 10f shipping container as a powerhouse (Figure 2), with all mechanical, electrical and control equipment pre-installed in a factory. Such a compact system significantly reduced the costs and the length of time needed for project implementation. It took only a few hours to install the container powerhouse at the site. Moreover, such a powerhouse could be moved out to another location, when needed.

The container has an extended pipe of approximately 30 cm in length that is exposed outside the container and was connected with the penstock pipe during the installation.

2.2 Intake and forebay tank

This SHP plant utilizes the existing agricultural aqueduct. It draws water from the Ichinose dam on the Tade River that flows through Yoshinogari Town. A head tank was constructed in the middle of the waterway. A 400 mm pipe under the road guides the water to the powerhouse. The management of the water intake from the Ichinose dam, which had been a problem for the village for many years, has been improved with the new water intake facilities.

The water from the pre-existing irrigation channel was diverted by making a small weir and a desilting tank as an intake for the SHP plant. The diverted water passes over a meshing screen and the garbage gets strained and flown out. The usable water for the SHP plant falls to pass through the screen and goes to the forebay tank (Figure 3).

Figure 3. Forebay tank and desilting tank



Figure 4. Newly made intake at Tade River



Figure 5. Newly made forebay tank on the existing water channel



2.3. Remote control and IoT functions

The Matsuguma SHP plant is equipped with an intelligent Internet of things (IoT) and control system. The many sensors log different data such as net head, output, total generation, bearings temperature, guide vane control, etc. The monitoring of the powerhouse is fully automatic. The guide vane of the turbine opens and closes automatically in case of an increase or decrease in the water level. The plant can be monitored and controlled remotely from anywhere in the world. In case of emergency (failure of the grid), the plant shuts down within 20 seconds and can re-start automatically once the grid is available.

3. BENEFITS

The SHP plant is a significant community project that provides many relevant socio-economic benefits. In terms of specific United Nations Sustainable Development Goals (SDG), the Matsuguma SHP supports the targets of SDGs 7, 8 and 13.

Economic benefits

The project has a substantial economic interest. It enables the community to generate the electricity for its own needs and become financially independent by selling excess electricity with high FIT prices. This business supports community development and brings financial security to households.

Social benefits

This SHP project has empowered the community by boosting a local business and setting clear community goals.

The local community company, created by the local households, gained valuable technical expertise during the construction of the SHP plant. Now the community company is the owner of the plant, fully responsible for the facilities. The project created local employment linked to the maintenance and management of the SHP plant for a minimum of 20 years.

The profit generated from selling the electricity has been used by the stakeholders to maintain the village, its roads, water systems as well as other facilities and to protect the local infrastructure from degradation. The additional income has increased the welfare and quality of life in the community.

The older generation believes that this SHP plant is a tribute to the previous generations and a valuable asset for the younger generations that will help the village to survive in the future.

Figure 6. Community members at the inauguration ceremony of the Matsuguma SHP plant



At the opening ceremony on 22 November 2020 (Figure 6), Masahiro Tara, President of Matsuguma Community Development Co., Ltd., said, “We kept the teachings of our predecessors and the residents came together to accomplish this business. We want to create a community where people can continue to live with a smile and a rich heart.”

Mr. Yoshinori Yamaguchi, Governor of Saga Prefecture (Figure 7), shared his big hope: “The direction of valuing the energy derived from nature is wonderful and I hope it will spread to various places as a model.”

Environmental benefits

The Matsuguma SHP initiative contributes to the Government’s efforts to promote renewable energy generation by converting unused available water into a useful product without consuming or affecting it.

In terms of reducing CO₂ emissions, based on the estimation that each kWh of electricity generated from a renewable energy source is equivalent of 0.555 kg CO₂, the 212 MWh of electricity generated annually by the Matsuguma SHP plant will result in an estimated reduction of 118 tons of CO₂ per year.

The income generated by the community will also help maintain the farmlands from degradation.

Figure 7. The Governor of Saga Prefecture at the powerhouse and intake



4. BUSINESS FIGURES

4.1 Key calculations

The plant construction cost approximately JPY 60 million (USD 600,000). Local farmers would not be able to mobilize and invest such a considerable amount of money without certain guarantees and favourable conditions. A critical incentive for planning and realizing this project was offered by the feed-in tariff, a governmental policy that supports the development of renewable energy sources by providing a

guaranteed, above-market price for producers. The official price offered by the Government of Japan for electricity generated from the Matsuguma SHP was 34 JPY/kWh (0.34 USD/kWh; under 200 kW). The community estimated that the SHP plant would generate approximately 212 MWh of electricity per year, implying an income of approximately JPY 7 million (USD 70,000) per year.

If the conditions stay the same, a break-even on the project investment will be achieved in nine years. It is expected that profit earning will be possible over the 20-year lifespan of this SHP project.

Table 4. Key Business Figures of the Matsuguma SHP

Total investment	Appr. JPY 60 million (USD 600,000)
FIT	34 JPY/kWh (0.34 USD/kWh)
Estimated generation of electricity per year	212 MWh
Expected income per year	Appr. JPY 7 million (USD 70,000)
Break-even	9 years
Lifespan	20 years

4.2 Community business

The Saga Prefecture government conducted and financed the initial study.

To realize the project, the local community established a company, Matsuguma Community Development Co., Ltd., with all the households as its shareholders. Positions and responsibilities were distributed among the community members. To start this small business, each household member contributed JPY 5,000 (appr. USD 50). In total, the company collected JPY 20,000 (USD 2,000).

Matsuguma Community Development Co., Ltd took a loan from a prefecture financial corporation at the interest rate of 1 per cent for 20 years to pay the total construction costs. The community did not receive any subsidies or financial support from other institutions.

The company, run by the local community, is the owner of the SHP plant: the community members participated in the installation of the plant, and now they are fully responsible for managing and maintaining it.

As per estimation, the plant will allow generating approximately USD 70,000 of income annually by selling electricity to the national electrical company. The community company plans to pay USD 50,000 to the financial corporation as loan repayment and use the remaining USD 20,000 to maintain the SHP plant and develop local facilities, such as roads, irrigations, waterways, etc.

5. LESSONS LEARNED AND CONCLUSIONS

For the prosperity and sustainability of rural communities, it is very important to ensure their self-sufficiency, supporting local people to work together, develop their skills and motivations, uniting them by clear goals and letting them efficiently use available resources.

Some lessons could be highlighted:

- 1. In different countries, there are many fresh water streams flowing from the mountains. These streams have an abundance of water which can be used to develop SHP locally.** For example, in Japan these streams were used in the past for the irrigation of rice and tea fields. These streams have an abundance of water which can be used to develop SHP locally. This is an effective way to develop and support local communities. This business model applied for the Matsuguma plant development has shown its viability and can be used in other mountain communities of the country.
- 2. Such SHP projects represent a win-win situation for the local communities as well as for the Government.** For example, in this particular case study, SHP helped the local community to stop migration, to become economically independent, at the same time contributing to the governmental goals to reduce the carbon footprint and achieve SDG.
- 3. It is important to develop such projects that create value for local communities, involving them in the decision-making process and making them key stakeholders.** When the local communities are integrated in the business model, they have a greater motivation to maintain and manage the plant well, since the plant becomes the “motor” of their welfare, sustainability and security for the future. For example, in this Japanese case, the slogan “By the community, from the community and for the community” is a good demonstration of how local people see the mission of the project.
- 4. The transparency and justice are important elements of a business model.** In the case of the Matsuguma community all of the households have become equal stakeholders of the created community company, with equal rights and responsibilities.
- 5. The success of such projects very much depends on the local policies, incentives and the governmental support.** In the case of the Matsuguma project, a reasonable break-even (in 9 years) could be achieved only thanks to the high FIT proposed by the Government and to the low interest rate provided by the local financial institution. The initial study was also supported and financed by the prefecture government, which made the project planning easier.
- 6. A compact SHP system, which can be easily installed, maintained and controlled, can make the whole project more efficient and secure.** The Matsuguma case shows that smart solutions can be found to reduce the costs of installation and operation.

1.4. Local invention for electrification of Murang'a county: an innovative off-grid small hydropower plant

CATEGORY:

SHP FOR SOCIAL AND COMMUNITY DEVELOPMENT

COUNTRY:

KENYA

Authors:

Sarah Acholla Kwach, Kenya Industrial Research and Development Institute (KIRDI), Alice Mumbi, Hydrobox Kenya Limited

Figure 1. Location of the Magiro small hydropower plants



Source: Google Maps

Table 1. Project Overview

SHP plant name: Magiro Power – Gitugu Power Plant, Kahinduini Power Plant and Kiawambogo Power plant

Location: Njumbi, Murang'a County

Installed capacity: 100 kW (Kahinduini – 60 KW, Kiawambogo – 22kW, Gitugu – 18 KW) but currently being upgraded to 533 kW

Water source: Waterfall of the Gondo River

Developed by: John Magiro, local entrepreneur

Ownership: 50 per cent Magiro Hydro Electricity Limited and 50 per cent Hydrobox Kenya Ltd.

Status of SHP projects: 3 SHP plants are operational

Benefits

Economic:

- Empowerment of local entrepreneurship
- Better economic sustainability of the county
- Reliable energy access at affordable prices

Environmental:

- Renewable energy generation that does not harm the environment

Social:

- Improved healthcare and education
- Improved living conditions of households
- More social and business services
- Possibility for women to start local microbusinesses
- More security on the streets

Support schemes: Grants from NETFUND, King Baudoin Foundation, Flemish government and others

Potential: Hydropower plants have a huge potential in rural African regions with waterfall sources

1. INTRODUCTION

Access to electricity in Kenya was reported at 71.44 per cent in 2020, according to the World Bank collection of development indicators, compiled from officially recognized sources (Trading Economics).¹ In Murang'a County, in central Kenya, most people still live without electricity. Most of these communities cannot be reached by the national grid due to long distances and the lack of proper infrastructure. (In cases when the grid could be reached, the connection costs are often too high).

Young entrepreneur John Magiro, wanted to solve the energy problem in his community. After completing secondary school, he experimented with simple tools such as a

bicycle dynamo to generate power from the Gondo River. Motivated by his first achievements, he used a waterfall to build a mini-hydropower plant. His first Gitugu hydropower plant could generate approximately 7.5 kW and was able to connect up to 75 houses through an 8-kilometre mini-grid. Even though the 18-year-old entrepreneur never attended any engineering classes, he turned to be the most important engineer in his community. In 2016, John Magiro became the winner of the Green Innovations Award of the National Environment Trust Fund of Kenya (NETFUND). This motivated him to set up his company Magiro Hydro Electricity Limited (MHEL) with a mission to light up Murang'a County, providing affordable, reliable and sustainable energy to the community by using off-grid hydropower.

Figure 2 (a) and 2 (b). Inventor and company founder, John Magiro



A year after his technological invention, the National Environmental Trust Fund approached him and trained him in hydropower generation. In 2018, John met with Belgian entrepreneur Thomas Polemans and together they established a company called Hydrobox Kenya Limited. This cooperation helped John Magiro upgrade his technology and develop a commercially viable business – Magiro Power. Currently, Magiro Power is a 50 per cent subsidiary of Hydrobox Kenya Ltd.

The team of Magiro Power operates three power plants that provide backup to one another (Gitugu, Kahinduini and Kiawambogo SHP plants). The plants are located on the Gon-

do River, which marks the border between Mathioya and Kangema Subcounties in Murang'a County. The distribution grid provides electricity to the communities of the Gikoe, Gitugu, Ireke, Mihuti, Kenya Njeru, Kirimahiga, Kahiga, Nyakanga, Keru, Githiru and Mukuini regions.

Entrepreneurial activity of John Magiro changed the lives of more than 3,000 people. Children can now study with proper light, farmers can use electric equipment and there are now domestic tools that make households work easier, safer and faster. The electrification has boosted the local entrepreneurship and commerce services. Life quality has been considerably improved.

Today Magiro Power trains and employs over 20 people, supporting local youth and women. Together with NETFUND it implements a project to promote women's and youth entrepreneurship through the productive use of electricity, business coaching and access to finance. In addition, it runs pilot projects with a cooling container, electric motor bikes and leasing of agricultural equipment with the purpose of increasing the productive use of electricity. These extra services are meant to transform communities from fossil fuel reliance to green energy, while increasing their productivity and income.

Between 2018 and 2019, Magiro Power acquired two other nearby off-grid rural electrification hydropower plants, Kiawambogo and Kahinduini.

The innovative off-grid SHP helps address, among other, challenges of energy security, unemployment, adverse climate change impacts and contribute to the achievement of sustainable development in the region.

John Magiro wants to distribute power to the whole of Murang'a County and connect more Kenyans to electricity. He believes that electricity would help people realize their dreams: *"I urge those who may not be excelling in education not to lose hope or be intimidated by the peers or the society, they can still pursue their dreams alternatively."*

Table 2. Project Stakeholders

John Magiro – inventor, founder and managing director of Magiro Hydro Electricity Limited

Hydrobox today owns 50 per cent of the MHEL company, developer of medium > 500 kW & on-grid hydropower plants

Kenya's National Environment Trust Fund (NETFUND) provides training and technical assistance to MHEL

2. TECHNICAL CHARACTERISTICS

Table 3. Key technical characteristics of the SHP plant

Item	Value
Turbine output	Gitugu – 18 kW (undergoing upgrade to 533kW) Kahinduini – 60 kW Kiawambogo – 22 kW
Site condition and parameters of the plants	Source of water: Waterfall, Gondo River Effective head in meters: Gitugu – approx. 30 m Kahinduini – approx. 19 m Kiawambogo – approx. 20 m Design discharge – 2.0 m ³ /s
Turbine	Cross-flow Efficiency of the turbine – 70%
Type of generator	Newage Stamford Alternators WEG W22 motor Generator spec – 1,500 rpm, 330 kVA & 300 kVA, 22 kW synchronous motor

The first hydropower plant was created through the experiments of John Magiro and upgraded over time. The plant uses a waterfall in the Gondo River and was composed of locally available standard engines and recycled bicycle parts.

Drawing inspiration from analyzing how the bicycle dynamo can generate electricity, John Magiro created a prototype using scrap materials; namely a bicycle rim as a pulley, a wooden turbine and a shaft, connected to a bicycle dynamo. Then he installed a pump as a turbine setup with an alternator of 3 kW. Later, the site acquired a cross-flow turbine with a 30 kW alternator. Nowadays, the company is in the process of upgrading the capacity of the plants to reach a total of 533 kW from two 250 kW turbines.

Thanks to the financial and technological assistance of Hydrobox, the Kahinduini power plant scaled up its installed capacity from 16 kW to 60 kW. Equipped with smart sensors and Internet of Things, the Hydrobox technology allows remote monitoring and control, as well as predictive operation and maintenance.

Currently Magiro Power has three power plants that are backups to one another. Significant efforts have been made to upgrade the network. This guarantees minimal downtime and, as a result, little or no blackouts.

3. BENEFITS

Magiro Power runs its business with the aim of bringing value to the community: *“Our community is the reason why we do what we do. We have seen the transformational effect that our electricity has had on our communities and it is the reason why we wake up with a smile every morning”.*

The community has benefited in many ways from the local hydropower production.

Economic benefits

Rural families typically spend a lot on kerosene to light up their homes and businesses, which is expensive and poses risks to health. Magiro Power’s fixed rate model allows for cleaner and cheaper lighting solutions.

The community can now access electricity at lower rates in comparison to those offered by Kenya Power, a national utility. (Inexpensive electricity is a result of using Hydrobox technology and containerized power plants.)

Magiro Power allows businesses to extend business hours because it produces electricity 24/7 with a 90 per cent up-time.

Electricity enables small and micro-enterprises to use electric equipment and tools, resulting in significant productivity and turnover improvements, which boosts entrepreneurship.

Environmental benefits

Using the run-of-river technology, the energy can be created without disrupting the environment.

This renewable energy source helps to reduce the CO₂ emissions from the alternative use of kerosene and charcoal.

Social benefits

Magiro Power supplies an affordable off-grid access to electricity to over 500 households. Besides domestic users, the company supplies energy to businesses, schools and hospitals. This improves the delivery of social and business services from a wide range of village-level infrastructure components, including schools, clinics, farms, markets, street lighting and water distribution. For example, the clinics can now receive patients in the evenings and nights. Small-scale farms can store milk in cooling installations to sell to consumers outside their local community.

One inhabitant of Kiahiti village, Muriu, said in the interview to People Daily on 29 November 2016:

“I am happy because I now have a continuous supply of power at a minimal cost and I do not suffer from power outages”.

The households benefit from improved quality of life. They have healthier and safer alternatives to kerosene lamps for lighting and charcoal for cooking. Supported by the appli-

ance leasing credit scheme, inhabitants can use washing machines, irons, refrigerators and other domestic equipment that relieve the pressure of daily household activities, which tend to fall disproportionately to women.

Studying conditions have improved: people have access to the internet, can study with light and hone their skills using computers, can watch TV, etc.

Light also brings security. In some villages, for example in Gikoe, there was a security problem due to lack of streetlights. Through its corporate social responsibility programme, Magiro Power addressed this issue by installing street lighting on the main routes and roads.

Magiro Power believes that access to affordable and reliable electricity can considerably improve the economic opportunities for women and youth. Therefore, the company has set up a business incubation programme together with its partners NETFUND and King Baudouin Foundation. The programme encourages women and young people to start their businesses by removing existing barriers, such as expensive and inaccessible electricity, and helping them via appliance leasing to grow their businesses (Figure 3).

Figure 3. Magiro Power empowers women



“We believe that economic development and women empowerment in Murang’a can be significantly boosted by creating an enabling environment for women to benefit from the potential of electricity to increase their quality of life and income,” – says the company (Magiro Power website).²

The support is multifold and includes, for example:

- Access to electricity by Magiro Power for an affordable amount per month and credit on connection cost;
- Business coaching provided by NETFUND including business plan development, access to technical and business expertise;
- Access to finance by linkage to several funds and award programmes;
- Appliance leasing.

In addition, Magiro Power provides employment opportunities to women and young people. Over 20 local people work for the company (Figure 4 (a) and 4 (b)). Women play an important role in the development and operation of the company: several managerial positions are occupied by female specialists, for example, Operations Managers and Financial and Administration Officer.

Figure 4 (a) and 4 (b). Employees of Magiro Power



4. LESSONS LEARNED AND CONCLUSIONS

- 1. Collaboration and strategic partnerships are fundamental for developing a competitive and viable business.** Joining hands with Hydrobox Kenya Limited in 2018, Magiro Power managed to fine-tune its technology and as a result to scale up its proposition of affordable electricity to households and businesses in rural areas across the county.
- 2. It is essential to be cost-efficient in energy production in order to offer affordable prices to rural communities.** Magiro Power manages to deliver + electricity to an expanded network of users by using Hydrobox technology (containerized power plants).
- 3. The potential for scaling up rural electrification projects in the country is high.** Such technology, as used by Magiro Power, can be adopted in other areas: it only needs a river nearby. The Magiro Power technology has already been successfully applied in two other off-grid projects.
- 4. Using off-grid systems can be a cost-effective option for**

rapid rural electrification. SHP plants could be a good solution: they can be developed from local materials, they are cheaper and more environmentally friendly compared to big hydropower plants.

5. **It is important to encourage local innovation and entrepreneurship.** Often hydropower projects are run by either the Government or foreign engineers who install sophisticated, imported systems that exceed the technical and financial capacity of local communities, rendering the system unsustainable. Magiro Power demonstrates a good example of an alternative solution: local invention and efficient partnership made the local SHP installation a successful project: “Power for Murang’a made in Murang’a”. Supporting local entrepreneurs helps the Murang’a region, and the country at large, explore further opportunities for economic development and poverty reduction.
6. **Digitalization can help small and medium enterprises to be more sustainable.** For example, Magiro Power benefits from using smart metering and Internet of Things: these make the operation of plants more efficient and, as a result, profitable.
7. **Growth of renewable energy technologies paves the way to a more sustainable future.** Electricity consumption is growing in Kenya. The wider replication of innovative renewable energy technologies, including off-grid SHP plants, can help the Government to more easily address the growing demand for electricity and contribute to the achievement of sustainable development goals.
8. **Creation of favourable business conditions empower women and youth to become entrepreneurs.** These conditions, as in the example of Magiro Power, can include: provision of inexpensive electricity and appliance leasing, as well as access to finance and capacity building programmes.

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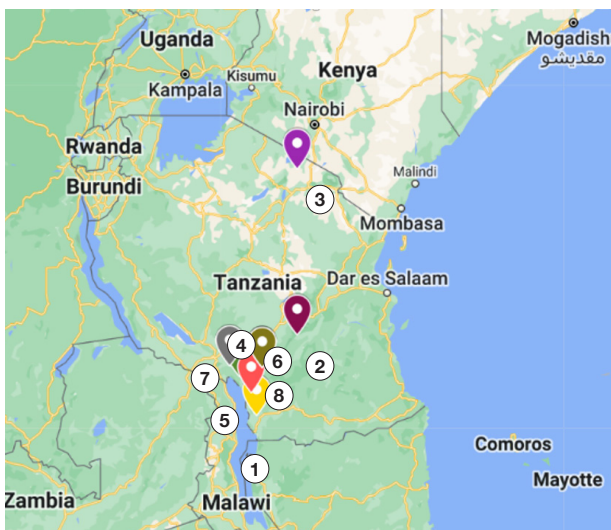
1.5. Electrification of rural areas in Tanzania

CATEGORY:
 SHP FOR SOCIAL AND COMMUNITY DEVELOPMENT

COUNTRY:
 Tanzania

Author:
 Jossy Thomas, Industrial Development Officer, Division of Decarbonization and Sustainable Energy, UNIDO

Figure 1: Approximate Locations of Eight Mini-Hydropower Projects in Tanzania



Source: Google Maps⁴

Table 1. Project Overview

SHP plant name and Location:

1. **Andoya Mini-Hydropower** (Mtandasi River)
 Mbangamao village, Mbinga District, Ruvuma Region
2. **Mbingu Mini-Hydropower** (Mfumbi River)
 Mbingu Village, Ifakara, Morogoro Region
3. **Usa River Mini-Hydropower** (Usa River)
 Usa River, Meru district, Arusha Region
4. **Ludilu Micro-Hydropower** (Salala Stream)
 Ludilu Village, Makete District, Njombe Region
5. **Madope Mini-Hydropower** (Madope River)
 Ludewa District, Njombe Region
6. **Lupali Mini-Hydropower** (Lupali River)
 Njombe District, Njombe Region
7. **Ijangala/Tandala Mini-Hydropower** (Ijangala River)
 Makete District, Njombe Region
8. **Mpando Mini-Hydropower** (Mpando Stream)
 Njombe District, Njombe Region

Installed capacity: 4,881 kW (cumulative)

Key actors: Government of Tanzania, UNIDO and GEF

GEF grant: USD 3,350,000

Ownership: private investors, charity, NGOs, community co-operatives

Status of the SHP projects: finalized in 2018

Benefits

Economic benefits:

- Selling energy to local communities and neighbourhoods

Environmental benefits:

- Reduction of approximately 335,658 tCO2e directly

Social benefits:

- New jobs created, capacity building, knowledge dissemination, electricity access in rural areas, better living and studying conditions

Support schemes/incentives: with the financial support of GEF, UNIDO, European Union

1. INTRODUCTION

Tanzania is one of the Least Developed Countries (LDCs) in Sub-Saharan Africa. According to the World Bank's data (2020), only approximately 39.9 per cent of the country's total population of 59.7 million has access to electricity (72.9 per cent of urban and 22.0 per cent of rural population).^{1,2}

To address this gap in electricity access rate between the rural and urban population, an appropriate energy mix is required to ensure a sustainable decentralized energy supply in the country. Among the renewable energy sources, the proven potential for small hydropower (SHP) in Tanzania is approximately 480 MW, and less than 10 per cent of this potential has been tapped so far.³

Realizing the potential and the energy challenge in Tanzania, the Global Environment Facility (GEF) and the United Nations Industrial Development Organization (UNIDO) undertook a project in 2012 to promote SHP-based grids to augment sustainable rural electrification.

The project strengthened human and institutional capacities at all levels and supplemented the country's effort in improving the rural electricity rate. The project team undertook resource assessments to analyze the SHP potential of Tanzania, conducted feasibility studies for identified demonstration sites, disseminated the scientific, engineering and technical skills and built the infrastructure necessary for the design, development, fabrication, installation and maintenance of the SHP plants in the country.

Key achievements of the project

Establishment of the Technical Centre

The Small Hydropower Technical Centre (SHP TC) (Figure 2) hosted at the College of Engineering and Technology, University of Dar es Salaam (UDSM) was established to provide technical support and consulting, information dissemination, training and capacity building services in the country. Within the project, the SHP TC fabricated five cross-flow turbines locally in Tanzania: two with a capacity of 5 kW, two with a capacity of 25 kW and one with a capacity of 1 kW.

Strengthening national capacities

The project strengthened the country's institutional and individual capacities in the area of the SHP technology (Figure 3). The capacity building activities included study tours to SHP plants and manufacturing facilities, trainings on development and detailed design of SHP plants as well as on fabrication of cross-flow turbines, scholarships, etc.

Figure 2. Promotion of the SHP Centre



Figure 3. A Group Picture of the Technology Transfer Training in Indonesia



Demonstration plants in different parts of the country

Within the project, eight demonstration hydropower sites were developed, with a cumulative installed capacity of 4,881 kW (surpassing the original installed capacity target by 1,681 kW). These hydropower plants provide significant socio-economic advantages for local communities and environmental benefits. For example, the plants are expected to reduce greenhouse gas (GHG) emissions resulting from the use of traditional energy sources in rural Tanzania by over 300,000 tons of CO₂ equivalent per year. These eight demonstration sites are briefly described in Table 2.

Table 2. Overview of Eight Projects

Name	Developed by	Water source	Location	Technical characteristics	Total installed capacity
Andoya Mini-Hydro-power Project	Andoya Hydroelectric Power Company (AHE-PO), a local entrepreneur from Mbinga	Mtandasi River	Mbangamao village, 14 kilometres away from Mbinga Town, which is 1,050 kilometres away from Dar es Salaam	Two units of Francis hydropower turbines, each with 500 kW	Total installed capacity is 1,000 kW
Mbingu Mini-Hydro-power Project	Saint Franciscan Sisters of Charity in the village of Mbingu, Ifakara	Mfumbi River	Mbingu village, 13.5 kilometres away from the Sisters convent and Mbingu village, which is 550 kilometres away from Dar es Salaam City	One unit of Francis hydropower turbine, a generator and a concrete penstock	850 kW
Usa River Mini-Hydro-power Project	Kiliflora limited, the largest flower farm in the country based in the town of Usa River	Usa River	Meru district, 25 kilometres away from Arusha in the northern part of Tanzania, approximately 620 kilometres away from Dar es Salaam city	One unit of Turgo turbine	230 kW
Ludilu Micro-Hydro-power Project	Evangelical Lutheran Church of Tanzania mission, Ludilu Parish in collaboration with the private sector	Salala Stream	Ludilu village. It is located approximately 120 kilometres away from Njombe, which is approximately 700 kilometres away from Dar es Salaam City.	One unit of cross-flow hydropower turbine	68 kW
Madope Mini-Hydro-power Project	Njombe Development Office (NDO), a dedicated entity made up of a collaboration between Njombe Roman Catholic Diocese and ACRA (an Italian non-governmental organization)	Madope River	Lugarawa village, Njombe Region, approximately 100 kilometres away from Njombe Township and approximately 700 kilometres away from Dar es Salaam city	One Pelton hydro-power turbine	1,700 kW
Lupali Mini-Hydro-power Project	Benedictine Sisters of Saint Gertrude Imiliwaha Convent, which is under the Roman Catholic Njombe Diocese	Lupali River	Boimanda village, 50 kilometres away from Njombe Township. Njombe is approximately 700 kilometres away from Dar es Salaam City	One unit of Francis hydropower turbine	353 kW
Ijangala Mini-Hydro-power Project	Tanzania Diaconical Centre, a charity organization in Tandala village	Ijangala River	Tandala village, 12 kilometres south of Tandala village, approximately 90 kilometres away from Njombe	Three units of 120 kW Francis hydro-power turbine	360 kW
Mpando Mini-Hydro-power Project	Community-based cooperative association of farmers	Mpando Stream	Imalinyi, approximately 20 kilometres away from Njombe.	Two units of 160 kW Kaplan hydropower turbine	320 kW

Table 3. Project Stakeholders

Donors

- GEF
- UNIDO
- European Union
- Switzerland

Partners

- Rural Energy Agency
- Andoya Hydro Electric Power Company
- Ministry of Energy and Minerals
- College of Engineering and Technology
- Division of Environment – Vice President's Office
- Tanzania Electricity Supply Company Limited
- International Center on Small Hydro Power (ICSHP)

Project stakeholders

This multi-element project has been possible through the collaboration of various stakeholders, including project developers, the Government of Tanzania and the financiers. Apart from the project developers, other key stakeholders are presented in Table 3.

2. BUSINESS MODEL

The SHP projects have different financing and ownership structures, which are presented in Table 4.

Table 4. Overview of hydropower plants and their financing structures

Project name	Type of managing organization	Project financing					
		Total (million USD)	UNIDO/GEF	REA	Own equity	Bank loan	Other
Andoya Mini-Hydropower Project	Private	4.00	12%	11%	23%	54%	-
Mbingu Mini-Hydropower Project	Charity	5.50	4%	-	1%	-	95%
Usa-river Mini-Hydropower Project	Private	1.80	8%	3%	77%	12%	-
Ludilu Micro-Hydropower Project	Community and private	0.40	61%	26%	-	-	13%
Madope Mini-Hydropower Project	Charity and NGO partnership	9.00	6%	5%	14%	-	74%
Lupali Mini-Hydropower project	Charity	1.85	11%	39%	1%	49%	-
Ijangala/Tandala Mini-Hydropower Project	Charity	1.23	19%	54%	3%	11%	13%
Mpando Mini-Hydropower project	Community cor-porative	1.24	18%	11%	1%	64%	6%

3. BENEFITS

Out of the eight demonstration SHP plants supported under this UNIDO project, four were fully operational in 2018: Andoya, Mbingu, Usa River and Ludilu. The benefits of these four cases were well documented, verified by the evaluation committee and are presented in this case study (the information presented below is as of 2018).

The hydropower plants provided different socio-economic and environmental benefits to the rural communities, such as reliable power supply to local villages, possibility to sell excess power and generate additional revenues, new jobs created, replacement of carbon emitting technologies such as backup diesel generators and reduction of CO₂ emissions and others.

The benefits for individual projects are highlighted below.

Andoya Mini-Hydropower Project

Socio-Economic Benefits

The power generated is supplied to three villages: Kilimani, Mbangamao and Lifakara with approximately 200 households. The excess power goes into the Tanzania Electricity Supply Company isolated mini-grid at Mbinga, which was previously powered by diesel generator sets. The project created permanent employment for 20 people and temporary employment for approximately 60 others, including semi-skilled and unskilled workers around the project area.

Environmental Benefits

The project replaced diesel generators used to supply the Mbinga area through the isolated mini-grid. The project resulted in the prevention of direct GHG emissions amounting to approximately 6,300 tons of CO₂ equivalent per year.

Mbingu Mini-Hydropower Project

Socio-Economic Benefits

The electricity generated is supplied to a sisters' convent, which provides various social and economic services including health facilities, schools and milling activities. The hydropower plant is providing power 24 hours a day to several institutions within the Saint Franciscan Sister of Charity including Saint Franciscan Sister of Charity Mbingu convent (accommodates 200 sisters), Saint Judas Thaddeus Health Centre (operating room, ultrasound, pathology clinic), an orphanage (54 children), a secondary school for girls (260 girls), a kindergarten school, workers' houses, a spiritual centre and workshops (candle making and carpentry). In total, this plant supplies energy to an estimated 1,000 people—600 women and 400 men.

Environmental Benefits

The project provides clean energy for socio-economic activities in the sisters' convent as well as productive activities in Mbingu. The project resulted in the prevention of direct GHG emissions by 2,680 tons of CO₂ equivalent per annum.

Usa River Mini-Hydropower Project

Socio-Economic Benefits

The power generated meets the energy demand of the flower farm facilities at Usa River. The project intends to supply the excess power to neighbouring communities. The weir also serves as a bridge connecting two different communities. Kiliflora farm employs more than 1,300 people in various activities. The project facilitated a good working environment for the workers and resulted in savings that are partly directed to supporting community development projects in the area. Thanks to the project, seven enterprises have been created employing 157 people—145 men and

12 women. As part of its civic responsibilities, Kiliflora farm organized training for nine enterprises on different vocational activities.

Environmental Benefits

The flower farm was using standby generators due to the erratic situation of the grid power supply. The hydropower plant changed the situation. Before the installation of the hydropower plant, the farm used approximately 20,000 litres of diesel fuel every month. Currently, almost 100 per cent of their power needs are provided by the hydropower plant. This helps the company to achieve significant savings (cutting expenditures for fuel) and as a result mitigate CO₂ emissions. The project resulted in the prevention of direct GHG emissions amounting to approximately 1,450 tons of CO₂ equivalent per year.

Ludilu Micro-Hydropower Project

Socio-Economic Benefits

The project supports approximately 150 households, institutions and micro-industries as well as agro-processing activities at Ludilu village. This site has been operational since August 2017 with 50 customers (45 households and 5 small- and medium-sized enterprises) connected to the distribution network. And it is planned to extend the distribution network. The local beneficiaries include an Orphanage (17 children), a carpentry shop, a tailoring training college, an agro-processing enterprise and a welding machine. The village is very isolated, thus making it difficult to gain access to social services. The availability of power is therefore very important for the economic empowerment and improvement of living conditions in the village.

Environmental Benefits

The project helped reduce the use of kerosene and firewood for lighting in the village, safeguarding the forests in the village, which have been seriously diminishing. The project resulted in preventing direct GHG emissions amounting to approximately 450 tons of CO₂ equivalent per year.

4. LESSONS LEARNED AND CONCLUSIONS

- The successful development of SHP in a country requires a favourable business environment** (availability of local skills, policies, financial and technology transfer mechanisms, incentives for the business, etc.). Realizing this, the Government of Tanzania together with UNIDO and donors developed a comprehensive project, which aimed not only to build demonstration plants, but also to create enabling conditions for the further uptake of hydropower.
- It is essential to create local institutional and individual capacities.** For example, in this project in Tanzania, the trainees from private, academic and government institutions had an opportunity to learn about SHP technologies and approaches in theory and practice. Two study tours were conducted to Vienna, Austria and Bandung, Indonesia. A group of participants was trained on the fabri-

cation of micro-hydropower and cross-flow turbines. This knowledge and experience will be of the highest value for the development of future projects in the country.

- Demonstration projects help to build experiences, develop local capacities and know-how. But it is also important to disseminate good practices.** In this project, the demonstration sites became the centres of research and capacity building: the local experts were able to develop skills in designing, developing, fabricating, installing and maintaining SHP plants. After the project finalization, the information and training materials were developed and distributed among the different stakeholders.
- Development of SHP in rural areas can provide good business opportunities for local entrepreneurs and community cooperatives as well as be part of charity activities.** In Tanzania, several demonstration projects are driven by business and community interests. The local plants are managed by different stakeholders, e.g., local charity organizations, community cooperatives and private investors.
- It is important to consider the knowledge management, continuity and sustainability aspects when developing hydropower projects.** In Tanzania, one of the significant project achievements was the establishment of the Technical Centre. It continues providing know-how, training local experts and consulting on the development of SHP in the country. In addition, each of the eight demonstration plants has its own sustainability plan: how it is going to maintain and develop its activities and financial flows over a period of time.

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1.6. Shiwang'andu Small Hydropower Plant: sustainable electrification of rural Zambia

CATEGORY:

SHP FOR SOCIAL AND COMMUNITY DEVELOPMENT

COUNTRY:

ZAMBIA

Author:

Mwape Chikonkolo Mwewa, Energy Consultant – Polyjute Enterprises Co. LTD, Zambia



Source: Google Maps⁴

Table 1. Project Overview

SHP plant name: Shiwang'andu SHP plant

Location: Shiwang'andu District, Muchinga province, Zambia

Installed capacity: 1 MW

Water source: Mansha River

Key actors: ZESCO Limited, UNIDO, GEF, REA

Construction cost: USD 7,506 million

Ownership: ZESCO Limited

Status of the SHP project: Commissioned and operating

Benefits

Economic:

- New opportunities for developing business activities and establishing a district status of the area

Environmental:

- Reduction of CO₂ emissions by 1,669,800 kg

Social:

- Improved quality of life and education
- Better conditions for operating schools, health centres, churches, etc.

Potential: Zambia has abundant renewable energy resources, which can be used to facilitate electrification in rural areas in a sustainable way.

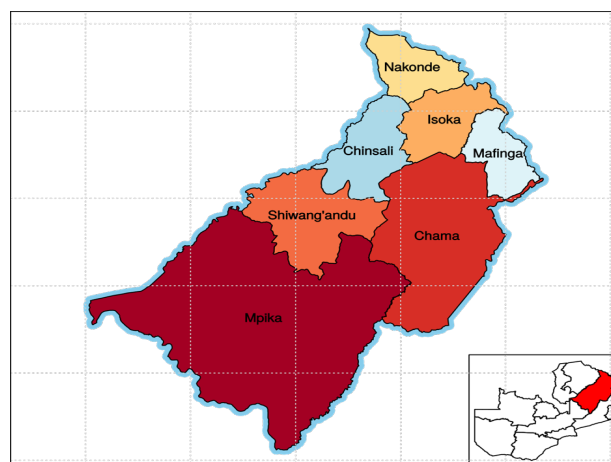
1. INTRODUCTION

In Zambia, 85 per cent of installed electricity capacity is hydro based and the national access to electricity rate stands at 31 per cent. However, 67 per cent of the urban population is connected as compared to only 4 per cent connected of the rural population. The Government has set an overall target of universal electricity access for Zambians by 2030, primarily by using the potential of country's vast renewable energy sources (USAID, 2021):

Before 2012, residents in the rural villages of Shiwang'andu District, Muchinga Province, had never been connected to the national grid. Located in isolated communities, they relied on biomass as a source of energy for cooking and kerosene for lighting at night. Only a few wealthy people had access to limited electricity supply from diesel-powered generators, which they would run 2 hours per day on average.

On 5 December 2012, the late 5th president of Zambia H. E. Michael Chilufya Sata commissioned the Shiwang'andu mini-hydropower plant to supply power to over 25,000 people in the district.

Figure 2. Map of Muchinga Province



Source: Muchinga Province Provincial Administration²

The Shiwang'andu power plant, the first after the Kafue Gorge hydropower plant was commissioned in 1976, was constructed as part of the renewable energy project implemented by the United Nations Environmental Programme division of Technology, Industry and Economics (UNEP DTIE). The project was realized with the financial support of the Global Environmental Facility (GEF) and the state-owned energy utility, ZESCO Limited. The United Nations Industrial Development Organization (UNIDO) acted as an executing agency. The key partners in Zambia included the Ministry of

Energy and Water Development, the Development Bank of Zambia (DBZ) and the Rural Electrification Authority of Zambia (REA). The project implementing agent was the International Center on Small Hydro Power (ICSHP) of the Ministry of Water Resources of China.

The Shiwang’andu run-of-river plant consists of two 500 kW units. The 33 kV distribution line (almost 250 kilometres-long) connects the local communities with 24-hour access to electricity.

The electricity access considerably changed the life of the community: it boosted the business activities, income generation and improved the living conditions of people. ZESCO employees and locals were trained by ICSHP in the operations and maintenance of the plant, which made it possible and easy to manage it locally.

Plant construction was carried out with environmental considerations. A cofferdam diverted water during dam construction. This ensured that the downstream waterfall, an important tourist attraction in the area, continued its normal flow. A 1.5-metre fish gate within the dam helps migrating river life, such as fish, crabs and shrimp.

Figure 3. Shiwag’andu SHP plant



2. TECHNICAL CHARACTERISTICS

Table 3. Key Technical Characteristics of Shiwang’andu SHP Plant

Turbine Type	Axial Flow Tubular Type GDJ530
Generator	SFW500-14/1430 (horizontal shaft)
Design Discharge	27.5 m ³ /s
Gross head	13.5 m
Net water head	12.8 m
Design flow	10.2 m ³ /s
Annual output	682 x10 ⁴ kWh
Firm output	563 kW (75% flow of 5.5 m ³ /s)
Transformer	1.2 MVA (0.4/33 kV)

There are two 0.5 MW tubular turbines. Power is generated at 0.4 kV and transmitted at 33 kV via a wooden pole line. The total coverage of the transmission line is approximately 250 kilometres with between 1,000 and 2,000 connections.

Figure 4. Two 0.5 MW tubular turbines



Figure 5 (a) and 5 (b). Participatory approach for skills transfer

Table 2. Project Stakeholders

- The Government of Zambia, Ministry of Energy and Water Development
- United Nations Industrial Development Organization (UNIDO)
- ZESCO Limited
- United Nations Environmental Programme (UNEP)
- Global Environmental Facility (GEF)
- Development Bank of Zambia (DBZ)
- Rural Electrification Authority of Zambia (REA)
- Center on Small Hydro Power (ICSHP) of China

5a.



5b.



3. BUSINESS FIGURES

The GEF and ZESCO Limited provided financing for the project, with a total budget of USD 7.506 million (USD 2.95 million from the GEF grant and USD 4.556 million of financing from the Government of Zambia through ZESCO Ltd).

The project served as a demonstration of mini-grid development in the country. Lessons learnt in the project became a good basis for establishing a legal, institutional and policy framework for renewable energy-based mini-grids and enabling favourable conditions for independent power producers (IPPs) and build-operate-transfer (BOT) business models.

Table 4. Business Figures of Shiwang'andu SHP Plant

Total investment	USD 7.506 million
Estimated generation of electricity per year	682X10 ⁴ kWh
Break-even	10 years turnover period
Lifespan	40 years

4. BENEFITS

Benefits of the project are multi-fold:

Connectivity

Facilities of the local infrastructure connected to Shiwang'andu include residential houses, schools, hospitals, clinics, churches, shops, tourism lodges, farms, district government offices, such as the District Commissioner's (DC) offices and police, communication towers, TV receivers, chief's palaces and Zambia Wildlife Authority camp (Mano Camp) in the North Luangwa National Park.

Social benefits

The initiative provides access to energy to almost 30,000

people. Over the course of the project, more than 300 locals were hired, trained and 8 of them have been employed permanently to run the power plant.

Having access to electricity considerably enhanced the quality of life, options for generating income, employment opportunities and local services. People started engaging in such activities as establishing hair salons, raising chickens, fabricating door frames and windows, setting up traditional hammer mills for processing staple foodstuffs, and running pubs, restaurants and resorts.

As a demonstration of its dedication to corporate social responsibility, the power plant's operator, ZESCO Limited, built a clinic for the community, planted 80,000 fish fingerlings in the dam and trained 20 locals in fish farming.

"Today we are planting fish in this dam, the thing I never thought was possible. The power plant has created employment, put our area on the map and improved the health and quality of life of the people. I am happy that the district of Shiwang'andu is one of the fastest developing in Zambia, all because of this power station. I thank ZESCO, UNIDO, REA and the Government of Zambia for this development," said the late local chief Mukwikile who played an important role in persuading the Government to develop the hydropower plant.

Furthermore, almost 20 phone/TV signal (communication) towers have been connected to the grid improving the communication quality in the area.

Education benefits

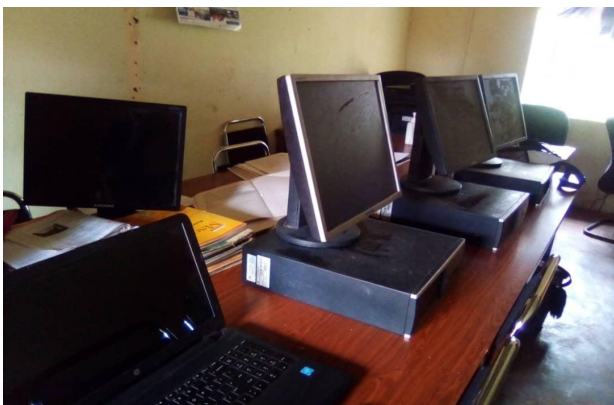
The Shiwang'andu grid connects a number of schools, including the Katibunga Catholic Seminary, Lwanya Basic School, Mwilwa Basic School, Kapisha Basic School, Timba Basic School, Shiwang'andu Secondary School, Kabangama Basic School, Mulanga Basic School, Mwilwa Basic School.

"The electrification of Kapisya Primary School is a game changer because now we can use the electrical equipment such as computers, charge phones, cookers, TVs, radios, etc. The school is now able to teach computers and kids are able to watch TV. To some it is the first time to do that because most of them come from poor families that cannot afford to buy TVs. We expect mindset change and hard work from the pupils, which will result in good pass rates. We have seen an increase in the number of teachers wishing to be transferred to Kapisya Primary School due to the presence of electricity. Previously, we only had four teachers, now we have seven, only limited by the number of houses. I expect the rate of cutting trees to reduce because we can now use electrical stoves as opposed to firewood or charcoal. Kids in the boarding sleep in well-lit rooms. We thank the Zambian Government and their cooperating partners for this project," said Mr. Mutale Dominic, the former Headteacher at Kapisya Primary School.

One parent, Mr. Stanley Musonda, added: *"This project has shown a sustainable way of developing rural areas. I partici-*

pated in the construction of the power station by working as a semi-skilled worker. The money I earned was used to build apartments, buy animals (goats, cows). Because of the experience and recommendation letter the International Center on Small Hydro Power gave me, I got a chance to be trained by the Government as a community-based health practitioner. Many of my friends acquired skills such as building, welding, repairing small equipment and are able to make money using these skill sets."

Figure 6. Computers used in schools



Health benefits

Local health facilities were connected to the power plant, including the Kapisha clinic, Shiwang’andu hospital, Shiwang’andu clinic, Mukungule clinic and Katibunga clinic.

There has been a general improvement in the quality of health services as a result of electricity access. *“The supply from the power station is stable and has facilitated and improved the storage of vaccines and medicines under recommended temperatures using electrical fridges, which was not possible before. Utilization of electrical equipment such as vacuum pumps has helped to reduce the infant mortality rate in the district,”* said Mr. Gershom Sichelwe, who is in charge of the Shiwang’andu clinic.

Sister Kapya Hope, a registered nurse at the Kapisha clinic, expressed gratitude for the improved electricity access to the clinic, which was previously powered by solar energy. *“It was difficult to work during the rainy season. Now we have power 24 hours and a backup solar power systems. We do our work professionally even when we have a maternity case at night. The reporting system to our senior authorities at*

the district has also been enhanced via the computer and internet availability.”

Quality of Housing

The quality of housing structures has improved (Figure 7). The increased buying power of local people made it easier to build nice houses.

Figure 7. Housing units before and after the hydropower plant was built



Environmental benefits

It is expected that up to 6.6 GWh would be generated annually by the Shiwang’andu SHP plant, replacing approximately 603,000 litres of diesel, thus saving approximately 1,669,800 kgCO₂e annually (assumption: 1 litre of diesel = 10.96 kWh and emits approximately 2.67 kgCO₂e), or 171,600 kgCO₂e per year if wood pallets are utilized for equivalent energy generation.

Economic benefits

Access to electricity improved the business environment in the community.

For example, the local shops now use refrigerators. Fresh vegetables, meat, fish and other products can be stocked and sold. The opening hours of businesses are extended.

The facility supplies electricity to C&J Farms, a subsidiary of the Shiwang’andu estates. In the past, they relied on wood for energy supply. Due to the availability of energy, they were able to build a milling facility where over 2,000 small-scale farmers sell their products.

The Shiwang'andu plant also provides energy to Kapisha hot springs, thereby supporting the tourism sector. Mark Harvey, owner of the Kapisha hot springs, confirmed the reduction in energy expenditure (from USD 320 per month to approximately USD 40 per month for electricity).

5. LESSONS LEARNED AND CONCLUSIONS

Hydropower can boost the development of rural areas: socially, environmentally and economically.

In order to support technical and financial viability and sustainability of projects, the following could be relevant:

1. **Using simple yet effective equipment can help reduce costs of an energy project and transfer skills to the local people.**
2. **Legal, institutional and policy frameworks are essential elements for successful mini-grid development.** The Zambia National Energy Plan was an important framework for the development of the Shiwang'andu SHP project.
3. **Capacity building at local, national and regional levels** to promote renewable energy-based mini-grids is of key importance.
4. **Good planning is key** to quickly use up the capacity of a mini-grid for productive purposes and quick payoff.
5. **Putting in place pilot mini-grids based on renewable energy to demonstrate commercial ideas can be a helpful instrument** to drive the interest of the private sector towards future projects.
6. **Creating project management,** coordination and information dissemination systems are important for projects sustainability.

The experience of this project can be relevant for developing other mini-grid projects in the country. ZESCO and UNIDO mobilized funds for the pre-feasibility studies of 12 sites for possible hydropower plant development.

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2. Technological solutions for SHP

2.1 The Cascade Hydro-PV-pumped Storage Complementary Generation System

CATEGORY:
TECHNOLOGICAL SOLUTIONS FOR SHP

COUNTRY:
CHINA

Authors:
NARI Group Corporation, Xuqing, Shanpengzhu, Hejie, Zhaoyu, Yanyingfei; China Electric Power Research Institute, Chengxu, Yanpeng; Sichuan University, Chenshijun; Xihua University, Wangjun, Sunzhang.

Table 1. Project Overview

SHP plant name: Sichuan Xiaojinchuan Sinohydro Development Co. Ltd

Location: Aba State, Sichuan Province, China

Installed capacity: 250 MW

Technology applied: The Cascade Hydro-PV-pumped Storage Complementary Generation System

Key actors: NARI (developer)

Costs: USD 1,837,426 (the cost of this R&D demonstration project)

Ownership: State Grid Sichuan Electric Power Company

Status of the project: implemented, the system operating since 30 May 2022

Benefits

Economic:

- PV absorptive capacity increase of the cascade basin by more than 3 per cent.

Environmental:

- Renewable energy generation;
- Reduction of approx. 2,272.5 tons of CO₂ per year (Note: considering only savings achieved due to the technology used and not the total savings from the plants).

Social:

- Improvement of the stable operation level and quality of the regional power grid;
- Community empowerment

Potential for replication: This technology can be popularized in areas rich in hydropower-photovoltaic-wind resources

1. INTRODUCTION

At the 75th United Nations General Assembly, China expressed its readiness to strive towards carbon neutrality by 2060. At present, the country's coal consumption accounts for more than 50 per cent, and fossil fuel energy accounts for nearly 85 per cent, of China's total energy use (Data - the World Bank, 2014).¹ In order to meet the goal of massively reducing its CO₂ emissions, the country needs to change its energy mix and increase the share of renewable energy.

Aligned with that goal, the country explores the potential of hybrid (complementary combined) power generation systems; for example, those that integrate together cascade hydropower, conventional hydropower, photovoltaic power and variable-speed pumped storage.

Xiaojin County has been selected for the development of a demonstration project. The Tibetan and Qiang nationalities live in this area. Due to frequent regional mountain torrents and landslides, the reliable power supply capacity of the Xiaojin power grid is poor. One of the goals of implementing this project was to improve the safe and reliable power supply capacity of the Xiaojin power grid, which is of great significance to the regional economic development, unity and sustainability of local communities.

Figure 1. The Chunchangba Hydropower Plant



As part of the demonstration project (Figure 1), the Meixing photovoltaic power plant, as well as four hydropower plants, were built in the Xiaojinchuan River Basin, including three

cascade small hydropower (SHP) plants (Mupo, Zanla and Mengguqiao) on the Fubian River and another hydropower plant (Chunchangba) on the Wori River. A new pumped and storage unit was added to the existing Chunchangba hydropower plant (based on the upper and lower reservoirs of Chunchangba). The developed hybrid power generation system has the following capacity: 195 MW hydropower + 50 MW photovoltaic power + 5 MW pumped storage.

In order to manage complementary combined power generation, the following factors need to be taken into consideration. First, the photovoltaic output can fluctuate greatly, with the climate playing an important role. Second, cascade hydropower generation is comprehensively affected by such factors as storage capacity, water level, operating conditions, water balance, etc. Ensuring real-time regulation, efficient control and complementarity of photovoltaic and hydropower energy sources is a very challenging but essential technical task.

This case study presents a technical solution: an intelligent operation control and dispatching system which helps successfully operate the cascade hydropower-photovoltaic-storage complementary power plants, addressing different needs and challenges. This technical solution was tested and put in place in 2022.

The results of the testing demonstrate that the system allows photovoltaic prediction, real-time regulation and optimal control of cascade hydropower-photovoltaic storage complementary power plants, supporting the autonomy of the key technologies.

Such an intelligent operation control and dispatching system provides economic benefits, but also increases the efficiency of water and electricity consumption, improving the security and stability of the power grid (Figure 2 illustrates the central control room).

Figure 2. The Central Control Room



Table 2. Project Stakeholders

1. System design: NARI Group Co. Ltd (China)
2. Civil engineering: NARI Group Co. Ltd (China)
3. Management and consulting: Power China Hydropower Development Group Co. Ltd (China)
4. Owner: State Grid Sichuan Electric Power Company (China)

2. TECHNICAL CHARACTERISTICS OF THE PLANT

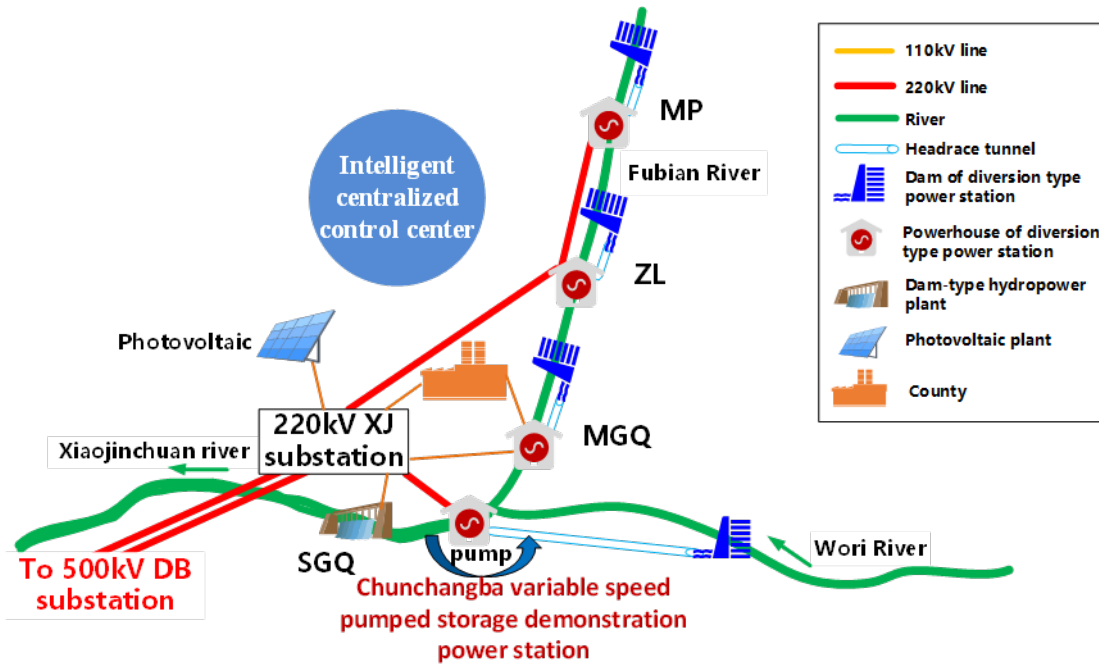
Table 3. Key Technical Characteristics of the Cascade

Item	HPP ¹ N1 Mupo	HPP N2 Zanla	HPP N3 Menggu-qiao	HPP N4 Chun-changba	Photo-voltaic Plant MeiXing
Turbine output	3 x 15 MW	3 x 20 MW	3 x 13 MW	3 x 18 MW	
PV output					50 MW
Variable speed pumped storage output				5 MW	
Total output	250 MW				
Site condition and parameters of the plants: effective head	129 m	153 m	50 m	159 m	
Maximum power fluctuation rate of water light transmission	<5%				
Real-time adjustment accuracy deviation	<2%				

An intelligent operation control and dispatching system is based on a hierarchical dispatching control framework, which is divided into a control layer and a dispatching layer. The control layer can realize the coordinated control, smooth control and predictive control of cascade hydropower-photovoltaic-storage complementary power plants. The smooth control function uses the millisecond regulation characteristics of hydropower unit output, and the pumping & storage unit, to stabilize the photovoltaic minute

1 HPP – Hydropower plant

Figure 3. The complementary power generation



Note: ZL — Zanla SHP plant, MP — Mupo SHP plant, MGQ — Mengguqiao SHP plant, SGQ - SanGuanQiao hydropower plant (downstream of Chunchangba plant).

Liu Jianming, national key research and development plan responsibility expert said: *“The demonstration project has improved the dispatchability of the regional water-photovoltaic-storage complementary power generation, and improved the safe and stable operation capability of the regional power grid”.*

level low-frequency fluctuation as well as the second level high-frequency fluctuation. The predictive control function combines the high-precision photovoltaic prediction data to formulate short-term and ultra-short-term power generation plans, realizing the optimal dispatching and economic operation of water light output.

The system was successfully tested and installed in May 2022. The maximum power fluctuation rate of water light transmission is less than 5 per cent per minute and the real-time adjustment accuracy deviation is less than 2 per cent. All performance indicators are above the national and industrial standards and fully meet the project design requirements.

3. BENEFITS

The technology provides important benefits, some of which are presented below.

Economic benefits

- The described technology of operation control and dispatching is a profitable business due to growing market demand (the company has total annual sales of more than USD 6 million (data for 2021);
- The operation control and intelligent dispatching system of the cascade hydropower-photovoltaic storage complementary power plants supports the overall high-quality controllable power supply.

Environmental benefits

According to the National Bureau of Statistics, each kWh of electricity is equivalent to approximately 0.404 kilogrammes of standard coal. The system helps to reduce the solar energy curtailment (a loss of potentially useful energy): the annual additional photovoltaic power generation in this project is approximately 2.25 GWh. Therefore, it can help reduce standard coal consumption by approximately 909 tons and avoid approximately 2,272.5 tons of CO₂ emissions. (This is only the calculation of CO₂ emissions that can be avoided due to photovoltaic generation and does not include the emissions that can be avoided by hydropower generation.)

$$(50 \times 1,000 \text{ kW} \times 1,500 \times 0.03 = 2,250,000 \text{ kWh})$$

$$2,250,000 \times 0.404 = 909,000 \text{ kg} = 909 \text{ tons}$$

Social benefits

The project, supported by the control and dispatching technology, contributes to the grid stability and, as a result, to the sustainable development of local communities.

4. BUSINESS FIGURES

Benefits from increasing electricity generation

The output of photovoltaic power generation is fluctuating and intermittent and affects the safety and stability of the local power grid when the plant is connected to the grid. Therefore, photovoltaic power will be limited where the photovoltaic plant is connected to the power grid. The national average annual rate of solar energy curtailment is 3 per cent. The combined operation control and intelligent dispatching system of the cascade hydropower-photovoltaic-storage complementary power plants can improve the photovoltaic power generation and utilize all available solar energy in the Xiaojinchuan River area.

The photovoltaic installed capacity in the Xiaojinchuan River basin is 50 MW, the photovoltaic power generation price is 0.14 USD/kWh. There is approximately 1,500 hours of photovoltaic utilization per year.

*The direct benefit is $50 * 1,000 \text{ kW} * 0.14 * 1,500 * 0.03 = \text{USD } 315,000$*

Benefits from the power grid auxiliary services

There is a payment for the power grid auxiliary services such as peak load regulation and frequency regulation of the power grid. The calculation is based on the 5 MW variable-speed pumped and storage. The capacity price is taken as 60 USD/kW per year. The direct benefit is $5 * 1,000 * 60 = \text{USD } 300,000$.

5. LESSONS LEARNED AND CONCLUSIONS

Combining different energy sources can be a challenge. Some experiences are highlighted below:

1. **Adding additional energy can be a new challenge for the operation of a power grid.** To ensure the power grid stability, there is a need for the complementary and coordinated control of new plants. The controlling and dispatching technology is of great importance: it can help smooth the fluctuation of photovoltaic output and efficiently manage different sources of energy.
2. **In areas where the potential for the construction of new SHP plants is saturated,** but which have abundant solar energy sources connected to the same grid as hydropower plants (like in south-western China), the hybrid energy systems could be an attractive option. For example, the Xiaojinchuan River and also other basins in Sichuan, such as the Woluo and Yazui Rivers, are rich in hydropower and solar natural resources, which makes these areas suit-

able for developing complementary energy systems with SHP and photovoltaic plants. In these areas hydropower and solar power complement each other.

3. **The success of hybrid energy projects depends largely on local policies, incentives and governmental support.** For example, in China, in line with the goal to achieve carbon neutrality, there is policy support for such projects in place.
4. **The findings of this demonstration project can be useful for future plants,** helping to improve the efficiency of consumption of natural resources and of renewable energy.

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2.2 Hydroshaft Power Plant: a sustainable and simple design solution for existing as well as new lateral structures

CATEGORY:
TECHNOLOGICAL SOLUTION FOR GREEN HYDROPOWER

COUNTRY:
GERMANY

Authors:
Bertalan Alapfy, Technical University of Munich (TUM),
Markus Reisenbüchler, TUM

Figure 1. Geolocation of the Großweil Hydropower Plant

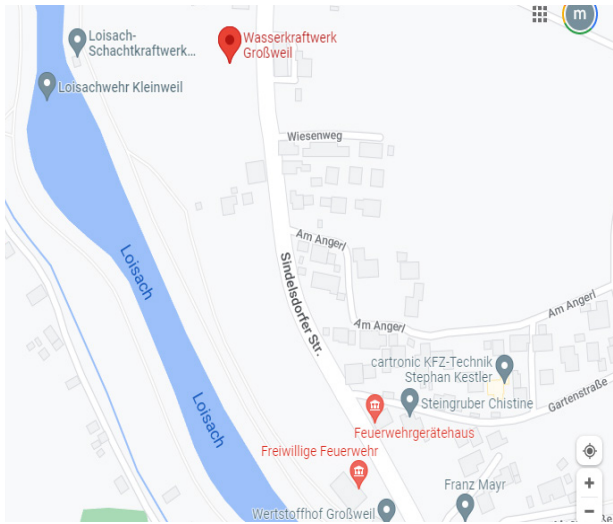
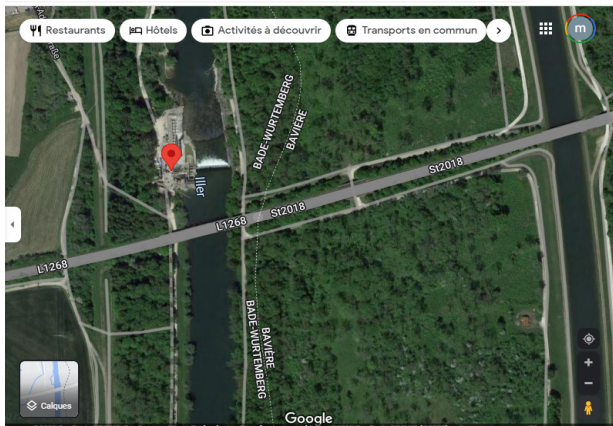


Figure 2. Geolocation of the Dietenheim Hydropower Plant



Source: Google Maps

Table 1. Project Overview

SHP project name: Hydroshaft Power Plant (HSPP)

Location: in Großweil, the Upper Bavarian mountains (1) and in Dietenheim, near Ulm (2)

Installed capacity: 420 kW and 312 kW

Water source: Loisach River (1) and Iller River (2)

Key actors: Hydroshaft GmbH, Technical University of Munich, **Wasserkraftwerk** Großweil GmbH, Fontin SKW Dietenheim GmbH, Erhard Muhr GmbH, Geppert GmbH, Alapfy Engineering & Consulting

Construction cost: Großweil – EUR 5.4 million, Dietenheim EUR 2.9 million

Ownership: private

Status of the SHP project: Construction of the HSPP-Großweil was finalized in 2020, and of the HSPP-Dietenheim in 2021.

Benefits

Economic benefits:

Compact design, low construction volume

Environmental benefits:

Passable for fish and bedload

Social benefits:

Decentralized reliable power supply

Potential: The technical solution can be used in different parts of the world and applied to existing, not used for electricity generation lateral structures as well as to completely new ones.

1. INTRODUCTION

As a source of renewable energy, hydropower plants contribute to climate mitigation efforts, but if not properly designed and constructed, they might also cause problems for the natural environment due to ecological interventions in rivers. Considering these undesired effects, the legal requirements for new plants in Europe have become considerably stricter with the European Water Framework Directive, which prohibits ecological deterioration. Nature conservation associations have been calling for a general ban on new construction for several years. Despite the difficult framework conditions, regenerative power generation from hydropower has a great potential. Practical, ecological and economically feasible hydropower technologies become of key importance to address the task of ensuring a sustainable use of rivers for energy production.

The Technical University of Munich (TUM) was motivated to develop a compact run-of-river low-head hydropower con-

cept for a nature-compatible use, which is suitable for small hydropower (SHP) potentials as well as for plants in the larger capacity range. For many years, the team built of scientists and engineers was working on the idea of developing a barrier-free power plant that is integrated in the dam body and permanently overflowed. With a help of physical models and a 35 kW prototype plant, a new design, Hydroshaft Power Plant (HSPP), was successfully developed and tested. With this innovative design, there is no need to divert the course of the river. Instead, one or several shafts housing the submerged turbine-generator unit are placed in the river and form a structural part of the damming structure.

The fact that the shafts can both be embedded in existing, not used for electricity generation lateral structures and within completely new structures makes the concept very attractive.

The first larger natural pilot-plant (1) was built in Germany in the Upper Bavarian mountain river Loisach at an existing rough ramp site and successfully commissioned in February 2020. The project was financed by a consortium of the local community, the public utility and a private investor, and subsidized with a grant from the state of Bavaria. The second plant (2), fully financed by private investment, was integrated into an existing concrete weir at the Iller River near the city of Ulm, Germany, and started successful operation in November 2021.

“Hydro4U will demonstrate that the Hydroshaft Power Plant is not only a solution for renewable energy in Germany but worldwide,” Markus Reisenbüchler (Project Coordinator - Hydro4U)

“With the successful implementation of the Hydroshaft Power Plant at the Iller, besides ecological sustainability, the concept has also reached economic viability. But there is still a lot of room for improvement and all learnings are now applied within Hydro4U to develop the optimal standardized technical setup of the HSPP concept and reach global market readiness, also for challenging environments.” Bertalan Alapfy (Owner’s Engineer - HSPP Dietenheim; Project Coordinator - Hydro4U).

Recently TUM launched the Horizon2020 innovation action “Hydro4U” to further develop the “Hydroshaft Power Plant” concept. The University coordinates a consortium of 13 international expert institutions focusing on optimizing innovative and sustainable hydropower concepts and demonstrating them in Central Asia. Within this action, a modular pre-fabrication design is being developed for the HSPP, which will enable significant project cost reductions and ease the implementation also on remotely located construction sites whilst maintaining high quality standards.

Table 2. Project Stakeholders

Main stakeholders include:

Hydroshaft GmbH
 Technical University of Munich
 Wasserkraftwerk Großweil GmbH
 Fontin SKW Dietenheim GmbH
 Erhard Muhr GmbH
 Geppert GmbH
 Alapfy Engineering & Consulting

2. TECHNICAL CHARACTERISTICS

Table 3. Key Technical Characteristics of HSPP

Item	Value
HSPP-Großweil	
Turbine output	210 kW
Total output	420 kW
Electricity generation per year	2.5 GWh
Site condition and parameters of the plants	H = 2.4 m; $Q_T = 22 \text{ m}^3/\text{s}$
Turbine	Kaplan
Type of generator	Permanent-Magnet-Generator
HSPP- Dietenheim	
Turbine output	312 kW
Total output	312 kW
Electricity generation per year	1.6 GWh
Site condition and parameters of the plants	H = 4 m; $Q_T = 9 \text{ m}^3/\text{s}$
Turbine	Kaplan
Type of generator	Permanent-Magnet-Generator

2.1 Project HSPP Großweil

The Großweil project on the Loisach River has challenging site conditions in a nature conservation area. The area is listed in the inventory of Natura2000 reserves including two endangered fish species from the Red List, namely the Danube salmon (*Hucho hucho*) and the bullhead (*Cottus gobio*). The rough ramp, which is installed diagonally in the riverbed, is located at the end of a river bend and was built in the 1970s according to the rules applicable at that time with a steep inclination of 1:10–1:15. The riverbed on the upstream side was silted up to the ramp crest with the consequence of shallow flow depths, which meant that problematic hydraulic and sediment transport criteria prevailed for intake structures. Due to its sub-alpine catchment area,

the river is characterized by rapidly changing discharges and high bedload and driftwood loads.

Considering these challenging conditions, the operator Waserkraftwerk Großweil GmbH made a decision to include the innovative concept of the HSPP, which was still under development at the time, in the submitted permit application in 2012. A previous application for a conventional hydropower plant was rejected before. The energy company's application was supported by the promising investigation results from the research work at TUM. These results were a basis for a successful approval procedure as well as for financial subventions from the state of Bavaria.

The technical and water-legal process of the plant development in Großweil was extremely labour-intensive and lengthy. One of the factors affecting the construction works was the confrontation with the fishery and nature conservation activists (it was resolved by a court decision to permit the construction). Another constraint was difficult underground conditions. After solving the challenging issues, the construction started in spring 2018.

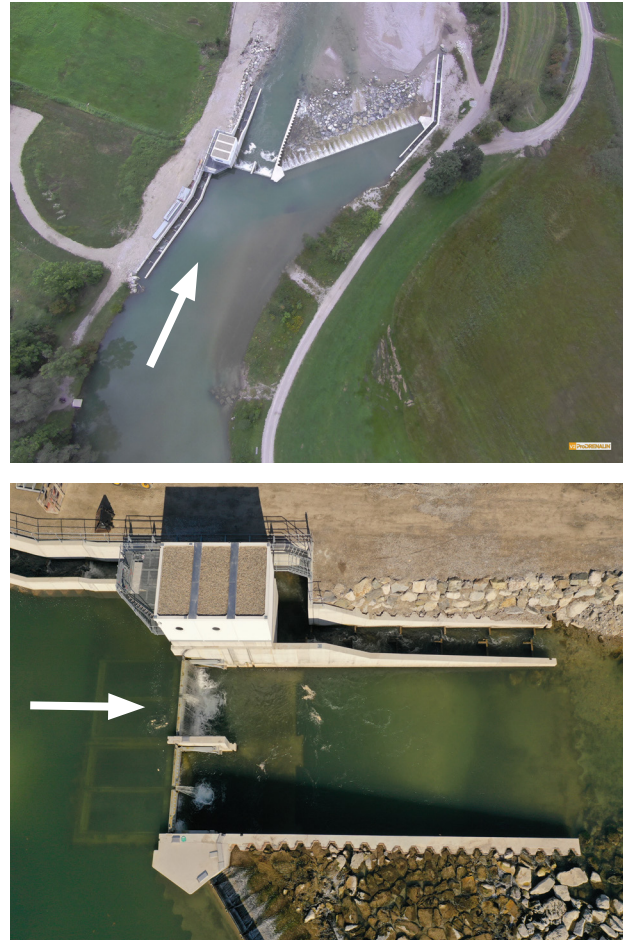
Technical solution

The final layout for the Loisach power plant was based on the results of the basic hydraulic investigation of the physical model and the prototype plant. The question concerning the effects of the spatial inflow could only be answered qualitatively on the basis of flow investigations with double and triple shaft systems under variable boundary conditions, because a meaningful Froude model would have required a disproportionately large geometric model. Supported by numerical simulations, only a general dimensioning recommendation was available with the specification that a spatial (i.e., three-sided shaft) inflow with as uniform a distribution as possible should be aimed for. More unfavourable inflow conditions should be equipped with larger inlet surfaces. The design recommendations were taken into account, whereby it had to be assumed that no optimal inflow distribution could be expected due to the left-sided power plant positioning within the main flow path of the river.

The aerial photographs (Figure 3) taken in August 2020 at a flow of approximately $20 \text{ m}^3/\text{s}$ show the complete structural arrangement of the 420 kW plant. The main components consist of a double shaft on the left side equipped with two double-regulated submersible Kaplan turbines from GEP-PERT ($Q_T = 2 \times 11 \text{ m}^3/\text{s}$) and two rake modules each, developed and manufactured by the hydraulic steelworks company MUHR. At the end of the shaft the damming, multifunctional and vertically movable pressure segments with permanent overflow and flow through the fish-descent openings are positioned. The right-sided, newly reconstructed weir with adjustable flap-gates is used for water level compensation and also provides improved discharge capacity in the event of flooding. With this movable weir attachment, which must be permanently slightly overflowed according to ecological considerations, a head of approximately 2.5 metres is reached with average flow. On both riverbanks, vertical slot passes

for fish-upstream migration were constructed: the larger one on the left side having a design flow capacity of 600 l/s and on the right side of 200 l/s . Since the left foreland at the power plant site is flooded during flood-events, the technical building was placed flood-secure and directly next to the shafts. In principle, this functional building could have been erected completely outside of the power plant unit, whereby the desired natural appearance of an overflow lateral structure could have been preserved.

Figure 3. Arrangement Overview - and Double-shaft with Two Rake Modules Each



2.2 Project HSPP-Dietenheim

The HSPP-Dietenheim and the associated fishway with near-natural bypass channel in the diversion section of the Iller River were built from September 2020 to September 2021 after a six-year approval and legal process. The actual project development began back in 2010, but at that time the project was still planned as a conventional bay-type hydropower plant. Then, the project was redesigned according to the new concept developed at TUM, integrating convincing ecological advantages, and submitted for approval in its final version as HSPP in 2015. Despite strong opposition from nature conservation groups, the scientific arguments created primarily by an extensive study programme on fish

protection and fish migration at the hydraulic laboratory Obernach of TUM were able to convince the approval and technical authorities as well as the courts involved in the process.

Technical solution

The HSPP is connected to the previously existing weir body, which was built in the 1980s to prevent erosion of the ecologically degraded riverbed (Figure 4). Power is generated by utilizing the average head of 3.8 metres at the weir and the specified ecological flow in the diversion section, currently in the range of 3–9 m³/s.

Figure 4. The Iller-weir Dietenheim before and after the Construction of the HSPP



Energy conversion is achieved by driving a 312 kW oil-hydraulic double-regulated GEPPERT turbine-generator unit (TGU), which is installed in a concrete shaft. The permanent magnet generator, directly coupled to the turbine shaft, is mounted in a watertight steel housing.

The main difference from the Großweil project is that the concrete shaft is divided into two parts — the wet section and the dry section — separated by an inclined concrete partition. Figure 5 shows the excavation works for the new HSPP in the riverbed.

Figure 5. Excavation and Partial Removal of the Weir Structure for the New HSPP



First, the water flows through a fine screen with 15-millimetre bar spacing, which protects the TGU from sediment and other material, into the wet area. The shaft is covered with two identical trash rack modules, both equipped with an electrically driven screen cleaner. A hydraulically driven adjustable front gate with two fish migration windows is installed on the downstream side.

In the dry section of the shaft is the access to the bearing bushings of the guide vane, as well as the hydraulic power unit, which is used for the adjustment of the TGU as well as the front gate. In addition, the generator and sensor cables of the TGE are brought together in two intermediate terminal boxes. Access to the dry area is via a 7.5-metre-deep access shaft, which is directly attached to the power plant shaft. The access shaft is equipped with a watertight pressure seal and is located below the headwater level during normal operation, making the power plant almost completely invisible. For inspection, maintenance or repair work, an aluminium frame is placed on top of the access shaft and the water level inside is lowered before the pressure seal is opened. In the rare event that work needs to be done in the screen area or the wet area of the shaft, a modular steel revision frame can be used to drain the entire powerhouse shaft. Access to the shaft will be via the weir crest if required.

Figure 6. Aerial View of the Finished HSPP - Dietenheim in Operation



The electrical and plant controls equipment is placed in a small building on the left bank, which is connected to the dry area of the shaft with a watertight cast iron pipe, providing a secure and dry connection for power and sensor cables. A newly constructed vertical slot pass and natural connection channel complete the project, improving the up- and downstream ecological consistency while providing an annual renewable energy yield of approximately 1.6 GWh. An overview is shown in Figure 6.

3. BENEFITS

The realization of the HSPPs has generated various benefits.

Economic benefits

Thanks to these power plants, the households in Großweil and Dietenheim can now benefit from energy independence, having sufficient and reliable supply of energy all year round. The annual energy yield in Großweil is 2.5 GWh and in Dietenheim 1.6 GWh.

Social benefits

The innovative Hydroshaft concept received a lot of attention from residents as well as external visitors coming from different regional and professional backgrounds. The hydropower plants became a touristic attraction, positively impacting the social and economic life in these cities.

Environmental benefits

With the construction of new fish migration structures, the old ramp in Großweil and the concrete-weir in Dietenheim are no longer fragmenting the river's ecological continuity. Additionally, downstream fish migration is now possible via the openings in the HSPP gates, located in the main stream of the intake area, as a main ecological element of the HSPP concept. The improved passableness of the river for bedload and driftwood transported by it is equally important. A dynamic development of the downstream riverbanks could be observed in Großweil already within the first year of operation. Overall, the project not only maintained, but also improved the ecological conditions at the site.

The city of Großweil (appr. 1,400 residents) is now climate neutral. With an average annual production of 2.5 GWh and a specific abatement factor of approximately 800 g CO₂ eq/kWh of hydropower, in total 2,000 t of CO₂ are saved. The figures are very similar for the Dietenheim project.

4. LESSONS LEARNED AND CONCLUSIONS

An accurate project management planning and an adequate plant design are among the most critical factors for successful HSPP construction. A broader overview of lessons learnt is presented below.

1. During the construction, it is essential to pay attention to potential risks and consider possible mitigation measures, for example:

The importance of shorter construction time planning

In comparison to conventional, bay-type hydropower projects, the earth and civil works are challenging, as the construction pit is placed directly in the riverbed. Both projects were planned very individually and their technical composition was rather complex with individual interfaces, resulting in substantial shifts in the original time schedules and therefore long construction periods (Großweil—approx. 2 years, Dietenheim—approx. 1 year). The combination of long construction periods and the positioning of the construction pit in the river raised the risk of damage from flooding during the construction period. The flooding happened in both projects, leading to unplanned additional costs.

In order to reduce construction risk and therefore costs, it is essential to significantly reduce the construction time. This could be achieved, on the one hand, by a higher proportion of prefabricated elements and, on the other hand, by further simplifying the technical composition of the power plant components with standardized interfaces. Further cost reductions could be achieved through modularization and standardization of the site design and the technical equipment (turbine, hydraulic steelworks, electrical engineering).

The importance of a flood management plan

The measures above should be combined with a well elaborated flood management plan avoiding large setbacks in case of flooding. The installation of the turbine-generator units and other electro-mechanical equipment should be conducted within short time and only during stable weather conditions, as unstable weather is the time when flooding of the shaft can cause major setbacks. Unfortunately, this was the case in Großweil, as one of the turbine pits was flooded before all connections for electrical cables and the hydraulic-oil pipes of the unit had been sealed, resulting in river water entering the generator housing causing significant damage to the machine. Afterwards the unit had to be taken out again for repair, setting the project back by several months. These risks, however, depend also on the design of the chosen turbine and the mounting concept.

2. Such innovative technical solutions as HSPP can help to exploit the hydropower potential efficiently even at already anthropogenically impacted rivers.

The pilot projects described in this case study demonstrated that the shafts can be embedded both in existing, not used for electricity generation lateral structures as well as within completely new structures (greenfield development). HSPP can be a good technical solution for high ecological and operational demands: it allows to integrate environmental upgrades, such as fish ladders and fish downstream migration openings.

For example, in the Loisach River, with the complete submerged arrangement of the power plant unit within the lateral structure qualitatively attractive inflow conditions could be reached. At the same time, a direct and barrier-free flow path for descending fish is guaranteed. In addition to the downstream ecological consistency, floods, driftwood and bedload can be efficiently handled, because in the lowered operation state of the gates, an advantageous and powerful overflow current with a great flushing effect is generated and the residual energy prevents deposition even in the downstream area. The original river dynamics are almost completely preserved and flood protection is enhanced by a movable gate(s).

3. Cost-efficient technical solutions and simplified design can facilitate the implementation of SHP projects.

In both projects, the construction and installation methods were more or less conventional, also due to the lack of improved technical solutions. With the comparatively high feed-in tariff in Germany, the project costs can be covered, but a high return is not expected, which makes such kind of projects commercially not so attractive considering the elevated financial risks of hydropower development in general. To make this proven eco-friendly solution available and viable on a global scale, the recently launched European Union Horizon Project “Hydro4U: Sustainable small-scale hydropower in Central Asia” (Grant No 101022905; www.hydro4u.eu) focuses on reducing the prevailing limitations, which will be achieved through a cost-efficient, modular and prefabricated design and workflow considering the complete project development value-chain. The Hydro4U project will include the demonstration of the further developed and optimized HSPP within a demonstration activity in Central Asia.

4. There is a good potential for the replication and scaling of SHP plants around the world

Although further hydropower development in Germany is limited, there is enormous low-head hydropower potential at existing lateral structures in other countries. This potential can be exploited to cover growing energy demands with base load-capable electricity generation from not only renewable, but also ecologically friendly hydropower.

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2.3 The retrofitting of existing civil structures as economic and sustainable solution for small hydropower plants

CATEGORY:
TECHNOLOGICAL SOLUTIONS FOR SHP

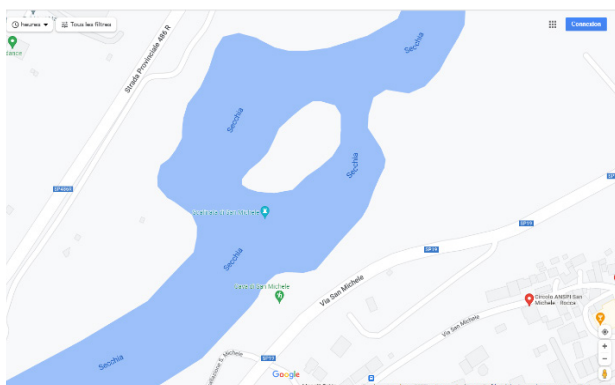
COUNTRY:
ITALY

Authors:
Emanuele Quaranta, Scientist, European Commission Joint Research Centre, Italy

Figure 1. The hydropower plant in San Michele dei Mucchietti – view from above



Figure 2. Geographic location



Source: Google Maps

Table 1. Project Overview

SHP plant name: San Michele dei Mucchietti Hydropower Plant

Location: San Michele dei Mucchietti (Italy), Municipality of Sassuolo (MO) and Castellarano (RE)

Installed capacity: 1.8 MW

Water source: Secchia River, existing weir used for irrigation channels

Developers: A public-private partnership—a cooperation between BI Energia S.r.l., Investee Company by Consorzio di Bonifica Emilia Centrale (public entity) and Iren Energia S.p.A.

Construction cost: EUR 8.5 million

Status of the SHP project: The construction was completed in 2018

Benefits

Economic:

- Savings achieved thanks to technical solutions
- Reduced operating costs

Environmental:

- Renewable energy generation without water resource subtraction from the riverbed
- Solution in case of a drought
- The carbon emission savings
- Maintenance and preservation of existing civil structures

Social

- Satisfied the energy needs of 3,500–4,000 families
- Employment of 50 workers during the construction phase
- Tourist attraction
- Possibility for cycling and pedestrian passage

Potential: The proposed solutions (such as double connection pipes between the lateral basin and the river & embankment of the lateral reservoir) might be adaptable to other hydropower projects where civil structures are already in place.

1. INTRODUCTION

San Michele dei Mucchietti—in the community of Sassuolo, Province of Modena, Emilia-Romagna—was selected for the construction of a new hydropower plant. The place is located on the important Secchia River, which rises in Tuscany and flows through the Emilia-Romagna region.

The in-place weir was built in the 1980s to provide water for the region’s irrigation through two channels, no longer

feedable due to the lowering of the river bed. The weir created a reservoir of approximately 800,000 m³ useful to serve the two irrigation channels, one for drinking water supply and one for industrial supply. The water supplies were managed by legally different entities.

In 2008 (Sassuol Oggi, 2016)¹, local energy companies BI Energia S.r.l., Investee Company by Consorzio di Bonifica Emilia Centrale (a public body) and Iren Energia S.p.A. realized the significant potential and important benefits of constructing a hydropower plant in the area, using existing civil structures and water distribution network. They joined hands and distributed roles and responsibilities in the complex project.

The joint management of the structure and reservoir allowed them to achieve a reduction of construction and operation costs.

Table 2. Project Stakeholders

Investors:

- BI Energia S.r.l., Investee Company by Consorzio di Bonifica Emilia Centrale (52.5 % share)
- Iren Energia S.p.A. (47.5% share) (Gazzetta di Reggio)²

Constructing companies:

- Parenti Costruzioni
- Peri

2. TECHNICAL CHARACTERISTICS

Table 3. Key Technical Characteristics of the San Michele dei Mucchietti Plant

Items	Values
Installed power capacity	1.8 MW
Electricity generation per year	6–7 GWh/year
Site condition and parameters of the SHPP	Source of water – Secchia River dam Average flow rate: 10.54 m ³ /s Maximum flow rate: 26 m ³ /s Gross head: 9.7 m Nominal concession power: 998.20 kW
Turbines	Two Kaplan turbines with a vertical axis of installed power equal to 1,207 kW and 603 kW; Overall efficiency of the turbines ≈ 90%
Generators	Two synchronous generators with nominal power equal to 1,476 kVA and 800 kVA

2.1 Technical solutions overview

This project of installing an SHP plant is based on retrofitting existing barriers and civil structures with the following technical solutions:

1. Double connection pipes between the lateral basin and the river: the pipes were oversized initially and used to allow the water to get back into the river from the lateral reservoir. In the project, one of the two pipes was separated, which allowed to split the flows. The inlets have been protected on the front by a concrete sill with the double function of:
 - stopping the hydropower intake when reaching the minimum water level in the river to ensure the level necessary for the irrigation
 - protecting the intake from silting

Compared to the one initially assessed for the construction of an independent intake, this design choice allowed a substantial and quantifiable saving of EUR 300,000. It also helped to avoid a complex cutting operation of the bank of the lateral reservoir and its waterproof structure restoration.

2. Viability and access: the existing accesses made it possible to avoid constructing expensive new roads and trails.
3. Embankment of the lateral reservoir: this solution ensured the protection of the plant from floods. It helped avoid the cost of EUR 200,000 needed to construct protection screens, huge stone boulders and walls higher than the two-hundred-year period flood level.

A system of the SHP plant uses a difference in level created from the weir without water resource subtraction to the riverbed. Table 3 highlights the main characteristics.

The plant was constructed downstream of the shoulder of the existing weir. It is underground, below the countryside level, with driveway access only for small vehicles, useful for maintaining the power plant equipment.

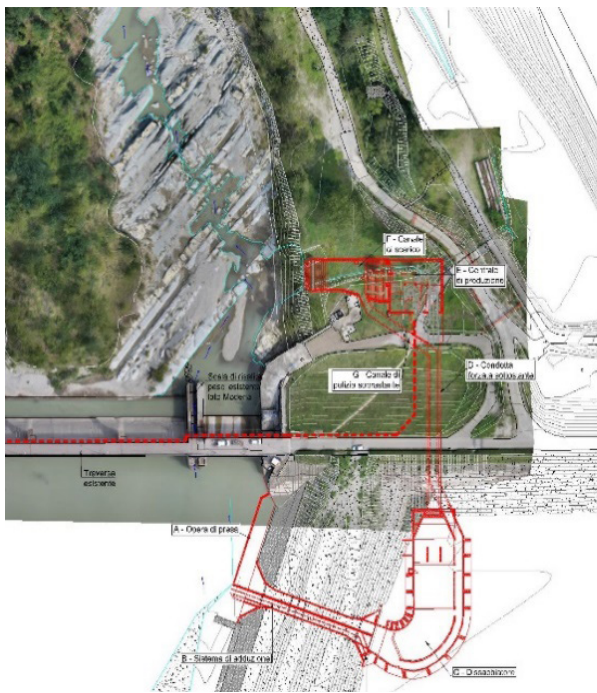
The proximity of the weir's downstream face was considered while doing the excavations. The constructors adopted secant and tangent poles with higher costs than a traditional solution (building on the ground floor). The proposed solution costed around EUR 90,000. The existing weir is an essential element of the local infrastructure: the inhabitants use it for cycling and pedestrian passage. The higher cost of the work was compensated by the social benefits and public acceptance of the intervention.

2.2 Construction techniques

The design choices involved rather complex building activities, responding to different needs, which are:

1. The need to ensure that pedestrians and cyclists could walk and ride through the road over the weir for the entire duration of the works with safe interference management
2. The need to ensure the stability of the weir's earth shoulder, structural and hydraulic elements of the embankment between the lateral reservoir and the river
3. The need to maintain the existing water supplies for the entire construction period and develop a detailed schedule for the construction of the interfering works
4. The need for temporary works to keep the construction site safe (also concerning flood events)

Figure 3. The layout of the plant—an aerial photo



Source: Ada Francesconi

The penstock, of approximately 60 m, has an internal diameter of 3.6 m and crosses the earth shoulder of the weir, cutting it in the transverse direction. The embankment links the central body of the weir to the adjacent slopes. It also preserves the lateral water volume, guaranteeing a perfect static and hydraulic seal. Above the penstock, the constructors installed a concrete channel to discharge the above desilting tank, implementing a trench excavation with support of the fronts through secant poles and construction of the penstock on site. These works reduced interference

with the adjacent structures and those above the embankment. The adopted solution costed EUR 1,160,000.

The design idea of using a concrete pipe instead of a steel one allowed to avoid the installation of the dielectric joint between the pipe and the bifurcated pipe, thus obtaining a constructive advantage. This joint would have been housed in an inspection well of important size and high costs.

After identifying the technical solution in the trench excavation and concrete penstock, it became necessary to study the on-site building. A mobile formwork on wheels was designed by the technicians of the construction companies of Parenti Costruzioni and Peri. They made it possible to create the pipeline in two semicircles, proceeding with the first phase of concrete casting, and then reuse the same inverted formwork for the second phase casting of the upper cap of the penstock. The movement of the formwork up and down along the pipeline was assured through tracks. The construction stages are shown in Figure 4.

Figure 4. Working phases:
(a) building of secant poles



(b) support and excavation



(c) lower semicircle reinforcement



(f) joining of the penstock and bifurcation



(d) formwork of the lower semicircle



(g) second phase of concrete casting



(e) first phase of concrete casting



(h) penstock



Photos: Ada Francesconi

3. BENEFITS

The SHP plant is a very important project for the Sassuolo community. Key benefits are described below.

Economic benefits

- Using the existing structures made it possible to reduce the required civil works and construction costs, saving approximately EUR 500,000. This amount corresponds to a reduced cost of 277 EUR/kW
- The construction of expensive new roads and trails was not needed, thanks to the availability of the existing accesses

Social benefits

- Energy generated satisfies the annual energy need of 3,500–4,000 families (7–10 GWh/year) in the Sassuolo community (Sassuolo Oggi, 2016)¹
- Fifty workers were employed in the construction phase for over 18 months
- Hydropower is being promoted to inhabitants and tourists through special visiting tours. The SHP plant has become a local highlight
- The weir can be used for cycling and pedestrian passage

Environmental benefits

- The construction does not impact the river regime. The water resource is returned into the Secchia riverbed about 100 m from the intake
- The plant can work as a water provider in case of drought
- The carbon emission saving is approximately 3,600 CO₂ tons/year³

4. LESSONS LEARNED AND CONCLUSIONS

1. **The retrofitting of existing structures allows to reduce costs and impacts of SHP construction and test new technologies and methodologies.** It also helps to better maintain the existing structures that, otherwise, may undergo degradation. The benefits are significant in terms of energy generation and water distribution.
2. **The community's needs should always be considered to achieve greater acceptance and support of the project.** In the described project, it was important to respond to the need of having opportunities for cycling and pedestrian promenades over the weir.
3. **The potential of retrofitting existing hydraulic structures is very relevant not only in Italy, but also worldwide.** New technologies are currently under development to improve the retrofitting strategies.

Replication potential

The proposed solutions (such as double connection pipes between the lateral basin and the river & embankment of the lateral reservoir) might be adaptable to other hydropower projects where civil structures are already in place.

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Acknowledgement

The Author would like to acknowledge Ada Francesconi of Conorzio di Bonifica Emilia Centrale for the provided information and pictures.

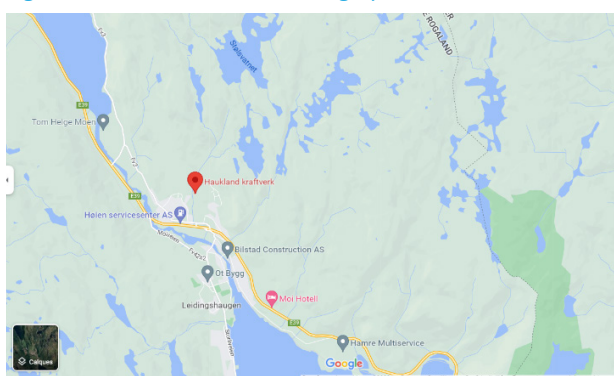
2.4 Automated data-driven optimization of small hydropower cascades

CATEGORY:
TECHNOLOGICAL SOLUTIONS FOR SHP

COUNTRY:
NORWAY

Authors:
Annette Mossel and Liana Haugan, HYDROGRID GmbH

Figure 1. Haukland Kraftverk Geographic Location



Source: Google Maps

Table 1. Project Overview

SHP name: Haukland Kraftverk
Location: Moi, Lund municipality, Rogaland, Norway
Total output: 4.9 MW
Water source: Hauklandsbekken River and Brekkebekken River; Reservoirs of Stølsvatn, Gjelevatn, Skårstemvatn and Stemmevatn
Ownership of SHP: Dalane Kraft
Technology used: HYDROGRID Insight from HYDROGRID GmbH
Status: Optimization based on the HYDROGRID solution since August 2020

Benefits

Economic:

- Increased revenue
- Reduced operating costs
- Reduced risk
- Optimized market forecasting
- Increased market competitiveness: the operating company could grow its market, selling its management services to SHP plants in Norway as well as abroad.

Environmental:

- Automated management of environmental regulations
- Efficient use of water (preventing reservoir spill) with respect to the environmental conditions of the site

Social:

- Better SHP Operations' team focus on high value-added tasks with reduction of manual efforts

Potential: The entire value chain (ranging from hydrological forecasting, automated dispatch power trading to predictive maintenance) would benefit from automated and optimized processes and related technologies.

1. INTRODUCTION

Dalane Kraft AS is a Norwegian medium-sized hydropower producer with 100 years of experience and a hydro portfolio of roughly 45MW installed capacity. Currently, the company owns and operates nine power plants in Rogaland County in Norway. It has several cascades in the range up to 10 MW.

Haukland is one of its cascades, a small hydropower (SHP) plant with the capacity of 4.9 MW located in south-western Norway, at the centre of Moi, Lund municipality. The power plant uses water from the Hauklandsbekken and Brekkebekken Rivers.

Today’s power plant is the third power plant on the site. The first power plant at Haukland came into operation in 1913. Later, various conversions and expansions were made until Haukland power plant came into public ownership in 1943. Later, the first power plant was replaced and in 1949 the second power plant was put into operation, and remained in operation until 2013. Then the old power plant with two turbines and a pipeline was replaced with the current power plant with a buried waterway.

Despite its small capacity, it was a challenge to operate this plant. The site has a complex topology (Figure 3) and Dalane Kraft AS faced technical, environmental and other constraints.

Figure 2. Haukland Power Plant



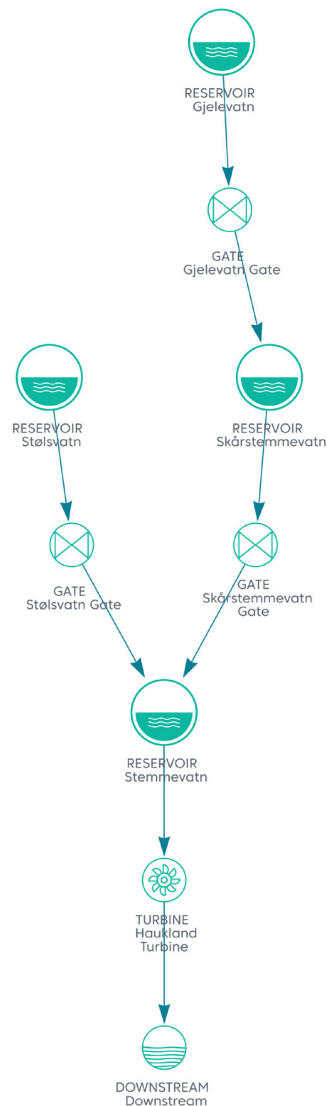
The key challenges are summarized below:

- Multiple connected reservoirs
- Multiple gates used for flow control
- Different catchment areas with different inflow conditions and planning horizons
- Accurate short-term planning for the small basins, in particular Skårstemmevatn, is highly challenging since overflow not only causes spillage but also can lead to the flooding of a bridge located in the close surroundings
- Flexibility of upstream reservoirs is only usable at a short-term notice and only for a limited number of hours when hydrologically possible

It was important for Dalane Kraft AS to find an optimization solution which could help to control parameters of all reservoirs and achieve efficient energy production. Over the last few years, the company intensified its efforts to implement an automated production system, trying to achieve two main goals:

1. Real-time automation: to coordinate a system of multiple reservoirs, gates and turbines in real time is key to avoid spill and imbalance costs;
1. Price-driven dispatch: to exploit the revenue opportunities created by market volatility while ensuring that all technical and environmental constraints are being respected.

Figure 3. Topology – Haukland Power Plant



To achieve the ability to instantaneously react to short-term changes of market and hydrological parameters, the key success factors are:

1. Reliable availability of data
2. Robust and secure data communication
3. Short response time of the optimization model itself.

As a prerequisite for a reliable and robust data communication, the level of automation of the plant’s control system is key. Over the last years, Dalane Kraft expended significant efforts to digitize and automate its operational processes. To achieve a fully automated production system, the company has developed KraftSCADA, a remote SCADA control solution (2018). The KraftSCADA solution is coupled with the optimization system, HYDROGRID Insight which supports the transfer of telemetric data to calibrate the inflow. HYDROGRID Insight offers an innovative and dynamic data-driven approach that helps optimize hydropower plants of varying capacity in an automated way.

HYDROGRID Insight models Haukland’s complex cascade system as a digital copy that comprises Haukland’s multiple reservoirs, gates and turbines while taking into account its different flow times as well as its technical and environmental constraints. Haukland’s actual telemetry is transmitted with an hourly granularity over a standardized and secure RESTful API endpoint (a REST API is a medium for two computers to communicate over HTTP [Hypertext Transfer Protocol], in the same way clients and servers communicate), HYDROGRID Insight utilizes the telemetric data to calibrate their optimization and inflow model and calculates optimal plans for generation and gate opening on an hourly basis. The dispatch plan and gate instruction is read into Dalane Kraft’s KraftSCADA – to fully automate the steering of the power plant. Furthermore, HYDROGRID Insight calculates limit order bid files for the Day-Ahead Market, allowing Dalane Kraft to fully exploit the opportunities provided by power market volatility and, thus, maximize revenues of the Haukland cascade system.

In 2016, Dalane Kraft decided to use their expertise from their own SCADA system by offering operating services of SHP plants to SHP plants both in Norway and abroad.

This case study presents in detail how HYDROGRID Insight is working and what benefits it provides to the SHP operating company.

Global hydropower industry context: a trend of digitalization

The intensified volatility of meteorological and market conditions has led to an increased demand for automated and real-time optimization solutions. Given the type of input – such as rainfall, power demand or market price data – optimization solutions face a complex set of non-linear problems. Additionally, various environmental and operational constraints require a complex planning process, resulting in a need for more resources, both with regard to time and personnel. Consequently, the ability to react in real time is a major challenge for most hydropower producers. However, existing solutions for planning and optimization require high investments and manual resources. Therefore, they are usually not profitable for many operators of small- and medium-scale hydropower plants, which excludes them from the possibility of optimized power plant control. The lack of possibilities for optimal plant control in real time leads to SHP producers not fully utilizing the available physical generation flexibility in their portfolio. New technical solutions are needed to make small- and medium-scale hydropower usable as “green battery” (storage power plants) as well as to promote further investments in renewable energy through higher profitability.

The international hydropower industry is currently going through a massive digitalization process, and such technologies as machine learning with its wide range of

methodological solutions (e.g., deep learning using neural networks) can be used to optimize hydropower operations for all players in the market. The potential for automated and optimized processes spans the entire value chain, ranging from hydrological forecasting to automated dispatch power trading and predictive maintenance.

An optimized dispatch strategy leading to efficiency and profit gains can be achieved by solving the implicit non-linear problem of hydropower optimization, using mathematical models combined with optimization and machine learning approaches. The complexity of the optimization depends on the following parameters:

1. Number of components of the plant topology (gates/hatches, interconnected water bodies, turbines)
2. Characteristics of the connections between the individual plant’s components
3. Flow times and delays
4. Environmental restrictions
5. Technical restrictions
6. Catchment areas characteristics (size, topology, etc.)

The number of relevant parameters, combined with their possible range, results in a high degree of complexity for optimization solutions that are hard to solve by using cumbersome manual processes or individual statistical models for each underlying problem. New technological solutions support process efficiency, save time and can help operations teams to focus on other important tasks.

Table 2. Project Stakeholders

SHP plant operator/owner: Dalane Kraft
Technology provider: HYDROGRID GmbH

2. TECHNICAL CHARACTERISTICS

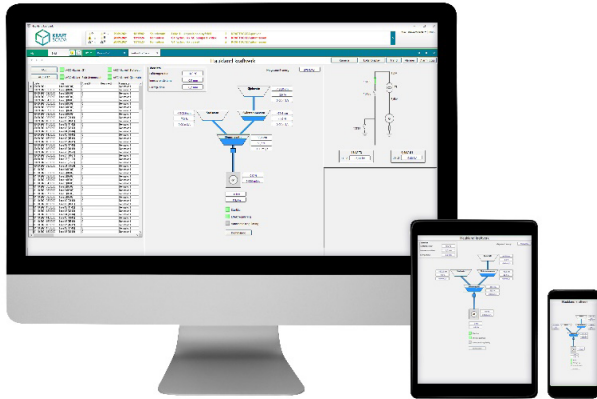
Table 3. Key Technical Characteristics of Haukland Kraftverk

Item	Value
Turbine output	4.9 MW
Total output	4.9 MW
Electricity generation per year	21 GWh
Site condition and parameters of the SHP plant:	Source of water: cascade of 250 metres from the Stemmevatn Reservoir Average yearly inflow: 2.05 m ³ /s Gross head: 252.5 metres Max throughput: 2.2 m ³ /s
Turbine	A horizontal Francis turbine

2.1 Data communication between the plant's control system and the optimization solution

The plant's KraftSCADA control system, which was developed by Dalane Kraft, is coupled with the external optimization solution, HYDROGRID Insight.

Figure 4. KraftSCADA interface



The KraftSCADA technology provides the following key features:

- Remote control and monitoring (including gates)
- Fully automated operation of a hydropower plant (e.g., sending of automated setpoints)
- External IT interfaces provide a high flexibility and ability to integrate with external IT systems (e.g., HYDROGRID Insight)

To establish a fully automated optimal dispatch solution, the data communication between the plant's control system and the optimization solution must be reliable, robust and secure. To provide an optimal dispatch plan, HYDROGRID Insight requires the actual plant's telemetry on a continuous basis. To enable optimal reactions to changes in market and hydrology, the plant's telemetry should be available in high granularity, ideally hourly. Furthermore, all communication between the plant's control centre and the optimization solution must be secure and allow for automated communication feedback in real time.

The plant operation centre has full control over all data at all times.

Figure 5 illustrates the data flow between Dalane Kraft – Haukland and HYDROGRID Insight.-

This ongoing telemetry feeds into the virtual copy of Haukland, modelled within HYDROGRID Insight. The modelling of the plant is done beforehand in a separate step and incorporates all relevant technical parameters of the actual plant as well as environmental restrictions. The precise modelling of gates is, in particular, relevant for the complex Haukland cascade, as gates play a significant role in balancing out the water flow in the system, avoiding spilling and imbalance costs. Consequently, an accurate gate mapping is key to exploiting the full potential of HYDROGRID Insight's optimization. To optimize Haukland, one key aspect was the ability of HYDROGRID Insight to model level-dependent gate openings, resulting in a 3D gate mapping model. Furthermore, HYDROGRID Insight's 3D gate mapping enables correlation to water level, flow rate and gate opening. Haukland's gates can be automatically controlled by using Dalane Kraft's KraftSCADA.

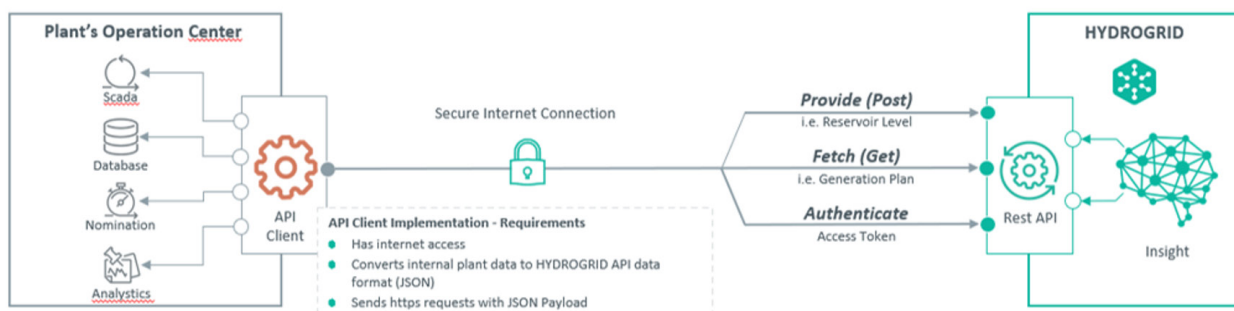
Consequently, KraftSCADA picks up both the optimal dispatch plan and gate opening plans via HYDROGRID Insight's API endpoints to control all components of the Haukland cascade in a fully automated, yet optimal, manner.

2.2 Optimization methodology of HYDROGRID insight

State-of-the-art approaches to cascade optimization are based on stochastic dynamic programming models. These are taking the variations of all the input variables into account, providing probabilities for all possible scenarios as a result. However, this yields a dramatic increase in computational resources needed as the complexity of an asset's topology grows. This increased calculation time renders the real-time reaction to changes in the market or hydrology nearly impossible.

To overcome this challenge, HYDROGRID Insight solves the cascade optimization problem using a more heuristic stochastic modelling approach based on proprietary al-

Figure 5. Data communication between a hydropower plant and HYDROGRID Insight



gorithms. The in-house developed technology focuses on successfully reducing the calculation time. For example, the computing time of Haukland was reduced from 20 minutes to below 3 minutes. Furthermore, HYDROGRID Insight's modelling approach is fully data-driven. The underlying plant model is continuously re-trained based on the actual plant telemetry and other external input data. Combined with proprietary solutions for inflow and price forecasts using machine learning, HYDROGRID Insight provides one integrated optimization solution for short-, medium- and long-term planning. Thereby, HYDROGRID Insight is capable of automatically identifying changes in hydrology or market conditions and automatically adjusts the entire planning horizon.

As a result, the data-driven approach of HYDROGRID Insight allows for high quality yet efficient optimization of multiple power plants. For Haukland, HYDROGRID Insight helped achieve a reduction in computing time by 65 per cent.

2.3 Power trading with HYDROGRID insight

Aside from the automated and optimal dispatch of the Haukland cascade, the other main goal of Dalane Kraft was to utilize the inherent cascade's flexibility in order to maximize its financial results. One of the many advantages of real-time optimization systems is their ability to accurately forecast and react to changes in the power market and adjust the hy-

dropower generation accordingly. Thereby, the nomination process can be shortened and changing from market order to limit order bids becomes possible.

Currently, Dalane Kraft is trading Haukland's generation at Nord Pool AS Day-Ahead-Market. As its flagship feature, HYDROGRID Insight calculates an optimal Spot market position at any point in time. This position is either provided as a Market or Limit Order, depending on the needs of the customer. Historically, the Spot market nomination of Haukland's production was executed based on a Market Order – an hourly generation plan that is immediately sold irrespective of the actual price in the market. To better exploit market volatility and to maximize Haukland's revenues, Dalane Kraft decided to shift from a market order strategy to a limit order strategy, which is in turn provided by HYDROGRID Insight as a limit order bid. A limit order bid is a production matrix, providing the predicted generation on an hourly basis at different strike prices. Subsequently, the actual generation plan is derived by executing the bid against the actual realized prices in the Day-Ahead Market.

2.4 Hydrogrid Insight practical example: real-time optimization and control of the Haukland SHP

One of the main benefits of Dalane Kraft using HYDROGRID Insight was the reduction of manual effort within the

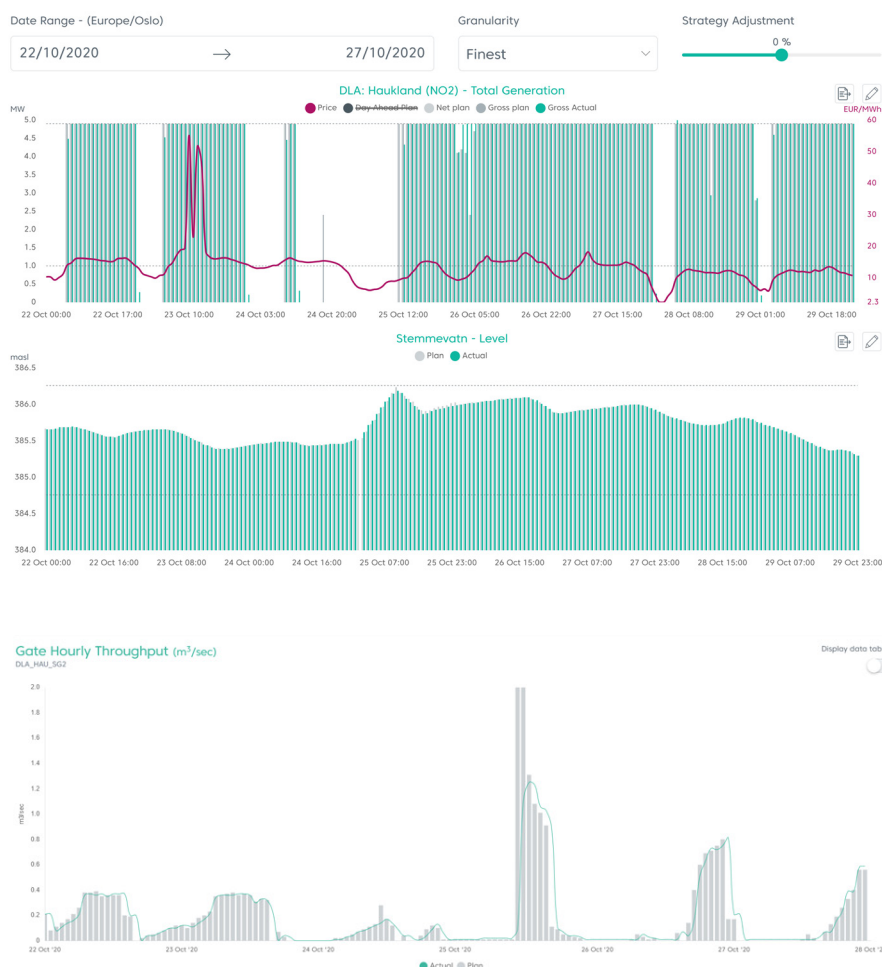


Figure 6. Gate Optimization at the Haukland Power Plant

organization’s operations team, in particular for the small reservoir Skårstemmevatn, which previously induced a high manual workload due to its inherent inflexibility and operational constraints. In Figure 6, a typical reservoir development and dispatch situation of Skårstemmevatn is shown. With HYDROGRID Insight, the risk of overflow on 25 October 2022 was automatically identified and circumvented by optimizing the plant’s gate opening plan. This plan was, in turn, quickly picked up by Dalane Kraft’s KraftSCADA preventing reservoir spilling and thus avoiding imbalance costs. As a result, the full flexibility of the Haukland cascade system was exploited.

A second main goal of Dalane Kraft using HYDROGRID Insight was maximizing revenue by exploiting the inherent flexibility of the Haukland cascade. Using HYDROGRID Insight, price-driven dispatch can be performed.

Figure 7 shows one example of the automatic price-driven dispatch calculated by HYDROGRID Insight for the Haukland

cascade. Whenever the hydrological situation allows, the production is aligned with the power market prices.

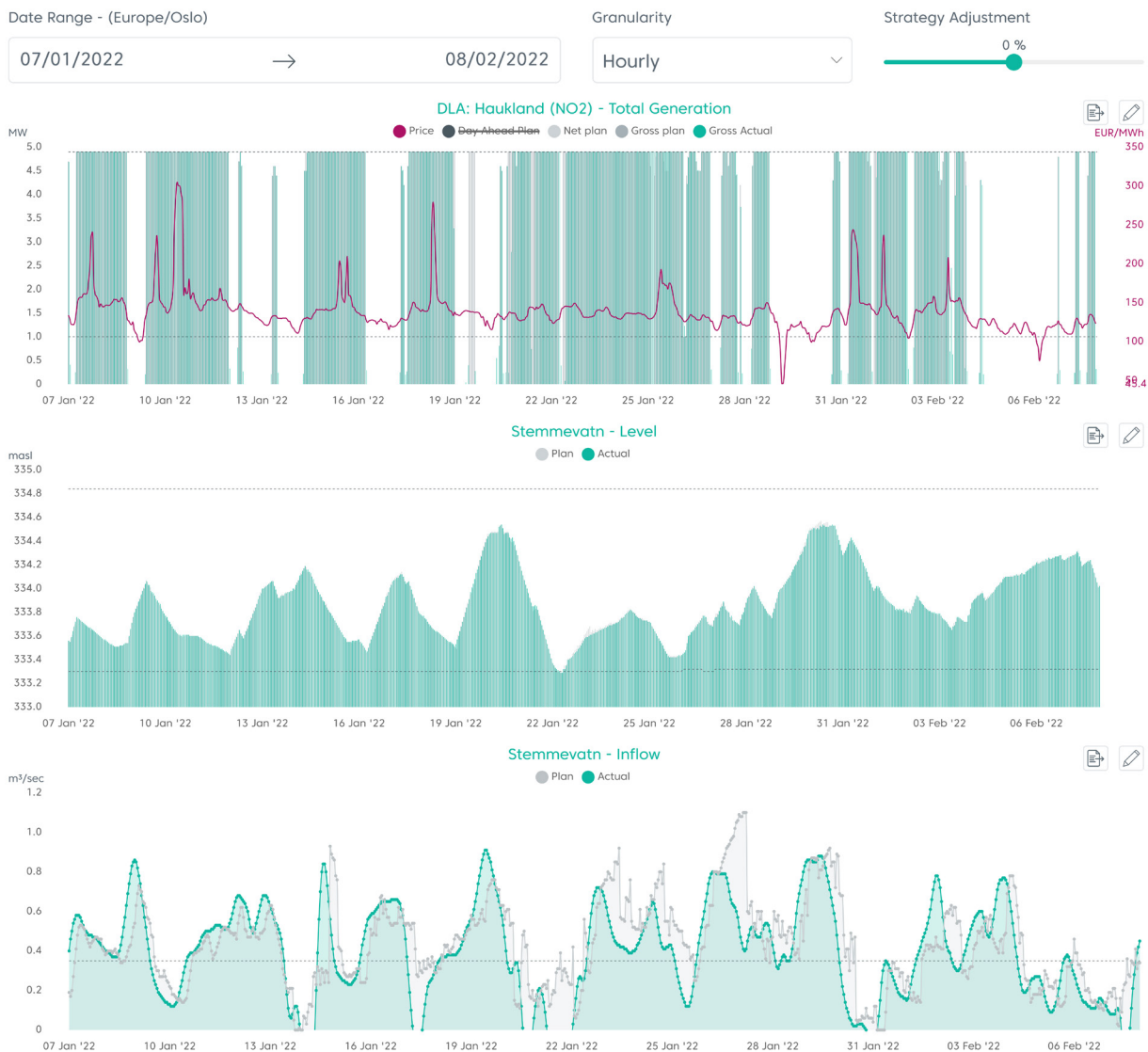
3. BENEFITS

Key benefits of using HYDROGRID Insight technology for the operation of the Haukland SHP plant are described below.

Economic benefits

- The data-driven approach of HYDROGRID Insight allows for high quality, yet efficient, optimization of multiple power plants with a low numerical effort and with minimum personnel expenditure. This brings considerable reduction of operation costs.
- HYDROGRID Insight helps the operating company to fully control all data at all times. This enables Dalane Kraft to react extremely quickly to external changes and exploit the opportunities provided by power market vola-

Figure 7. Example 1 of HYDROGRID Insight’s price-driven dispatch of the Haukland power plant



tility. Thanks to the HYDROGRID Insight, Dalane Kraft can execute the limit order strategy, minimize power trading risks and maximize revenues of the Haukland cascade system. Depending on the hydrological situation and the market price development, the financial outperformance ranges from 5 per cent to 12 per cent (equivalent to EUR 70,000–200,000).

- HYDROGRID Insight is an affordable solution also for Small Hydro Power Plants of below 5MW, which do not require high investment and manual resources. Implementing this optimization solution, Dalane Kraft does not put its profitability at risk.
- This optimization approach supports the market strengths and competitiveness of the operating company: Dalane Kraft can position itself as a top expert in operating SHP plants not only on the Norwegian market, but also on the international level, growing its portfolio with new clients.

Social benefits

HYDROGRID Insight helps reduce the manual effort within the organization's operations team and free resources for other important tasks.

Environmental benefits

- HYDROGRID Insight automatically ensures that all environmental restrictions of the project are followed.
- Maximizing the efficiency by optimizing water utilization (preventing reservoir spilling) and increasing the electricity production from renewable energy sources.

4. LESSONS LEARNED AND CONCLUSIONS

1. **Complex SHP cascades can considerably benefit from an innovative IT data-driven optimization** approach. Such a technology as HYDROGRID Insight can help achieve real-time automation and price-driven dispatch.
2. **The potential for automated and optimized processes spans the entire value chain.** In the HYDROGRID case study, these processes included hydrological forecasting, to automated dispatch power trading and predictive maintenance.
3. **New technical solutions are essential to make small- and medium-scale hydropower usable** as “green battery” as well as to promote further investments in renewable energy through higher profitability.

Acknowledgement

The authors would like to acknowledge Dalane Kraft for their forward thinking and innovative attitude and for a fantastic collaboration.

2.5. Hybrid Configurator to unlock unexploited renewable energy potential (Zambia)

CATEGORY:
TECHNOLOGICAL SOLUTIONS FOR SHP

COUNTRY:
Zambia

Authors:

Christian Scholz, Mostafa Bahaaeldin, Andreas Wetzel; Fichtner GmbH & Co. KG

Table 1. Project Overview

Installed capacity: 11.7 MW hydropower, 12 MW solar PV
Water source: Mwomboshi River
Status of the SHP project: Conceptual level
Status of the technology used: Developed
Technology described in this case study: Fichtner Hybrid Configurator

Benefits from using the technology:

- Lowering development efforts and costs as well as infrastructure costs;
- Availability of electricity at an affordable price.

Potential of using the technology:

The technology can be used for analyzing and designing different hybrid energy systems.

1. INTRODUCTION

In Africa, there is a large unexploited renewable energy potential, especially for rural electrification. A combination of different renewable energy sources can be beneficial for ensuring attractive levelized cost of electricity (LCOE). Hybrid renewable energy systems allow synergies for cost reduction, lowering development efforts and infrastructure costs. They also help to increase the supply access and shift the peaks thanks to higher renewable penetration, storage potential and resource diversification.

Fichtner GmbH has used multiple geographic information systems (GIS), simulations and computational tools feeding one in-house developed environment called Fichtner Hybrid Configurator (FHC), which helps to design hybrid power plants and analyze their technical and financial impact. The FHC can analyze and simulate different energy generation sources such as renewable energy sources (wind power, solar photovoltaics (PV), hydropower, biomass, geothermal power, etc.) and storage technologies, but also diesel or gas generators, taking into account the requirements of the electricity grid.

As part of the ongoing development of the Hybrid Configurator, the Mwomboshi hydropower plant (HPP) on the Mwomboshi River in the Central Province of Zambia was selected as a case study to present the benefits of a hydropower-PV hybrid system and illustrate the methodology and principles of the Fichtner Hybrid Configurator.

The configurator helped to optimally size the hydropower and PV plants together to supply renewable energy to a typical small Zambian grid, achieving the most economic value. The results of the optimum sizes were rendered and showed the potential to increase the power access with the lowest possible LCOE.

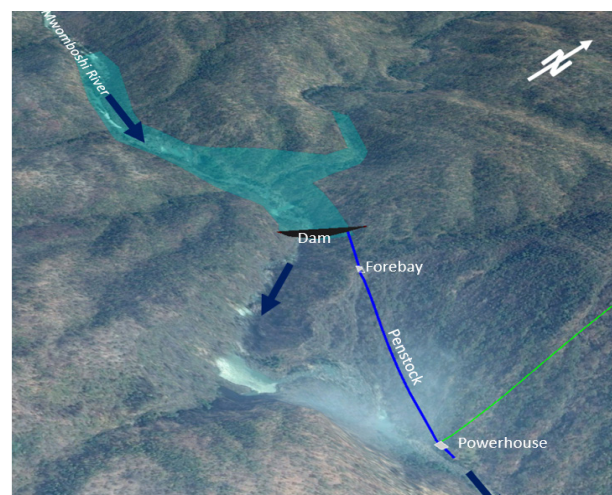
Through the combination of an 11.7 MW HPP with a 12 MW PV plant, the coverage of the load profile in the grid could be increased from 69.4 per cent to 81.4 per cent by having only a slight increase in LCOE from 0.072 USD/kWh to 0.076 USD/kWh.

2. TECHNICAL CHARACTERISTICS

Description

Through GIS-based screening for potential hydropower sites in Zambia, an attractive hydropower site was identified. The selected section of the Mwomboshi River has a natural slope of 190 metres over a length of 1 kilometre, which is ideal for the development of a hydropower plant.

Figure 1. Principal layout of the Mwomboshi site



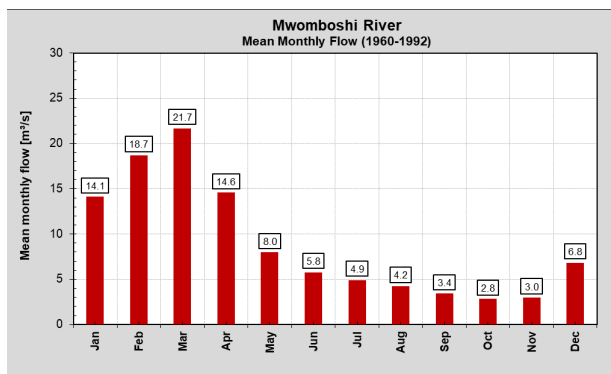
Source: Google Earth

Figure 1 shows the selected river stretch and gives an overview of the conceptual design of the power plant. The design was developed within the framework of a desk study by using free available topographical data. The hydropower plant consists of a concrete gravity dam with an intake structure and subsequent concrete headrace channel which ends at

the forebay. The forebay and powerhouse structure are connected with surface steel penstocks. The powerhouse itself is equipped with two Francis turbines. A short trailrace channel diverts the water back to the Mwomboshi River.

The Mwomboshi River has a mean annual flow of $9 \text{ m}^3/\text{s}$ with mean monthly flow ranging from $21.7 \text{ m}^3/\text{s}$ during the wet season (January–April) in March to $2.8 \text{ m}^3/\text{s}$ during the dry season (May–December) in October (Figure 2).

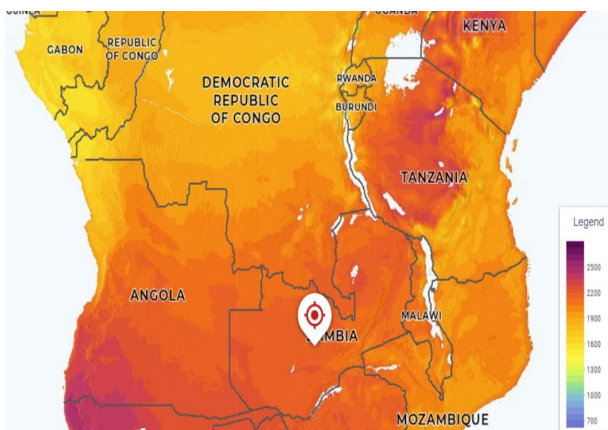
Figure 2. Mean monthly flow at the Mwomboshi River in 1960–1992



Using the in-house developed software called HydroPower-App (HyPApp), Fichtner considered several design options for the Mwomboshi HPP by varying dam height and design discharge and estimated quantities and costs of civil works as well as hydromechanical and electrical equipment. The best plant size in terms of the least LCOE and load coverage of the load profile in the grid was then determined by applying the Hybrid Configurator (see below).

The solar PV potential in Zambia is regarded as very good compared to other countries in Sub-Saharan Africa, with irradiation levels reaching above $2,000 \text{ kWh}/\text{m}^2/\text{year}$ at the Mwomboshi site (Figure 3).

Figure 3. Solar resources (Global Horizontal Irradiation) in part of Sub-Saharan Africa



Source: SolarGIS

Fichtner utilized the market standard software PVSyst to accurately simulate a typical reference block of PV plant at the site of interest. A configuration with fixed-tilt PV modules and string inverters was selected to guarantee the highest possible plant reliability due to the remoteness of the site and limited availability of suppliers' services near the site. The simulated block of the PV plant was then linearly scaled up in fine steps by Fichtner Hybrid Configurator until the optimum capacity was reached.

Application of the hybrid configurator

The Fichtner Hybrid Configurator software was certified according to VDE-PB-014 for bankable hybrid plant simulations. This software helps to design hybrid power plants (including storage technologies) and analyze their technical and financial impact. It allows simulation in fine timesteps down to one-second resolution for extended operation periods of up to 40 years. The software has been programmed in MATLAB (a programming and numerical computing platform used to analyze data, develop algorithms and create models). The Fichtner Hybrid Configurator simulates each configuration for their entire project lifetime considering, for example, PV module degradation or operation maintenance cost of the hydropower plant. This way the optimum system configuration can be determined for each key financial or technical parameter.

The following principal input data were used for the application of the Fichtner Hybrid Configurator for the Mwomboshi case study.

For the hydropower plant:

- hydrology (mean monthly or daily flows);
- reservoir capacity curve;
- operation limits (minimum admissible turbine flow, dead storage);
- Capital Expenses (CAPEX) and Operational Expenditures (OPEX) of the hydropower plant in relation to dam height and discharge.

For the PV plant:

- site-specific satellite irradiation data (kWh/m^2);
- degradation of the PV plant over its lifetime;
- specific CAPEX and OPEX of the PV plant.

Financial parameters:

- operation time: 25 years;
- discount rate: 10 per cent;
- analysis period: 25 years;
- interest rate of debt: 3.0 per cent.

Within the framework of this case study, the following load profiles were considered:

Figure 4. Typical load curves for a smaller grid in Zambia, one typical day and one year profiles

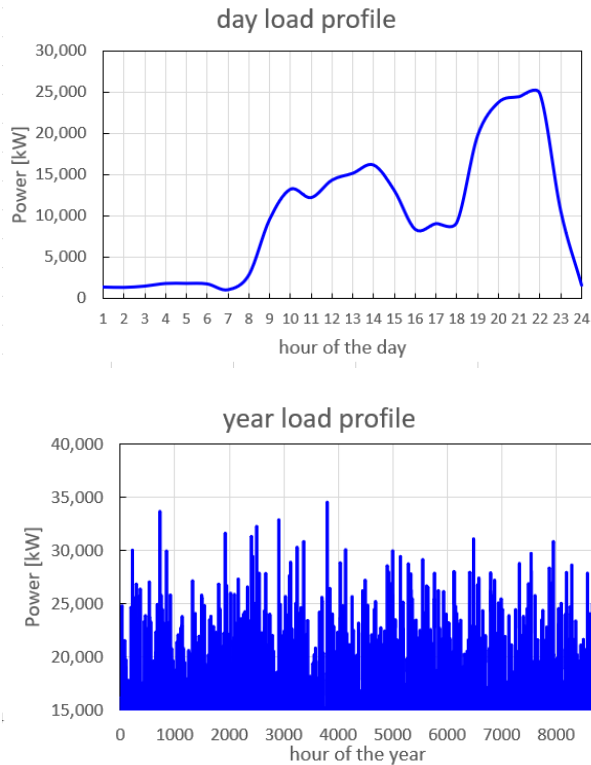


Figure 4 shows a typical load curve for a smaller grid in Zambia over one year with a maximum load of approximately 34 MW and a mean annual load of 8.3 MW.

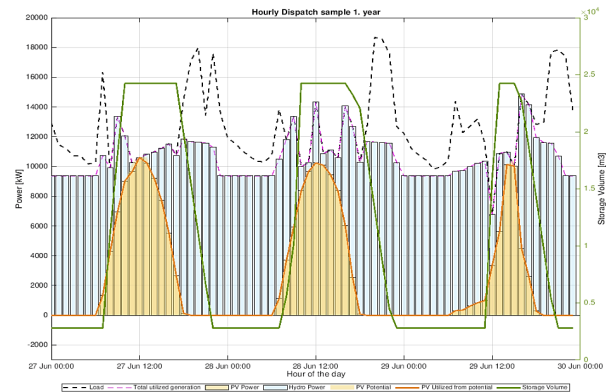
In the case of the Mwomboshi HPP, the Fichtner Hybrid Configurator considered a design discharge varying from 6 m³/s to 12 m³/s and a dam height varying from 10 metres to 30 metres. The upper limit for the PV plant size was set at 35 MW. The different design options for the Mwomboshi HPP (dam height, design discharge) were combined with different PV power plant sizes and evaluated against the calculated LCOE.

The Fichtner Hybrid Configurator includes a dispatcher (or main power plant controller) which performs the energy management. The goal is safe, reliable and cost-efficient operation depending on the load and other technical input parameters.

Figure 5 shows a three-day period in June (an example of a year from the 1960–1992 data series) with a mean monthly flow of approximately 5.8 m³/s. The left y-axis indicates the power in kW and the right y-axis presents the storage volume. The Fichtner Hybrid Configurator follows a merit order in a way that the PV power plant shall first feed into the grid, and if the PV power is enough to cover the load in the

grid then the hydropower plant will be switched off. Otherwise, the hydropower plant will cover the gap between load and available PV power. Each time the hydropower plant is switched off or the hydropower plant is operated at partial load, the storage is filled as can be seen by the green line in the figure. The violet line represents the total generated power of the hybrid plant. The code of the configurator is written in such a way that the total generated power will not exceed the load demanded in the grid.

Figure 5. Visualization of the methodology of the Fichtner Hybrid Configurator



The light blue bars in the figure indicate the produced hydropower. It can be noted that during the night the storage is empty and the hydropower plant is operated as a run-of-river plant with the available inflow of 5.8 m³/s and a power output of approximately 9.6 MW. Only during the daytime when the PV plant is operating, the storage will be filled, which then after the PV plant is switched off at approximately 6 pm, enables the hydropower plant to operate for four hours almost at full load (11.7 MW).

Figure 6. LCOE in conjunction with different design discharge and dam heights

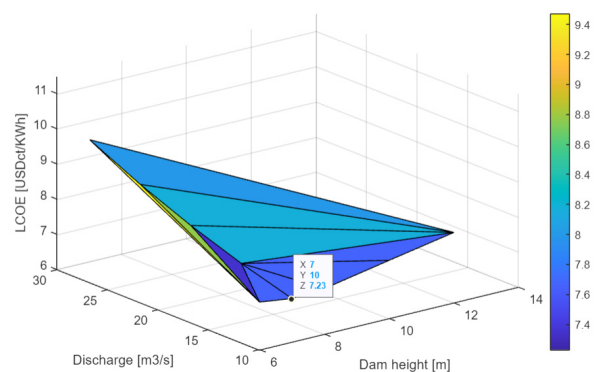
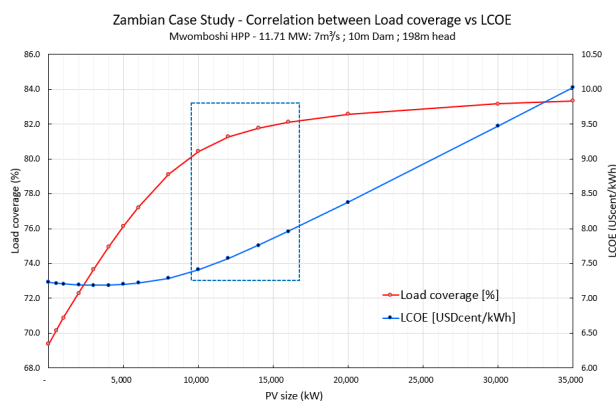


Figure 6 shows that the least LCOE is at 7 m³/s design discharge and 10 metre dam height. The hydropower plant has a rated power of 11.7 MW and a total rated head of 198 metres. This hydropower plant layout achieves a load coverage of 69 per cent having an LCOE of 0.0723 USD/kWh. The storage volume of the reservoir is approximately 24,250 m³. Con-

sidering a design discharge of 7 m³/s, the reservoir will be emptied within less than an hour. Higher dam heights with bigger storages have been calculated but are not economic at the Mwomboshi site since the civil cost will increase tremendously with increasing dam height without having special financial incentives, such as a peaking tariff.

Figure 7 shows the correlation between the load coverage (left y-axis) and the LCOE (right y-axis) with varying PV plant size (x-axis) from 0 MW to 35 MW.

Figure 7. Correlation between load coverage and LCOE of the hybrid system with different PV plant sizes



If the focus is only on the least LCOE, then a PV plant with an output of 4 MW, LCOE of 0.0719 USD/kWh and a load coverage of almost 75 per cent could be achieved by the hybrid power plant. Compared to the hydropower plant without PV, the LCOE was slightly decreased but the load coverage could be improved by 6 percentage points from 69 per cent to 75 per cent. By looking at the load coverage graph (Figure 7), it is noted that the graph has a logarithmic function with saturation at approximately 83.5 per cent. The blue rectangular in the figure indicates an economical range with a PV plant size from 10 MW to 16 MW where the LCOE (0.074–0.080 USD/kWh) varies only slightly but there is still considerable gain in load coverage (80.4–82.1 per cent). The final setup for the hybrid power plant ultimately needs to be determined in conjunction with the power utility in order to best respond to their needs while also considering the stability of the grid.

3. BENEFITS

The technology helps to achieve different benefits as outlined below.

Economic benefits

The technology helped to design an optimized hybrid power plant that combined PV and hydropower to supply renewable energy to a typical small grid in Zambia. Accurate design and planning mean reliability and availability of electricity with an attractive LCOE. This can be very important to investors and development entities. The technology supports the hybridization of multiple renewable energy systems helping

to achieve cost reduction, lowering development efforts and infrastructure costs, etc.

Social benefits

Availability of electricity at an affordable price means improved living and business conditions for local communities and supports the fight against hunger and poverty.

Environmental benefits

The use of renewable energy sources, such as solar PV and hydropower, helps to reduce the use of, for example, solid biomass in an unsustainable way, which can lead to health diseases and deforestation.

4. LESSONS LEARNED AND CONCLUSIONS

Reliability and availability of energy in such regions as Sub-Saharan Africa has a huge significance, in economic, social and environmental terms.

Modern software can be very useful to investors and development entities, helping to reduce risks and costs and develop multiple renewable energy systems in the most sustainable way.

Innovative technologies such as the Fichtner Hybrid Configurator are powerful tools that help unlock the large untapped renewable energy potential in Africa, as they are able to simulate all relevant renewable energy sources such as solar PV, wind power and geothermal power, including hydropower and green hydrogen, making the Configurator perfect for green energy-based electrification in rural areas.

Furthermore, the hybridization of existing dam reservoirs to evaluate floating PV concepts could be another area of application. However, advantages of using a common feed-in point are facing legal and financial challenges. Thus, special Power Purchase Agreement (PPA) structures would have to be developed (either separate for PV and hydropower or a joint PPA) and incentives need to be implemented to provide storage capacity and for changing or adjusting the operation scheme.

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3. Green SHP

3.1. Unlocking the hidden hydropower potential of wastewater treatment facilities (Ukraine)

CATEGORY:
GREEN SHP

COUNTRY:
Ukraine

Authors:

Dmytro Stefanyshyn, Institute of Telecommunications and Global Information Space; Ashot Petrosian, «Hydroenergetica LLC Company»

Table 1. Project Overview

SHP plant names: 1) Poltava SHP plant and 2) Kapustyanska SHP plant

Location: 1) Near the city of Poltava
2) Zaporizhzhia City

Installed capacity: 1) 190 kW and 2) 484 kW

Water source: 1) Suprunivska sewage treatment facility
2) Kapustyansky Reservoir

Key actors and owners: 1) LTD “Poltava Hidro” 2) LTD “Hidropauer-1”

Construction cost: 1) EUR 500,000 2) EUR 1,000,000

Support schemes/incentives: Feed-in tariff

Status of the SHP project: Both plants were commissioned in 2018

Benefits

Economic:

- Profitability of projects
- More efficient operation of waste water treatment plants

Environmental:

- Use of existing infrastructures, without damaging the ecology of rivers

Social:

- Not harming the local communities

Potential: This experience can also be useful for other countries with availability of existing reservoirs, ponds, sewage and waste water treatment infrastructure.

1. INTRODUCTION

Small hydropower (SHP) plays a marginal role in the renewable energy sector of Ukraine. In 2020, SHP accounted for less 2 per cent of all hydropower production in the country. As opposed to the state-owned large hydropower sector, SHP belongs to the private sector and has been developed as a renewable energy source eligible to benefit from the feed-in tariff (FIT). Private investors are keen to promote SHP as an environmentally-friendly alternative to large hydropower and other energy sources. However, in the Ukrainian context, it is often a source of great concern for environmentalists and local communities, particularly in the case of developing new plants on untouched rivers. Often SHP plants are developed spontaneously, without due regard for environmental issues. There are some cases when SHP projects destroy river ecosystems and harm local communities.

Climate change is another concern for SHP in Ukraine, with summer droughts causing a decline of river runoff. Small rivers in the country may disappear especially in low-water periods and that will significantly limit the operation of SHP plants.

At the same time, Ukraine possesses a hidden hydropower potential for SHP development, which includes existing non-powered dams, municipal and industrial reservoirs and ponds, as well as the widespread sewage and wastewater treatment infrastructure. This hidden potential has not yet been thoroughly studied in the country although it could boost the implementation of successful SHP projects while reducing their potential adverse environmental impacts.

This case study presents the hidden SHP potential of Ukraine and provides two examples of successful SHP development in the country, which demonstrate that hydropower projects can be economically attractive as well as environmentally friendly.

The first one is the Poltava SHP plant developed by LTD “Poltava Hidro”. The plant is located in the village of Horbanivka near the city of Poltava at the Suprunivska sewage treatment facility. The project was supported by the Ukrainian office of the World Wildlife Fund (WWF) and is considered by WWF as sustainable and green. The project implementation started in 2014 and was finalized in 2018.

The second one is the Kapustyanska SHP plant developed by LTD "Hidropauer-1". It is located in the city of Zaporizhzhia on the Kapustyansky sludge reservoir. The project was successfully commissioned in 2018.

Peculiarities of SHP development in Ukraine

Although Ukraine has a relatively developed river network formed by more than 63,000 rivers and streams, the total feasible technical **hydropower potential in the case of local rivers, taking into account the country's area, is one of the lowest in Europe** and in the world. The majority of rivers flowing through the territory of Ukraine show a relatively low and uneven runoff, with up to 70 per cent or more of their annual runoff occurring during short periods of floods. In addition, most rivers where SHP plants are situated or planned have relatively small height differences from source to mouth.

At the beginning of 2020, there were 167 SHP plants in operation in Ukraine with a total installed capacity of 119.6 MW. The share of SHP in total hydropower production in the country varied from 1.2 per cent in 2010 to 1.9 per cent in 2020. At the same time the capacities of solar and wind power considerably rose since 2010, reducing the share of hydropower in the renewable energy mix of Ukraine. In 2020, the share of SHP in the country's non-traditional renewable energy mix (*excluding large hydropower*) became the lowest (less than 2 per cent) compared with solar power (73 per cent), wind power (16 per cent), household solar power (8 per cent) and biomass and biogas power (2 per cent).¹

However, due to the FIT, the number of SHP plants in the country continued growing. In 2021, their number increased by 9 new installations and reached 176. New SHP plants were built as part of existing cascades that are already in operation (on the Southern Bug and its tributaries, Sluch, Ros and Seret Rivers) and on some free-flowing rivers (mainly on the rivers of the Ukrainian Carpathians). Recently, developers started paying attention to the existing hydraulic infrastructure and its so-called hidden hydropower potential. For example, in 2021 one SHP plant, with a capacity of 1 MW, was under construction on the existing reservoir of the Dobrotvir thermal power plant on the Western Bug River (Figure 1).

Figure 1. The Dobrotvir Reservoir

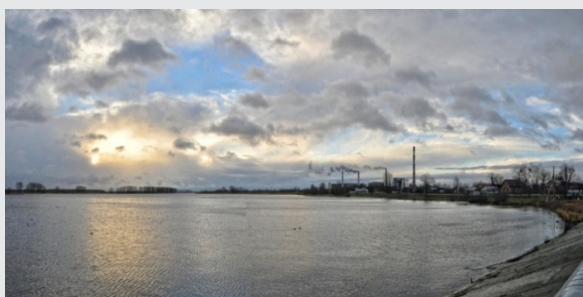


Photo by Mykola Swarnyk / Source: Wikipedia³

In total, there are more than 1,103 reservoirs in Ukraine in operation, with a total water volume of approximately 55,500 million m³, and 50,793 artificial ponds (reservoirs with a capacity not exceeding 1 million m³) with a total water volume of 3,969.4 million m³. Just some of the reservoirs and ponds, approximately 200, have been used in hydropower. Most of them have other purposes that include water conveyance by canals, thermal and nuclear power generation, irrigation, municipal and industrial water supply, fishing and recreation (Figure 2). There is also a large number of small non-powered dams performing the functions of flow regulators (Figure 3 and 4).

Figure 2. Hydraulic structures of the Pecheneg Reservoir on the Siverskyi Donets River, Kharkiv region



Source: YouTube⁴

Figure 3 and 4. Two sluice-regulators on the Goryn' River, near the village of Voskodavy (a), and the village of Metkiv (b), Rivne Region

(a)



Source: Mapio⁵

(b)



Photo by Dmytro Stefanyshyn

An important challenge to SHP development in Ukraine is resistance from environmentalists and local communities. This resistance is largely a result of unsustainable SHP practices in the past. The concerns are related to rehabilitated SHP plants on rivers in the plain region of Ukraine and to new SHP plants built recently on the small rivers in the Ukrainian Carpathians. Overall, SHP development in Ukraine carries significant environmental and water-related risks because of the scarcity of water resources in small rivers. There were many examples of non-compliance with existing building codes, violations of the Water Code requirements as well as the requirements of the Law of Ukraine on “Environmental Impact Assessment” (EIA) on the side of both SHP developers and regulatory agencies.

As for the social context, SHP in Ukraine is part of the country’s Integrated Power System (IPS). At present, none of the SHP plants in the country are stand-alone, independent schemes supplying electricity for local communities or any other private needs. Therefore, commonly, local communities do not have any economic benefit from those facilities. That circumstance inevitably gives rise to socio-environmental conflicts, especially when SHP developers aim to use untouched rivers.

Moreover, between 2013 and 2020, the installed capacity utilization rate (ICUR) of Ukrainian SHP plants decreased from approximately 44 per cent to 20 per cent (Table 2).¹ Such a significant decrease of ICUR may be explained first of all by the reduction of water discharge in the rivers on the territory of Ukraine, which occurred during that period. In turn, the water shortage issue may be explained by the adverse impacts of climate change, which has intensified in recent years. Secondly, it might have been a result of the insufficient substantiation of many SHP projects, especially new ones, in particular, due to the overestimation of feasible hydropower potential because of poor hydrological forecasting.

Table 2. The SHP development dynamic in Ukraine between 2013 and 2020

Year	2013	2014	2015	2016	2017	2018	2019	2020
Installed capacity (MW)	75	80	87	90	95	99	114	119
Electricity production (GWh)	286	251	172	189	212	231	242	209
ICUR (per cent)	44	36	23	24	25	27	24	20

In the future, climate change could significantly affect the SHP sector of Ukraine, which uses natural water resources. Extreme weather events such as summer droughts with declining river runoff are expected to become more

common. Some small rivers in the country may disappear altogether or their runoff, especially in low-water periods, will significantly limit the operation of SHP plants. There have already been such cases.

2. TECHNICAL CHARACTERISTICS

Table 3. Key Technical Characteristics of Poltava SHP Plant

Item	Value
Installed capacity	190 kW
Design head	36 m
Design discharge	0.7 m ³ /s
Expected electricity generation per year	1.24 GWh
Installed capacity utilization rate ICUR	75 per cent

Table 4. Key Technical Characteristics of Kapustyanska SHP Plant

Item	Value
Installed capacity	484 kW
Design head	32 m
Design discharge	2 m ³ /s
Expected electricity generation per year	2.1 GWh
Installed capacity utilization rate (ICUR)	75 per cent

The Poltava and Kapustyanska SHP plants have the highest ICUR values (reached approximately 75 per cent) among the country’s fleet of 176 operating SHP plants (2021). These plants were developed as non-conventional pilot projects in wastewater treatment facilities.

The Poltava SHP plant is located at the Suprunivska sewage treatment facility with a capacity of 40,000 m³ of treated wastewater per day. The plant was developed as a commercial project. During its construction, new technological pipelines were laid, replacing the damaged ones. This significantly increased the treatment facility’s reliability and reduced its environmental impact. The topography of the site makes it possible to provide a hydraulic head of treated wastewater of approximately 40 metres. The Poltava SHP installation (Figure 5) has a Crossflow two-chamber turbine with a capacity of 198 kW working at 17–100 per cent of water discharge with high efficiency and a 192 kW Asynchronous generator. The water supply to the turbine is regulated automatically; there is no personnel. The turbine bearings are located outside the turbine housing, which prevents oil from entering the water. While commissioning the Poltava

SHP plant, the General Director of “Poltavavodokanal” Vasyly Vorotintsev stressed that such experience can be extremely useful for energy saving at water supply and sewerage companies.

The second SHP, the Kapustyanska plant was implemented in the city of Zaporizhzhia on the Kapustyansky Reservoir (Figure 6 and 7). The main structures of the reservoir were built in the 1960s to accumulate sludge from wastewaters and water clarification before its discharging into the Kapustyanka stream and further into the Dnieper River. The SHP installation has a Crossflow two-chamber turbine with a capacity of 520 kW and a 500 kW Asynchronous generator. The Kapustyansky sludge reservoir has been equipped with an automated bypass system in case the SHP plant does not work. Due to this system, if necessary, water can be freely discharged from the reservoir.

Figure 5. Poltava SHP plant at the Suprunivska sewage treatment facility



Photo by Ashot Petrosian

Figure 6. Kapustyansky Reservoir site, the city of Zaporizhzhia



Source: Google Earth

Figure 7. Kapustyanska SHP plant



Source: YouTube⁶

3. BUSINESS FIGURES

Table 5. Business Figures of the Two Plants

Poltava SHP	
Expected income per year	EUR 195,000
Costs	Approximately EUR 500,000
Payback period	3–3.5 years
Kapustyanska SHP	
Expected income per year	EUR 260,000
Costs	Approximately EUR 1,000,000
Payback period	4–4.5 years

4. BENEFITS

Benefits of the SHP plants at waste water treatment facilities are presented below:

- These SHP plants are commercially profitable projects, due to the FITs;
- The SHP plants contribute to energy saving at water supply and sewerage facilities: by utilizing the potential of waste water treatment reservoirs, they make the operation of these facilities more energy efficient;
- Projects helped to upgrade the treatment facilities' infrastructure, increased its reliability and consequently reduced the impact of wastewater treatment facilities on the environment;
- These SHP plants do not cause a conflict of interest and do not negatively affect local communities;
- The SHP plants do not harm the ecology of the rivers, using the hidden potential of existing structures.

5. LESSONS LEARNED AND CONCLUSIONS

1. SHP plants implemented in the wastewater treatment infrastructure can be successful business projects.

For example, being eligible to benefit from the FIT, the Poltava SHP plant enables generating a total income of approximately EUR 195,000 per year. This project's payback period is estimated at approximately 3–3.5 years. For the Kapustyanska SHP plant, its total income may exceed EUR 260,000 per year and the payback period is estimated at approximately 4–4.5 years.

2. SHP should be developed taking into consideration environmental and social issues and not only business interests.

Currently, SHP in Ukraine has been predominantly developed within the framework of commercial projects. Some of these projects parasitized on the FIT system, causing significant damage to river ecosystems and local communities. These bad practices must be avoided in the future. The good examples (as those described in this case study) show that it is possible to develop plants on wastewater treatment infrastructure in an environmentally friendly way without harming the ecology of rivers or the interests of local communities and other stakeholders. Such SHP projects contribute to energy conservation and rational use of available resources.

3. In some countries, like in Ukraine, all energy plants are part of a country's Integrated Power System and the energy produced is being supplied to the national grid. Such situation can be a basis for social conflicts since local communities and businesses do not see any "personal" interest in building new plants. The development of independent energy supply schemes, which would focus on providing energy for particular

communities, areas, businesses, could support the upscale of small hydropower plants.

4. Some factors can decrease the installed capacity utilization rate of SHP plants.

For example, in Ukraine one of the possible reasons is water shortage, which is likely caused by the adverse impact of climate change. Another reason could be poor hydrological forecasting. Both factors need to be taken into consideration while developing new projects. In the context of the climate change and shortage of water sources, the development of green SHP plants becomes even more important.

5. Wastewater treatment facilities could be considered as one of the most prospective areas for future SHP development.

The hidden hydropower potential of these facilities can be unlocked through specific regulations and incentives. On the one hand, it is important to define no-go areas for SHP development to prevent bad practices. On the other hand, the governments should propose incentives for SHP development within existing human-made water infrastructure: non-powered dams, municipal and industrial reservoirs and ponds, sewage and wastewater treatment runoff pipes, systems for the distribution of water for agricultural or other purposes.

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