WORLD SMALL HYDROPOWER DEVELOPMENT

REPORT 2019

Case Studies

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Outline

Introduction

This section comprises 18 case studies of successful small hydropower (SHP) implementation in a range of communities and aims to add a more detailed, practical perspective on the transformative potential of SHP and the best practices. Case studies give specific examples of communities that use SHP for productive use to meet their needs and improve quality of life. The purpose of this new section is to make the learnings drawn from such experiences easily accessible, forming a knowledge base that can benefit communities, decision-makers and developers elsewhere.

The cases demonstrate how reliable access to electricity provided by SHP revolutionizes the daily lives of communities worldwide, in particular in rural areas, creating employment opportunities, stimulating economic development, strengthening the capacity of existing infrastructure and local institutions, while minimizing negative environmental impacts. The following five aspects of SHP development are covered in the case studies.

SHP for productive use: While lack of access to electricity holds back economic development, SHP can create new opportunities for local businesses by providing power infrastructure, as demonstrated by the examples of 165 SHP projects developed under the Sarhad Rural Support Programme in Pakistan and the Gura SHP developed by the Kenya Tea Development Agency in Kenya. In these cases, reliable access to electricity through SHP allowed local enterprises to expand and create new business opportunities through higher efficiency and productivity, and reduced costs.

SHP for social and community development: Lack of electricity also constitutes a significant barrier to human, social and community development, specifically impacting vulnerable groups, including women and young people. The examples of SHP projects in the Dominican Republic, Nicaragua, Zambia, Tajikistan, Japan, the Democratic Republic of the Congo and China demonstrate that SHP can create conditions for communities to improve their quality of life, create employment, increase the standard of public service provision, improve overall health and education and achieve greater autonomy, even in areas affected by armed conflicts.

SHP financing: Access to financial resources is one of the most common barriers to SHP development across the countries due to high upfront investment required for launching a project. It is often the case that local banks' ability to support SHP projects is constrained by single borrower exposure limits imposed by central banks, with their own internal guidelines being predominantly based on collateral borrowing. However, innovative mechanisms have been developed by some international and local banks to support projects such as SHPs. Thus, the Risk Sharing Framework of the European Bank for Reconstruction and Development offers local partner banks funded or unfunded risk participation schemes, which, for example, supported the development of the Akhmeta SHP in Georgia. Ping An Bank, a commercial Chinese bank, offers customized financial assistance for SHP construction and operation in poverty-stricken areas of the country.

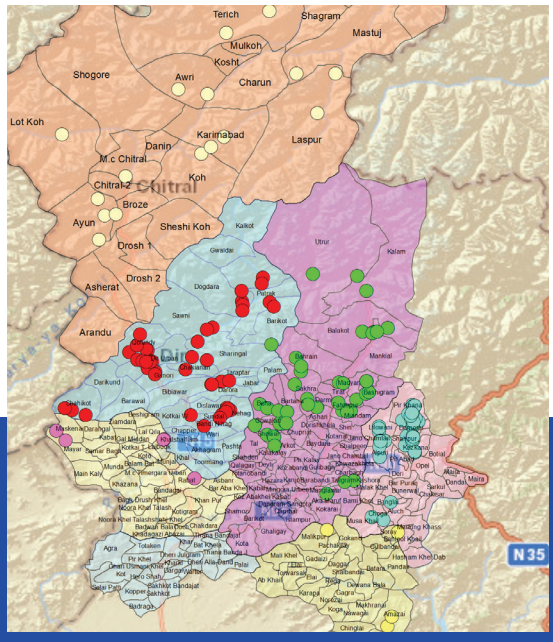
Technology, innovation and smart SHP: SHP development can also be restricted due to a lack of suitable sites, in particular, when the most attractive potential has already been harnessed or when strict environmental or other regulations limit further development in areas with available potential. However, as the case studies demonstrate, a range of technical solutions exist that can help adapt the technology to local regulations and bring it to more communities. These include using existing hydro-technological infrastructure for the installation of an SHP, as in the case of the Zagrody SHP in Poland; the innovative fish lift sluice system developed by Der Wasserwirt; the Turbulent turbines, which allow harnessing the potential of low head streams; and hydrokinetic turbines developed by Smart Hydro Power which can be installed in rivers but also in existing infrastructure such as canals or water regulation dams.

Incentive policies for SHP development: Another common barrier to SHP development is a lack of a regulatory framework that would encourage the use of SHP and make the sector more attractive for investment. The example of Panama demonstrates how SHP development can accelerate with the support of appropriate incentive policies.

Green SHP: Unregulated SHP development can result in significant ecological impact, including river dehydration, changed river ecology, reduced river connectivity and affected migratory fish and other aquatic species. To maintain the ecological safety of the sector, the future of SHP development should be in the form of green SHP, supported by regulations, guidelines, incentive policies and practices. Two case studies outline the measures taken in China and Austria to promote SHP construction and rehabilitation in line with the principles of ecological sustainability.

1. SMALL HYDROPOWER FOR PRODUCTIVE USE

1.1 SARHAD RURAL SUPPORT PROGRAMME: SMALL HYDROPOWER IN PAKISTAN



Sources: Esri, DeLorme, NAVTEQ, USGS, NRCAN, METI, iPC, TomTom

Atif Zeeshan Rauf, Sarhad Rural Support Programme

Seven years ago the non-governmental organization Sarhad Rural Support Programme (SRSP) started developing small hydropower (SHP) projects in Malakand Division, Khyber Pakhtunkhwa, Pakistan with funding from the European Union under the Programme for Economic Advancement and Community Empowerment (EU/SRSP-PEACE). A key goal was to produce clean and renewable energy while promoting small hydropower (SHP) for productive use and rural development. Today, the expanded programme benefits a population of well over half a million people (mostly off-grid) – and helps improve economic prospects and life quality for marginalized groups in one of Pakistan's harshest environments.

In 2012, SRSP (Box 1) decided to develop village-level SHP schemes in six districts of Malakand Division, a remote and inaccessible part of Khyber Pakhtunkhwa Province of Pakistan, in partnership with the European Union under the Programme for Economic Advancement and Community Empowerment (EU-PEACE). The area is home to an estimated 2.2 million people, many of whom live in isolated villages. Around a quarter of the population have no connection to main grid electricity, as the state never extended power infrastructure in these localities in part due to poor governance, bad access roads, harsh winters and the ever-present risk of natural disasters.

Active across Malakand Division for many years under the wider EU-funded regional support programme, SRSP recognized the large technical potential for hydropower given plentiful water resources including glacial-melt water streams and rivers. Working at the community level, SRSP also saw how the lack of access to electricity had the effect of holding back the region's economic and social development. From an early stage, SRSP put these two factors together, strengthening its commitment to SHP for productive use and considering the transformative potential of SHP technology in terms of poverty mitigation for marginalized groups.

Developing and managing SHP projects in six districts of Malakand Division

SRSP's SHP projects were developed under the umbrella of the EU-funded PEACE (Box 2). The SHP initiative comprises about 165 SHP projects across six separate Malakand districts – Buner, Chitral, Dir Lower, Dir Upper, Shangla and Swat. Collectively, the SHP projects have an installed capacity of 21.3 MW generating renewable and sustainable electricity for

the benefit of an estimated 625,000 people from largely off-grid and marginalized communities.

With experience on wider development issues in the region, SRSP understood that for the hydropower schemes to succeed, it was essential to involve and engage the local communities. Throughout each project development, SRSP works closely with community-based institutions, including village organizations, or apex-level support organizations at Union Council level, along with support from programme technical teams to identify potential sites for establishing the local SHP projects.

Box 1. Sarhad Rural Support Programme's overall SHP portfolio

In the early 2000s, SRSP, based on learning from local and regional experiences, initiated two SHP projects in Chitral District, Khyber Pakhtunkhwa, Pakistan. These SHPs used locally manufactured technology to produce 80 kW of clean and renewable energy to benefit at least 1,000 rural poor. Initiation of these two prototype SHPs as a starting step was indeed a 'giant leap' into the future. Being a learning organization, SRSP, in the following years, through available resources improved technical and technological aspects to enhance the efficiency of SHPs developed in its programme areas. As of October 2019, SRSP initiated 353 SHP projects producing 33 MW of electricity to benefit 928,000 people in selected districts of Khyber Pakhtunkhwa and newly merged Tribal Districts.

Following site identification, SRSP programme officers undertake detailed socio-economic and technical feasibility studies. These studies consider a range of issues and factors including productive use, water rights, demand and ability to pay for electricity, community impact, the community's role in project management, plant operation and maintenance – as well as its role in identifying new business opportunities that access to electricity could potentially bring in. From the technical perspective, appropriate turbines are selected based on the requirements of the specific site (Box 3).

In terms of the management at the local level, the community-based institution guided by programme staff form a Power Committee. This committee is comprised of community members, oversees the construction of the scheme, and once operational, manages and maintains the plant. This includes appointing paid operational staff, setting tariffs and managing income from the scheme.

Box 2. Sarhad Rural Support Programme

The Sarhad Rural Support Programme (SRSP) is a non-profit non-government organization working in Khyber Pakhtunkhwa and parts of Federally Administered Tribal Areas (FATA) in north-western Pakistan. Established in 1989 by members of civil society and individual members of the Government of Pakistan, it is an intermediary organization based on the rural support programme approach to community empowerment and economic and livelihood development. This essentially is a belief in bottom-up, flexible, community-driven development and the idea that marginalized communities have within them the capacity for self-support. In recent years, renewable energy has become one of the SRSP's largest portfolios with SHP, in particular, attracting significant funding under the six-years EU PEACE Programme (Programme for Economic Advancement and Community Empowerment). SRSP has a strong commitment to developing community ownership, which it sees as critical to long-term sustainability of projects. Its SHP initiatives supply cheap, stable, environmentally friendly and sustainable electricity across Malakand Division.

Box 3. Using different turbines to generate hydropower

Based on the requirement of the specific sites, different turbines are used to generate renewable energy at the local level. These include cross flow, Pelton, Kaplan or pump as turbine. To maximize efficiency, direct coupling of locally manufactured turbines with alternators and a gear box system are introduced. Programme logic control (PLC)-based panels are used for the first time in SHPs at this level. For controlling fluctuation in voltage, electrical load controllers (ELC) are used in these units. High standard brushless alternators are part of the system depending on site requirements such as altitude, temperature and ELC factor. In most units, cylindrical steel poles are used to avoid wooden poles thus avoiding deforestation. For controlling line losses, properly designed and tested conductors are also used along with transformers.

Usually one to two operators and seven to eight members of respective Power Committees handle operation and routine maintenance of smaller units, while periodic maintenance of the larger plants usually requires help from outside service providers. Initially, SRSP oversees operation and

maintenance of SHPs, but depending on the size of the plant, legal ownership is usually transferred to respective community-based institutions, and the Power Committee remains responsible for the SHP system management and maintenance.

The benefits of SHP: transforming local communities and creating employment

For 90 per cent of the households in the project area, the 165 SHPs implemented by SRSP provide the first ever access to electricity – with huge practical implications for the lives of the estimated 625,000 beneficiaries. The overall quality of life is significantly improved. An obvious and immediate change in many homes is that the electric light replaced the dim and dirty kerosene lamp or pine-torch, allowing women to work from home. Children study better at night, which in turn improves their attendance and performance at school. Meanwhile labour-saving electric appliances, such as washing machines, cut the drudgery of housework (Figure 1), while wood-burning stoves are replaced with cleaner and quicker electric versions. Communications are improved too, with power for phone-charging at home, families are able to keep in touch, and access to infotainment provides a window on a wider world, reducing the isolation of remote villages.

From an employment perspective, the SHP schemes have provided direct employment and income to 500 operators at SHP project sites. Furthermore, in terms of SHP for productive use, reliable access to electricity in Malakand has helped local businesses, such as bakers, tailors and flour mills, to expand to meet local market demand, and new business opportunities have also been created. For example, local companies can now dry fruits such as red persimmon using electric driers to produce a better quality product with a higher market demand, and some businesses are now able to process and sell wild olives.

Local businesses have also been able to bring in much needed income from outside of Malakand. For example, local hotels are attracting more tourists from other parts of Pakistan now that they have reliable electricity for lighting and services. Meanwhile, access to electricity has helped more women earn income in small businesses such as fruit drying, embroidery, washing, beauty parlours and baking. Their priority is usually to invest in their children through schooling and the extra money means that daughters, as well as sons, have opportunities for advancement.

Hydropower projects have also helped to develop local community institutions in Malakand Division. For example, electricity has boosted the capacity of local health centres and hospitals, which now having good lighting for examinations and procedures, can run pathology tests, and are able to refrigerate vaccines and other medications. From an educational perspective, local schools have improved lighting (Figure 2) allowing students to study even during an overcast day and giving students access to computers and improving teaching capacity; while in some Malakand villages, IT centres have been set up, providing both computer and Internet access and training courses

'In terms of SHP for productive use, reliable access to electricity in Malakand has helped local businesses, such as bakers, tailors and flour mills, to expand to meet local market demand, and new business opportunities have also been created.'

Figure 1. Following the establishment of SHPs in remote communities, marginalized people like these Kalaash girls have more opportunities to use electrical appliances. This contributes to a reduction in domestic workload for many women and girls, freeing up time for educational or economic activities. It also contributes to productive use, as some Kalaash women set up small businesses of washing clothes from home.

(Figure 3) for marginalized groups such as the Kalaash community in Chitral District. With further service provision and development, locals report that there is now less pressure to leave their villages.

Environmentally, the SHPs have made a remarkable contribution in providing renewable, clean and sustainable energy to the local population in the programme areas, which in turn has reduced the usage of fossil fuels and the pressure on precious forests. The current portfolio of 165 units with a combined capacity of 21.3 MW has been a major contributor in the reduction of CO_2 emissions by 66,000 tons/year. Similarly, these 165 units have reduced the amount annually spent on kerosene oil from EUR 3 million to EUR 0.3 million, which is a huge economic benefit to the local population.

Box 4. Malakand SHPs: from the stream to the home

These SHP projects use falling water diverted from a stream or small river, to turn a turbine located in a seismic-resistant powerhouse. The turbine rotates a shaft, which drives an electrical generator. Electricity is distributed through overhead lines with connections to individual customers. Customers have circuit breakers to set the maximum amount of power that can be drawn and a digital kilowatt hour meter to measure their total electricity consumption. The SHP runs continuously except during maintenance periods. Local operators supported by respective community-based institutions have a regular (daily and monthly) operation and maintenance schedule to follow, which includes greasing bearings, keeping channels free from debris and removing snow from power lines. The total cost of installing a hydropower scheme, including cabling, has averaged EUR 1,000 per kW. However, this amount varies considerably depending on the location and the complexity of the site. Each customer has an electricity contract with the Power Committee and pays a connection fee of approximately EUR 15 and a monthly fee for the kilowatt hour of electricity used. The local Power Committee sets the tariff. A typical domestic rate is around EUR 0.035 per kWh, with an allocation of around 60 kWh each month.

Lessons for future SHP development

Lesson 1: SHP can have a transformative effect on economic and social development

SRSP's initiative demonstrates that developing a power infrastructure and providing 24/7 electricity to an off-grid, rural population can have a transformative effect in terms of economic and social development. These SHP projects have revolutionized daily life for Malakand's rural low-income population – creating direct employment, generating economic growth via new opportunities and business start-ups, strengthening the capacity of existing infrastructure and local institutions, and improving the quality of life in the home. SRSP's projects show that it is possible to bring the huge benefits of electricity to remote and challenging parts of Khyber Pakhtunkhwa Province. Given that these projects have been successfully implemented in Malakand, it is likely that SHP for productive use can be replicated in other remote, off-grid communities across Pakistan and in other countries.

Lesson 2: The importance of active engagement with local community institutions

The project promotes active engagement with local community institutions at all the stages of project development, from identifying potential sites to setting up legitimate community structures to keep the SHPs operational and share the benefits of the plants widely. SRSP views local capacity building as an integral part of the project design. In just a few years, many of the units start to produce

Figure 2. Like many other children in Khyber Pakhtunkhwa province, Ashlina Gul is happy to have electricity in her classroom, which makes it easier for her to practice her reading and writing skills. The environmentally friendly electricity is generated locally at an SHP plant in Shangla District.

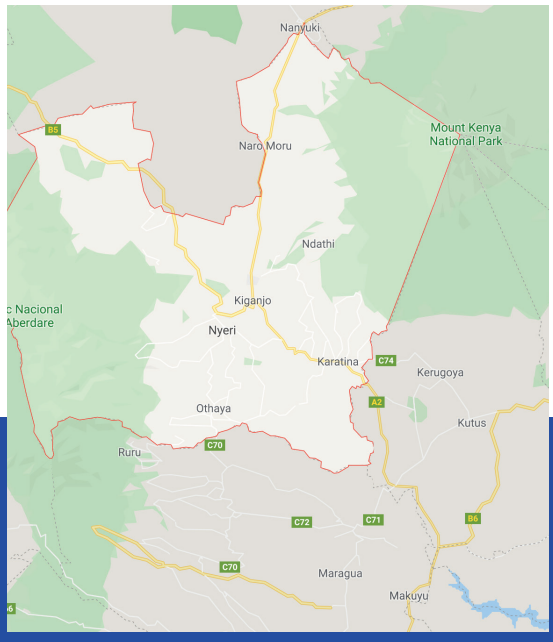
Figure 3. Girls and boys from the Kalaash community, the Dardic Indo-Aryan indigenous people from Chitral District, are gradually improving their technical skills boosting their employment chances. Thanks to locally generated electricity from SHP, the children are able to undertake computer training and go online, giving them access to information and offering a window on the outside world. Local businesses also benefit from Internet access including local hotels, which can now more easily attract tourists from outside of the region.

a surplus of electricity, which is a definitive indicator of local capacity development. This proven success has encouraged further funding from the Government of Khyber Pakhtunkhwa for a significant expansion of the programme to benefit an additional 150,000 people.

Lesson 3: The power of ensuring continuous technical improvements to electricity supply

SRSP recommends making continuous technical and technological improvements with a view to improving and enhancing electricity production and ensuring that there are no major delays or fluctuations in the electricity supply. This in turn increases confidence in the supply among communities who become increasingly willing to pay for services. Regular payments against the services provided ensure the availability of a surplus income, which can be reinvested in local communities and social enterprises. This encourages long-term sustainability of SHP projects and ensures that project benefits are multiplied.

1.2 GENERATION OF ELECTRICITY TO INCREASE ENERGY ACCESS IN TEA-GROWING AREAS BY KENYA TEA DEVELOPMENT AGENCY: 5.8 MW GURA SMALL HYDROPOWER PROJECT IN CENTRAL KENYA



Source: Google Maps

Sarah Kwach, Kenya Industrial Research and Development Institute (KIRDI); Eric Nguchitta Njoroge, Kenya Tea Development Agency (KTDA)

Located near the Aberdare National Park, high up in Kenya's Gura Valley, KTDA's 5.8 MW Gura SHP plant generates clean and reliable electricity for four tea factories, increasing productivity and reducing the factories' carbon footprint. It also helps bridge the rural infrastructure gap by selling surplus electricity to the state utility, increasing income for tea farmers and improving local electricity supply and access.

Kenya's tea sector accounts for most of Kenya's exports and provides livelihoods for more than 500,000 tea farmers. However, energy access in tea growing areas, including access to electricity, remains limited and unreliable, contributing to the escalating costs of tea production. Further, according to recent World Bank figures, 4 million households in Kenya are still without power, predominantly those located in rural areas.[1]

Part of the problem is the inability of the national utility, Kenya Power and Lighting Company (KPLC), to fund national grid expansion, coupled with limited government financial resources to develop large-scale projects which require a long gestation period. Nonetheless, the Kenyan Government's Vision 2030 development plan has set the ambitious target of universal access to electricity by 2030 – and to achieve this, the Government is retreating from its traditional role in power provision and enabling the private sector to play a more active part in filling the substantial infrastructure gap.

Increasingly, private sector actors are coming around to the idea that they can play a significant role in the Kenyan power market by helping to tackle the challenges associated with optimizing electricity access in rural areas. A good example of this is the recent experience of the Kenya Tea Development Agency (KTDA), which is gradually moving its plants from the national grid to use its own captive, renewable energy for its processing needs. Through its subsidiary KTDA Power Company (KTPC) and in conjunction with KTDA-managed tea factories and regional power companies, it has made investments in several small hydropower (SHP) projects, the main focus being the development of SHPs for productive use, income generation and the empowerment of local community.

[1] World Bank (2017). Mini grids in Kenya : a case study of a market at a turning point (English). Energy Sector Management Assistance Program (ESMAP). Washington, D.C.: World Bank Group.

Specifically, the development by KTPC of the 5.8 MW Gura SHP in Nyeri County clearly illustrates the potential for SHP for productive use in the Kenyan context. Located high up in the Gura Valley, this SHP generates clean and reliable electricity for four tea factories. Besides increasing productivity, the project has created an additional revenue stream for tea farmers by selling excess electricity to the national utility under a feed-in tariff (FIT). This in turn has improved local electricity supply for rural communities. The successful implementation of this mini-grid project may well serve as a model for private investors interested in SHP for productive use in Kenya (Box 1).

Box 1. KTDA's Power Company energizing Kenya's tea-growing areas

Set up in 2010, the KTDA Power Company (KTPC) invests in the energy sector and manages SHP projects owned by tea factory companies. A wholly owned subsidiary of KTDA, it was established to manage the implementation of SHP schemes, coordinate and manage SHP power plants.

KTDA is the single largest tea producer in the world and accounts for 61 per cent of tea produced in Kenya. It is owned by about 570,000 small-scale tea farmers through their 69 privately owned tea factory companies, which cultivate tea across the 16 tea-growing counties of Kenya. In the KTDA model, smallholders manage their own business, with farmers receiving between 60 and 70 per cent of the final auction price of tea, the remaining 30–40 per cent used to cover processing and operational costs.

With rising energy costs, KTPC on behalf of KTDA, has been exploring ways to reduce energy production costs while increasing power supply reliability and reducing greenhouse gas emissions. In the initial plans, KTPC developed a portfolio of SHPs with an aggregate generation capacity of 28.6 MW across 10 sites on rivers close to the tea factories in central Kenya. The first phase of the hydropower roll-out programme is based on the development of three hydropower plants – the 5.8 MW Gura SHP (Nyeri), the 5.6 MW North Mathioya SHP (Muranga County) and the 0.9 MW Chania SHP (Kiambu) located along the eastern side of the Aberdare Range. Each of these hydropower plants serves several tea factories in their geographical locations – and in the case of the Gura SHP plant, these include Iriaini, Chinga, Gathuthi and Gitugi.

The development of the Gura SHP

Named after the nearby Gura River, the 5.8 MW Gura SHP is located at the boundary of the Aberdare National Park, high up in the Gura Valley in Othaya Division, Nyeri County, and is approximately 220 km from Nairobi. This SHP project is run under the efficient management of Gura Regional Power Companies (RPCs) and KTPC. Successfully installed in 2016 by KTPC, it cost over US$ 9 million. It is one of the three hydropower projects funded by a credit line by the French Development Agency (AFD). Equity investment from the tea factories represented 35 per cent of the total project cost and 65 per cent was through a loan.

Overall, the Gura SHP project covers an area of about 5 ha and has a water canal about 6.4-km long, of which 2 km runs through a managed forest and the rest through tea farms. It is connected to the national grid through a dedicated 11 kV line and the power house is located close to Munyange Village.

The project has three main objectives. First, to generate captive electricity to enhance access to reliable electricity much needed by KTDA's four tea factories – Iriaini, Chinga, Gathuthi and Gitugi. Second, to supply surplus electricity to the state-owned utility company, KPLC, under a power purchase agreement (PPA). And third, to reduce the factories' carbon footprint while increasing productivity, incomes and other business opportunities.

Before the development of the Gura SHP in 2016, the waters of the Gura River had not been used in any major economic activity other than basic farming and for domestic use. Further, the four tea factories situated in the surrounding area received electricity only intermittently from the national grid and relied on a backup generator during electricity power outages. The escalation of power bills led to a reduction in tea farmers' earnings despite factories employing a mix of initiatives, including regular energy audits and replacement of standard machine parts (such as withering fans and motors) with high efficiency ones, to bring down the overall energy consumption. On an average, individual tea factories spent approximately US$ 290,000 to over US$ 600,000 each year on electricity, depending on the factory size. Additionally, the tea production process produced high levels of emissions.

The development of the Gura SHP has had direct impacts in terms of providing green electricity from SHP for productive use. Annually, the project delivers a total of 18 GWh of reliable, alternating current (AC) electricity to four factories (Box 3), freeing them from the national grid, thereby improving the efficiency of the tea factories and reducing the emissions that harm the environment.

Box 2. Technical features of the Gura SHP

The Gura SHP is a small-scale run-of-river hydropower plant, which is made up of components such as a weir, settling tanks, channel, forebay tanks, penstock pipe, turbine and generator. More specifically:

- Its installation involved the horizontal mounting of two 2,830 kW Francis turbines with the output power supplying the four tea factories.
- The weir is located upstream in the forest, approximately 2 km from its boundary (forest guard house). The level of the weir is 2,066 metres.
- The settling tank is laid down parallel and on the right bank of the river and upstream of the waterway. It has the following characteristics – size 34.6 x 5.55 metres, height between 5.0 and 5.3 m, storage volume 231 metres.
- Power house.
- Penstock with an approximate length of 400 metres.

Box 3. Monthly electricity supply by the 5.8 MW Gura SHP to the four tea factories

Name of factory	Amount of power supplied in (kWh/month)
Chinga	220,000
Gathuthi	200,00
Iriaini	180,000
Gitugi	140,000

Box 4. Multilateral support for SHP in Kenya

Multilateral donors including the World Bank, the African Development Bank (AfDB), the Global Environment Facility (GEF) and the United Nations Development Programme (UNDP), support and fund SHP development in Kenya. One example is the "Greening the Tea Industry in East Africa" programme, funded by the United Nations Environment Programme (UNEP), GEF and AfDB and implemented by East African Tea Trade Association (EATTA). Through this programme, the Kenya Tea Development Agency (KTDA) in collaboration with a number of tea factories under its management are implementing a number of small-scale run-of-river hydropower projects across the various tea-growing regions of Kenya. An economic analysis has shown that SHP projects have a large and positive impact on agricultural production and productivity.

Figure 1. Gura SHP

Moreover, the Gura SHP is able to sell surplus power of approximately 1.5 MW per month to the national grid under a FIT. This provides the tea farmers with an additional revenue stream while stabilizing KPLC power supply to nearby villages in Nyeri, which were previously faced with poor power quality and frequent power outages.

The benefits of the Gura SHP initiative: Reliable energy, lower costs, power islands and job creation

The private sector-driven project enhances opportunities for public-private partnerships and provides major benefits to different groups, sectors and stakeholders. For example, the tea sector benefits from more reliable energy and lower energy costs, local communities benefit through access to electricity, and the grid benefits through access to low-cost surplus electricity and over time, through significantly increased investment in hydropower once the barriers are removed. The global environment also benefits with every kilowatt hour of hydroelectricity replacing emissions from burning fossil fuels to generate power on the grid or from backup diesel generators.

The four shareholding tea factories are the dominant users of the Gura SHP, primarily meeting their industrial power needs and reducing production costs. Reliable electricity from the Gura plant makes the factories more efficient by cutting dependence on the unreliable national grid, which reduces the cost of production. The savings from this reduced energy production cost has made the produced tea more competitive in the world market. Further, selling excess electricity to the national utility under a FIT creates a new revenue stream for tea farmers. The FIT policy allows private power producers, in this case KTPC, to sell and obligates the distributor (KPLC) to buy on a priority basis electricity generated from renewable energy sources at a pre-determined fixed tariff for 20 years. This FIT ensures the long-term viability of the SHP system.

Importantly, if there is a technical issue affecting the Gura SHP, the Gura regional company can still purchase power from KPLC until this technical issue has been resolved. From KPLC's perspective, the organization can purchase wholesale electricity, as needed, from the mini-grid instead of having to invest funds in developing new capacity. Further, the mini-grid can operate as a power island when the national grid is down, increasing the flexibility and reliability of electricity supply.

In addition to having direct access to reliable electricity, local communities benefit in several other ways. The project led to employment opportunities, especially during civil works for workers of various skill levels, thereby increasing the local income. The operation phase also created at least 10 new jobs as employees of the plant. Similarly, the project generated demand for various kinds of related services in parallel sectors such as transport and trade leading to increased economic activity and further employment in the local area. The availability of local employment encouraged the local population to remain in the local area, thereby reducing urbanization. Meanwhile, the income generated from selling excess electricity to KPLC has trickled down to tea farmers as dividends or bonuses contributing to poverty alleviation.

The project has wider environmental benefits through the provision of a clean source of electricity and, thus, contributing to the achievement of the UN Sustainable Development Goals. Moreover, the project is also consistent with the objectives of the Kenyan National Task Force on Accelerated Development of Green Energy to install SHPs.

Lessons for future SHP development

KTDA is replicating this model in other tea factories across the country to support their strategic goals of reducing their energy production costs while also protecting the environment. The successful implementation of the Gura hydropower mini-grid project may also serve as a useful model for private investors and other stakeholders interested in developing SHP for productive use in Kenya, specific lessons including:

Lesson 1: A practical and mature technology, SHP can contribute green electricity directly and effectively for productive use in Kenya

Although very few power plants in Kenya are under the private sector management, the Gura initiative demonstrates that SHP can be successfully used for productive use in Kenya. SHP should be considered a practical and mature technology for improving electricity supply and access. This development model has many advantages including short implementation times, low initial financial investment and environmental impact and the potential to serve the power demand of populations living in remote areas. It also involves community participation in construction.

Lesson 2: The importance of the integrated ownership model

The Gura SHP project was established on the basis of an integrated ownership model, which has been important to the successful development of the initiative. Specifically, KTDA has a wholly owned subsidiary, KTDA Power Company (KTPC), which is responsible for the coordination, the setup, the technical operation and maintenance of the plant. The four tea factories directly contributed funds for acquisition and formed a Gura SHP Company Board to supervise SHP construction. Gura SHP Company supplies captive power to the four KTDA tea factories, and sells any excess electricity to the majority state-owned utility company KPLC. Further, the tea farmers also have a role in organizing community contributions and making available the savings from the reduced costs of energy for the maintenance of the SHP system. It should also be noted that having a community committee or a cooperative responsible for tariff setting helps to ensure that the tariff system provides enough income to cover costs, maintenance and repairs, while offering reliable revenues for private investors.

Lesson 3: The benefits of building a local community

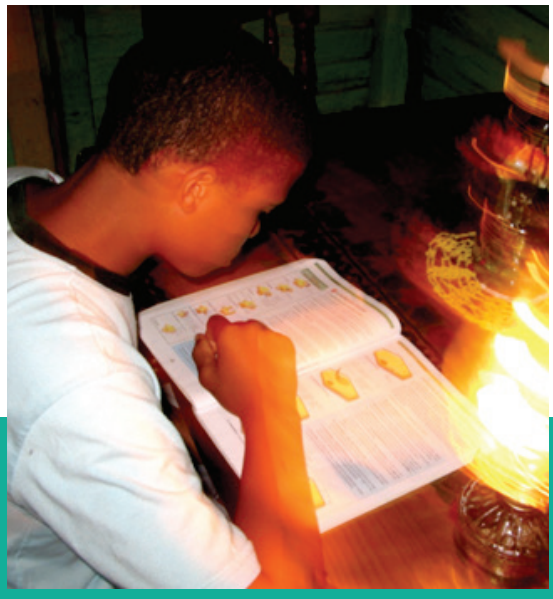
The project-driven approach provided technical training on the assessment, management, operation and maintenance to projects developers and the local population. This means qualified technicians will be available to provide maintenance and other services beyond the life of this project. Increased skills in and awareness of SHP, will allow for a sustainable replication in other tea-growing areas across the country.

Lesson 4: Using the private sector to fill in the infrastructure gap

Private sector actors can play a critical role in the power market to alleviate challenges associated with optimizing electricity access in rural areas, as they can offer more connection impact per investment dollar, improved reliability and customer service for end users (including demand stimulation interventions), and the ability to serve as a conduit for bringing "future-grid" technologies in the country's power system. For these reasons, the Kenyan Government is providing assistance to private investors with resource assessments and feasibility studies to increase the installed SHP capacity in the country.

2. SMALL HYDROPOWER FOR SOCIAL AND COMMUNITY DEVELOPMENT

2.1 COMMUNITY SMALL HYDROPOWER IN THE DOMINICAN REPUBLIC



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The Dominican Republic has seen a steady growth in small hydropower (SHP) projects over the last decade, particularly in community micro-projects which have proved effective in addressing the basic needs of rural poor while contributing towards environmental protection. They also strengthen local capacity, making groups and organizations more autonomous in constructing their own social and community development.

Despite having the highest Gross Domestic Product (GDP) growth rate in Latin America,[1] the Dominican Republic shows high inequity in terms of access to basic services for its population, rating 94th in the world in terms of Human Development Index.[2] Electricity provision is also a major problem, with 2.5 per cent of people having no access to electricity at all with this figure rising to above 4 per cent in rural areas. Where there is provision, the electrical systems are of low quality and unreliable, characterized by frequent interruptions and high loss rates in transmission and distribution – so that in 2017 the World Economic Forum ranked the Dominican Republic 125th out of 137 countries for quality of electricity supply.

The situation is most critical in rural and isolated areas, where lack of electricity constitutes a significant barrier to human, social and community development, specifically impacting vulnerable groups, including women and young people. While the Dominican Republic has limited electricity availability, its climatic and physiographic conditions, such as mountainous terrain, steep slopes, narrow valleys and abundant water resources, are favourable for SHP development and the SHP sector continues to attract interest amongst national and international entities.

The growth in community SHP projects across the Dominican Republic

A direct response to the country's pronounced structural problems, the first community SHP projects were installed in the Dominican Republic more than 20 years ago. Today some 55 community SHP systems are in operation (Figure 1).

[1] The GDP growth rates in the Dominican Republic between 1992 and 2019 averaged 5.5 per cent.

[2] United Nations Development Programme (UNDP) (2018). *Achieving universal access to electricity*. Policy brief No. 1. IEA, UNDP and IRENA, New York.

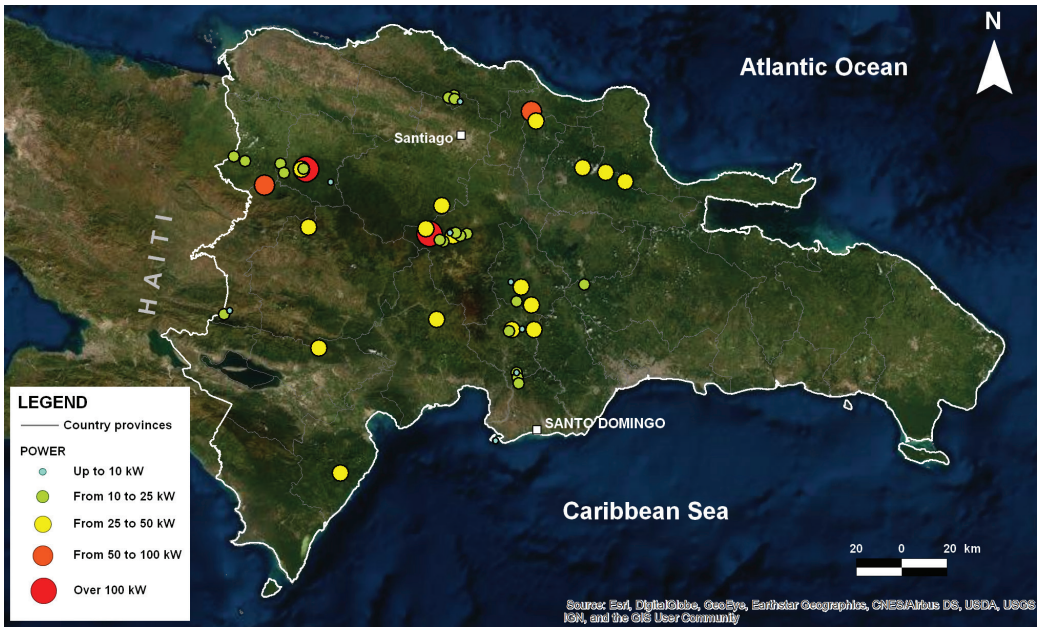


Figure 1. Map of projects in the Dominican Republic

Developed under the leadership of the Dominican non-governmental organization (NGO) Guakía Ambiente and the Global Environment Facility (GEF) Small Grants Programme, these community SHPs enjoy the support of multiple stakeholders including the Government of the Dominican Republic (through the Rural and Suburban Electrification Unit), the Inter-American Foundation, NGOs, the public and private sectors, as well as community-based organizations (CBOs). Collectively, these SHP projects have an installed capacity of over 1.4 MW generating clean, environmentally friendly electricity, which guarantees reliable, electrical supply to more than 5,000 families, or over 20,000 people, many of whom are from rural, marginalized communities. From the environmental perspective, globally these projects directly contribute to climate change mitigation (SDG 13) with more than 25,000 tons of CO_2 absorbed.

Promoting local empowerment, cooperation and multi-stakeholder synergy

During all stages of the projects, there is a strong emphasis on local empowerment, cooperation and multi-stakeholder synergy, which are considered key elements for a successful sustainable development strategy at the local level. From the outset the projects are community-driven, with local groups requesting a reconnaissance visit and preliminary evaluation of the potential for SHP in their area. Communities participate in subsequent feasibility studies as well as the implementation phase, where they establish project management committees and work brigades, before the start-up of the installed SHP systems.

'Collectively these SHP projects have an installed capacity of over 1.4 MW generating clean, environmentally friendly electricity which guarantees a reliable electrical supply to more than 5,000 families.'

'Initiatives have a strong commitment to learning by doing and communities are taught the skills necessary to install, use and maintain the SHP systems themselves.'

Furthermore, initiatives have a strong commitment to learning by doing and communities are taught the skills necessary to install, use and maintain the SHP system themselves, which helps build local capacity. Projects are based on highly sustainable management systems, with CBOs responsible for managing all aspects of their respective installations and the community in the overall charge of technical and financial administration. There is also a strong focus on the collaboration of grassroots groups, which receive training to drive forward wider social and community development.

The creation of effective partnerships and initiatives sees the participation of multiple stakeholders, at different levels and across different sectors, working together to respond to the specific and expressed needs of local communities. From a governance perspective, specific strengthening of the governance framework via Government legislation, including Law 57-07 on Incentives for the Development of Renewable Sources of Energy, has had a positive impact on the development of the overall process, creating the bases for replication and up-scaling of community SHP initiatives. While the creation of the Dominican Network for the Sustainable Development of Renewable Energy (REDSER), a national entity which comprises local organizations managing community SHP systems, continues to help voice the community perspective in national energy policy.

Specific benefits of community SHP: from reducing energy costs to promoting autonomy and social and community development

Access to electricity has significantly improved the quality of life of the people living in rural and isolated communities across the Dominican Republic, making it possible to light their homes, charge a mobile phone, and utilize labour saving devices such as washing machines and refrigerators. Women's lives in particular are impacted by a reduction of time spent on household tasks creating opportunities for them to engage in other activities including education, political participation and infotainment, which contributes directly to Sustainable Development Goal (SDG) 5, to "Achieve gender equality and empower all women and girls".

The extension of electricity also allows schoolchildren to study at home at night and this is consistent with an improvement in academic achievement observed in the majority of the communities, contributing to SDG 4, to "Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all" (Figure 2).

Financially the SHP systems have resulted in major savings in terms of energy costs for the rural poor. Prior to project implementation families spent typically between US$ 12 and US$ 30 per month on their energy needs, including on kerosene lamps, candles and batteries. Once the systems are in place this is reduced to between US$ 3 and US$ 6 per family per month, an average saving of between US$ 100 and US$ 300 each year. This action directly contributes to SDG 1, to "End poverty in all its forms everywhere" and SDG 10, to "Reduce inequality within and among countries". It also contributes to SDG 3, to "Ensure healthy lives and promote well-being for all at all ages" as the availability of clean energy reduces household pollution caused by kerosene and other fossil fuels.

Figure 2. A case of self-improvement: Tony Gómez from Fondo Grande (north-west of the Dominican Republic) studying by the light of a kerosene lamp (left). On the right: Tony graduating from a university thanks in part to access to electricity generated by a community SHP.

At present, more than 50 enterprises have been developed through the use of electricity produced by these SHP systems, including eco-tourist facilities which receive over 2,000 tourist visits each year and bring in the much needed revenue to local areas (Figure 3). This productive use of electricity directly contributes to SDG 8, to "Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all".

Figure 3. Inocencia Hernández, a community leader and manager of the Angostura Ecotourist Complex, a community enterprise that uses electricity generated by a community SHP in the centre of the country. More than 50 enterprises have been developed and supported through the use of electricity produced by community SHP systems across the Dominican Republic.

Projects also promote organization, autonomy and social capital – or increased community capacity based on people's empowerment as individuals or in groups. The initiatives are shown to make communities more active and autonomous in decision-making, while also stimulating inclusivity, community participation and representation. For example, during construction of the initiatives communities elaborate common rules for system management, while beneficiaries are made aware about the importance of paying for the electrical services that they receive. This directly contributes to SDG 16, to "Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels".

Linked to this sustainability is the creation of multi-stakeholder partnerships, and the initiatives see the participation of numerous stakeholders at different levels working together to respond to the concrete and expressed needs of local communities – contributing to SDG 17, to "Strengthen the means of implementation and revitalize the global partnership for sustainable development". As well as facilitating fundraising, stakeholder engagement can contribute to replication and up-scaling of the model of intervention. For example, the Government of the Dominican Republic has assumed its own line of intervention and continues to promote community hydropower systems as an efficient and cost-effective solution for the electrification of isolated rural areas.

Moreover, the projects have the effect of stimulating greater awareness of the environment and environmental protection at the local, national and global levels. Specifically, beneficiaries become aware of the importance of preserving forest cover in the area where they live as it ensures the stability of water flow for electricity generation. In practice, this means that the projects ensure the conservation or reforestation of the intervened basins. In this way more than 70 km^2 of land have been restored or conserved, directly relating to SDG 15, to "Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss".

Lessons for future SHP development

Knowledge of community SHP projects has spread from area to area within the Dominican Republic motivating local groups to start their own initiatives and leading to a growth of community SHP projects over the last decade. Moreover, due to the adaptability of the model, and based on local empowerment and multi-stakeholder cooperation, the project has great potential to be scaled through South-South cooperation, including in neighbouring Haiti, where communities and institutions have already started to replicate similar processes across the country (Figure 4). Specific lessons for future SHP development include the following:

Figure 4. South-South cooperation: People from Magazen community in the north-east of Haiti, transporting a community SHP generation system, which was inspired by community SHP projects in the Dominican Republic.

Lesson 1: Empowerment of people and community groups is a key element for sustainability

Initiatives in the Dominican Republic demonstrate that the SHP projects are most successful and sustainable, if there is a commitment to the empowerment of people and community groups, for example by building local skills and capacity. Moreover, it is recommended that interventions should be orientated to educating people and groups to be able to make their own decisions and contribute themselves at the appropriate level. Similarly, participating groups may need strengthening, including by building leadership, improving communication, and helping with the clear delineation of roles and functions.

Across all initiatives, engendering a commitment to solidarity and a belief that common goals can be reached by synergic work with different stakeholders proved influential. As with other schemes of mutual help in the Dominican Republic, the SHP projects allowed groups to face challenges and generate a sense of ownership towards the community in which they live. Moreover, solidarity is considered a key element in increasing cost effectiveness of interventions and promoting a continuous improvement spiral.

Lesson 2: The importance of cooperation and multi-stakeholder synergy

Promoting the creation of multi-stakeholder platforms was significant and influential. Through this approach, different entities, each accomplishing its own vision and mission, intervened in a coordinated way to reach commonly established objectives. Importantly, this increased cost effectiveness of actions, while reducing the risk of duplicating efforts.

Lesson 3: The need for community autonomy in management of the SHP system

NGOs or cooperation partners should be mindful of the need for their interventions to help generate autonomy amongst beneficiaries (including social groups) so that they may manage their own development without further intervention in the future, thus ensuring sustainable development.

Lesson 4: An integral approach is recommended, with interventions carried out in a medium- and long-term planning framework

Projects are interventions oriented to solving specific problems and/or responding to concrete needs of the beneficiary groups. Nevertheless, their sustainability and contribution to development depend fundamentally on social factors and the approach used during implementation. According to this perspective, projects should be a means to implement coordinated processes, which are oriented to reaching broader goals.

Lesson 5: Establishing a link between protecting the environment and livelihoods

Establishing a link between the protection of natural resources and livelihood generation proved fundamental in converting people and social groups into custodians of their territory and the ecosystems contained within it. This occurred when individuals and groups accepted that a healthy environment provides a better life quality, including better incomes.

2.2 TWO SMALL HYDROPOWER PLANTS IN NORTH-CENTRAL NICARAGUA – BEN LINDER ASSOCIATION OF RURAL DEVELOPMENT WORKERS[1] (ATDER-BL)

Rebecca Leaf, ATDER-BL,
Jose Luis Olivas, APRODELBO

Spanning a period of 30 years, the ATDER-BL small hydropower (SHP) project in the mountains of north-central Nicaragua has helped promote rural education and health services, while reducing deforestation in the watersheds. It is also very insightful, in particular underlining the importance of ensuring SHP projects are 'intertied' to the national grid in regions with a dry-rainy season weather pattern.

With an emphasis on local capacity building, this long-standing SHP and rural electrification grid project consists of two SHPs in north-central Nicaragua – the 190 kW Bocay SHP which has been in continuous operation since 1994 and the 914 kW El Bote SHP which came online in 2007.[2] It was designed, built and is operated by the Ben Linder Association of Rural Development Workers (ATDER-BL), a Nicaraguan non-profit, non-governmental organization (NGO) made up of Nicaraguans from local communities and foreign volunteers from the USA and Canada.

The SHPs are located in the village of El Bote in El Cuá municipality and in the town of Bocay in Bocay municipality in Nicaragua's Isabelia mountain range, a low range with elevations between 400 and 1,300 metres. The climate is sub-tropical with a rainy season that usually lasts for eight months of the year and a dry season that lasts for around four months from mid-January to mid-May. The average annual rainfall at higher elevations is approximately 2,500 mm per year, which, together with the hilly terrain, makes this a good area for run-of-river SHPs equipped with impulse turbines.

Access to electricity in this region, given poor road infrastructure and geographical inaccessibility, was historically low. In fact when the project was initiated three decades ago, the electrification rate in the Bocay municipality was 0 per cent and only 3 per cent in El Cuá municipality where hydroelectricity was supplied by a 43 kW SHP. Since then things have progressed. Today the two SHPs (Box 1) and the electric grid system are providing continuous electricity to over 9,000 homes across localities, health clinics, schools and businesses and in El Cuá the electrification rate exceeds 70 per cent.

[1] Asociacion de Trabajadores de Desarrollo Rural – Benjamin Linder.

[2] Current working capacities of the two plants are reported in the case study.

Financially, the ATDER-BL project initially used a combination of private and public donation funds and a major bank loan for the construction of the SHPs and the three-phase, medium-voltage electric line that connects them and interties this rural system to the Nicaraguan national distribution grid. However, during the last decade the project has paid off the bank loan and is operating on a self-sustaining basis, covering all of its operation and maintenance costs and generating a small margin each year that is being used to continue building more grid extensions to increase the rural electrification coverage.

The project focus: building local capacity and watershed conservation

Since its inception in 1987, ATDER-BL's main aim was to convert the fast-flowing creeks and streams of the area into electricity to promote local economic growth and improve social services, such as healthcare and education. However, El Cuá and Bocay municipalities faced major challenges throughout the 1980s - with poor local road infrastructure, non-existent telecommunications, and the risk of landmines and military activity as the region was within the northern zone of the 'Contra War'.

Consequently, the project focused on building local capability and self-sufficiency, with technical training a top priority and this was initially provided by skilled foreign volunteers from the USA and Canada. Furthermore, a metalworking shop was built in El Cuá and equipped with a lathe, milling machine, welding machine and drill press. Training was provided to local technicians and the turbine for the Bocay SHP was manufactured by local machinists and welders, partly as a training exercise. The workshop opened to the public and undertook metalwork jobs and repairs of farm tools for the local population in El Cuá town, the surrounding rural area and the nearby agricultural cooperatives. Auto mechanical skills were acquired as the few vehicles that operated in the area were also brought in for repair. Training in topographical surveying and drafting was also provided and the mapping of the towns of El Cuá and Bocay was useful to the municipal governments and a good practice for the new surveying crew.

When in 1989 a donated 40 kW diesel generator was installed in Bocay, the local lines workers were trained and installed the town's first small electric grid. Training in simple home wiring followed immediately. Overall, training was hands-on and focused on activities of interest and benefit to trainees and the community, e.g. providing extra income from welding or machining shop work, mapping the streets, installing electricity in family homes.

The training process, though slow in part due to the low educational level, was very successful over the long term and ATDER-BL maintains the same basic policies today. These include that any employment created will be given to young people from beneficiary communities; personal characteristics, not formal educational level, are the criterion for selecting candidates; if specialized technical training is needed and unavailable at the local level, the project will hire a Nicaraguan specialist from the cities, or failing that a foreign specialist will be accepted on a temporary basis; training in occupational safety will always be included; permanent employees must all have an affinity for team work and knowledge sharing; and that directors will transparently share with workers all relevant funding, budgeting and accounting information.

These principles helped develop a cohesive, stable, well-motivated and active work force. For example, as well as developing the Bocay and El Bote SHPs, the project engineering and field work team has undertaken over 50 prefeasibility, feasibility, hydrology and design studies for SHPs across Nicaragua. The El Cuá machine shop crew, after building the Pelton turbine for the Bocay SHP, installed over 20 SHP systems (3–25 kW) at remote sites, with turbines manufactured in-house.

A second important focus has been on watershed conservation for SHPs. Calculations of long-term operating costs for all SHP projects include assignment of a percentage of the income from hydroelectricity sales annually for watershed conservation. The El Cuá and Bocay municipalities are located in the 'buffer zone' of the Bosawás Biosphere Reserve, so stopping the alarming rates of deforestation in the watersheds has been a high priority. The project has found that the most effective approach is to dedicate funds each year to working with farm families in the watershed on soil conservation measures and agricultural improvement. Helping families produce more food and higher-yield cash crops reduces their need to clear-cut more of the sub-tropical forest they still have standing. It should be noted that severe poverty in the rural areas is one of the principal causes of deforestation in this northern region of Nicaragua. Moreover, improving agricultural productivity reduces rural poverty, and important progress can be made with a relatively small amount of well-focused, on-going funding taken from SHP sales income.

Benefitting community development, public education and health services

Access to electricity has been a major benefit and the system of two SHPs and electric grid has grown over the years to include 280 kilometres of medium voltage electric lines (24.9/14.4 kV) and 160 kilometres of low voltage lines (240/120 V). These SHPs provide continuous electric service

Box 1. Technical aspects of Bocay and El Bote SHPs

The 190 kW Bocay SHP has a gross head of 200 metres, a 1,400 metres penstock and a single Pelton turbine with two injectors, which was built locally with engineering design support from volunteer engineers in the USA and some free guidance from Canyon Industries, a US turbine manufacturer. It has been in continuous operation since 1994. The control system, initially installed, was a ballast load control governor for Island operation only. However the controls were later upgraded to include synchronization capability. The 914 kW El Bote SHP in El Cuá has a gross head of 120 metres, a 385 metres penstock and two Pelton turbines, both double-injector, purchased from Canyon Industries. Operating since 2007, El Bote SHP has dual controls that allow for selection of Island or Intertie operation.

Figure 1. Bocay and El Cuá municipalities on the map of Nicaragua

to 9,000 houses, farms, schools, churches, health posts, small business and government offices in the El Cuá and Bocay municipalities. Since the 914 kW El Bote SHP entered in operation, the number of local customers has increased by 15 per cent per year, while the electrification rate in the El Cuá municipality has increased to 70 per cent, up from 3 per cent in 1987.

An interesting aspect of rural electrification is the positive impact on rural public education and health services. In communities where electrical services become available, within the first year the health centre becomes better staffed and equipped, and more years of instruction are added at local schools. In the village of El Bote, for instance, prior to electrification the school only offered classes at first, second and third grade of primary education. However, within a year of electricity becoming available, the full six years of primary education were being taught in the same small school building using the classrooms for morning, afternoon and evening classes. Within three years, the school building was improved and expanded, and secondary school classes were started.

This expansion of basic education is actively promoted by the local parents' association and is triggered by access to electricity – largely because electrical service makes the village a more desirable place to live, helping attract certified teachers from larger towns which in turn boosts the education system. Similarly, when villages with electricity become more attractive to qualified nurses or medical staff, a half-abandoned health post can become an effective small health centre that provides reliable basic daily medical attention to the local community.

Electricity access also led to an early expansion of services in both municipalities, starting with the development of a welding and machining workshop and a technical training centre in El Cuá, a carpentry shop with electric tools in La Pita (in El Cuá municipality) and a rice-milling machine in Bocay, all of which led to increased local capacity and generated permanent jobs. Economic development has since progressed. For example, through private local initiatives a wide range of services are now available in the urban municipalities including gas stations, barber shops and dental clinics with electric tools, dozens of eateries and restaurants, ice-cream shops, tire-repair shops, Internet cafés, radio and TV repair shops, hostels, computer schools and recreation centres. The agricultural sector also benefits from a dairy processing plant as well as hundreds of coffee-depulping machines with electric motors which operate on the medium-sized local farms.

Figure 2. Community participation in the construction of a micro-turbine project

Figure 3. Manufacturing a cross-flow turbine at the El Cua metalworking shop

The largest energy consumers are two public hospitals which consume 12,000 kWh per month and approximately 20 cell phone repeater towers installed over the past five years which each consume 1,500 kWh per month. Despite development, the average energy consumption has remained constant at 46 kWh per customer per month. This is largely because while business has developed quickly in urban areas, the project has continued to build grid extensions to small poor rural communities. In these communities, customers have a lower average monthly consumption of 23kWh and mainly use electricity for lighting, infotainment and charging their mobile phones. Productive, commercial and institutional electricity demand in this rural area, with three medium-sized towns and one very small town, has never surpassed 20 per cent of domestic demand – and it is believed that large-scale productive use of electricity will not take place in rural areas due to the distance to the city, poor road infrastructure and the threat of landslides in the rainy season.

Figure 4. Equipment in EL Bote powerhouse

During the entire period of operation of the El Bote SHP (2007–2019), the sale of excess hydroelectricity to the national grid has provided the project with a second income, beyond the sale of electricity to local consumers. This has allowed the project to repay its bank loan, carry out watershed conservation work, purchase necessary parts and materials for maintenance and repair of the hydropower plant, build up a reserve fund for future SHP equipment replacements, and continue gradually expanding the electric grid to benefit more farm families through access to electricity. The central Government has also built grid extensions in the project area as part of the national rural electrification campaign. These connect to the project grid allowing the project to collaborate with the national programme.

Lessons for future SHP development

Lesson 1: Island versus intertied operation of SHPs

Both the 43 kW SHP, which provided the first electricity to El Cuá (1985), and the 190 kW Bocay SHP plant (1994) were designed as 'Island' hydropower plants for rural electrification in remote areas. Having operated these plants over a 15-year period allowed ATDER-BL to closely observe the technical, social and economic aspects of SHP in Island mode – particularly in the context of the seasonal water flow regime with a rainy and dry season weather pattern. ATDER also observed the development of six Island SHPs over a prolonged period in other parts of Nicaragua.

The type of Island SHPs built for rural electrification in remote communities is usually designed with an installed capacity equal to the peak demand projected over 20 years at a constant growth rate. If an annual growth rate of 4 per cent is assumed, the peak demand will double after 20 years. As peak demand is predominantly domestic lighting demand that occurs between 6 pm and 8 pm, with a daytime demand about 50 per cent of the peak and midnight demand about 25 per cent of the peak, the first major problem with SHPs operating only in Island mode becomes apparent – the expensive investment in installed power capacity is seriously under-utilized. With the shape of the 24-hour demand curve just described, an Island plant will operate with a plant factor of only 22 per cent during the first year, increasing to not more than 44 per cent over the 20-year growth period.

This leads directly to the second problem with Island SHP – that hydroelectricity sales income, limited by local demand, is often insufficient to cover SHP and island grid operation and maintenance costs. All Nicaraguan Island SHPs have struggled, especially during the first years of operation, due to lack of sufficient electricity sales income. Some have

Figure 5. Dam of the El Bote hydropower plant

collapsed for this reason. With barely enough income to pay the low salaries, they do not have sufficient resources to buy much needed spare parts for the hydropower plant or pay for the repair of a service transformer in the electric grid. When the plant is out for repairs for a long period of time, the service to the community becomes unsatisfactory and a descending spiral starts. Nicaraguans will not pay high tariffs for electricity. If an SHP plant built with donated foreign funds does not operate satisfactorily, they prefer to let it stop generating and be shut down – and the local people will wait for the Nicaraguan central Government to bring in a diesel generator and provide electric service with subsidized fuel.

The third problem with the Island SHP model in areas with the rainy and dry season weather pattern is that projects can experience water shortage in the stream during the dry season. In Nicaragua water flow during the two driest months is less than 20 per cent of average flow during the rainy season and with insufficient water to sustain full time hydroelectric generation, rationing of electricity becomes necessary. It should be noted that rationing requires SHP civil works to have a reserve water storage volume available,

Figure 6. Annual cleaning of sediment from the headpond at Bocay

Figure 7. ATDER-BL technical team in the Bocay powerhouse

such as a head pond at the dam or a very large forebay. It is advisable to let the head pond fill up during the low demand midnight hours and use this stored water to cover the peak load the next day. However, as the customer numbers grow and the stream flow remains relatively constant from year to year, even the head pond storage will not be enough and the electricity service must be suspended all morning and early afternoon during the dry season to allow the plant to generate for one or two hours of peak demand with the small water reserve that is available.

With the above in mind, when in 2003 the opportunity arose to finance the 914 kW El Bote SHP facility, ATDER-BL designed the plant to be intertied to the national grid rather than as an Island SHP. This required building a 30 km, 24.9 kV three-phase line to interconnect from El Cuá to the nearest circuit of the national grid. This extra investment has been worth it. The intertie to the national grid allows the El Bote SHP to sell its excess hydroelectricity generation to the national system during the rainy season, whilst enabling the purchase of additional energy that customers require and that cannot be covered by the SHP due to water shortage during the dry season.

Similarly in 2007, ATDER-BL also built an additional 22 km of a three-phase medium-voltage line further to the north to intertie the Bocay SHP, enabling it to sell a small amount of excess hydroelectricity generation during the rainy season and purchase much needed electricity during the dry season, eliminating dry-season energy rationing in Bocay municipality.

Importantly, in 2001 the Nicaraguan Government mandated the distribution companies operating the national grid to

purchase electricity generated by SHPs at stable prices fixed by the Energy Board of the national legislative body. Though lower than the overall national energy purchase price, they are high enough for project viability.

During the first five years of El Bote SHP operation, approximately 25 per cent of the annual generation was consumed by local customers in El Cuá municipality, whilst 75 per cent was sold as excess generation to the national grid. However local demand has grown rapidly and in recent years 80 per cent of El Bote generation is consumed locally and only 20 per cent is sold to the national grid. During the entire period of operation of El Bote to date (2007–2019), the sale of excess hydroelectricity to the national grid has provided the project with a second income, above and beyond the sales to local consumers.

The intertie to the national grid is not perfect. The remote rural circuits of the national grid in Nicaragua tend to be poorly maintained, too long and a service quality standard does not exist. Frequent blackouts of variable duration are common, especially during the rainy season – voltage sags, over-voltage peaks due to re-closures at the distant substation, poor voltage regulation over the 24-hour cycle and phase imbalance from the national grid, are all part of life. Nonetheless the tremendous advantages of having an outlet for all excess hydropower generation and being able to purchase from the grid any electricity that customers require that the SHPs are unable to generate, far outweigh the difficulties with the intertie.

'Island SHPs built for the purpose of rural electrification should be intertied to the national grid – doing so will promote local economic development, increase rural electrification, while also supplying the grid with inexpensive renewable energy.'

Overall, it is strongly recommended that all Island SHPs built for the purpose of rural electrification should be intertied to the national grid as soon as possible. Doing so will promote local economic development, increase rural electrification while also supplying the grid with inexpensive renewable electricity.

Lesson 2: Run-of-river versus daily reservoir

For an SHP that serves a local domestic load with a significant load peak, a strictly run-of-river hydropower plant based on a small stream will not provide satisfactory service in a climate with a rainy season-dry season weather pattern. This is due to a shortage of water during the dry season. In hilly terrain with high heads available, it is usually not difficult to choose a dam site that permits building a low dam (2-4-metre-tall) that will impound water with a storage capacity sufficient for daily flow regulation during the dry season and the transition months. It is recommended to incorporate daily storage capacity in a head pond whenever possible, both when the SHP operates as an Island plant and when it is intertied. In the case of the latter, daily water flow regulation permits the plant to follow the local demand cycle, thereby reducing the need to purchase electricity from the national grid (which is more expensive) to cover the peak hour demand.

A 2008 inspection carried out on the Bocay SHP and the El Bote SHP by a watershed biologist indicated that the presence of the head pond, the daily regime of water usage and the periodic purges of the sediment from the head pond once or twice a year were not damaging the health of the streams. Moreover, the flora and fauna in the stream bed and along the edges of both streams was found to be identical upstream and downstream of the head pond and in good health.[3]

Note: *The authors would like to express their gratitude to all of the Nicaraguan and International organizations that provided funding to get the projects started, and special thanks to the volunteers from Tecnica-USA and Canadian civil engineering collaborators whose contributions in the early stages established the technical foundations for the work that followed.*

[3] As Nicaragua does not have species of fish or other aquatic animals that swim upstream to spawn, the low dams do not cause a barrier of any environmental or natural significance.

2.3 THE 700 KW ZENGAMINA SMALL HYDROPOWER PLANT AND MINI-GRID: BUILDING ON 12 YEARS OF OPERATIONAL SUCCESS IN ZAMBIA

Laurent Nahmias-Léonard, Brian Kelly, Virunga Power

In a remote district of Zambia's North-Western Province, the Zengamina small hydropower plant (SHP) harnesses the power of Africa's fourth largest river, the Zambezi. Developed by local stakeholders, the SHP project and mini-grid have been providing access to electricity in this energy-deprived area for over a decade, improving local living conditions and helping to promote social and community development.

The 700 kW Zengamina Power SHP (Figures 1 and 2) project and mini-grid are located in the Ikelenge District in Zambia's North-Western Province and are close to the country's intersection with the Democratic Republic of the Congo (DRC) and Angola. Traversed by the Zambezi River, historically access to electricity in this area has been very low with the Ikelenge District over 250 kilometres away from the Zambia Electricity Supply Corporation (ZESCO)-operated national grid. Traditionally, locals have relied on wood or kerosene for cooking and heating and there is a prevalence of unsustainable slash and burn subsistence farming. In general, the lack of reliable energy has perpetuated a cycle of poverty across the region.

The completion of the Zengamina Power SHP scheme in 2007, a run-of-river SHP (Box 1) which harnesses the power of the fast-moving Zambezi River, has had a significant positive impact on local development. As well as providing clean, reliable and affordable electricity to the local hospital, schools, businesses and access to electricity for local households, it has promoted wider sustainable development of the rural community. More specifically, over the last decade the SHP development has created hundreds of new direct and indirect jobs in the community, triggering massive investment in social institutions by the Zambian Government and raising the region's living and working standards.

The origins, development and expansion of the Zengamina SHP initiative

The project dates from 2001 and recognized that there was a critical need for a reliable and affordable alternative to diesel to power the 100-year-old Kalene Mission hospital, which offers critical care to patients from three countries – Zambia, the DRC and Angola. In response, a group of local stakeholders set up the non-profit North West Zambia Development Trust

(NWZDT) to raise funds for the Zengamina SHP development. Early funding came from several British charities, churches and private individuals.

Construction of the Zengamina SHP, which was named after a local Chief, began in March 2004. Taking advantage of the Zambezi River as a huge natural resource, the SHP plant officially opened in July 2007 and began supplying electricity to Kalene Hospital, as well as local clinics, schools, an orphanage and local households. The original project costs were US$ 3 million – approximately US$ 2 million for the SHP itself and US$ 1 million for the distribution network. As well as NWZDT, a sister company, Hydro Electric Power Ltd (HEP), was later established to further develop the initiative and build and operate similar SHP schemes based on the experience of the Zengamina SHP.

Today the grid covers 30 km, while over 30,000 people benefit from the connections provided to schools, healthcare institutions, houses, small and large businesses and mobile phone towers. Despite the great positive impact, limited resources have reduced the scheme's potential, which has excess capacity and unmet customer demand. To address this, HEP has recently established a partnership with Virunga Power (Box 2) to gain strategic support and help optimize mini-grid operations and facilitate the Zengamina's expansion with a view to providing electricity access and associated economic benefits to more people in the area.

The joint venture between Virunga Power and HEP will expand the generation capacity of the Zengamina Power SHP to 1.4 MW. Moreover, the joint venture will hybridize the generation assets by adding solar power of up to 1 MW. Alongside the generation expansion, Virunga Power will extend the existing Zengamina distribution network leading to a total reach of over 2,500 connections or local rural households. In conjunction with the expansion, the partners will seek to achieve an optimal level of tariff for long-term financial success, formulate strategies to continue stimulating productive uses of energy through partnerships with NGOs and local businesses, and introduce new technology and build an effective team with local expertise to enhance the operational excellence of the grid. Longer-term, the partners plan to develop a Zengamina Cascade by adding several small hydropower generation projects upstream from Zengamina and further extending the mini-grid.

Box 1. Technical Information

A run-of-river project, Zengamina Power SHP utilizes the fast-moving Zambezi River, Africa's fourth largest river, to generate electricity for the local area. The Zambezi at this location drops 17 metres (56 ft) over a 350-metre (1,150 ft) length of rapids. The facility includes a 100-metre-wide weir, 400-metre canal, 70-metre penstock, powerhouse and tailrace – and installation of an Ossberger cross-flow turbine, step-up transformer and substation, and 35 km of 33 kV line as the backbone and 10 km of low-voltage line. The 700 kW SHP is built to allow easy expansion to 1.4 MW. Construction on the project began in March 2004 and it was officially opened on 14 July 2007.

Box 2. Virunga Power

Virunga Power is an owner, investor, developer and operator of SHP-based mini-grids in Kenya, Tanzania, Burundi and Zambia. It has a strong focus on SHP, such as the Zengamina project, given the technological and scaling advantages. SHP is a proven and durable technology that leverages an abundant and familiar resource in Eastern and Southern Africa to create long-standing energy infrastructure. Moreover, SHP provides base load energy generation that can operate without storage and eventually serve as an ideal complement to other intermittent renewable energy sources, such as solar and wind power. Additionally, it supports larger-scale projects that enable improved customer services as well as significant cost savings that are passed to end-users as grid parity costs of energy. Virunga Power also promotes the use of a 'grid-as-anchor' model that bridges on-grid and off-grid areas by simultaneously distributing power to new rural areas and selling any excess power into the national grid. This allows developers to optimize projects based on resources rather than anticipated demand and provide affordable end-user tariffs – a strategy HEP and Virunga Power plan to employ in the expansion of the Zengamina Power SHP initiative.

The benefits of the Zengamina Power SHP: promoting community development, economic growth and supporting the United Nations Sustainable Development Goals

The Zengamina SHP project has transformed the Ikelenge District by providing the electricity needed to build a self sustaining local economy. It has provided access to clean, reliable, renewable electricity to thousands of people who previously had no access or who were dependent on expensive, unreliable electricity from polluting diesel generators.

This has had a positive impact on the standard of public service provision in the hospital, clinics and many schools, improving the overall health and education of the local population. Public institutions have been renovated and many new buildings constructed, with US$ 30 million worth of contracts awarded for public works. Furthermore, these institutions are now fully staffed. Previously the hospital and schools typically had half the number of nurses and teachers required as qualified professionals often avoided "hardship rural postings", which offered none of the modern conveniences taken for granted with electricity access.

Beyond improved living conditions, this project provides continuous electricity supply needed for medical equipment in the hospital, computers for businesses and schools, and other appliances previously limited by power restrictions. Furthermore, the project created direct jobs and life skills through construction and maintenance of the SHP (Box 3).

The new access to electricity also stimulated indirect jobs by enabling the growth of small businesses in the area, creating a more dynamic local economy. In fact, the initiative proactively partnered with a number of local businesses to create jobs and increase energy demand through income-generating productive uses of energy. The development of a new pineapple processing plant was supported as was the development of new stone crushing and block making factories. This work led to both increased income generation in the local community and higher energy usage which helped to pay back the infrastructure development costs of the project. In an area where unemployment rates were nearly 80 per cent, these local jobs were extremely important. Overall, this project has transformed opportunities and living standards in this rural community and there is still potential for further development.

Box 3. Creating jobs and skills through Zengamina Power SHP

"Over 400 local people helped with the original construction and up to 40 per cent of the workforce were women. We also worked hard to successfully transfer operations and maintenance of the plant from international experts who helped us establish, to a local team who now manage the generation and transmission infrastructure. In our operational team we have individuals who were born before there was power in this remote area, went to school, then college, had work experience with us, and are now on staff. That is something we are proud of, and shows the changes brought about within a generation."

–Dan Rea, social entrepreneur involved in the construction of the Zengamina Power SHP

The recently established partnership between Virunga Power and HEP will drive the expansion of these positive economic and environmental impacts to the broader area. In addition to expanding the capacity and distribution of the project, HEP and Virunga Power are proactively identifying additional productive use partners for the area.

The Zengamina project and HEP and Virunga Power's mini-grid projects more broadly address several of the United Nations Sustainable Development Goals (SDGs) including SDG 1 "No Poverty", SDG 7 "Affordable Clean Energy", SDG 8 "Decent Work and Economic Growth", SDG 9 "Industry Innovation and Infrastructure" and SDG 13 "Climate Action". Most notably, this project addresses SDG 7 by expanding access to an affordable, reliable, and renewable energy service in a rural area.

Lessons for future SHP development

Over the past decade, the Zengamina initiative has become a prime example of a successful SHP and mini-grid development in Sub-Saharan Africa. The NWZDT team has several recommendations for other SHP developers and mini-grid operators based on the specific experience gained during project development and operation.

Figure 1. Zengamina SHP

Source: Google Maps

Figure 2. Zengamina SHP on the map of Zambia

Figure 3. Connection of new customers to the grid

Figure 4. Signing up for electricity connection

Figure 5. New small businesses

Figure 6. New equipment in the hospital

Figure 7. Community consultation with the chief and local leaders

Lesson 1: Set tariffs at the optimal price point from the start of the project

Rural electrification typically requires a subsidy for development and early operations given the low income and energy usage of rural customers. To ensure electricity was affordable for impoverished customers in the Ikelenge District, the team set the basic Zengamina tariff for individual households at only US$ 5–8 per month. They assumed that the high growth of usage in the area (usage per household and number of households connected) would compensate for this low price point. However, it was soon clear that a higher tariff was necessary for long-term financial sustainability and that the early focus should be on connecting higher users of power. Even with a capital subsidy, the service of low density, low-usage customers is uneconomic, certainly at lower tariffs. The lowest users may be better served by home solar power units.

According to the Energy and Extractives Global Practice, World Bank Group, studies indicate that consumers in developing countries are willing to pay significantly more

than existing tariffs if provided with an improved electricity service. Committing to a high service delivery standard and setting the optimal tariff from the onset of a project are essential to ensuring long-term operational sustainability. When combined, they can create a virtuous circle of operational improvement.

Lesson 2: Focus on productive use stimulation over simply increasing the number of connections

Many project developers focus on the number of new household connections as the key metric of success, often driven by funder Key Performance Indicators (KPIs). However, household connections alone will not drive substantial energy usage for a project – especially in the early stages. It is critical for developers to also identify types of businesses that will be successful in the region and partner with them to drive productive energy use. Despite Zengamina's emphasis on productive use activities, only 30 per cent of the generation capacity is being used over a 24-hour period, while the relatively short, domestic driven evening peak is now close to capacity. It is advisable to engage with other partners during the project's early stages to help drive a variety of productive uses of power from the very beginning. HEP and Virunga Power are striving to establish partnerships with NGOs and local companies in parallel with the expansion of Zengamina to ensure productive uses in the area.

Lesson 3: Embed dedicated local community members within the project team

Regardless of the financial and technical expertise of a development team, it is critical to recruit one or more local community members to help lead and champion the project. This dedicated local team member is necessary to ensure community awareness and involvement from the outset. A deep understanding of the site, local businesses and community preferences can ensure that the project succeeds and meets its potential for providing electricity and simultaneously stimulating productive uses of electricity in the area. As companies such as HEP and Virunga Power expand operations to other areas of Zambia and beyond, the need for a local teammate becomes even more important. Every project comes with a unique set of political, cultural and physical circumstances that only a local community member can effectively address and incorporate into the projects long-term strategy and implementation.

Overall, the Zengamina Power project is a pioneering example of the impact that SHP and mini-grid infrastructure can have on rural communities. Renewable SHP can provide durable, reliable and affordable electricity to areas not covered by the national grid – leading to transformative economic opportunities in rural communities. HEP and Virunga Power are excited to build on the success of this project by expanding its reach to more communities in the region.

2.4 200 KW BASID SMALL HYDROPOWER PLANT: INCREASING RESILIENCE IN THE TAJIK PAMIR

Thomas Gross, HYCON GmbH

In the isolated village of Basid in the Tajik Pamir Mountains, the rehabilitation of a small hydropower plant (SHP) has provided a firm basis for community development and economic progression. It has also helped protect the local environment, reducing deforestation and on-going soil degradation, which in turn has mitigated the threat from natural hazards.

The Tajik Pamir Mountains are amongst the most remote and poverty-stricken areas of the world and at an altitude of 2,000–7,500 metres above sea level extremely cold and harsh winters are the norm. Many of the region's villages suffer extremely poor access to electricity. Moreover, the ongoing impoverishment of communities is coupled with an unhindered degradation of natural resources including the soils and vegetation on which local people directly depend, with shrubs and local biomass fuels a primary source of energy. Although some SHP projects have been developed at village level, electricity is often produced by locally built, ineffective micro-hydropower plants (MHPs), which often generate supply sufficient for lighting only.

> **'With no connection to the regional electricity grid, sustainable business development in Basid has historically been out of reach for villagers, contributing to a lack of economic progression and community development.'**

Basid, a remote community in the upper Bartang valley, is a case in point. Built at 2,400 metres, it is a five-hour drive from Khorog, the provincial capital, if the road is accessible. The village is home to around 600 people across approximately 100 self-sufficient households, with most locals working in

subsistence agriculture, although there are a few skilled craftspeople. With no connection to the regional electricity grid, sustainable business development in Basid has historically been out of reach for villagers, contributing to a lack of economic progression and community development. Public infrastructure is limited to a school and medical point. Like many communities in the region, Basid's population has been largely dependent on burning firewood, shrubs and dung for cooking and heating. In fact, it is estimated that up until recently Basid households burned around 800 tons of firewood each year, including wood sourced from local forests. This led to deforestation and soil degradation in the local area already prone to natural hazards, such as landslides and avalanches.

Tackling local energy issues through rehabilitation of the 200 kW Basid SHP

The local community in Basid laid the foundations to resolve its own energy crisis by building the original Basid SHP and by purchasing a generator – though due to a lack of technical knowledge, the electricity supply proved unreliable and inefficient. Following thorough assessment and consultation, a Swiss-based non-governmental organization (NGO) PamirLink (Box 1) agreed to facilitate and support rehabilitation of the existing Basid SHP installation (Figures 1 and 2). As part of the SHP project, PamirLink provided technical expertise from Switzerland as well as European-manufactured electro-mechanical equipment to help develop a more efficient run-of-river scheme (Box 2). Given the commitment to reducing local consumption of natural resources, the rehabilitation project successfully achieved a design output of 200 kW, which, according to a baseline survey, was the capacity needed to substitute biomass fuel for the Basid community's cooking and heating needs. It also allowed for productive use of electricity during day time. The project set a minimal supply of 1.5 kW per household as a target.

Source: Wikimedia Commons

Figure 2. Basid on the map of Tajikistan

Figure 1. Basid SHP

Box 1. PamirLink

PamirLink is a Swiss-based NGO which offers support to rural communities in Tajikistan's Pamirs Mountains. The organization has particular focus on sustainable tourism and renewable energy to improve livelihoods – the rationale being that by providing access to a sustainable and renewable energy for domestic and productive use, the consumption of natural resources (shrubs, wood, dung) for heating and cooking is reduced. In this way, project activities also help to reduce deforestation and soil degradation, while preserving dung as agricultural fertilizer. A further productive end-use of SHP energy is generating an important additional source of income for local communities.

Box 2. Technical Information for 200 kW Basid SHP

Providing know-how and expertise from Switzerland and European-manufactured electro-mechanical equipment was the cornerstone of this sustainable rural electrification project. For the 200 kW SHP run-of-river scheme, water is diverted by a temporary weir from a side stream of the Bartang River. The water follows a 750-metre-long channel, which is partly made from concrete. From the forebay, the Gross Head of 27 metres is maintained with a penstock (DN 700 mm). For electricity generation, a cross-flow turbine is installed. The turbine is coupled directly to a 240 kVA synchronous generator with a rated speed of 600 min-1. To govern the SHP, an automated hydraulic system was installed. The cross-flow turbine, the generator and the governing system were all manufactured in Europe.

Community involvement was a key success factor in generating the necessary local ownership, and the local people contributed labour and building materials such as stones to the project. In the implementation phase, the hydropower station was handed over to the community, which established a village organization to act as a council for the management and operation of the Basid SHP facility. The village organization currently collects electricity fees and sets the electricity tariff, including subsidies for less well-off households. The electricity revenues finance four full-time jobs for operators who have been recruited from the village population. PamirLink maintains regular contact with the village organization, providing and exchanging information and technical know-how related to the project on a monthly basis.

Financing the project proved challenging and community contribution aside project costs totalled around US$ 300,000. The Swiss Government contributed about half of the budget through the Renewable Energy and Energy Efficiency Promotion in International Cooperation (REPIC) initiative. The remainder was collected through a crowd funding campaign led by PamirLink and from other donations

Improving overall resilience and promoting community development

Rehabilitation of the Basid SHP improved the overall resilience of the Basid community. Importantly, access to electricity has improved the economic situation with the local people increasing their income level. For example, the local carpenter has increased productivity and reduced costs by permanently using electrical appliances rather than relying on a costly fuel-powered generator; while the local shop has increased its capacity and productivity by using electrical appliances such as a refrigerator and electric cook stoves.

The reduced consumption of firewood also has an economic impact. With an average price of over US$ 5 per m^3 of firewood, saving 670 m^3 of firewood means making available US$ 4,000 per year for other purposes or reducing household expenditure by US$ 30–40. Villagers have also reduced the time spent collecting locally grown wood, shrubs or dung, which has enabled them to invest their energy in other income-generating activities. Moreover, as less dung is used as a fuel source for cooking and heating more is available as fertilizer, in turn reducing the costs of farming and improving local incomes.

Replacing biomass fuels not only improves local income but also has a significant impact in improving health, especially for local women. Access to clean energy and the reduction in firewood or dung usage for cooking reduces smoke emissions, CO_2 and particles in the air, with clear benefits for respiratory health.

In providing access to reliable and affordable energy for villagers, the project has also improved quality of life and allowed a degree of community planning for the future. Following rehabilitation, the plant achieved an average output of 175 kW which meets the village's energy needs with domestic consumption currently at 100 kWh per month. To enable social development, the energy also needs to be affordable. Currently, the tariff is set at US$ 0.015 per kWh. On average Basid households pay US$ 1.50 per month for electrical energy. With this tariff, the Basid village organization is able to save approximately US$ 900 per year for future investment in value retention and rehabilitation.

Furthermore, villagers have also started to develop coping measures for natural hazards. Becoming an owner of the SHP has encouraged the local population to take care of their investment and the basis for their improved livelihoods. This has led to an increased awareness of natural hazards such as floods, mudflows and landslides, rock falls and avalanches. Parts of the SHP, including the headrace channel, are exposed to such hazards, and the diversion weir was built as a temporary structure in view of the annual floods caused by snowmelt. To cope with such threats, the local community constantly maintains the infrastructure, has improved preventative measures and adjusts the layout where needed, with a view to keeping the installation running for as many hours per year as possible.

Importantly, the rehabilitation has had the key effect of protecting natural resources in the area. With the power plant in operation, consumption of wood and similar fuels has reduced. This has lessened the pressure on the sparse local natural resources. Reducing the consumption of firewood in particular has a major impact, with local deforestation reduced to a minimum. Moreover, existing and newly growing trees and bushes help to stop soil degradation and prevent future landslides or avalanches, and their protection can be considered an effective Disaster Risk Reduction(DRR) measure.

Access to sustainable energy – aiming at the UN Sustainable Development Goals (SDGs)

As a renewable energy project, the 200 kW Basid SHP supports several UN SDGs including SDG 7 Target 1 which aims to ensure universal access to affordable, reliable and modern energy services by 2030. Specifically this SHP initiative provides 650 villagers access to reliable and clean energy, where previously only a handful of locals had access to electricity via fuel or diesel generators.

Gaining access to a reliable energy supply also helps generate additional income and productive usage of electrical energy equates to around US$ 1.50–3.00 per kWh, contributing to the country's gross domestic product (GDP). With an average annual consumption of a small enterprise in these rural areas of about 300 kWh, the economic impact is approximately US$ 500 per year per business. In this way the project clearly augments GDP in rural Tajikistan in support of SDG 8, to 'promote sustained, inclusive and sustainable economic growth', and is in line with indicators regarding the annual growth rate of GDP per capita and per employed person (Indicators 8.1.1 and 8.2.1). Values given for the Basid SHP are comparable with other renewable energy and energy efficiency projects in Tajikistan. Moreover, the productive end-use of clean energy is key for sustainable development and the primary way to increasing income in Basid and the surrounding hamlets. Higher household income further enables villagers to increase their consumption which again fuels small businesses. By providing energy we therefore initiate a positively amplifying process.

The third major impact is the reduction in soil degradation and protection of forest areas, which supports SDG 15 (15.1–15.3) on the sustainable usage of natural resources, mainly forests. The Basid SHP renovation, and subsequent reduction in firewood consumption, means sustainably managed forest areas are increasing and the local degradation of soil is being reduced. In fact, the SHP substitutes at least 50 per cent of the consumed biomass fuel. Reducing wood consumption by 400 tons per year equates to 670 m^3 of wood or what is being naturally regrown on 330 ha of forest per year.[1] This reduction in the consumption of biomass fuel also has an impact on greenhouse gas emissions and substituting 400 tons of firewood per year means eliminating 130 tons of CO_2 emissions per year in the Basid area.

Lessons for future rural electrification projects

Lesson 1: The importance of community involvement for sustainability

The Basid local community has taken ownership of the SHP project, maintaining the system and investing in the power plant which helps to ensure project sustainability. More specifically, the local community mutually agrees the electricity tariff, which includes subsidies for economically less well-off households. The collected income pays for trained operators and the surplus is saved for future investments. The necessity of saving money was evident when the local operators together with the manufacturer of the turbine made a first in-depth inspection and annual revision of the turbine. The extra cost of this major maintenance encouraged the Basidis to learn how to maintain the facility themselves, which in turn increases the lifespan of the power plant.

Lesson 2: Take a wider or more holistic approach

The project's main aim was not simply the installation of a hydropower plant but rather to improve the overall resilience of the village and to protect natural resources. By providing access to SHP electricity in sufficient quantities, the project enabled the people of Basid to substitute biomass fuel for clean, renewable energy even during wintertime. This has several wider benefits. For example, it has improved livelihoods freeing up the local workforce that previously spent much time collecting wood and there has been an economic impact on the households with electricity facilitating new opportunities for income generation. Environmentally the project saves biomass or wood equivalent to the annual growth of 330 ha of forest, preventing some 130 tons of CO_2 emissions, and biomass reduction has a positive impact on respiratory health amongst local residents.

Lesson 3: Projects can raise awareness of potential for natural disasters in disaster-prone areas.

A welcome project side benefit is that it has raised awareness amongst the local community of the potential for natural disasters. Moreover, local residents are beginning to take preventative measures to ensure a maximum availability of their source of energy. Nevertheless, the fact remains that the Basid SHP is a power plant in the Pamir Mountains which is a challenging environment, particularly during winter. A still unresolved problem is the icing up of the intake and the channel and the ice is too thick to be removed manually. When this occurs the power plant is taken off-grid during a season when the energy is most needed.

Source: Tobias Hoeck

Figure 3. Villagers collecting shrubs

[1] Mean annual increment: 2 m^3/ha/year; source: Food and Agriculture Organization (FAO).

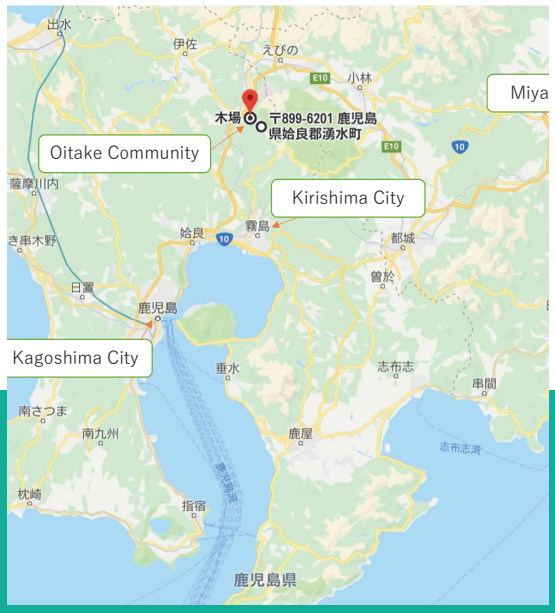
Lesson 4: Possibility of a 'snowball effect' in other villages

The successful development of the project has been reported locally leading to requests from nearby villages and hamlets around Basid to be connected to the SHP or for them to benefit from their own SHP initiatives. PamirLink is currently planning to extend the grid to Dorj, a nearby hamlet. This requires approximately another 4 kilometres of transmission line and will allow for about a dozen of households to access the grid.

Lesson 5: The need for thorough assessment and continued support

This project shows that rural electrification projects need to have a thorough assessment of the situation of a village to identify the various dimensions of impacts of such interventions. Although the main aim is to enable local communities to run their own power plant independently and sustainably, the rural communities also need to be supported during and after the project cycle to enable them to secure the envisaged benefits. In the case of the Basid SHP, PamirLink is still in regular contact with beneficiaries with information and technical know-how exchanged on monthly basis.

2.5 30 KW OITAKE SMALL HYDROPOWER PLANT IN KAGOSHIMA PREFECTURE, JAPAN



Source: Google Maps

Yoshinobu Watanabe, Zafar Alam, Raditya Rahmanhuda Rusmiputro, Nakayama Iron Works Co. Ltd.; Keijiro Okajima, Shigenori Yamamoto, Seiko Service and Engineering Co. Ltd.; Faisal Rahadian, Asosiasi Hidro Bandung; Arun Kumar, Indian Institute of Technology — Roorkee; Tokihiko Fujimoto, Shizuoka University

Small hydropower (SHP) is seeing unprecedented growth in Japan as the Government and private sector commit to a greater utilization of this abundant natural energy source to help boost economic and social development, particularly in rural areas. One such example is the Oitake SHP in Kagoshima prefecture, which uses a pre-existing irrigation canal to generate clean SHP energy locally. It also has an innovative design; the project re-working a common shipping container as the plant's powerhouse.

In Japan, SHP is considered a reliable and sustainable source of electricity, which resulted in its development and adoption whenever there is an adequate quantity of unused flowing water at the local level. Moreover, in recent years the Japanese Government has simplified the water rights application system, while also setting targets to initiate thousands of SHP projects across the country.

Overall, Japan has abundance of small streams, particularly in mountainous regions, and in the past many small channels have been created for irrigation purposes. Some of these irrigation channels continue to be used today. Others, though in good condition, remain unused. Increasingly these channels are being utilized to produce SHP electricity to promote local development. This is particularly important for rural Japan, which has suffered from rapid depopulation due to a combination of an aging population and urban migration.

The 30 kW Oitake SHP, in Kagoshima prefecture, is one such example of using SHP as a strategy for rural development. A key aim of this project was to use available water in a rural area to produce clean energy and to stimulate the local economy. The Government's electricity tariff system and the availability of cheap rural land helped with project establishment.

Developing and implementing the 30 kW Oitake SHP project

A compact hydropower initiative, the 30 kW Oitake SHP project (Boxes 1 and 2) is located in Kagoshima prefecture, south-western Japan. Specifically, the project site is in Oitake community in the mountainous Aira District, 10 km west of Kirishima City. With strong agricultural roots, well-known Kagoshima exports include green tea, sweet potato, radish and Pongee rice.

'The Oitake SHP uses a common shipping container as a powerhouse, with all mechanical electrical control equipment pre-installed in a factory, significantly reducing the costs and the length of time needed for project implementation.'

Uniquely for SHP projects of this type, the Oitake SHP uses a common shipping container as a powerhouse, with all mechanical, electrical control equipment pre-installed in a factory (Box 3, Figures 2 and 3). This has the effect of significantly reducing the costs and the length of time needed for design and project implementation, in particular in relation to civil engineering and the fact that there is no need to design and construct the powerhouse.

In terms of output, the plant started generating electricity in May 2018 and currently has a capacity of 30 kW. At the site, a small stream of water has been diverted from an existing irrigation canal used to irrigate local paddy fields in the village – and in this way the project utilizes local water resources prior to agricultural usage. Diverted water is first stored in a small 6 m^3 steel water tank before being carried through the penstock to rotate the turbine. The generated electricity is sold to the nearby electricity grid benefiting from the feed-in tariff (FIT) offered by the Government of Japan.

One implementation challenge was the selection of a suitable turbine as SHP turbines under 50 kW have limited availability in Japan. To ensure proper planning and follow-up of this small community-based SHP project and to provide the appropriate electromechanical equipment, a professional hydropower consultant was employed. Subsequently, a cross-flow T-15 turbine, manufactured by Asisiasi Hidro Bandung in Indonesia, was selected for this compact hydropower system, while other electric and control equipment was manufactured in and sourced from Japan.

The compact hydropower system, which is a new concept in SHP technology in that it replaces the need for building a powerhouse, was co-developed by Nakayama Iron Works CO Ltd (Saga, Japan) and Sieko Sevice Engineering Co. Ltd (Fukooak, Japan). The project civil works were undertaken by the developer, which is a civil engineering company, Shigekazu Co. Ltd (Kagoshima, Japan), operating in the local area. The project, which was started in June 2017, required a total investment of approximately US$ 460,000 and is fully self-financed by the developer.

The benefits of the Oitake SHP: developing rural areas and supporting the United Nations Sustainable Development Goals

The installation of the Oitake SHP has several distinct benefits, which include helping the Government to achieve its sustainable development goals from the local level, and helping to support and promote development in a rural area.

More specifically, the project has boosted rural growth and the growth of a local company, with the developer, a civil engineering company, financially benefitting from the FIT offered by the Government. This FIT applies to all renewable energy resources including SHP. The official buying price offered by the Japanese Government for electricity generated from the Oitake SHP is JPY 34 per kWh (US$ 0.31 per kWh; under 200 kW), which means that the developer will receive approximately JPY 7.3 million per year (US$ 67,500). It is envisaged that the local developer will break even on its investment within seven years, while earning a profit over the 20-year lifespan of this SHP project. Importantly, the relatively high FIT means the developer was able to plan financing of the Oitake SHP scheme.

From an environmental perspective, the Oitake SHP initiative contributes to the Government's efforts to promote clean energy sources and to achieve its wider sustainable development goals and agenda, the project promoting renewable energy generation by converting unused available water into a useful product without consuming or affecting it. In terms of specific United Nations Sustainable Development Goals (SDG), the Oitake SHP supports SDG 7, to "Ensure access to affordable, reliable, sustainable, and modern

'The project has boosted rural growth and the growth of a local company…it is envisaged that the local developer will break even on its investment within seven years, while earning a profit over the 20-year lifespan of this SHP project.'

energy for all", and SDG 8, to "Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all".

The Oitake SHP project also contributes to SDG 13, to "Take urgent action to tackle climate change and its impacts by regulation emissions and promoting developments in renewable energy". In terms of reducing CO_2 emissions, as each kWh of electricity generated from a renewable energy source is the equivalent of 0.555 kg CO_2, the 180 MWh of electricity generated annually by the Oitake SHP will lead to an estimated reduction of 100 tons of CO_2 per year.

It also contributes to social and community development by boosting a local company in a rural area. Like many rural areas in Japan, there has been a strong trend towards urbanization across Kagoshima prefecture for more than half a century, largely due to lack of jobs and facilities in rural villages. Furthermore, industrial growth remains low. SHP development is considered as an attractive option for this area particularly in that it can help to increase local employment and stimulate local business. In the case of the Oitake SHP, the project developer and owner runs a local civil engineering company close to the project site. All civil engineering works were done in-house and the company gained valuable technical know-how in the construction of the SHP system. The company also worked on the development stage of the project for over a year and gained new business in maintaining the system and managing the SHP facility. Moreover, the project has created local employment linked to maintenance of the SHP plant for a minimum of 20 years.

Figure 1. The head tank from the intake

Note: *The head tank from the intake; made up of steel, it is 3 metre long, 2 metre deep and 1 metre wide. This tank stores water for 1.5 minutes and its main purpose is to stabilize the head at the site and to provide a continuous and constant flow.*

Lessons for future SHP development

Lesson 1: There are major benefits of using a compact hydropower system which houses the powerhouse in a shipping container

The uniqueness of this compact hydropower system is the use of a shipping container as a powerhouse. This design concept significantly reduced the cost of civil engineering and the amount of time required to construct the powerhouse. Containers similar to the one used in the Oitake SHP are cheap and easily available around the world. All mechanical, electrical and control equipment is installed in the factory (to factory standards) and the finished product can be simply put on the site with the help of a local civil engineering company. Utilizing local industry makes the installation of the SHP system even cheaper and faster. Furthermore, this compact hydropower system is very easy to move and install, which potentially will make it of interest to developers in other countries.

Lesson 2: SHP can benefit local communities and companies while helping countries meet their SDG goals

Installing this kind of SHP can benefit rural areas by promoting economic and community development and help companies in terms of technical know-how and increased business. They can also help governments meet the UN SDGs. One obstacle to implementing this kind of project is the difficulty in sourcing electromechanical machines and the total project investment costs, though the FIT system provides a degree of financial security for the SHP developers and investors.

Figure 2. The powerhouse

Note: *The powerhouse is actually a container used in shipping industries and in the case of the Oitake SHP it was ordered from a Korean company. All electrical and mechanical equipment has been installed inside this container, in what has been called a compact hydropower system.*

Box 1. Technical details of the 30 kW Oitake SHP project

Items	Values	Remarks
Turbine output	33 kW	Cross-flow
Total output	30 kW	
Electricity generation per year	215 MWh	Estimated
Total investment	JPY 50 million (US$ 460,000)	Approximate
FIT	34 JPY/kWh (US$ 0.31/kWh)	
Expected income per year	JPY 7.3 million (US$ 67,500)	Approximate
Present output	30 kW	

Box 2. SHP energy generation and income

Site condition and parameters of the SHP:

Effective head – 63 metres

Design discharge – 0.07 m3/sec

Turbine – Cross-flow T14 (D225, B55) from Asosiasi Hidro Bandung (Indonesia)

Efficiency of turbine – 76 per cent

Type of generator – IPM generator from Yasukawa Electronics (Fukuoka, Japan)

Generator spec – 1,450 rpm, 37 kW

Generator + GD + DC efficiency = ~94/95/95 per cent

Concept design of compact hydropower – Nakayama Iron Works Co. Ltd (Japan)

and Seiko Service and Engineering Co. Ltd (Japan)

Civil Engineering, consultant and owner – Shigekazu co. Ltd (Local, Japan)

Box 3. Concept design – using a shipping container to house the installation

A unique aspect of the 30 kW Oitake SHP is that it utilizes a 12-feet shipping container to house the powerhouse. This design concept offers several major benefits. The container acts as a strong shelter to protect the plants mechanical and electrical equipment. Moreover, this compact hydropower system is easy to carry and install, and reduces the time for construction and civil works, lowering costs and shortening overall delivery time with no requirements for assembly work or other precision work on site. With the system assembled and tested in a factory, the quality level, such as the finished wiring work, is very high. This compact hydropower system is also very easy to maintain – as the whole system can be lifted by crane and taken directly to the factory for testing, repair and general maintenance.

Figure 3. Equipment of the power plant

Note: *Equipment installed inside the container; the equipment in yellow is the cross-flow turbine which is connected to a grey generator. The equipment in three boxes is the control panel, behind which the resistor and transformer are installed.*

2.6 MUTWANGA SMALL HYDROPOWER PLANT IN THE DEMOCRATIC REPUBLIC OF THE CONGO: VIRUNGA'S BOLD HYDROPOWER PLAN, TRANSFORMING LIVES IN A CONFLICT AREA

The European Union Delegation in the Democratic Republic of the Congo; Virunga National Park

Investment in hydropower infrastructure, as a way of promoting community development, is an innovative approach for a national park, especially in a conflict-torn region in one of the poorest countries in the world. With the European Union assistance, Virunga National Park in the Democratic Republic of the Congo (DRC) is becoming the economic drive for the entire North Kivu region, pushing forward a bold hydropower plan for rural electrification, amidst illicit activities and armed groups, in a far from stable state.

In eastern DRC, rural electrification is being promoted by the oldest national park on the continent as a pathway to security and community development in a region marked by poverty and conflict. Virunga National Park is part of both the Nile and the Congo basins – the largest watershed in Africa and the second largest in the world. As such, Virunga sustains a system of lakes and rivers that contain a considerable amount of harnessable energy, which the park is using to revitalize the local economy in the form of sustainable hydropower.

By constructing low impact, run-of-river hydropower plants outside Virunga National Park's boundaries, the aim is to supply reliable and affordable electricity to households and the local economy, which will reach 4 million people who live around the park.

Virunga National Park and development through the Virunga Alliance

Virunga National Park (Figure 1), if badly managed, can become an economic burden for the people of North Kivu. Protection of 2 million acres of park land represents an opportunity cost of over US$ 250 million per year to the local economy if there is no alternative industry, such as tourism, to offset the cost.

As it stands, up to US$ 100 million in illegal revenue is generated from the park, which includes an estimated US$ 34 million in illegal charcoal, US$ 42 million in illicit fishing and tens of millions in illegal land grabs. Worryingly, these trafficking networks provide the main source of income for armed groups and weaken the Congolese state through associated corruption. Together, they contribute to a conflict economy that feeds on widespread unemployment, which, in turn, drives people to join the armed groups. This conflict

economy also perpetuates poverty by preventing a secure environment in which a legitimate economy can thrive.

In response to these challenges, in 2013 Virunga National Park launched the Virunga Alliance, which brings together public authorities, civil society and the private sector in North Kivu around a shared vision of development. The organization has three main goals –conservation of natural resources, reduction of poverty and promotion of peace. A key role is played by rangers, who represent the state and apply the law in the territory of the park and, with some restrictions, in its periphery. The rangers patrol, seize illegal shipments, prosecute members of armed groups, arrest suspects and bring violations of the law to justice. Beyond the protection of the flora and fauna, their action is essential to the stabilization of the entire region.

In addition to its sovereign missions, the park is also an economic operator with a development agenda extending across North Kivu. It articulates its interventions around three pillars – tourism, sustainable energy and support for entrepreneurship and agricultural transformation. Overall, the plan's centrepiece is the rural electrification programme, which makes reliable, lower-cost electricity available to approximately 4 million people living around the park. It also aims to help thousands of small businesses to grow, thereby stimulating regional employment, which, in turn, boosts local empowerment and community development.

As Emmanuel de Merode, the Director of Virunga National Park, explains, "Every MW of electricity generated empowers the community by creating around 1,000 jobs, 5–10 per cent of which go to ex-combatants. When people are empowered they have the choice to control their future and move into productive society, and away from armed groups."

Figure 1. Virunga National Park

Note: *Managed by DRC's national parks authority, the Institute Congolais pour la Conservation de la Nature (ICCN), Virunga National Park is emerging as a regional leader by engaging in the implementation of community development projects in North Kivu. Its bold rural electrification plan is based on investments in hydropower.*

Hydropower in Virunga: SHP Mutwanga I and II

The small hydropower plant (SHP) Muwanga I, Virunga National Park's first SHP project, was launched in 2012 at the town of Mutwanga, which is in the Beni territory in the North Kivu province, about 40 kilometres by road from the Kasindi border crossing into Uganda. Just outside the border of Virunga National Park, Mutawanga sits at the base of the western slopes of the Rwenzori Mountains and the area has 42,000 inhabitants living across some 6,400 households.

The Mutwanga I SHP (Figures 2 and 3) runs with water from the Butahu River, flowing down Mount Rwenzori. The plant is a run-of-river station and is based on the diversion of river waters for just a few hundred metres. This creates a lower environmental impact than setups that require dams or flooding.

Figure 2. Mutwanga SHP

Note: *Water feeding the Mutwanga II turbine is taken from the Butahu River, as Mutwanga I, but higher up. This allows for a higher fall and more power production.*

Figure 3. The powerhouse of the Mutwanga SHP

Note: *A plaque outside the Mutwanga SHP, which houses both turbines, commemorates the launch of the plant in December 2012, with assistance from the European Union's 9th European Development Fund (EDF).*

The SHP initiative has a capacity of about 400 kW servicing over 600 homes, 43 businesses and two industrial investments. It also provides free electricity to schools and hospitals. Following the impressive societal benefits of the plant, an additional turbine, adding another 1 MW to Mutwanga I, was installed in early 2019 this year (Box 1). With the commissioning of Mutwanga II, 600 additional households will be connected in phase 1 which started in March 2019. Currently, phase 1 is in progress with 121 new clients connected and 283 clients expected to be connected by June 2019.

The overall aim of the upgrade was to further boost the local economy, in particular, by providing additional energy to power the SICOVIR soap factory which consumes a growing part of the local farm production. It also allowed more small- and medium-sized enterprises (SME's) and households to be connected to the grid. It is important to note that no other power supply is available in the region. While there is some household and business electricity connectivity via public and private generators or small solar panels, the vast majority of the population has not had access to electricity.

Box 1. Technical specifications of SHP Mutwanga I and II

A run-of-river hydropower plant, the SHP Mutwanga I has an installed capacity of 380 kW. A concrete dam directs part of the water through a 172-metre-long channel towards the forebay. Water flows through a penstock and drops 18 metres to feed a cross-flow turbine. A small gearbox allows running the alternator at the right speed.

Mutwanga II was completed in 2019. This second run-of-river hydropower plant was built to increase the power capacity to 1.35 MW. The turbine was installed in the building housing the Mutwanga I turbine, so as to reduce construction costs.

Mutwanga II collects its water through a small concrete dam. Due to the steep terrain, water is then conveyed through a 1,050-meter-long pipe along the cliff and a 1,180-meter-long channel to the forebay. Water drops 211 metres to reach a Pelton turbine which has two injectors. The high head makes it possible to reach 1.35 MW even with limited water flow rates. In terms of distribution, 6 kilometres of medium-voltage network and 24 kilometres of low-voltage network has been built and is currently in operation.

The benefits of SHP — transforming lives and local communities

The arrival of electricity has led to a complete transformation of life in the villages around the park. Specifically, the hydropower plants generate electricity for some 600 clients, including approximately 400 households and 200 businesses, as well as a hospital, four schools, an administrative building, a military camp, an orphanage, and the local radio station. The SHP initiatives also power over 60 street lamps.

> **'Apart from the electricity produced, the plants themselves will have significant impacts on livelihoods and contribute to agricultural transformation in the region.'**
>
> ***–Emmanuel de Merode, Park Director***

The park has set up an energy company, which is building the grid system, and has also initiated a small loans scheme linked to electricity consumption. Households that are connected to the grid are given a small electric cooker, which in itself implies local health benefits as it reduces charcoal use and the associated smoke-induced respiratory illnesses. In practice, households use electricity mainly for lighting. This has enabled children to study at home and home-based professionals, such as tailors (Figure 4), to work longer hours and work later in the evening. SHP-generated electricity has also improved access to infotainment and is used for powering radios and televisions and for charging mobile phones.

The conservation implications of this development are far reaching. Traditionally, most households in the periphery of Virunga National Park rely on wood or charcoal to meet their energy needs. This has led to deforestation and habitat destruction in the park. The clean energy provided through the hydropower investments is an alternative to illegal charcoal, which is also an important source of revenue for the armed groups.

The high demand for electricity by both pre-existing and start-up businesses helped to guarantee a client base ready to consume as much electricity as the hydropower plants are able to produce. Moreover, from an economic perspective, there has already been an increase in entrepreneurial ventures from palm oil processing plants to artisanal corn mills. For example, two industrial facilities, the SICOVIR soap factory (Box 2) and V Enzymes have been set up since the launch of the hydropower plants; while at least two others are currently being installed, including a chocolate factory and a chia seed processing plant.

In terms of employment, the Mutwanga I and II hydropower plants have contributed to the creation of 160 direct jobs in the two industrial facilities, as well as some 3,000 indirect jobs along the peasants' palm oil value chain (2018 figures). Furthermore, hydropower development has also benefitted the fishing industry around Lake Edward by enabling investment in refrigeration along the supply chain, thus increasing the size of the market.

Figure 4. A woman working as an apprentice in a tailor's shop connected to the hydroelectric grid

Note: *Electricity allows the tailors to utilize electric sewing machines and to work later into the evenings, increasing their productivity and weekly income.*

Figure 5. Working in the palm oil sector

Note: *Palm kernels purchased from local growers are processed into oil then sold to aggregators, who in turn sell it to the SICOVIR soap factory.*

Box 2. Agricultural transformation and the SICOVIR soap factory

The SICOVIR soap factory, the largest factory of its type in the eastern DRC, was only made operational as a result of the electricity generated by the Mutwanga SHP plants. Located on the edge of Mutwanga, construction of the SICOVIR facility began in September 2013 with operations starting in spring 2016. SICOVIR continues to provide much needed employment to the local community through permanent skilled jobs as well as short-term, low-skilled jobs. A large part of the soap factory was installed following the SHP development and it is estimated that 157–188 jobs per month can be directly attributed to electrification – job creation corresponding to a conservative ration of 337–449 jobs per MW of installed capacity. The factory also purchases crude palm oil, palm kernels and palm kernel oil from local producers via local depots and buys other agricultural goods, including wood, beans and rice, directly from local producers. Given that the majority of people in the Mutwanga area are supported by agriculture and by cultivating palm for sale, there is a significant potential for positive economic impacts across a broad population base through these agricultural purchases.

Box 3. Revitalizing the palm oil sector

According to 2018 figures, the Mutwanga I and II hydropower plants have contributed to the creation of some 3,000 indirect jobs along the palm oil value chain.

Moreover, SICOVIR guarantees farmers with an almost unlimited market for their production of oil palm fruit if the quality standard is met. Currently, the soap factory is obliged to buy up to 150 tons of palm oil per month from the Kisangani region to ensure its operations – limited palm kernel production in the region, coupled with artisanal extraction of oil severely affects availability and oil quality. Furthermore, through the 'Palm trees of Kivu' project, SICOVIR is now collaborating with the Virunga Foundation and an international network of organizations specialized in the development of agricultural sectors to boost the recovery of the palm oil sector in the Mutwanga region. Funded by the European Union, the project is helping to revitalize palm cultivation and palm oil processing in this area of the park and some 3,165 farmers in the area will be involved in the project, with more than 18,000 people benefitting from improved well-being of households. Virunga National Park will learn from this pilot with a view to launching similar projects in other areas of the park and for other agricultural sectors such as coffee, cocoa and maize.

Lessons for future SHP development

Lesson 1: Progress can be made even during times of conflict with the right support

Economic development in rural communities, in particular, communities in conflict, such as those in the eastern DRC, is a complex and challenging goal. The list of Virunga's complex challenges is long and includes illegal trafficking of charcoal and fish, corruption, political instability, rebels, armed conflict and violence. However, the payoffs of rural electrification in this particular case study are promising. A main take-away has been that substantial progress can be made even during times of conflict, as long as the right support is in place. As Emmanuel de Merode, Parks Director, indicates:

'The construction of the second hydroelectric plant started under artillery fire during the M23 conflict, but we had a motivated team and the plant was built within the specified deadlines and within budget. The lesson is that it is possible with the right approach and commitment. Fortunately for us the EU, our main donor, has been very understanding of that need. It is when the risks are highest that we need the most support. This explains, more than anything else, the success of the programme's continuity.'

Progress is still going strong and investment has been growing as the societal benefits are becoming visible. In 2015, a larger hydropower plant of 13.5 MW was completed at Matebe, and a network of distribution lines was constructed to take electricity out to nearby communities. Over 3,000 households and 125 SMEs are connected to this network, with new connections taking place at a rate of 25 per day. Some 15 villages have received free street lighting, which has had a major impact on the social lives and physical security of their inhabitants and this will be rolled out for many villages in the near future. Furthermore, the construction of an additional hydropower plant, a 15 MW SHP in Luviro, was started in 2017 and this plant is scheduled to go online by March 2020.

There are the day-to-day challenges of running power plants in the environment of instability, poverty and corruption. The two case study plants offer the administration lessons in trial and error. The challenging next steps will be for practitioners and researchers to show whether the impacts of the Mutwanga case study are scalable across larger hydropower projects, whether or not this economic development can help reduce violent conflict and armed group participation in the region and whether these sorts of projects ultimately benefit both local communities and conservation efforts.

2.7 SMALL HYDROPOWER DRIVING LOCAL DEVELOPMENT: TAKING XINGSHAN COUNTY, HUBEI PROVINCE, CHINA AS AN EXAMPLE

Source: NordNordWest/Wikipedia, https://creativecommons.org/licenses/by-sa/3.0/de/legalcode

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Considered a "starting pillar industry", SHP has underpinned the rapid development of Xingshan County, promoting industrial production and development, attracting investment and significantly boosting GDP. It has also helped to promote social and community development, increasing local incomes, alleviating poverty and helping to meet basic public needs.

Xingshan County is located in Hubei Province in the mountainous north-western corner of Yichang prefecture, China. The county, which is affiliated to Yichang City, has an area of 2,327 km^2 and a total population of 260,000. Overall, it boasts of 156 streams which form two major river systems, the Xiangxi River and the Liangtai River. With a total annual runoff of 2,096 million m^3, the county's theoretical hydropower potential amounts to 318 MW and the developable potential capacity is 242 MW.

SHP is arguably Xingshan's most famous brand and the county has long identified hydropower construction as a "starting pillar industry", while formulating a national economic development strategy of "hydropower industry starts, mineral industry makes breakthroughs, and forestry and fruit industry booms" (Box 1). One of the first 100 pilot counties to achieve rural primary electrification, Xingshan County was also listed as one of the 400 rural electrification counties in China during the 10th Five-Year Plan period (2001–2005).

Over the last 50 years, Xingshan has developed and built 84 hydropower stations with a total installed capacity of 220 MW, an annual power generation of 650–690 GWh and a per capita installed capacity of 1.3 kW. Xingshan County forms an electric power industry system integrating construction, generation, supply, utilization and management. Besides improving life quality, SHP development has significantly increased local fiscal revenue and promoted economic development across multiple sectors including local industry, agriculture, commerce and trade.

The benefits of SHP – improving life quality, promoting industrial production and development and attracting investment

The benefits of SHP development have been wide-ranging. SHP has improved life quality in rural areas in particular by solving the issue of poor rural illumination. Before the exploitation of SHP, rural areas in Xingshan County were mainly illuminated by burning pine torches and kerosene lamps. Continuous SHP development has powered rural lighting while also achieving self-sufficiency and delivering large amounts of electricity to the state grid. Electricity access has also meant washing machines and rice cookers now feature in many family homes.

SHP has also enabled electrical processing in rural areas. Traditional workshops, which depended on manpower and animal power in rice and noodle processing, oil extraction threshing, have been replaced by modern electric machinery that has significantly improved production efficiency. Over the last 30 years, the annual output value has increased from US$ 10.8 million to US$ 32.4 million, resulting in the creation of 1,520 jobs.

The county's long-term SHP commitment has also promoted industrial development. While solving the problem of daily electricity consumption in urban areas, Xingshan County used a large amount of surplus electricity to develop industrial production with a particular focus on mining and mineral and agricultural products processing – enabling a significant structural shift from agriculture-oriented to industry-oriented production.

Overall, SHP enterprises provide 1,500 jobs per year. Mining enterprises, accelerated by SHP projects, have an annual mining capacity of over 2 million tons and have created more than 1,000 jobs. Similarly, the Xingfa Group, a leading enterprise, which is mainly engaged in mineral product processing, has established two chemical parks in the county and is a major employer, achieving annual sales revenue of more than US$ 150 million.

> **'Xingshan County used a large amount of surplus electricity to develop industrial production… enabling a significant structural shift from agriculture-orientated to industry-orientated production.'**

SHP has also stimulated investment and promoted cooperation in Xingshan. Due to its abundant SHP resources, Xingshan County has been able to absorb social capital to participate in SHP exploitation. The county has 21 state-owned hydropower stations, 54 installed units, 145,050 kW of installed capacity and a designed annual power generation of 546.67 GWh. It also has 61 hydropower stations developed with private capital, with 123 installed units, a capacity of 75,395 kW and the designed annual power generation of 294.41 GWh.

Since 2011, Xingshan County has also established an industrial park in Pingyikou and attracted a number of new industries with high technology content, good economic returns, low resource consumption and low environmental pollution. So far, eight enterprises have settled in the park, providing over 600 jobs. Annual sales revenue has increased by nearly US$ 1,500 million and total taxes exceed US$ 150 million.

Meanwhile, the agricultural product processing industry has been vigorously developed. Projects include the production of Gegen (kudzu vine root) vinegar and base wine, tea processing, ecotourism and sightseeing, undergrowth cultivation, and biological organic and inorganic compound fertilizer production. In the tourism logistics industry, five logistics transportation enterprises and 10 commercial enterprises have also been introduced, and planning and investment have supported Nanyang Hot Spring and Longmen River tourism in the county. Moreover, Xingshan Gaolan River Water Conservancy Scenic Area, Gufu River Water Conservancy Scenic Area and Nanyang River Water Conservancy Scenic Area have been successfully branded as "Hubei Provincial Water Conservancy Scenic Areas" by Hubei Province.

Figure 1. The powerhouse of the Mantianting SHP

Using SHP to stimulate economic development and social consumption, increase personal income and taxation, and help meet basic public needs

SHP has driven economic development and boosted the GDP growth in Xingshan County which was low in part due to the lack of access to electricity. For example, in 1978, there were less than 20 industrial enterprises in the county and an industrial output value of only US$ 1.7 million, accounting for only 28 per cent of the total industrial and agricultural output value. By 1994, the number of industrial enterprises had increased to over 4,000 and the industrial output value reached US$ 77 million.

In terms of the county's industrial economy, resource development enterprises and resource transformation enterprises in chemicals, electronics, machinery, building materials, papermaking and processing have all developed rapidly. While the output value per kWh of electricity reached US$ 0.21, the power consumption and conversion rates were the highest in the province. In 2016, the county's GDP was over US$ 1.5 billion, around 19 times that of 2011.

SHP has also effectively promoted the rapid growth of social consumption in Xingshan County. By 1994, around 95 per cent of rural households used electricity, with 31 per cent replacing firewood with electricity. Overall, the average annual electricity consumption reached 410 kWh, driving the consumption of power and related products. Further, SHP development has significantly increased personal income, the monthly per capita disposable income of local people increasing from US$ 71.6 in 1990 to US$ 1,630 in 2017.

'In 2016, the county's GDP was over US$ 1.5 billion, around 19 times that of 2011. Further, SHP development has significantly increased personal incomes, the monthly per capita disposable income of local people increasing from US$ 71.6 in 1990 to US$ 1,630 in 2017.'

The amount of local taxes raised has also increased, and the county is no longer dominated by the traditional agricultural economy nor characterized by insufficient tax sources and long-term national financial subsidies. Similarly, the proportion of industrial economy in Xingshan County has gone up continuously over the last 30 years of development, while the SHP industry still accounts for a considerable proportion of the county's fiscal revenue.

SHP has also helped in the development of other sectors including local building materials, transportation, catering, commerce, construction, tourism, agricultural and other product supply and other service industries. This has provided a large number of indirect employment opportunities and accelerated the development of the county's mines, industrial park construction and urban construction, and contributed to meeting the county's industrial demand for water. Meanwhile, sufficient electric power has boosted Xingshan's tourist industry, with Zhaojun Village Scenic Area now gaining popularity among tourists, the Gufu River project proving a major attraction, and rural tourism and farmhouse tourism developing rapidly to become important channels to increase farmers' income.

Moreover, SHP helped with water supply engineering to satisfy basic electricity and water needs of urban areas and industries. The county has eight townships and some village committees have implemented unified water supply from the water supply company. SHP has also been used to address long-term water shortages caused by geographical and environmental factors as is the case in Huanglian Town, which used SHP-generated electricity for cascade water diversion.

By utilizing power to implement artificial water diversion, the irrigation needs for various economic crops such as citrus, tobacco and vegetables have been effectively met; and reservoirs, such as Gudongkou and Qinglongzhai, play an important role in flood control and crop irrigation. At the same time, the development of SHP projects has led to the construction of many rural roads across the county.

SHP and social responsibility – poverty alleviation, assisting migrant groups and supporting local education

The Xingfa Group assisted both Shukongping Village and Maocao Village of Shuiyuesi Town in Xingshan County to alleviate poverty. Specific measures, which are directed at areas with an average monthly income per capita lower than US$ 581, were adapted to local conditions and often creatively combined national green hydropower with New Countryside Construction. Poverty alleviation methods

were employed along with infrastructural improvement. In the two villages assisted, a total of 97 households were lifted out of poverty.

The Xingfa Group also engaged in poverty alleviation and relocation for residents of areas affected by hydropower, and this has focused in particular on the construction of three migrant resettlement communities – Maocaoping Community, Guanzikou Community and Gaolan Community. The Maocaoping Community has already been built and 30 migrant families have been resettled in a development, which has undergone a significant improvement in living conditions and environment, and access to facilities, utilities and transport.

The Xingfa Group also implements a fundraising policy for company employees' children, who are admitted to universities, thereby reducing economic stress; and it assists employees in need and provides assistance to employees with special difficulties or suffering from major illnesses to help prevent impoverishment of workers' families.

Lessons for future SHP development

Lesson 1: SHP can promote the coordinated development of the regional economy

SHP has brought prosperity to all industries and the development of SHP projects has enabled effective utilization and availability of resources in different regions. It has also facilitated the synchronous advancement between developed and less developed regions, between industry, agriculture and tertiary sectors, and between county and village households. Moreover, it has contributed to narrowing the gap between regions and industries, and promoted the coordination of economic development.

Figure 2. Drifting in the Basin of Chaotianhou SHP

Lesson 2: The importance of building public infrastructure to support SHP-inspired economic development

For many years, high traffic levels restricted Xingshan's agricultural products and farmers' income. In order to fully benefit from SHP-related economic development, it was necessary to support the construction of transportation infrastructure including highways, ports and piers, and rural ferries. The construction of these projects has optimized the road network in the county and has laid the foundation for regional economic development and poverty alleviation.

Lesson 3: The importance of green SHP construction

SHPs with a small installed capacity, ageing equipment and low efficiency have been phased out with a view to protect the natural environment. In 2017, the Gengjiahe hydropower station, which was built in the 1960s, and the Jiangjunzhu hydropower station built in the 1980s, were both dismantled. Moreover, from 2017, ecological water discharge projects were fully implemented by 28 hydropower stations in the Gaolan, Nanyang and Gufu river basins to ensure continuous water flow throughout the year.

Lesson 4: The need to guarantee future development

Xingshan County is rich in SHP resources. In future, it will make better use of these resources and will actively engage in scientific development to improve SHP efficiency and usage with a view to protect the ecological environment. Through scientific and technological progress, the county will oversee the mechanization, automation and intelligent transformation of existing SHP stations to enhance the efficiency of power generation and supply. It will also make use of SHP and other power resources to accelerate the extensive use of electric machinery, production equipment, automobile and other sectors. It will also strive to reduce the application of gasoline and diesel engines, and contribute to reduce air pollution and protect the natural environment.

Lesson 5: GEF value-added services

During the 12th Five-Year Plan period (2011–2015), Xingshan County engaged the Xingfa Group as a leading enterprise and actively sought policy support from the joint project of ICSHP and the Global Environment Facility (GEF). The Xingfa Group implemented central and provincial financial support, gaining over US$ 10.7 million in self-raised and subsidy funds from central and provincial governments, and carried out efficiency improvements, capacity expansion and the

transformation of the Houzibao, Cangpinghe, Jiuchonghe and Nanyang hydropower plants in the Nanyang River Basin. In 2017, Xingshan County launched an initiative aiming to increase the efficiency and expand the capacity of SHP projects on the Gaolan River and Gufu River.

Box 1. Xingshan's booming forestry and fruit industry

Before the 1980s, agricultural production in Xingshan County was dominated by grains with a low proportion of cash crops. From 1986 to 2005, taking advantage of the mountainous terrain, Xingshan County established its new economic development strategy, "hydropower industry starts, mineral industry makes breakthroughs, and forestry and fruit industry booms".

The county's lower-altitude areas focused on four kinds of oranges – navel orange, Jincheng orange, summer orange, blood orange and a kind of tung tree; the mid-altitude mountainous areas focused on four fruits and two leaves, which included walnut, chestnut, hawthorn, ginkgo, tea and flue-cured tobacco; while the high-altitude areas focused on two forest projects and one grass project, which included artificial forestation and hillside enclosure for forestation and forage.

During the 11th Five-Year Plan period (2006–2010) and based on the idea of "mountain exploitation, cultivated land remediation and base construction", the county focused on the "three specialities" of building a professional village, professional farms and specialized households. It also focused on three modernizations of projectization, standardization and commercialization, and prioritized the development of five big industries – livestock, fruit and tea, tobacco, vegetables and medicinal herbs.

In 2018, the total agricultural output value of the whole county reached US$ 343 million, 18 times higher than in 1989 and the annual per capita disposable income of rural residents was US$ 1,779. In terms of specific products, the citrus yield of the entire county totalled 96,918 tons, a 112-fold increase in less than 30 years, and 2,341 tons of tea was produced, up by 26.5 per cent. Meanwhile, some 251,000 tons of vegetables were grown increasing the self-cultivation and self-sufficiency of farming communities and the tobacco yield reached 1,992 tons, up by 35.6 per cent, while the output of traditional Chinese medicinal products was up over a quarter reaching 4,782 tons. Moreover, the local farm industry had a total of 288,900 pigs and 184,200 goats, a significant increase from previous years.

3. SMALL HYDROPOWER FINANCING

3.1 THE AKHMETA 9.4 MW SMALL HYDROPOWER PLANT IN GEORGIA

David Managadze, European Bank for Reconstruction and Development

The Akhmeta SHP in Georgia was financed under an innovative Risk Sharing Framework, a co-financing instrument between the European Bank for Reconstruction and Development and local partner banks. It also meets strong environmental standards, the plant feeds off an old Soviet-built irrigation scheme, which has kept local environmental impact to a minimum.

Located in Kakheti, a well-known wine region in eastern Georgia, the Akhmeta SHP (Figures 1-3) was constructed in just 10 months – a considerably shorter timeline than the average time required for SHP development. In part, this was due to its insightful design. The project leveraged an old Soviet-built irrigation structure, built in the 1970s and part-rehabilitated in 2007–2010, which connects to both the Alazani and Ilto rivers. Dams in the rivers, channels, tunnels and aqueducts comprise this well-functioning system that irrigates two local districts from mid-June to the beginning of September.

> **'The Akhmeta plant generates 50 GWh of clean energy per year – a significant achievement for a small hydropower project amongst the vineyards and based on a decades-old irrigation network.'**

Since the completion of the 9.4 MW hydropower plant in 2013, the irrigation structure has been used for renewable energy generation outside of the irrigation season over the rest of the year. The Akhmeta facility generates 50 GWh of clean energy on an average per year translating into an annual reduction of 15,000 tons of CO_2 emissions – a significant achievement for an SHP project amongst the vineyards and based on a decades-old irrigation network. Moreover, energy production is reliable as it is not linked to the hydrology of the basin but rather the irrigation channel, which has a constant year-round flow.

The European Bank for Reconstruction and Development (EBRD) Risk Sharing Framework

The Akhmeta SHP is notable for its use of the EBRD's unique financing model known as the Risk Sharing Framework or RSF. A key feature of this flexible co-financing instrument is that the EBRD takes on part of the risk of sub-loans made by partner banks to eligible clients (Boxes 1 and 2). This framework allowed the EBRD to finance the Akhmeta SHP in a way that neither local banks nor direct foreign investments could have done efficiently on a direct financing basis.

It is often the case that local banks' ability to support projects similar to the Akhmeta initiative is constrained by single-borrower exposure limits imposed by central banks, their own internal guidelines predominantly based on collateral borrowing. The RSF can help overcome this and other related obstacles. Of the overall costs of the Akhmeta development, which totalled around US$ 10 million, US$ 7 million was allocated for project financing and construction under the RSF co-financing instrument between EBRD and the local partner banks. The planned payback period is 10 years. Apart from the developers, partner banks benefit too – the RSF is supporting them in financing projects under a financing structure that allows for knowledge sharing and capacity development. As David Managadze, EBRD Senior Banker and Akhmeta HPP co-financer explains:

'In SHP development, it can be challenging to finance a small hydropower project, especially given the necessary legal and environmental requirements and it can be a large sum, which developers have to find up front. This is where the EBRD's RSF can have a positive impact. As in the case of the Akhmeta SHP development, the RSF was instrumental in successful project realization, particularly in the way it gave the necessary added security to the local banks, which themselves gained in terms of their own capacity building and knowledge share.'

'It can be challenging to finance a small hydropower project especially given the important legal and environmental requirements...this is where the EBRD's Risk Sharing Framework can have a positive impact.'

Taking a wider view, the Framework's usefulness in financing SHP development suggests a strong potential for further application. The RSF could play an important role in enabling the EBRD to assist local partner banks in meeting the growing financial needs of successful small and medium enterprises and local investors interested in the development of SHP projects in Georgia and even the wider Caucasus region.

Box 1. The EBRD Risk Sharing Framework

An important EBRD financial instrument, the Risk Sharing Framework or "The Framework" enables the EBRD to offer Partner Banks (PBs) funded or unfunded risk-participation schemes usually taking 50 per cent (exceptionally 65 per cent) of the risk of sub-loans extended by the PBs to eligible clients that have met pre-agreed eligibility criteria. Sub-loans under the Framework can amount up to EUR 20 million and have a maximum tenor of 10 years.

Box 2. The European Bank for Reconstruction and Development

A multilateral developmental investment bank, the EBRD uses investment as a tool to help further progress towards market-orientated economies. It is owned by 67 countries as well as the European Union and the European Investment Bank. Since its creation, the EBRD has invested over US$ 130 billion in over 5,200 projects globally. Key EBRD goals are to support countries shift towards a low-carbon future and help countries on the path to sustainable growth. The EBRD assesses the environmental and social impacts of all the projects it invests in and works with clients to achieve good international standards. In 2016, the EBRD rolled out the Green Economy Transition Approach, which puts investments benefitting the environment at the heart of its activity. It encourages public participation through pre-investment consultation, information disclosure and regular dialogue with civil society and stakeholders. Over the last 10 years, the EBRD has made significant investments in the Georgian power sector including hydropower projects in Akhmeta, Upper and Lower Svaneti, Lukhuni, Kazbegi, Adjara, and Racha-Lukhuni. The EBRD also invested heavily in the 315 km high-voltage Black Sea Transmission Line, which runs between the east and west of Georgia and connects to the north-east of Turkey, stimulating unprecedented investment in renewable energy in the region.

Box 3. Hydrolea: Specializing in SHP in Georgia

Hydrolea specializes in the development of small-scale hydropower plants and the company was the main developer and investor for the 9.5 MW Akhmeta SHP. It is also the current owner. Since the Akhmeta project, the company's first SHP initiative, Hydrolea has developed and financed several other SHPs in Georgia. These include the 195 MW Pshavela SHP in the Kakheti region, which runs off the Stori River, and the 3 MW Debeda SHP, which runs off the Debeda River in Georgia's south-eastern Kvemo Kartli region. Hydrolea is also developing two SHPs in Mestia municipality in the Zemo Svaneti region of western Georgia – the 8.1 MW Kasleti-1 SHP, which has an estimated annual output of 46.4 GWh, and the 8.1 MW Kasleti-2 SHP, with an estimated annual output of 45.8 GWh.

Benefitting both the environment and the local communities

The Akhmeta project sets an example both in terms of the way it supports global environmental goals and how it provides specific benefits to local communities and local people.

From the environmental perspective, the Akhmeta SHP contributes to the UN Sustainable Development Goals (SDGs) designed to ensure access to affordable, reliable and modern energy for all (SDG 7) while answering the call for urgent action to combat climate change and its impacts (SDG 13). From the sustainability perspective, the plant is ideally located in an already modified water system with low biodiversity sensitivities, no water usage conflicts or social sensitivities. Having a "social licence" to operate was considered a key project component and the developer was keen to be involved in early engagement and informal communication with the local community to ensure there were no specific objections to the initiative. Following early and thorough consultation, the local population offered their unanimous support and the developers, a group of local investors with experience in the Georgian power sector, continue to maintain a positive relationship with local people, who have benefitted from the Akhmeta SHP in many ways.

First, now that the structure is used in part for energy generation purposes, it has yielded incremental revenues for the owner of the irrigation network and ensured a valuable additional source of funding for repair and maintenance of the overall irrigation infrastructure. Proper maintenance and repair have in turn provided security to local farmers and the local agricultural communities of this famous wine region that are dependent on the irrigation system for their livelihoods.

Second and on a practical level, the development of the Akhmeta plant created various full and part-time jobs (Box 4) in construction for members of the local communities. It also created permanent posts linked to the plant's operation. There is also an expectation that in the medium term, there will be an upgrade of locally sourced skills in hydropower technology and there will be an important and related transfer of technological knowledge to the region.

Box 4. SHP for local job creation

'Previously, I was working only two months a year on a labour contract. This was during the melioration season. As a consequence of the Akhmeta SHP, I am now employed all year round as the plant is connected to the Zemo Alazani Channel. The plant is significant locally, it provides jobs and irrigation security for local agricultural communities, and it's actually the first industrial object built in Akhmeta since the 1970s.'

–Alexandre, Akhmeta, Akhmeta SHP worker

Lessons for future SHP development

The Akhmeta SHP development introduces a significant demonstration effect, particularly in terms of the financial structuring for hydropower projects of a similar size. Moreover, it sets an example in terms of environmental and social standards, which in the case of the Akhmeta SHP, were fully in line with the EBRD's rigorous environmental and social requirements related to sustainable development.

Lesson 1: The RSF as a useful business model

The identification of a proper financial structure will play an important role in the further development of the SHP sector. The Akhmeta project's successful utilization of the EBRD RSF, particularly the way this co-financing instrument provided security, knowledge sharing and PB capacity building, should be closely considered a business model for investors interested in future SHP development in Georgia, the region and farther afield.

Lesson 2: The importance of environmental standards and community engagement

The developers designed, constructed and currently operate the plant in compliance with good international standards and practices related to sustainable development.

Figure 1. Akhmeta SHP, Georgia

Specifically, EBRD performance requirements related to assessment and management of environmental impacts and issues, and biodiversity conservation were met. Importantly, so too were requirements on information disclosure and social engagement. The Akhmeta project serves to remind future investors of the importance of community dialogue. The developer's dedication to an early engagement with the local community paved the way for the project's success ensuring that the initiative benefitted from the broad community support and a "social licence" to operate. Moreover, the project's aim to improve local skills in hydropower, transferring the future technological knowledge to the region and forging the way for further technological self-reliance, is an important aspiration.

In general, the Akhmeta SHP will be of particular interest to local stakeholders in Georgia given its abundant water resources, which carry a significant potential for generating hydroelectric energy. The country has approximately 26,000 rivers, which total 60,000 km in length and the EBRD estimates that 20–25 per cent of these are amenable to SHP. The untapped potential of this energy resource, once developed, could further reduce fossil fuel imports into Georgia and boost green energy exports to neighbouring countries and Europe.

Figure 2. Inside Akhmeta SHP

Box 5. Akhmeta SHP and its main technical parameters

Diversion and waterway	
Type of intake	Free overflow weir with sand trap
Length of penstock	1,050 metres
Penstock diameter	2,000 mm
Power plant	
No. of units	2
Turbine type	Francis horizontal shaft
Design discharge	12 m^3/s (2 x 6 m^3/s)
Design head	96 m gross (84 m net)
Installed capacity	9,364 kW (2 x 4,682 kW)
Energy production	P50 = 52 GWh/a; P75 = 48 GWh/a
Plant factor	P50 = 63%; P75 = 59%

The project implementation was based on four main contracts – civil works, electro-mechanical, supply of pipes and construction of the transmission line (Box 6). Additionally, the project developer had several contracts for supply of equipment and construction materials to be used by electro-mechanical and civil works contractors. All contracts were based on reasonable and fair conditions and were in line with international standards.

Box 6. Summary of contracts

Contract type	Comment
Engineering design	Contract with the owners engineer with proven experience and track record. The design was reviewed by the EBRD's engineer and found appropriate and in line with good engineering practice.
Civil works	Contract with civil works contractor. Scope of works: intake, penstock trench, powerhouse, tailrace channel. The contract follows the International Federation of Consulting Engineers (FIDIC) for small works (Green Book), which is a good model for such work, and is accepted by both the EBRD and the PB.
Supplemental equipment and materials supply contracts	Several contracts on supply of various equipment and materials needed for civil works contractors – closing gates and mechanisms, machinery (crane, generator) and construction material (sand, gravel).
Electro-mechanical equipment	Contract with an electro-mechanical equipment supplier. Scope of works: supply and installation of a compact Francis type hydro turbine with generator, main inlet butterfly valve for the turbine, hydraulic pressure units, cooling water system, control SCADA system, 2 x three phase 6.3/ 35 kV step-up transformers rated 5.2 MVA, station service transformer with switchboard 400 V, medium voltage cubicles (7.2 kV and 35 kV), cabling system.
Penstock	Supply and install contract with pipe supplier with proven experience and track record.
HV line and grid connection	The grid connection was executed by the state-owned transmission network owner, the sponsor bearing the costs of services and purchase of transmission line. A single 6.3/35 kV transformation station was built next to the powerhouse. A 35 kV power line with a total length of 2.3 km connected these to the existing 35 kV grid substation, hence allowing connection to the transmission line that is part of the national grid.

3.2 A COMMERCIAL BANK'S INNOVATIVE SMALL HYDROPOWER LOAN MODE FOR POVERTY ALLEVIATION

Xu Gang, Shi Hong, Wu Xiaoling, Ping An Bank; Zhengfu Rao, Zhaoheng Hydropower Group

Ping An Bank, a commercial Chinese bank, has identified the small hydropower (SHP) industry as an important sector to alleviate rural poverty. Offering customized financial assistance for hydropower construction and operation in poverty-stricken areas, the bank has found a way to use innovative financial tools to boost rural economic and social development, while promoting poverty reduction and sustainable development.

Based on research on the advantages of different resources in poverty-stricken areas, Ping An Bank, a Chinese joint-stock commercial bank, has identified the SHP industry as an important sector for potential poverty alleviation in China. By providing financial assistance for the construction and operation of hydropower projects through customized "loan + bond" mechanism, the bank has established an ecosphere in which hydropower assists agriculture and integrates with infrastructure, energy supply, empowerment and the holistic approach[1] to poverty alleviation.

Apart from hydropower financing, Ping An Bank also works with its sister companies of Ping An Group on Village Doctor and Village Education projects, actively providing support to poor households through initiatives, which promote good health and high-quality education. Overall, the bank's target to alleviate poverty through hydropower poverty projects is consistent with three United Nations Sustainable Development Goals (SDGs) 1, 3 and 4, to eliminate poverty, to promote good health and well-being and to ensure quality education.

Ping An Bank and the hydropower poverty alleviation loan

Ping An Bank established its Poverty Alleviation Finance Office in 2018, the main platform of which has been implementation of the Industrial Poverty Alleviation Loan and other assistance methods, which

[1] The approach is officially referred to as "hematopoietic" poverty alleviation, which implies a set of measures, both economic and humanitarian, that are intended to enhance the endogenous motivation for rural development and permanently lift people out of poverty, including various arrangements to create work opportunities and improve labour productivity, and provide job training and skill building, turning the anti-poverty approach from "blood transfusion" to "hematopoiesis".

focus on advantageous resources and industries in poverty-stricken areas.

A key strategy has been to rely on core enterprises to actively build the "holistic poverty alleviation" mode, which closely connects banks, governments, enterprises and poor households. The overall aim is to encourage poor households to participate in all aspects of the industrial value chain and help marginalized groups to improve their quality of life while increasing their incomes.

Following in-depth research, Ping An Bank identified the hydropower industry as an important sector for poverty alleviation. According to statistics from the Ministry of Water Resources, 700 of 832 poor counties in China have abundant hydropower resources. Further, SHP construction is fast, the technology is mature and the impact on the local ecological environment is relatively small. In comparison to other industries, development is mainly on-site and the effects can be rapid with, for example, employment opportunities increasing the local income during the construction period.

Further, hydropower generation not only directly solves the issue of electricity shortages in remote and poverty-stricken areas, but also helps promote the growth of other industries, thereby playing an important role in the rural economic and social development and poverty reduction.

However, the remote location of SHP projects and the lack of traditional collateral mean that SHP financing can be both difficult and expensive. In fact, financing has become the bottleneck for poverty alleviation through SHP development. With this in mind, Ping An Bank customized a hydropower poverty alleviation loan mode to specifically support the construction and operation of hydropower projects in poverty-stricken areas (Figure 1).

'Financing has become the bottleneck for poverty alleviation through SHP development. With this in mind, Ping An Bank customized a hydropower poverty alleviation loan mode to specifically support the construction and operation of hydropower projects in poverty-stricken areas.'

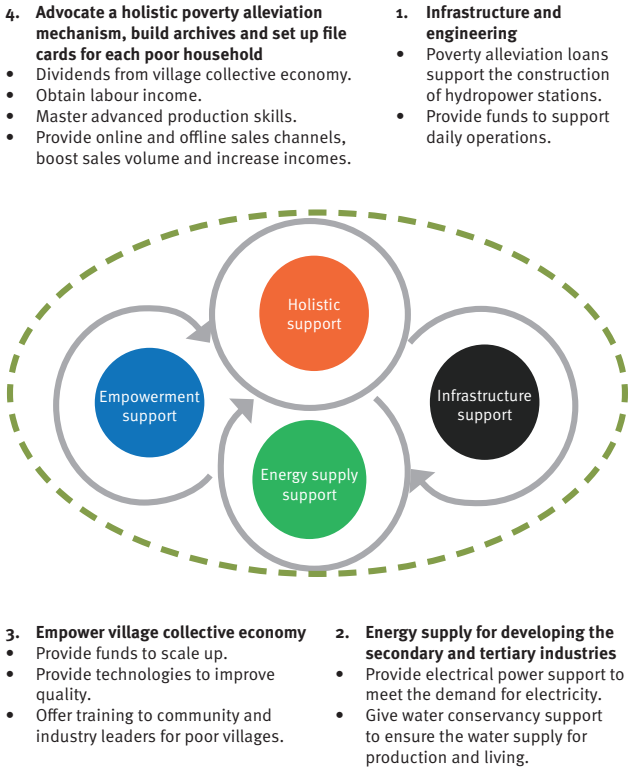

Figure 1. Ping An Bank's Hydropower Poverty Alleviation loan mode

This model has been widely recognized in China and it has won many awards including the 2018 Shenzhen Financial Innovation Award, while Ping An Bank too bagged many awards including the 2018 Outstanding Contributor to Targeted Poverty Alleviation, Targeted Poverty Alleviation Pioneer Institution, Annual Excellent Brand for Innovative Agricultural Poverty Alleviation and the Pioneer Institution for Financial Poverty Alleviation. It was also selected as one of the "Thirty Excellent Cases" by the State Council Leading Group Office of Poverty Alleviation and Development.

Benefits and outcomes for communities: Infrastructure, energy supply, empowerment and haemopoietic support

The first tier of the Ping An Bank's hydropower poverty alleviation ecosphere is infrastructure support. The bank provides financial support for the construction and operation of hydropower stations, customized with the non-traditional risk control mode of hydropower loan business and the innovative "211" assistance mode. This benefits tens of thousands of poor households, directly or indirectly.

More specifically, in 2018, the bank issued a total of US$ 198 million of hydropower poverty alleviation loans with hydropower enterprises benefitting from preferential interest rates. Special

poverty alleviation funds were allocated according to a certain proportion of the loan amount, and poverty alleviation activities were carried out in accordance with the specific assistance programme, negotiated with the bank.

Further, the bank has guided poverty alleviation funds to assist many state-level poverty-stricken counties in Yunnan, Guangxi, Sichuan and other provinces. Collective village economies have been helped to develop agricultural products and agricultural product-processing industries, which in turn aids in poor households' increase in wages, dividends and income through labour. Amongst the bank's hydropower poverty alleviation projects, employee assistance, cash assistance or material assistance have directly benefitted around 1,190 people in poor households.

The second and third tiers of the hydropower poverty alleviation ecosphere are energy supply support and empowerment support, respectively. Energy supply support means that once operational, hydropower projects backed by Ping An Bank, can provide power and water supply support for the development of secondary and tertiary industries in poverty-stricken areas.

The third level is empowerment support, which describes the bank's mobilization of resources to provide financial and technical support for the development of the village collective economy. For example, with the help of agricultural technology training from the State Council Leading Group Office of Poverty Alleviation and Development, the bank organized regular trainings of community leaders, which included arranging in-depth discussions on industrial policies and online marketing, facilitating a connection between planting and breeding projects. It also visited specialized cooperatives and planting bases, and provided ongoing technical support and mentoring for one year after the completion of the training. Overall, this support targeted 380 students from 31 poverty-stricken counties in 14 provinces including hydropower poverty alleviation areas.

The final tier of the hydropower poverty alleviation ecosphere is haemopoietic support. For example, Ping An Bank helped develop distinct agricultural products in hydropower poverty alleviation areas, assisted in building the "Ping An Orange" brand, and provided both online and offline sales channels to support poor households in expanding product sales. In less than one year, the accumulated sales revenue reached US$ 0.7 million.

The effects of the previously mentioned tiers have benefitted communities and helped in poverty alleviation. Poor households profit from real economic benefits by sharing dividends from the village collective economy, gaining income from labour services and assistance in the sales of agricultural products. They also benefit from the help received to improve production skills, while gaining experience in product sales and expansion of sales channels.

Case studies on small hydropower loan financing

Small hydropower projects in Yingjiang, Yunnan Province

Ping An Bank issued a 10-year industrial poverty alleviation loan (US$ 33 million) to a hydropower company in Yunnan Province for the construction and operation of the Songpo hydropower station (27 MW, commissioned in 2018) and the Yinhe hydropower station (12.6 MW, commissioned in 2012).[2] The projects benefitted 1,279 people across 325 poor households in Yingjiang County, one of the nation's poorest counties. In addition to issuing one-time compensation and continuous dividends, the hydropower company also signed an assistance agreement with poor households. Over the next five years, the two hydropower stations aims to fund targeted poverty alleviation measures through the yearly savings made from the preferential loan interest rate agreed upon with Ping An Bank. The project aims to help poverty-stricken households by developing planting and breeding processing industries, and support other poverty alleviation measures in the township. It will help village collectives, which are mainly used to subsidize students, support poor households and the rural elderly, and carry out practical technical and skill training in rural areas.

In 2019, the hydropower company allocated US$ 239,800 to help village collectives develop industries in this area. It is supporting the establishment of specialized cooperatives for tsaoko and walnut processing in Songpo Village, while promoting industrial upgrading through a "cooperation and farmers" model. This model saw villagers buy shares in the form of agricultural products and further enhanced the added value of products through drying, sorting and packaging. The cooperatives used 20–40 per cent of profits for dividends, thus providing a stable income for poor households.

Small hydropower project in Zhaotong, Yunnan Province

Ping An Bank issued an industrial poverty alleviation loan of US$ 39 million to a hydropower company for SHP construction and operation in Daguan County, Zhaotong City, Yunnan Province. To help local villagers achieve long-term poverty alleviation and stability, the bank adopted the industrial chain poverty alleviation model of "agriculture-related enterprises

[2] China defines SHP as hydropower plants with capacity up to 50 MW.

+ cooperatives + farmers", which combines enterprises and the local government. The project involved donating money to set up farmers' professional cooperatives, planting morel (mushrooms) on approximately 20 acres of land, which have been transferred to the resettlement sites in Baoshan of Xinzhai Village. The farmers' professional cooperatives absorb poverty-stricken households in the resettlement sites and encourage them to participate in dividends via labour.

Ping An Bank is also coordinating with the cooperative to sign a purchase order contract with a fungus product processing company in Yunnan to ensure a sale price of not less than US$ 9 per kg of fresh morel. Moreover, the bank is cooperating with enterprises to support the local government in its Warm Winter Campaign by distributing winter funds to 149 poverty-stricken households (209 people) in Yuele Town.

Supporting United Nations' Sustainable Development Goals (SDGs)

Ping An Bank's hydropower poverty alleviation project is consistent with the UN SDGs especially SDG 1 to "end poverty in all its forms everywhere". The bank's multiple efforts to build a hydropower poverty alleviation ecosphere have focused on one central point: to implement the sustainable holistic poverty alleviation mechanism and make it possible for poor households to achieve sustainable poverty eradication.

When conducting hydropower poverty alleviation projects, the bank requires measures to directly benefit poverty-stricken households. For example, poor households can be employed by supporting infrastructure construction such as hydropower projects in poverty-stricken areas and setting up planting and breeding cooperatives according to local conditions. On the other hand, the bank has made clear that the focus of poverty alleviation is on a holistic approach. This aims to select industrial projects that can bring employment opportunities, upgrade employment skills or bring more entrepreneurial opportunities to poor households, in combination with local resources. Moreover, it takes advantage of technologies and channels of hydropower enterprises and industrial projects while boosting the economic income of poor households. Overall, this benefits enterprises, the Government and poor households, and also helps promote sustainable poverty eradication in support of UN SDG 1.

Meanwhile, the Village Doctor and Village Education projects support UN SDG 4 to "ensure inclusive and equitable quality education" and SDG 3 to "ensure healthy lives and promote well-being for all at all ages". To consolidate poverty alleviation and avoid a return to poverty, Ping An Bank cooperated with partners such as Ping An Good Doctor, Ping An Financial Leasing, Ping An Property & Casualty and Ping An Annuity to support projects. Over 100 training sessions for village doctors were organized and funding was provided for seven Ping An Wisdom Primary schools.

The Village Doctor project improves the level of village healthcare through provision of scientific and technological equipment and promoting health management for villagers by arranging regular doctor visits to villages, with an aim to reduce poverty caused by illnesses.

Through the "4+1" comprehensive education assistance action, the Village Education project utilizes technology to empower rural education, enhancing the level of educational development in local poor areas and helping to improve the level of school teaching. This not only ensures that students from rural areas enjoy access to good education but also helps to eradicate intergenerational transmission of rural poverty.

Lessons for future SHP development

The hydropower loan poverty alleviation projects successfully implemented by Ping An Bank cover three major river basins including the Jinsha River, Xijiang River and Irrawaddy River. It will continue to replicate and expand to more provinces in the future. Combined with the existing successful hydropower poverty alleviation cases, the lessons learned can be summarized as follows:

Lesson 1: Importance of the innovative hydropower loan mode and pre-loan risk

The loan mode has several distinct characteristics; it covers the principle of pre-loan risk. In light of traditional insufficient collateral for SHP development, it customizes a variety of portfolio guarantee modes including overall mortgage of hydropower assets, pledge of electricity tariff, phased guarantee, equity pledge and insurance. Prior to completion, the third party (including affiliated companies) takes responsibility for phased guarantee. After completion, the mortgage guarantee of fixed assets, right of land use and the pledge guarantee of electricity tariff (and pledge registration made in the receivable system of The People's Bank of China) will be handled. The shareholders and controllers provide several joint liability guarantees for the whole loan period, and the procedures for pledging the borrower's stock rights will be completed.

Lesson 2: Taking into account effects and local factors

Long-term assistance applies to all hydropower projects under the "211" projects. In order to meet the expected

effects of assistance, the project design includes specific provisions such as the form of assistance, the corresponding number of people and amount of each form of assistance. The implementation plan of poverty alleviation funds is led and designed by the bank. Overall, the bank must take into consideration multiple local factors such as local resources, job opportunities, improvement of local skills, and the potential for business development, in order to promote effective and sustainable poverty alleviation.

Lesson 3: 'Closed-Circle Poverty Alleviation' in four steps

To ensure that the hydropower poverty alleviation circle can benefit poor areas in the long run, and in a meaningful way, Ping An Bank has put forward the "Closed-Circle Poverty Alleviation" in four steps, an approach in which circles are linked with each other in an orderly holistic mechanism (Figure 1).

The first step is poverty alleviation training, which should target the industrial backbone of poor villages. For example, this includes those in charge of farmers' cooperatives, large families involved in planting and breeding, managers of agricultural enterprises, village cadres, rural college students and rural personnel with entrepreneurial experience.

Training comprises special lectures, mobile classrooms and agrotechnical base learning. It provides comprehensive knowledge and skills learning including planting and breeding technology, industrial policy, online marketing, e-commerce logistics, modern agricultural management and financial management. Moreover, training institutions provide technical support and tutor guidance for one year after the initial training has taken place. The overall aim is to develop capacity and skills, which in turn will promote the development of industry with an aim to reduce rural poverty.

The second step is industrial haematopoiesis. This involves making real concessions to support hydropower enterprises which actively take part in poverty alleviation activities, guides poverty alleviation funds to promote the development of the rural collective economy in poor areas and provides financial support and agricultural assistance for high-quality industrial projects.

The third step is to create a brand for each village. By selecting the characteristic industries of villages, assisting in creating an agricultural product brand with distinct elements, mobilizing multiple resources and facilitating e-commerce sales, it actively promotes increased income amongst poor households.

The fourth step is Village Doctor and Village Education, an initiative backed by Ping An Insurance Group, which supports basic literacy in poor areas and promotes physical examinations, disease prevention and training to avoid poverty caused by illness.

4. TECHNOLOGY, INNOVATION AND SMART SMALL HYDROPOWER

4.1 ZAGRODY SMALL HYDROPOWER PLANT: AN IDEA FOR AN OLD MILL

Source: Google Maps

Łukasz Kalina, Enerko Energy

Located in south-central Poland, the small hydropower plant (SHP) Zagrody is built in the conservation zone of an old water mill complex. Although this is the 40th SHP developed in Świętokrzyskie Voivodeship Province, the initiative is amongst a handful projects to use hydro-complex technology in the form of the Archimedes' screw – a relative newcomer to the SHP world having only arrived on the scene over the last decade.

The project developed by Instytut OZE Ltd, the Zagrody SHP is built in the immediate conservation zone of the water mill complex in Markowizna, in Sitkówka-Nowiny commune in Kielce County. The complex comprises the best-preserved mill in the commune, which includes a historic working water system. In this area, water mills are considered monuments of great historical significance given the commune's industrial heritage and Sitkówka-Nowiny alone is home to three mills.

The main river is the Bobrza, which is the longest tributary of the Czarna Nida and flows through the northern, north-western and western edge of the Świętokrzyskie Mountains. Around 50-km in length, the terrain of its catchment area occupies 379 km2. The area in which the Zagrody SHP is located is a protected landscape area. Operating since September 2019, it is only the fourth SHP in the province to use the Archimedes' screw. Equipped with this technology, which was provided by Enerko Energy Ltd, the Zagrody SHP produces 150 MWh of electrical energy each year.

Project works

Initial planning, development and financial identification were conducted over a two-year period. As the SHP project was located in a rural area, an environmental impact assessment was undertaken and a fish pass was designed. The project developers (Instytut OZE Ltd) secured relevant administrative permissions including on water rights and other requirements to enable construction. The SHP development was in the immediate neighbourhood of a technological monument, the old hydro-technological system based around the historic water mill, and pre-existing parts of the monument had to be preserved (Figures 1–4).

More specifically, installation of the Archimedes' screw was designed in parallel to the existing turbine cage where a water turbine used to work for the mill's needs. Moreover, the elevation of the new SHP building was covered with natural limestone to help maintain architectural consistency with the neighbouring building of the historic mill. The space between the channel of the Archimedes' screw and the residential building was used as a recreational terrace. Overall, the site is an attractive example of how to creatively repurpose a historic mill as a new hydroelectric power plant, using new technology, and without losing the site's local charm and its architectural, technological and historical significance. The developers have a significant experience in designing new hydroelectric installations in areas of water mills. The portfolio of the company already includes over a dozen such revitalizations. The company works on complex SHP designs including obtaining necessary administrative decisions based on the proxy granted by the investor.

Technical specifications: the Archimedes' screw

Equipped with an asynchronous generator (Cantoni Group), the Zagrody SHP is able to generate 37 kW. A key feature, which distinguishes this installation from others, is the inverter system (produced by the ABB group), which enables work with a variable rotation speed ensuring maximum use of the potential of flowing water.

The Archimedes' screw was made as a steel construction. The angle of the turbine axis in relation to the level is 22°. The screw itself consists of a steel tube and Archimedes' spirals wrapped on it with a diameter of 2,600 mm that are angularly offset from each other by 90° (Box 1). The hydrocomplex was placed on a concrete steel gutter. Enerko Energy Ltd also uses Archimedes' screws built in self-supporting steel structure and Kaplan turbines in various systems of S, PIT, Z types and of vertical axis. In addition to providing water turbines, the company constructs SHPs.

> **'Overall, the site is an attractive example of how to creatively repurpose a historic mill as a new hydroelectric power plant using new technology.'**

Box 1. Summary list of the main technical parameters of the SHP Zagrody hydropower unit

Type of turbine	Archimedes' screw
Flow rate	2.0 m^3/s
Head	2.5 metres
Runner diameter	2,600 mm
Runner speed	22.3 rmp
Installed capacity of the generator	37 kW
Average annual generation	150 MWh

Source: Enerko Energy

Automatics of SHP

The control and automation system of the power plant is based on the programmable modular PLC (Programmable Logic Controller) and the HMI (Human Machine Interface) panel enabling setting parameters of work of the hydropower complex and updated screening of current electric and mechanical parameters. Moreover, the operating panel is equipped with an Ethernet-standard port and software enabling online view on selected computers connected to the Internet, according to the same rules of access that direct operations. The controller, having modular construction, allows a hassle-free extension of its functionality in additional modules. It is worth highlighting that the controller is powered by constant voltage 24 VDC (Volts DC) by buffer power supply equipped with gel batteries enabling work in case of power failure. Under normal conditions, it functions as an automation system power supply and battery charger. In the case of power failure, it automatically switches off this function and transfers power from the batteries. Once normal access to power is resumed, it charges the batteries.

Further, the controller collects valuable up-to-date signals from a number of installed sensors as well as gauges of network parameters. Some of the most important monitored elements include the rotation speed, temperature, water level before and behind the grille, the logical positioning of equipment, water flow through the turbine, the level of dam opening, energy quality, energy production and the level of hydraulic power.

It should be noted that the power plant uses an inverter system, which ensures a smooth change of rotation speed of the generator. This is important as at particular hydrological parameters, this helps attain higher efficiency of the hydropower complex.

The power plant has also been equipped with the SCADA (Supervisory Control and Data Acquisition) information

system for communication, monitoring and the archiving of the exploitation parameters of the power plant (Figure 5). This helps in creating an efficient remote control mechanism to monitor the work of the system. Moreover, the solutions offered allow for more efficient processing through the remote collection of measurement data from the power plant and they enable in archiving as well. In turn, the implemented software enables showing data in the tabular, numeric or graphic form. This increases accuracy and functionality of the installation and enables the optimization of work and increased security and efficiency of the power plant.

Main benefits of project approach

The Zagrody SHP has used an already existing hydro-technological infrastructure for electricity generation, which has kept disruption to the local environment to a minimum. Moreover, the use of the Archimedes' screw and inverter system has boosted the plant's efficiency by making maximum use of the flowing water for local electricity generation. Overall, the initiative can be said to be in support of several United Nations Sustainable Development Goals (SDGs) including SDG 13 to "take urgent action to tackle climate change and its impacts" and SDG 7 to "ensure access to affordable, reliable, sustainable and modern energy for all".

Lessons for future SHP development

Lesson 1: The importance of engaging the private sector

The investment, which revitalized an inactive hydro-technological object, was made possible thanks to the engagement of the private sector. It is a good example of development of formerly functioning water mills using locally available hydropower potential. It is clear that the already existing infrastructure and comfortable terrain can be important factors in securing the high profitability of projects in such areas.

Lesson 2: Potential for further development in the hydropower sector in Poland

It is worth recalling the information about the hydropower potential of Poland provided by the Polish Association for Small Hydropower Development. In the 1950s, around 6,500 hydropower plants were operational in Poland. Today, this number is around 770 and over 81 per cent of technological potential (and approximately 50 per cent of economic potential) is currently not being used in Poland. According to current assessments, there are around 7,500 hydro-technological objects in Poland that are presently not being used for energy purposes. Poland has conductive conditioning for the development of hydropower, especially in the form of SHP, although the pace of activating the new production powers is still far too low. However, given that in Poland, the Renewable Energy Sources Act (RES Act) supports the development of hydropower installations, it is possible that there will be a boom in the SHP industry in the coming years.

Figure 1. Renovated water mill before transformation into SHP

Figure 2. A challenge during the installation of the Archimedes' screw was its transportation from the semi-trailer to the channel because of high trees located in the immediate neighbourhood

Figure 3. Finalized object

Figure 4. Construction area during the installation of the Archimedes' screw. The old hydro-technological system supplemented with the newly built fish pass is visible

Figure 5. View of the SCADA System

4.2 FISH LIFT SLUICE (AUSTRIA): INNOVATIVE, SPACE-SAVING FISH LADDER

Birgit Zraunig, Bernhard Monai, Der Wasserwirt

The "Der Wasserwirt" fish lift sluice system is a newly developed, versatile applicable fishway. Its compact design makes it particularly suitable for locations where fishways either cannot be built or can only be built with a high financial cost. Moreover, low overall building costs and low water consumption make the system an attractive option even where the state-of-the-art fishways are possible.

The fish lift sluice system is a relatively new, innovative and compact technology, which brings together two existing systems to facilitate fish migration–the fish lift and the fish sluice. Launched by Austrian developers, the technology is based on research and development undertaken with several Austrian stakeholders including Vienna's University of Natural Resources and Life Science and Graz University of Technology.

Previous roll-outs have already served to illustrate the system's adaptability. For example, if the upstream and downstream water levels of a facility are constant, a system with a float as a transport unit is deployed. In practice, the sluice is filled up to the upstream water level and the float with the transporting system rises up for the fish to exit upstream. In the case of variable upstream water levels, a stopper construction for the floating system has been developed, whereas, in the case of high variable downstream water levels, the float is replaced by a cable winch to facilitate transportation.

The system may have particular relevance for developers given the coming into force of the European Water Framework Directive, a framework which commits EU member states to achieve good qualitative and quantitative status of all waterbodies. In light of this legislation, many operators have utilized fish ladders at hydropower plants to re-establish fish migration. Often costly, these state-of-the-art systems need space that is not always readily available, making the innovative fish lift sluice system a practical alternative at such locations.

Development of the project and main concepts

The initial project development dates back to a 2014 feasibility study, which tested whether a combination

of a fish lift and a fish sluice could be used as a space-saving fish ladder system for SHP locations. The results demonstrated that the system could be effectively used as a fish ladder. Based on these findings, Der Wasserwirt launched a research project funded by the Austrian Research Promotion Agency (FFG) and the Carinthian Business Development Fund (KWF). In the development of the fish sluice, Der Wasserwirt cooperated with several partners on hydraulic dimensioning of the system and on developing monitoring systems to check the functionality and fish behaviour during migration through the system. Partners included Vienna's University of Natural Resources and Life Science, Graz University of Technology, Profisch and KÖR.

The main concept was to develop a combination of a fish lift and a fish sluice, both of which are already existing systems for fish migration. The primary aim was to develop a space-saving fish migration system without a closed container as a transportation system. The state-of-the-art fish lifts have closed containers that need a powerful hoisting system to transport the container filled with water and fish from the downstream level to the upstream level. Fish sluices do not have any transport systems. The combination works with a swimming transportation system in a shaft. The shaft has two openings, one at the downstream level and the other at the upstream level. Both openings have an electric slide that opens and closes depending on the corresponding operating phase.

In the first year, two pilot projects were developed and implemented in the southern Austrian region of Carinthia. Located in different fish regions, the projects tested the main ideas with two different shaft sizes. Further, during the tests, Der Wasserwirt developed two additional pilot locations, one with a strongly fluctuating upper water level (appr. 2.5 metres), and the other with a flushing pipeline to the upper water level and over-pumping the water in the shaft above the upper water level. During the second year of the project, these two concepts were implemented at the next pilot locations. During the monitoring of hydraulic states and fish behaviour, improvements were made to flow steering, flow variations and installation of structural elements.

The third research year is currently underway – and the primary aim is to optimize the over-pumping system with a further developed transportation system and a different flushing line. To make the entry level in front of the shaft more attractive for fish, installations with a self-cleaning function are being developed. As the system does not constantly release water to the downstream level, it also needs a leading flow water pipe. In future, the water pipe will be equipped with a residual water turbine. As each location has specific requirements, appropriate turbines are chosen to test different conditions.

System components and main benefits

Perhaps, the main benefit of the fish lift sluice is that it is a space-saving system. At locations with no upstream and downstream water-level fluctuations or less water, it can provide a very effective solution for fish migration.

In terms of system components, it consists of a shaft with two openings – one at the tailwater level and the other at the headwater level (Figure 1, Box 1). Both openings have an electric slide. The shaft filling works with a pipeline from the headwater into the bottom of the shaft. The attraction flow at the tailwater is generated by a pipeline from the tailwater. Both pipelines have an electric slide. Inside the shaft is a transport system consisting of a float and a perforated plate with a specific distance between them. Inside the shaft, a stopper system can be installed at the headwater level to always stop the transportation system at the same position. This system is very useful for locations with an unsteady upper stream level.

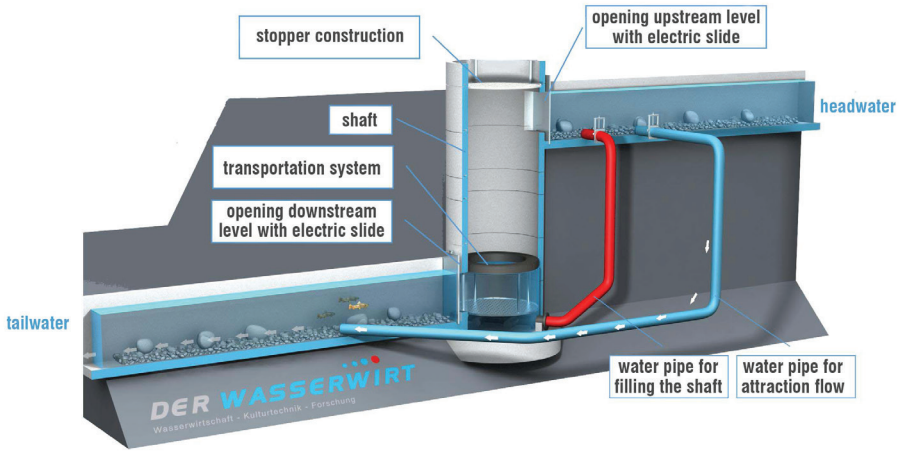

Figure 1. Components of a fish lift sluice
(For animation see "Der Wasserwirt 3D Animation Fish Lift Sluice" available from https://www.youtube.com/watch?v=K1rzygfdssY)

'The main benefit of the fish lift sluice is that it is a space-saving system. At locations with no upstream and downstream water-level fluctuations or less water, it can provide a very effective solution for fish migration.'

Box 1. How the fish lift sluice system works

The four process stages during operation:

Phase 1: Catch stage – Slide at the bottom is open. Fish can swim into the shaft.

Phase 2: Filling stage – Slide is closed and the shaft is filled with water. The transport system with fish is flooding simultaneously with the water level in the shaft.

Phase 3: Exit stage – Slide at the top will be opened. Fish can swim into upstream level.

Phase 4: Emptying stage – Slide is closed and the water in the shaft sinks to the tailwater level.

Depending on the size of the shaft and the height difference between headwater and tailwater, the four phases repeat two or three times per hour, during the operation.

Pilot plant Löllingbach

The pilot plant at Löllingbach (Carinthia) is a typical SHP. The Löllingbach is a small stream with a mean discharge of 497 l/s. The difference between headwater and tailwater is 2.4 metres. The operator has to evolve 60 l/s as residual water to the tailwater in winter and 150 l/s in the rest of the year. This is a small amount for a state-of-the-art fish ladder. The target species is the brown trout (*Salmo trutta fario*) with 40 cm. The shaft has a diameter of 1 metre.

Figure 2. Pilot plant Löllingbach

The implemented fish lift sluice needs approximately 10 l/s depending on the various operational phases. The difference is evolved with the water pipe for attraction flow. Several floods have taken place since the fish lift sluice was built in 2015. However, the system is very compact and the operator only has to initiate the scavenging process after the floods to reactivate the fish lift sluice. Figure 2 shows how well the fish lift sluice has been integrated into the stock.

Pilot plant Möll

The pilot plant at Möll (Carinthia) has an unsteady upper stream level (appr. 2.5 metres). The stream has a discharge of 18 m³/s. The operator has to evolve 600 l/s as residual water to the tailwater. The difference between headwater and tailwater is, depending on the unsteady upper stream level, between 4.3 and 6.8 metres. The target species is the Danube salmon (*Hucho hucho*) with 80 cm. The shaft has a diameter of 2 m. The implemented fish lift sluice needs approximately 150 l/s depending on the various operational phases. The difference is evolved with the water pipe for attraction flow. The fish lift sluice was built over the winter of 2015–2016. At this location, the camera monitoring system was used to observe the fish behaviour. The pictures in Figure 3, before and after installation, show that the fish lift sluice has been well integrated into the stock.

Figure 3. Pilot plant Möll

Thematic focus and sequencing

Initially, the project team designed the shaft with the openings, the transport system and the operation stages. The second stage saw the development of a small model for testing the transport system, which utilized plastic basins, a transport system and a pump to fill and empty the cone. Following the launch of the pilot project at Löllingbach, the control system was tested. The project team changed sequences and opening times and also installed a flush sequence to use after floods or in autumn when there are a lot of leaves in the stream. To control the function, the system has a remote maintenance tool that highlights which operation stage is active. For bigger and higher shafts, the sequences were optimized and a cost-effective stopper system was integrated for unsteady upper stream levels.

This system contrasts with the state-of-the-art fish ladders, which often need expensive slide structures to balance water-level fluctuations.

Monitoring and optimization process

The implementation of the pilot plants and a comprehensive monitoring during the operation enabled the project to test different types of transportation, filling systems, programme sequences with various dependencies, structural installations and streamings. Moreover, a camera monitoring system was used to observe fish migration through the system and fish behaviour during the four operation phases. This made it possible to identify the impact of various adjustments on fish behaviour such as installations that attract fish. The project also used a fish trap in the headwater after the shaft to control fish migration. The camera records enabled observation of migratory behaviour upstream and downstream, the fish using the system in both directions (Figure 4).

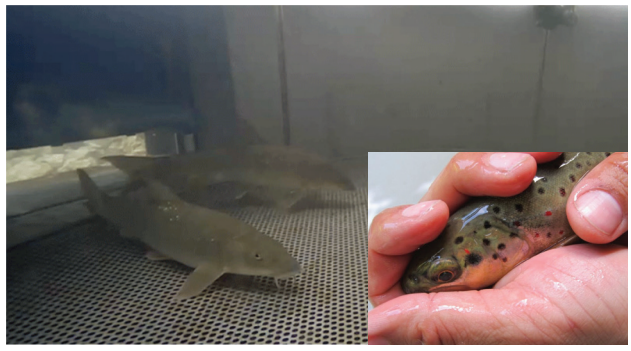

Figure 4. Monitoring with camera, fish mark and fish trap

These two pilot plants have a different exit strategy. The difference from the four other locations is that the water in the shaft is over-pumped above the upstream water level and then the fish are flushed to the headwater through a flushing pipeline. At one of these locations, various systems to scare away the fish to leave the shaft and enter the flushing pipeline were tested (Box 1).

Box 1. Overview of implemented pilot plants

	Location 1	Location 2	Location 3	Location 4	Location 5	Location 6
River	Löllingbach	Gurk	Möll	Traun	Görtschitz	Große Mühl
Maximum length of target species	Brown trout 40 cm	Danube salmon 80 cm	Danube salmon 80 cm	Brown trout (m. *lacustris*) 90 cm	Grayling + Brown trout 50 cm	Danube salmon 80 cm
Difference in water elevation	2.4 metres	3.4 metres	5–7.5 metres	9–10 metres	1.4 metres	9–10 metres
Features	none	Unsteady downstream water levels	Unsteady downstream water levels up to 2.5 metres	Over-pumping + flushing pipeline to the upstream water level, unsteady downstream water levels	Compact system (finished parts)	Over-pumping + flushing pipeline to the upstream water level, unsteady downstream water levels

Lessons for future SHP development

Lesson 1: Flow directions in front of the tailwater influence fish behaviour

The different pilot plants and the intensive monitoring showed that the flow directions in front of the shaft (tailwater) greatly influence fish behaviour. Camera records allowed the project team to optimize flow directions and intensity for every operation stage. The observation of the filling pipeline during the catch stage led to a different form of the pipeline in the shaft to improve the flow inside the shaft. Further, the opening times of the slides affected migration behaviour.

Lesson 2: The value of pilot projects

The implemented pilot plants provided the project with valuable data and real-world experience, particularly during the installation and operational phases of the fish lift sluice for locations with different conditions.

Lesson 3: Improving river continuum as water status

The system can be installed at locations where the state-of-the-art systems reach their limit. The fish lift sluice helps to restore the river continuum. It also helps improve the water status of streams and rivers.

4.3 TURBULENT: RESILIENT, COST-EFFECTIVE TURBINES DESIGNED FOR RIVERS OR CANALS WITH MINIMAL HEIGHT DIFFERENCES

Daniela Hurtado, Jasper Verreydt, Turbulent

Resilient and cost-effective, the Turbulent small hydropower (SHP) turbines are designed for very low head stream and involve minimal civil works and maintenance. Inspired by nature, they use a vortex system to deliver stable, low environmental impact and cost-effective renewable energy.

In recent years, there has been a revolution in terms of energy production and usage. Old energy solutions are being set aside in favour of options that are sustainable, decentralized and financially accessible. Due to the intermittency and unpredictability of wind or solar power production, hydropower has increasingly been seen as one of the most attractive ways of harnessing energy. However, there can be considerable environmental and economic issues associated with hydropower infrastructure such as large dams; and with significant investment needed upfront for installation, investors and project developers can be put off by the financial commitment associated with hydropower development.

While SHP technologies have been very successfully explored, it has been a challenge to create a solution for low head water channels that would be both scalable globally and financially accessible. This specific issue is the one that Turbulent SHP systems have been designed to address. Designed for streams with very low height differences and involving minimal civil works and maintenance, they use a vortex system to deliver stable, low environmental impact and affordable renewable energy – as evidenced by the company's latest commercial scale vortex turbine, which is currently in operation in real-life conditions in Green School in Bali, Indonesia.

Turbulent technology

Resilient and cost-effective, Turbulent SHP systems are uniquely designed for low head streams specifically those below 5 metres, and generate up to 200 kW per turbine and up to multiple megawatts of energy as a network of decentralized turbines, close to the end user with minimal civil works and maintenance. The design, inspired by nature itself, uses a vortex system based on the natural free Rankine vortex principle (Figure 1)

to deliver stable and cost-effective renewable energy through an individual turbine or a network of multiple turbines. The turbine design allows fish (and debris or sedimentation) to pass through unharmed, which also keeps maintenance low, while control software keeps efficiency high. Installation is straightforward and the system can be used anywhere in the world. Whether in an urban setting or as part of a rural off-grid project, this technology offers a practical solution for investors, developers and energy users. It demonstrates how energy production can work together with nature and without damaging the local ecosystems to satisfy growing global energy demands. Overall, costs are comparable to those of other renewable energy technologies and diesel.

'The design, which is inspired by nature itself, uses a vortex system to deliver stable and affordable renewable energy, without damaging local ecosystems.'

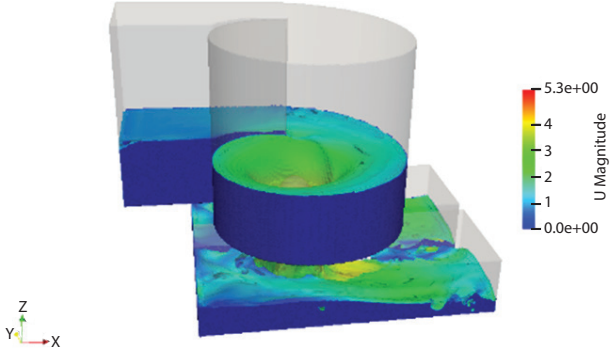

Figure 1. Vortex model 3D, Doñihue, Chile

Case description: Turbulent in Green School Bali, Indonesia

The 13 kW Turbulent installation is located in Green School, on the Ayung River in Bali, Indonesia (Figure 2). Green School Bali owns the site and has the water rights, which are often necessary for SHP installations.

The Turbulent turbine is a fully validated industrial scale vortex turbine operating in real-life rainforest conditions. It is being used to apply all lessons learnt in the previous prototype in Doñihue, Chile.

The installation provides energy to 500 students and a local farm. The main motivation has been to have reliable electricity day and night by finding a robust alternative to the previous SHP installation that was destroyed in a flood carrying debris downstream. Although Green School had made remarkable efforts to fulfil their energy needs with renewable energy sources, their photovoltaic installation could not generate more than a smaller percentage of the school's needs (since the sun's availability is unpredictable and at its peak gives only a few hours on sunny days) and the previous SHP project could not resist the rainforest storms or failed to deliver the estimated energy production from its capacity.

The new Turbulent turbine was designed for a flow of 1.5 m^3/s and a drop of approximately 1.7 m. It provides 13 kW of continuous energy and has been operational since March 2019. The power electronics consist of an induction generator directly coupled to the grid via a soft starter. With a local energy price of 0.08 US$/kWh and an LCOE (levelized cost of energy) of 0.04 US$/kWh (roughly the price to generate electricity with a gas-fired power plant), the total investment cost of the turbine will be paid off within six years (+15 per cent return on investment).

Box 1. Turbulent in Bali – an island of SHP potential

Turbulent's latest 13 kW SHP is keeping Green School Bali powered day and night, 100 per cent by renewables. It provides energy to more than 500 students and a local farm.

With its biodiversity, rice terraces and rainforests, the island of Bali is one of the main tourist attractions in Indonesia and home to one of the most sustainable schools in the world, Green School. Green School is a pioneer in terms of sustainable education and living off-the-grid, preparing global citizens of the future.

The school is situated right next to Bali's longest and most sacred river, the Ayung River. However, it took more than seven years and several tryouts to find a reliable SHP solution in harmony with the surrounding ecosystem but robust enough to withstand the unpredictable rainforest floods. Turbulent offered a suitable technological solution for the location – a resilient and cost-effective low-head SHP system.

In addition, Indonesia's recent net-billing law would now allow Green School to have a new revenue stream selling the excess energy generated with the Turbulent SHP plant back into the grid.

Since the turbine was inserted into an existing basin, all civil works were practically reused (Figure 3). The installation itself was completed in six days and the commissioning lasted for four days. However, future turbines can be installed most likely faster than in Bali, since a significant part of the commissioning time was used to install and test new control features, which will be already implemented for the upcoming projects. Turbulent engineers expect to reduce the commissioning time to less than a day.

Considering that traditional hydropower has a reputation for significative intervention in the local ecosystem, community acceptance for SHP is extremely important. In Bali, the local community did not only accept the Turbulent SHP plant as a reliable energy solution with zero negative impact but also celebrated the project with a blessing ceremony (Figure 8).

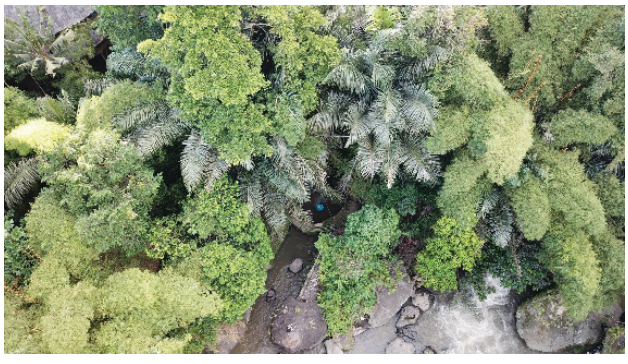

Figure 2. A view from above of the turbine in Green School Bali, Indonesia

Figure 3. Civil works of the 13 kW turbine in Green School Bali, Indonesia

Main benefits: scalable, cost-effective and easy to maintain

The Turbulent turbine currently provides more than 80 per cent of the energy for Green School. The turbine was transported mainly using a small truck but the last part of the transportation to the site was carried out with the help of the local Balinese people using a traditional technique of rolling wood beams.

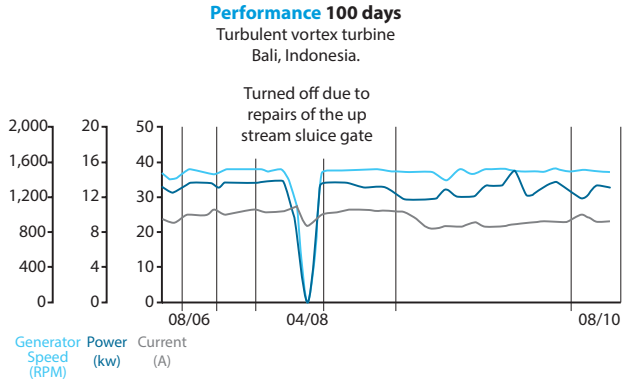

Figure 4. Power output, June–August 2019

Figure 5. Green School's self-made bamboo security fence

Figure 6. Installation and commissioning of the Green School turbine

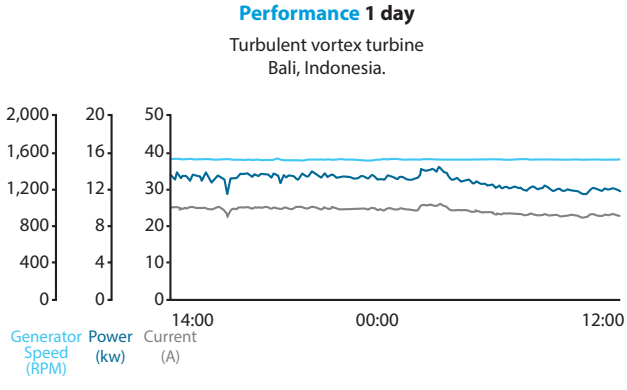

Figure 7. Daily power output in Bali

Figure 8. Blessing ceremony of the turbine in Green School Bali, Indonesia

Figure 9. Bamboo crane, Green School, Bali Indonesia

They also built their own eco-friendly bamboo crane and, together with the Turbulent team, placed the turbine inside the basin. Critically, these local workers have been successfully maintaining the turbine since its installation without any specific knowledge or skills led only by one local engineer from Green School who is in charge of all the renewable energy systems.

This is a major advance in SHP technology as most of the existing turbine solutions require costly components and often on-site expert engineers flying in for routine maintenance.

Having access to hydropower through a Turbulent installation has been a smart economic investment for the community as the return on investment is expected to be rated at over 15 per cent per year and the turbine has been continuously working at a capacity factor of 95 per cent or higher (for

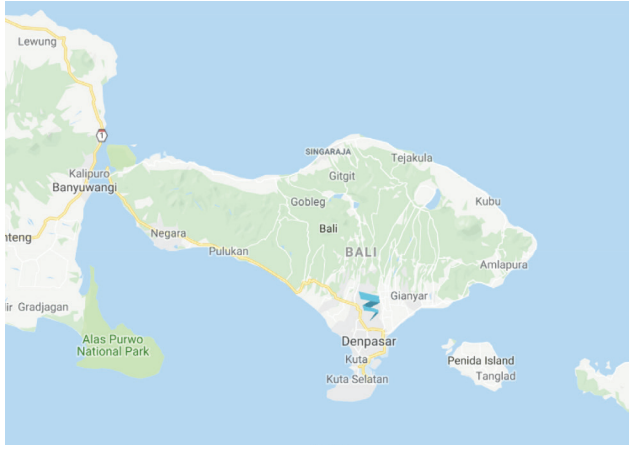

Figure 10. Green School on the map of Bali

Source: Google Maps

reference, the capacity factor of solar installations due to their intermittency is less than 20 per cent and due to fuel availability diesel generation sets are rated at roughly 66 per cent). The initiative has also provided employment to local workers for the duration of the project. Moreover, there are many potential sites around the Green School facilities and all along the Ayung River, so there is a high likelihood of future SHP installations. This means more employment for local workers, less dependency on other sources of non-renewable energy and a more sustainable power infrastructure in the region to enable economic development.

In Bali, the engineers from Turbulent were able to successfully implement and validate the lessons learnt from the previous installations, adding design improvements and new components that new projects in Otepää, Estonia, Versailles, France, Ylang, Taiwan and Mindanao, the Philippines will also benefit from (Box 2).

Box 2. Turbulent project improvements and goals

The following are the achieved improvements:

- The installation validated the scalability and industrialization of the turbine;
- A significant cost reduction by replacing the inverter/drive combination with a single soft starter;
- Working with renowned worldwide suppliers to guarantee high quality and provide excellent service on-site;
- For some critical components, especially in bigger projects, it would be best to have spare parts that can be easily used for replacement.

Goals for future projects include:

- A local tactile screen with an easy-to-use interface to operate the turbine;
- Moving towards off-grid projects;
- Scaling and installing projects for more than 200 kW per turbine and multiple megawatts with a network of decentralized turbines.

Turbulent and the United Nations Sustainable Development Goals (SDGs)

SDG 7 Affordable and clean energy: ensure access to affordable, reliable, sustainable and modern energy for all. Turbulent turbines are among the most cost-efficient, robust and easy-to-maintain turbines in the world that can be installed in both remote areas and rural settings in streams that formerly could not be harnessed for energy.

SDG 9 Industry, innovation and infrastructure: build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation. The technology offers a new way of thinking in hydropower. It is a resilient, decentralized, scalable and dam-less solution. With minimal civil works, it provides energy right where the energy is consumed.

SDG 11 Sustainable cities and communities: make cities and human settlements inclusive, safe, resilient and sustainable. The technology was designed in view of the remote communities. The company equips local communities with a sustainable, continuous and cost-effective energy source, which allows them to develop at a quicker pace.

SDG 13 Climate action: take urgent action to combat climate change and its impacts. Hydropower is the most consistently accessible renewable resource available to us. Turbulent dam-less plants have a minimal impact at the site, harnessing energy from rivers or canals that cannot be used with traditional hydropower solutions.

SDG 14 Life below water: achieve sustainable development of fisheries, fish stocks must be maintained at a biologically sustainable level. Inspired by nature, Turbulent uses vortex technology to allow fish to pass through unharmed, keeping the ecosystem safe while producing consistent energy.

Lessons for future SHP development

Lesson 1: Be prepared for extreme climate change

In tropical climates, all material must be able to withstand extremely high levels of humidity, therefore, appropriate coating is a must.

Lesson 2: Undertake accurate site review

An accurate site review is necessary to understand project feasibility. In Bali, Turbulent successfully tested a template for future site assessments in order to avoid overlooking important factors or working based on inaccurate information.

Lesson 3: For non-core parts, experienced subcontractors are necessary

One of the major difficulties was to adapt the new automatic system into an existing sluice gate that was not properly dimensioned to work fully automated. This meant a week and a half of extra work for the engineers.

Since components such as sluice gate or trash rack are not part of the core, future distributors, local partners and/or end clients should ensure the correct functioning of these components via experienced local contractors beforehand in order to avoid unnecessary delays during the installation process.

Lesson 4: Flow management on a short notice is essential at sites with flash-flooding

The Bali project experience has equipped Turbulent with a versatile toolset for flow management with a bypass gate right at the turbine and a flow control mechanism at the beginning of the turbine channel.

Lesson 5: Undertake a detailed steam analysis and ensure reliable study data

Any development of an SHP site will require a detailed engineering analysis of the stream. However, there can always be a margin of error due to uncertainty in water supply. The challenge for each hydropower technology is to have reliable study data of the site as well as to consider the margin of error to provide the most suitable solution for the site.

4.4 KINETIC HYDROPOWER AND COOLING CANALS

Karl Kolmsee, Smart Hydro Power

Smart Hydro Power, a German-based environmental engineering company, has developed what has become known as a 'swimming' hydrokinetic plant. The floating turbine, which works with the flow of water only, requires no infrastructure except a small anchor point. Originally this small 5 kW plant was designed for river use with a view of promoting rural electrification in the areas with poor access to electricity.

Given the seasonality of most rivers, the hydrokinetic turbine is also photovoltaic (PV) in a hybrid system, which allows for a stable power supply throughout the year – making the cost of the technology much lower than that of PV only or diesel generators. Moreover, the 5 kW underwater generator can also be used in existing infrastructure such as canals or water regulation dams.

The more stable flow and lack of debris ensure that the hydrokinetic systems generate electricity for approximately 8,760 hours per year with little or no maintenance and, depending on velocity, low or very low generation costs. Originally designed for river use, kinetic hydropower systems have been installed in canals in Germany, South Africa, the USA and at the NLC Neyveli thermal plant in Tamil Nadu, India.

Kinetic hydropower – light footprint and rural off-grid suitability

Unlike traditional forms of hydropower, which harness potential energy through architectural developments such as dams, Smart Hydro Power hydrokinetic technology projects use the flow of water only. From the development perspective this is a key benefit as no separate infrastructure is necessary other than a simple anchor point. Environmentally, the technology's light footprint also means limited impact on the local environment, wildlife and ecosystems.

Generating sustainable and renewable energy, hydrokinetic initiatives also support several United Nations Sustainable Development Goals (UN SDGs) including SDG 7 to "ensure access to affordable, reliable, sustainable and modern energy for all" and SDG 13 to "take urgent action to combat climate change and its impacts".

'A typical Smart Hydro Power hydrokinetic project requires one week of preparation and one week of installation, in most countries permits are not necessary as the technology does not require water rights as the natural flow of water is not changed.'

Like traditional hydropower technologies, hydrokinetic initiatives are base load power generation sources and in contrast to solar PV or wind power installations, they can provide a continuous supply of electricity throughout the year. This makes hydrokinetic an attractive technology for off-grid projects, which otherwise suffer the expense of high battery or replacement energy costs.

Moreover, the technology is relatively easy and inexpensive to put in place – a typical Smart Hydro Power hydrokinetic project requiring one week for preparation and one week for installation. The planning and permitting phase is standardized and requires no more than three months. In most countries permits are not necessary as the technology does not require water rights given that the natural flow of water is not changed. Furthermore, as the natural water flow is unaltered there are no unintended cultural or socio-economic consequences linked to the development of hydrokinetic projects.

Figure 1. Smart Monofloat river turbine

Smart hydrokinetic turbines only weigh 380 kg, which means they are also easily transported to remote rural locations by boat or by truck. Importantly, installation can be successfully undertaken using local labour or if necessary using a crane working on two traditional boats. Overall installation costs rarely exceed US$ 1,000 per turbine, and even less when projects utilize several turbines. Even where larger hydrokinetic turbines are used, installation is relatively simple especially compared to the projects that use traditional hydropower technologies or other power generation alternatives.

Technical specifications: Betz's law and natural kinetic energy

Hydrokinetic energy compares favourably to other renewable energy sources and traditional hydropower options, and it can offer a flexible solution to electricity generation particularly for rural off-grid projects. It should be noted that generation is limited to the natural kinetic energy of the flowing water, which is calculated in the following way: $p_{kin} = ½ \times d \times A \times v^3$ (with p = energy (W), d = water density (kg/m^3), A = area (m^2), v = velocity (m/s)).

Depth and velocity reduce the potential energy harvest with velocity being more important than depth. As is the case with wind turbines, Betz's law applies to hydrokinetic turbines as well. This means that the turbine can only capture approximately 59 per cent (16/27) of the kinetic energy (the Betz's coefficient) for the purposes of electricity generation.

Climatic conditions should be taken into consideration. For example, climate in India where the Smart Hydro Power hydrokinetic technology is being used in cooling the canals at the NLC Neyveli thermal plant in Tamil Nadu, is characterized by strong monsoon and a three-month dry season. The technical characteristics of hydrokinetic installations

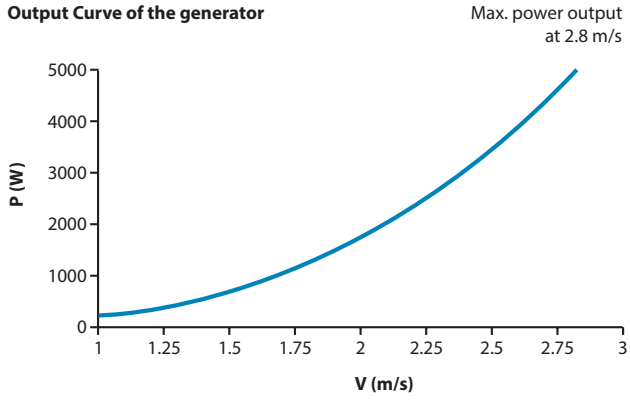

Figure 2. Power curve water velocity to power output

mean that rural off-grid electrification projects should, as suggested, be hybrid with solar PV complementing the hydropower generation. For on-grid projects using rivers as natural resources, this means an on average lower plant factor (defined as given generation output to nominal generation capacity), which increases the economic hurdles.

Using existing infrastructure

It is advantageous for the projects to use existing infrastructure thereby bypassing any limitations caused by the variable flow and velocity of natural water resources. Examples of such an infrastructure might include canals or tailraces associated with traditional hydropower plants or water regulation dams. Given the above circumstances, the plant demands a slightly different design. To adapt to shallow canals (Figure 4) the standard design does not use the diffuser (compare Figure 1 and Figure 3). This design adaptation reduces efficiency by approximately 10 per cent as the diffusor's coefficient of performance is 1.15 (Figure 5).

Figure 3. Smart Free Stream canal turbine

Figure 4. Smart Free Stream in an irrigation canal, USA

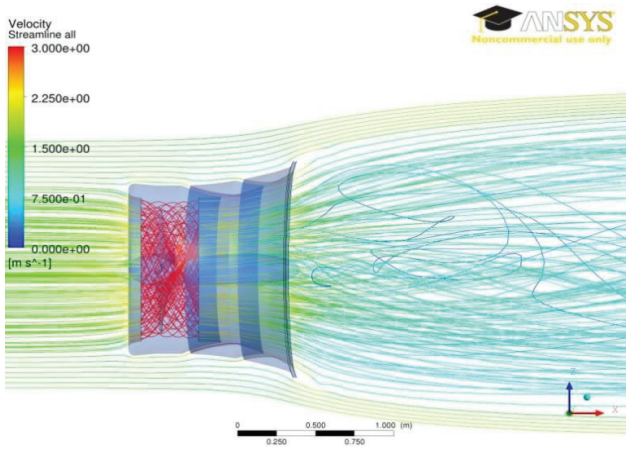

Figure 5. Diffusor of Smart Monofloat turbine simulation

It is also worth noting that although hydrokinetic river turbines, like wind turbines, are limited by Betz's law, canal turbines, by constraining the entire diameter of a structure, show a better output at the same velocity. This is partly caused by the absence of any possible deviation in pressure, whereas in the natural environment, water or air follows the path of least resistance (which is not always past the blades). It is also partly caused by the blockage giving rise to local impounding, which increases the pressure on the blades. While both effects are difficult to calculate, experiments have shown that a total constraint increases the power output at given velocities significantly.

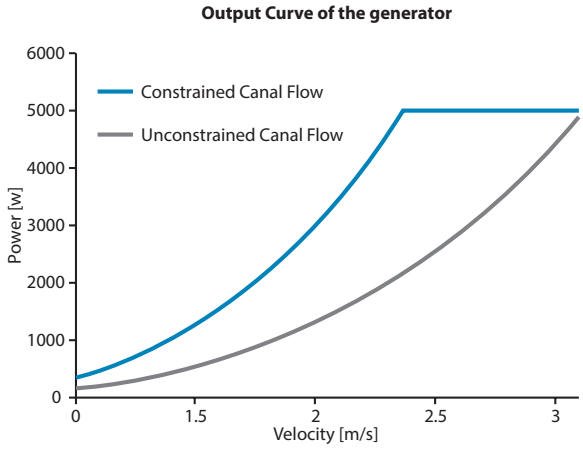

Figure 6. Smart Free Stream with constraint and unconstrained power curve

The unconstrained curve of the Smart Free Stream is less steep compared to the curve of the Smart Monofloat using a diffuser (compare Figure 2 and Figure 6). The fully constrained and unconstrained curves mark the area of measurable generation output given a certain velocity in a canal. While the effects of constraining a canal are difficult to calculate and predict, practical examples offer an interesting insight in canal hydrology.

Box 1. Kinetic hydropower plant in the cooling canal T.P.S –II, NLCIL, Neyveli, Tamil Nadu, India

The cooling canal of the thermal power plant (TPS-III, 1,470 MW) at Neyveli mining site is 5.7 metre wide and 3.5 metre deep. The last section of the main canal carries discharge (36 m^3) collected from four cooling towers. Measurements in the middle of the canal have shown velocities up to 3.1 m/s. Due to friction from the side walls the velocity at the sides is reduced to 2.5 m/s.

The installed plant, which has a nominal capacity of 20 kW and consists of four turbines installed in a row, has been running continuously since its commissioning in October 2017. Output varies between 13 and 15 kW. Electricity is injected into the plant's grid at low voltage level (415 V). While the achieved output is lower than the nominal capacity, detailed analysis of water flow and site hydrology have proven the results to be in line with technical capacities. Being the first installation of its kind, NLC and Smart Hydro Power's local partner IMP Powers Ltd view the installation as having enormous research and development value with many findings offering improvement potential for future hydrokinetic projects. So far research findings have established the following:

- The two turbines in the middle of the plant generate 4 to 4.5 kW each while the two turbines closest to the walls generate 2 to 2.7 kW each. Repeated velocity measurements along the width of the canal show that the velocity decreases significantly due to the walls' resistance (2.5 m/s instead of 2.8 m/s or 10 per cent).
- The frame holding the turbines is designed with flat steel instead of hydrologically optimized rounded steel causing strong turbulence and high installation costs due to the flow resistance.
- The frame structure using a 1.5-metre area below the water surface only results in water deviating from the blades' resistance towards the lower part of the canal and, therefore, causing turbulence behind the turbine.

The design of future hydrokinetic canal plants might be improved by the following:

- Using a diffusor or increased blades to cover the entire area of the structure minus the border of decreased velocities (0.5 metres below the surface, along the walls and over the canal ground).
- Hydrologically improving the frame by using rounded steel.

In this way output per turbine is increased and costs are reduced (mainly installation costs). Even without the changes, the plant generates at approximately US$ 0.051 per kWh (INR 3.5 per kWh), a cost level achieved by other renewable energy sources under ideal conditions only. The targeted annual unit production is 108,000 kWh. Overall, from October 2017 till 31 December 2017 a total of more than 38,000 kWh of electricity was pumped into the grid.

Lessons for future SHP development

Lesson 1: The importance of using existing infrastructure

While hydrokinetic plants are a valuable technology for promoting rural electrification, the seasonality of rivers limits their on-grid use. Using existing infrastructure is an option to make use of this low-cost renewable technology – with an industry grid replacing electricity from the grid or within a standard Power Purchase Agreement (PPA) setting.

Lesson 2: The technology is cost-effective

Initial results regarding the reliability and cost-effectiveness of the technology are encouraging. It is clear that scaling-up this relatively young technology to commercial projects with more turbines will further increase competitiveness.

Figure 7. Neyveli Lignite Corporation kinetic hydropower plant at Neyveli, India

Lesson 3: Low voltage and continuous generation of small hydrokinetic installations can stabilize the grid

Hydrokinetic technology is particularly appropriate for the specific Indian environment, which has relatively high technical grid losses and a widespread need for investment in grid improvement. While renewable energies with strongly variable generation output can destabilize the grid and cause high grid operating costs, small hydrokinetic installations with their continuous generation and low-voltage grid feed-in close to the point of consumption, instead lead to grid stabilization.

Lesson 4: Increased competitiveness linked to grid stability

In some energy regimes, such as Germany, the specific positive effect on grid stability is remunerated in addition to the energy volume generated. This would add to the competitiveness of hydrokinetic technology using existing canal infrastructure, which are numerous in India.

5. INCENTIVE POLICIES FOR SMALL HYDROPOWER DEVELOPMENT

5.1 INCENTIVE POLICIES FOR SMALL HYDROPOWER DEVELOPMENT IN PANAMA

Source: Wikimedia Commons

José Fábrega, Universidad Tecnológica de Panamá and National Research System of Panama (SNI)

Increasing demand for electricity and accessibility through new renewable energy technologies has led to a strong push towards renewable energy in Panama in recent years. Moreover, incentive policies and pro-renewable energy legislation also seem to have encouraged this development – including, in particular, in the small hydropower (SHP) sector, which has seen proliferation in the projects since 2005.

Panama is a country with abundant water resources, represented by a yearly average precipitation of 2,924 mm, which feeds around 500 rivers and 52 watersheds.[1,2] Furthermore, Panama has a growing demand for electricity and given its climatic conditions, there has been a push towards renewable energy in recent years. Renewable energy accounts for a significant proportion of overall power generation in the country. More specifically, in 2017, 10,936 GWh of electricity was generated in the country, with renewable energy sources accounting for over 70 per cent.[3]

In recent years, the Government of Panama has developed legislation to encourage the use of renewable energy, starting with the laws that focused on promoting mini-hydroelectric projects – though now other types of renewable energy, such as solar and wind power, are included. In this case study, the impact that the incentive policies are having on SHP in Panama will be reviewed and the number of projects and concessions will be employed as indicators. Moreover, it will also consider the existing organizational structure in the energy sector, as well as the legislation that promotes SHP and the use of renewable energy in Panama in general.

Organizational structure of the energy sector in Panama

Up until 1998, the energy sector in Panama was administrated by a public company. However, this was changed by Law 6 in 1997 (and its later amendments) as well as Decree Law 22 in 1998. These pieces of legislation introduced a new private business scheme for the sector.[4,5,6,7] Essentially this new legislation partially privatized the electrical service with the power generation being fully opened to competition. Transmission was managed by the Empresa de Transmisión Eléctrica S.A (ETESA), a mixed (public-

private) company, and power distribution was given to three regional companies in Panama.

For this new business model to work efficiently, it is necessary for the Government to dictate policies for the sector that ensure the supply and access to energy in the country, and also to promote the rational, sustainable and efficient use of energy. This task is performed by the National Secretariat of Energy (SNE), created by No. Law 43 of 2011.[4]

In addition, the National Authority for Public Services (ASEP), is responsible for guaranteeing the provision of services and is also in charge of monitoring tariff aspects, regulating revenues of the monopolistic sectors.[8]

Finally, for rural areas that are not served, as being unprofitable and, therefore, not appropriate for concession to the private sector, the Office for Rural Electrification (OER) was renewed by Law No. 6 of 1997. This office was attached to the Ministry of the Presidency, in order to promote rural electrification projects.[5]

Overview of the legislation

In terms of incentives for SHP generation, Panama established a legal framework in 2004 by passing Law No. 45, which creates incentives for hydropower generation and other renewable energy sources.[9] The law was regulated by the Executive Decree No. 45 of 2009, which specified the following incentives for small and mini-hydropower plants:

- Hydropower plants up to 10 MW are not charged for selling electricity directly or indirectly.
- Hydropower projects between 10 MW and 20 MW receive exemptions for the first 10 MW delivered for 10 years.
- Fiscal exemptions for importation of equipment, machinery, materials, etc.
- Fiscal incentives for projects up to 10 MW and with up to 25 per cent incentive of the original investment calculated in terms of reduction of equivalent tons of CO_2 emissions per year.[9,10].

Since SHPs are very likely to be employed by small towns or rural communities, it is important to mention Law No. 58 of 2011, which creates a rural electrification fund based on 1 per cent of generators' net gains.[11] Finally, Law No. 67 of 2016 modified Law No. 58 by exempting this 1 per cent tax to generators of 10 MW or less.[12] It is also worth noting that additional legislation exists to promote specific types of renewable energy for the provision of public electricity services. More specifically:

- Law No. 44 of 2011 (modified by Law No. 18 of 2013) establishes incentives for the promotion of the construction and exploitation of wind power stations.13
- Law No. 41 of 2012 establishes the incentive regime for the promotion of the construction and exploitation of generation plants based on natural gas.14
- Law No. 37 of 2013 (modified by SNE Resolution No. 1647 of 2013, Law No. 38 of 2016 and SNE Resolution No. 3498 of 2017) establishes the incentive regime for the promotion of the construction, operation and maintenance of power plants and/or solar installations.15
- Law No. 42 of 2011 (modified by Law No. 21 of 2013, Executive Decree No. 345 of 2013 and Law No. 47 of 2015) establishes guidelines for the national policy on biofuels and electricity from biomass in the national territory.[16]

Impact of policies

As previously indicated, the promotion of SHP development was formally implemented in 2004 by Law No. 45, even though this law was not regulated until 2009. Since then, there have been other laws approved to promote specific types of renewable energy other than hydropower, mainly due to the technological advances seen in the efficiency and application of those energy sources (wind, solar and biomass).

Additionally, the rural electrification fund (managed by the OER) has been employed in rural areas primarily for expanding the electrical grid over short distances (10 km), and for promoting the use of solar photovoltaic energy. In addition to the incentives stated under Law No. 45, the exemption of 1 per cent from the rural electrification fund tax for generators of less than 10 MW can be seen as another way in which SHP is promoted.

Figure 1 and Figure 2 help to assess the impact of the four pieces of legislation in the energy sector – Law No. 45 2004, Decree No. 45 of 2009, Law No. 58 of 2011 and Law No. 67 of 2016. The primary indicators are the number of projects and energy capacity for SHP and other types of renewable energy during the period between 1999 and 2017.

Figure 1 shows that for SHP up to 10 MW, the number of projects follows roughly a similar trend to that of hydropower stations with capacities above 10 MW for the two periods, 2001–2005 and 2013–2017. It is also important to note that since 2005, SHP projects became the renewable energy option with the greatest number of projects. However, this situation is changing with solar and/or wind power projects becoming more popular options. Figure 1 also shows that there is an observable increase in the number of SHP projects once Law No. 45 of 2004 and Decree No. 45 of 2009 were developed. In Figure 1, in the case of solar and wind power stations, it is evident that there has been an impact on the use of these sources since 2015. Moreover, it is important to note that the legislation aimed specifically at these sectors was passed in 2011 (for wind power) and 2013 (for solar power).

Lessons for future SHP development

Lesson 1: Legislation encouraging use of renewable energy including SHP seems to have a positive impact on the number of SHP projects

Panama has developed legislation to encourage the use of renewable energy. The country started with the laws focused on promoting mini-hydropower projects; however, recently the same has been done for other types of renewable energy such as solar and wind power. There was an increase in the number of SHP projects after 2005, which coincides with the approval of Law No. 45 of 2004. Although this legislation might not have been the only factor behind this rise, it seems to have had a positive impact. In the case of wind and solar power, there has been a dramatic increase in recent years, most likely due to the incentives in the laws issued and a more profitable technology development in recent years.

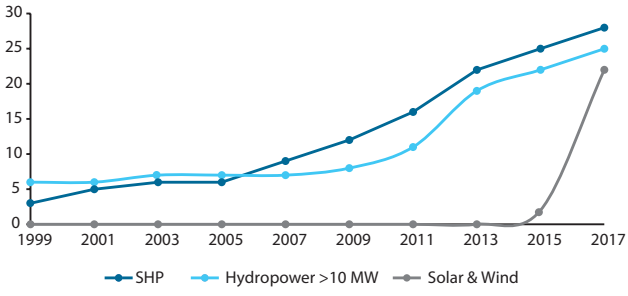

Figure 1. Total number of renewable energy projects in Panama between 1999 and 2017

Source: ETESA[17,18]

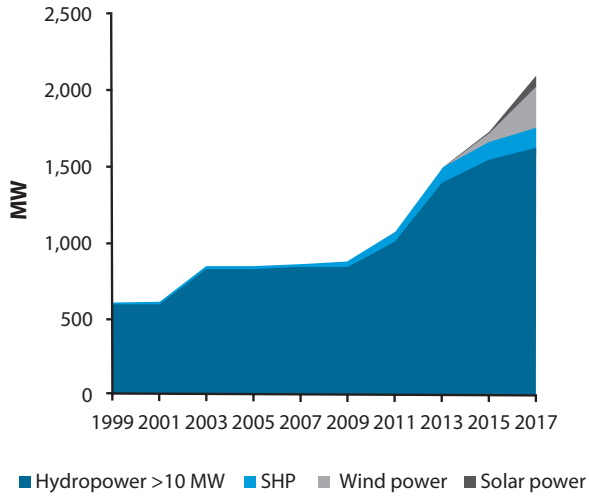

Figure 2. Total renewable energy capacity in Panama (in MW) between 1999 and 2017, including hydropower, solar and wind power stations

Source: ETESA[17,18]

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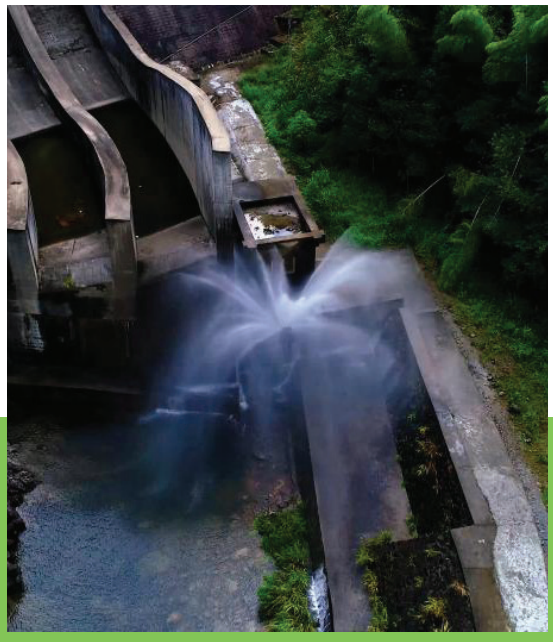
6. GREEN SMALL HYDROPOWER

6.1 GREEN SMALL HYDROPOWER DEVELOPMENT IN CHINA



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China's small hydropower development process

China's first small hydropower plant (SHP), the Shilongba SHP in Yunnan Province, started generating electricity in 1912 with an initial installed capacity of 480 kW. Since then the country has gone through the following four main stages of SHP development:

- In the initial stage, from 1949 to 1980, the speed of SHP development was slow and the scale small, though it played an important role in solving the issue of no power supply in mountainous and rural areas.
- During the slow development stage, from 1980 to 2000, the Central Government encouraged the local governments and farmers to set up SHP projects themselves to aid in rural electrification.
- The rapid development stage, from 2001 to 2010, driven by the reform of the national investment system and electric power system, saw the growth of social capital and all-round development of the rural economy and society.
- From 2011, SHP development has entered the environmental reform stage. Restricted by resources and environmental factors, the recent focus is to improve SHP quality and increase efficiency. This will promote people-orientated, safe, green and harmonious SHP construction and development.

> **'The recent focus is to improve SHP quality and increase efficiency, while vigorously promoting people-orientated, safe, green and harmonious SHP construction and development.'**

By the end of 2017, China had built over 47,000 SHPs, with the total installed hydropower capacity exceeding 340 GW. Of this figure, SHP exceeds 79 GW and accounts for 23 per cent of China's total hydropower generation. Over 62 per cent of China's SHP potential has been exploited, rising to a development rate of 82 per cent in some central and eastern provinces.

China's commitment to green SHP

In recent years, the Government's attitude towards SHP has changed from vigorous advocacy to strict regulation. However, there remains a strong commitment to "green hydropower", defined by the Chinese Ministry of Water Resources as "environmentally friendly, socially harmonious, with standardized management and meeting economic rationality criteria".

With increasing hydropower development in China, the environmental impact of the sector has become more prominent including the change in the hydrological features of the rivers. Partial river channels have dried up, river ecosystems and the downstream water for living and production have been affected, and gate-dams have reduced river connectivity. Also, the natural environment of migratory fish and other aquatic organisms are affected.

Presently, China's new rural hydropower resources are mainly located in remote areas, where the environmental conditions are fragile and the demand for electricity is low.

Further, some of China's older SHPs are considered unsafe for the environment and their electromechanical equipment is either ageing or obsolete. Units with obsolete design and manufacturing standards often compete for water with the rivers' ecosystems. In this light, green SHP development is a significant step towards maintaining China's environmental safety. It offers a strategy to maintain harmony between human water usage and the promotion of aquatic ecology, while helping to rapidly transform the SHP development approach by improving quality and increasing efficiency.

Green SHP research and practice

Academic research and seminars underpin China's development of green SHP. For example, in 2012, ICHSP conducted research on the influence of green hydropower on the environment of river systems in the south-western, south-eastern, north-eastern and north-western regions of China. It also analysed major influencing factors, screened key elements to evaluate green hydropower development and convened academic seminars to assess the effects of SHP projects on the environment.

Box 1. Changes and stages in solar hydropower plant in China

Changes in investment mechanisms
The power consumption of Chinese society soared in the 1990s following economic reforms and the opening-up of the Chinese economy. Realizing the great potential of SHP development, the Chinese Government took the lead in changing the SHP investment mechanism and led a reform of feed-in tariffs, while encouraging private-sector investment in the SHP industry, greatly alleviating power supply problems. Subsequent investment in SHP via shareholding mechanism thrived, bringing considerable income to investors. During this period, the proprietary rights of SHP moved from the state and collective ownership to private (or share) ownership.

Changes in benefit distribution
The advantages of developing via shareholding mechanisms stimulated the rapid exploitation of China's SHP resources, enriching specific groups and individuals. The 1990s saw intensive development, and good-quality SHP resources were concentrated with vested interests. Overall, the SHP profits were distributed to the shareholders rather than to the general public.

Changes in energy structure status
Since the 1990s, China has undergone 30 years of rapid development and based on this growth, various other energy technologies were developed including wind, solar and nuclear power. Other alternative energy construction projects were initiated too. In fact, the installed capacity of China's wind and solar power constructed over the past 10 years exceeds the installed SHP capacity, which was developed over the last 60 years. Meanwhile, SHP proportion of China's energy structure is decreasing with every passing year.

Changes in demand
The high-speed development of China's society and economy has continuously improved the living standards and production levels, and the basic demands of people have been transformed from simply wanting a resolution of power supply issues to water resource utilization at a higher level. For example, people around SHPs expect to share the economic benefits of generated power. Moreover, people's demand for water resources has changed too. Earlier, water was primarily used as a tool for generating electricity, whereas now, drinking, environmental protection, and tourism are being prioritized.

Changes in the Government's attitude towards SHP

The Government has established many environmental protection zones, natural reserves, biosphere reserves, soil and water conservation areas, and even conservation areas for drinking water. An increasing number of SHPs, established early in China's SHP development cycle, find themselves located in various reserves. Additionally, environmental issues related to their operation are increasingly visible. The Government has refurbished, used either punitive measures or shut down such SHPs in an attempt to address environmental issues. Overall, the Government's attitude towards SHP has changed from vigorous advocacy to strict regulation.

The Standard for Evaluation of Green Small Hydropower, which stipulates the definition and construction standards of green SHP, was formulated based on this research. Moreover, ICSHP is currently formulating "Guidelines for Control Techniques for Downstream Flow Reduction of Small Hydropower Stations" to help standardize the construction requirements for newly built or refurbished SHPs. Similarly in 2016, the Ministry of Water Resources released Guidelines for Promoting the Development of Green Small Hydropower. The current aim is to establish a standard management system for green SHP, develop incentive policies, and build a batch of green SHPs before the end of 2020. It is envisaged that the green SHP concept will be fully embraced by 2030.

The guidelines identified seven key tasks to promote green SHP, namely, strengthening planning constraints and optimizing the layout of development; scientifically designing, constructing and advocating for green development; implementing, upgrading and transforming, and promoting ecological operation; perfecting the monitoring network, safeguarding the demand of ecological water and promoting cascade cooperation; improving technical standards and playing a good leadership role; and accelerating technological breakthroughs and promoting technological innovation.

In 2017, the Ministry issued the Notice on the Establishment of Green Small Hydropower Stations, detailing the certification process and procedures, which require all SHPs to abide by the laws and regulations, meet the requirements of downstream water, have no water disputes and have basic conditions of Standard for Evaluation of Green Small Hydropower.

ICSHP has also led the development of the Green Hydropower Management Information System, with a view of improving the efficiency of green hydropower management and information collection, to standardize work procedures, improve overall management of green hydropower departments, and increase publicity and transparency. The system integrates digital technology with green hydropower and promotes smart management to help the system become the "Internet+" of green hydropower.

In 2017, following voluntary application, preliminary validation, verification and publication, 44 SHPs passed the assessment and were accredited as the first batch of green SHPs in China. Over 400 hydropower stations were registered and applied in 2018, of which 121 were accredited as green SHPs.

Implementing measures for green hydropower

The requirements for development layout, development scale, development method, construction and operation of hydropower resources must be clarified through planning, and spatial control should be carried out in the development stage. SHP development is strictly prohibited in ecologically fragile and important eco-functional areas, while areas with higher development level must be optimized for development. Development planning should be continually evaluated.

In the design and construction stage, full use should be made of existing topography and landforms to arrange SHP facilities so as to minimize disturbances to river morphology and ecosystems. Moreover, green SHP projects should keep away from sensitive development areas such as nature reserves, national key scenic areas, centralized drinking water sources, and reduce the impact on land vegetation and soil disturbance. Green SHP should also avoid river canalization, which changes the boundary conditions of rivers, adversely affecting the upstream, downstream and both banks of the river. Further, the ecological flow of the river must be scientifically verified and the discharge measures should be identified. The ecosystems' demand for river water should be guaranteed, and the impact on the hydrological situation should be minimized.

As far as renovation and refurbishment measures are concerned, ecological flow features prominently in green SHP development, focusing on eight specific areas (Box 2). One potential measure to be considered is the use of a weir. If the river, on which a hydropower station is located, is wide, shallow and flows slowly, a fixed or movable weir

can be built. It should be located at an appropriate part of a dried-up river section that has little impact on flood control for upstream villages. This will allow the section to maintain a certain water depth and meet the requirements of longitudinal connectivity of the river.

Further, sluices can be built at appropriate points in the dried-up river section if there is a need for flood-and-erosion control during the rainy season. A typical sluice used for this purpose is a flap gate at the bottom foundation that has discharge holes. At the lowest water level, the flow discharge capacity of the discharge holes shall not be less than the minimum discharge flow. Floodgates can be opened to release flood water at high water level during the flood season.

It should be noted that if the main river channel where a hydropower station is located is stable, the inflow is low during the dry season, the river is wider and the evaporation capacity is larger. Given that certain fish and other aquatic organisms may have certain water depth requirements, it may be necessary to build a longitudinal deep pool at an appropriate point on the dried-up river section to restore water.

In terms of operation and management measures, for hydropower stations that have a significant influence on the hydrological situation of rivers during low water periods, the generation-dispatching mode should be changed. Along with that, seasonally restricted operations should be implemented, which will allow water to flow directly back to the river during the low water period.

It is also recommended to coordinate the operation of cascade hydropower plants using a centralized control system. Such a system should utilize the hydrological survey information and water situation forecast results of the basin to guarantee the continuous discharge of water for improving river ecology.

Another operational measure is to establish an ecological flow monitoring network. This involves establishing monitoring sites at each discharge outlet of hydropower stations in the basin to monitor the discharge. Alternatively, river sections near the downstream part of the dam site of a hydropower station can be selected for installing flow-measuring devices.

The ecological flow monitoring technology should match with the conditions of the monitoring section, flow characteristics and discharge method. It is mainly based on real-time online monitoring and supplemented by other artificial comparison measurement so as to reflect the discharge flow objectively and accurately. Common measurement methods include traditional flow meter, Doppler (ADCP) flow measurement, real-time radar wave flow measurement, electromagnetic flow meter measurement, water meter measurement and hydraulic structure measurement.

Construction of green hydropower demonstration zone in Zhejiang

Target

The main aim is to undertake a comprehensive restoration of hydropower systems based on basins and regions, aiming to eliminate or alleviate environmental problems, such as drying-up of water or water reduction in river courses caused by hydropower stations. This is achieved through

Box 2. Ecological flow release

Use water diversion system

- For hydropower stations that adopt channel diversion, build a side weir by leaving an opening or bury drainage pipes in an appropriate place after the channel passes the dam to discharge the flow into the river channel.
- For hydropower stations that adopt tunnel diversion, utilize the original constructed adit tunnel near the dam to retrofit or excavate a new drainage tunnel. In this case, drainage pipes can be used to discharge the flow into the downstream river channel.
- For technically and economically feasible projects, “ecological generator units” can be installed in the outlet of drainage pipes.

Use spillway sluices with small opening

- For a gate-dam (sluice-dam) hydropower station, a one-hole or multiple-hole sluice gate can be closed incompletely, allowing for the control of discharge into the downstream river channel. After calculating and determining the sluice gate discharge opening using the sluice hole discharge formula, it can be controlled via a sluice gate stroke controller or by setting a limit pier (cement pier) on sluice floor slab.

Use spillway sluice

- According to the actual situation of the layout of a hydropower station, the operating gate (service gate) of spillway can be renovated. The middle gate or flap gate can be set and a hoist can be added to discharge the flow downstream.

Use dam-emptying facilities

- Utilize the original bottom outlets of the dam (such as the diversion bottom outlet, sediment orifice, reservoir emptying hole, flood discharging tunnel, spillway tunnel), add sluice gate control system, adjust dispatching and operation mode.

Set ecological base load or use reverse regulation

- For a dam-type hydropower station, which can meet the ecological flow requirements via electricity generation, it is unnecessary to set up special discharge facilities. According to the upstream water inflow condition, adjust the capacity of the reservoir and the characteristics of the generating unit of the hydropower station, optimize the dispatch and operation of the reservoir, and ensure continuous operation of at least one generating unit. Dispatch discharge flow through base load or reverse regulation and try to reduce the amplitude of variation of the downstream channel in one day as far as possible.

Install an ecological generating unit

- Besides the large generating unit, install the ecological generating unit, which can be set up separately, run for a long term and undertake the task of ecological discharge.

Release discharge by using bypass pipe of generating unit

- Open holes on the bypass pipe of water inlet valve of the generator unit and connect the drainage pipes, and discharge flow downstream after transformation by making use of the original water diversion facilities of the hydropower station.

Add dam water release facilities

- Add inverted siphon, water pumping system, spillway and other facilities at appropriate locations in the dam area to continuously take water from the upstream of the reservoir. After that, get water to pass through the dam and then release it into the downstream channel of the dam to meet ecological flow requirements.

both engineering and non-engineering measures designed to maintain and improve the ecological condition of rivers, optimize the allocation of water resources and scientifically utilize hydropower resources.

Activities

For some old diversion-type hydropower stations, especially those diverting water across the basins, water discharge facilities should be increased through technical refurbishment to maintain the ecological flow of the channels downstream of the hydropower stations.[1] Ecological weirs, rolling dams and landscape weirs should be built in dried-up or water-reduced river sections affected by hydropower dams and cascade hydropower stations. In this way, both the water supply for production and domestic use in the downstream can be safeguarded, and the water landscape of the river can be improved.

Moreover, the minimum ecological flow and control principle of a hydropower station shall be identified according to the characteristics of different rivers in different basins, while ecological flow monitoring facilities must be installed to dynamically manage the ecological flow.

Starting with the actual condition of hydropower stations, an ecological operation mode will be established, the operation and scheduling will be improved, and the optimal scheduling of water resources in the reservoir will be strengthened. In addition, the downstream flow in dry seasons should be effectively improved by accumulating stored water during the rainy season.

Depending on the level of local economic and social development, hydropower stations will be multifunctional, not only generating electricity but also facilitating water supply and flood control. Hydropower stations deemed unsafe, not environment-friendly and uneconomical will be gradually abandoned and dismantled.

[1] If condition allows, small ecological units can be added.

Promoting process

Runoff investigation and evaluation were conducted between the powerhouse and the dam. Moreover, an evaluation was done of the water-reduced and dried-up sections of 849 SHPs in Zhejiang Province, which had an installed capacity of above 500 kW. An assessment was made of the water environment and ecological degradation caused by water-reducing and dried-up river sections. Other process-promoting activities include:

- Active implementation of pilot projects in green hydropower demonstration zones in Lin'an, Anji and Kaihua. The total investment was over US$ 3 million; 8 green hydropower demonstration zones and 15 ecological restoration hydropower stations were built; and 5 hydropower stations were dismantled. The demonstration effect and ecological benefits were outstanding.
- Compilation of Technical Guidelines for Ecological Hydropower Construction. Further clarification of technical requirements and methods for green hydropower construction, as well as technical measures for ensuring the ecological flow of downstream of hydropower stations, environmental protection, restoration of dried-up sections and the continuous environment improvement of hydropower stations.
- Compilation of the implementation plan for green hydropower construction during the 13th Five-Year Plan period (2016–2020). Organization and compilation of the implementation plan for the construction of green hydropower demonstration zones in Zhejiang (2016–2020), and integration of the content of green hydropower construction into the 13th Five-Year Plan for water conservancy development in Zhejiang Province. During the period, Zhejiang Province plans to build 50 green hydropower demonstration zones in 39 counties (cities, districts) and complete the restoration of 300 hydropower stations.

Guarantee measures

The rules for the construction and management of green hydropower demonstration zones in Zhejiang Province were established. These rules cover the definition, content, procedures, implementation of the procedures, and project applications of the green hydropower demonstration zone. They also delineate responsibilities for different levels of water administrative departments and project owners.

The management regulations for existing hydropower stations were issued. More specifically, in June 2015, the Province issued the Compensation Principles for Dismantling Existing SHPs in Anji County, which can implement the compensation process according to the dismantling of hydropower stations and restoration of the environment.

The construction of a green hydropower demonstration area was included into the project segmentation contact system, the daily supervision and inspection system and the monthly work notification and report systems. It was also included in the "one thousand people and ten thousand hydraulic projects" on-site guidance and the service work and provincial assessment on "treating sewage and flood control water and drainage, ensuring water supply and grasping water saving".

Construction funds were raised through multiple channels including the Central Government, Provincial Government, the Global Environment Facility, private funds and bank loans. The fundraising channels for the project construction in the demonstration area were broadened to ensure the smooth implementation of the project. Moreover, the power generation loss was also measured and classified for the reimbursement in Jinhua and other cities (regions).

In terms of raising public awareness, a consensus on the promotion of the green hydropower demonstration area was gradually built from the higher level of government to grassroots hydropower stations through publicity, training and guidance.

Achievements in numbers

Overall, a total of 24 green hydropower demonstration areas have been identified, 53 hydropower stations have been refurbished, 24 rivers have been restored, 25 km of dried-up river sections have been restored, 3 discharge sluice holes ensuring ecological flow have been newly built and reconstructed and 37 weirs for maintaining ecological flow have been newly built.

Lessons for future SHP development

Lesson 1: Strengthen publicity, training and technological knowledge.

Lesson 2: Conduct basic investigation and clarify problems and working conditions.

Lesson 3: Set requirements, identify objectives clearly and formulate scientific layouts.

Lesson 4: Formulate standards and issue guidelines for promotion.

Lesson 5: Implement pilot projects, typical models, accumulate experiences and promote best practice.

Lesson 6: Conduct research on supporting policies, establish and improve incentive and guarantee mechanisms.

Box 3. The green SHP certification mechanism

Institution building

In terms of future development, a key aim is to set up a certification institution for green hydropower. This institution will gain policy supports in relevant laws and regulations, finance, price and other fields, set scientific certification standards and adopt transparent certification procedures. Scientific research institutes and industry associations can participate or provide appropriate technical support and consultation.

Green power certificate for SHP

SHPs that have passed the green hydropower certification shall be awarded certificates by the competent department of hydropower resources. Enterprises of power generation and sales can voluntarily purchase the green power certificates. Megawatts hour of power generated is equivalent to a green certificate, which is marked with the type, serial number, production date and other information of the eligible renewable power. The green power certificate supports the quota system of SHP generation, that is to say, it is compulsory to stipulate a certain proportion of green SHP power output from power generation enterprises or power grid.

Green power tariffs

Power supply companies shall set green tariffs separately for the power companies with a green certificate, and consumers shall be free to choose a suitable proportion of green power according to their electricity consumption. A certain additional price is charged per kilowatt hour to make up for the higher cost of green power.

Green certificate market

A new competitive market, which allows the trade of green SHP electricity and has a different pricing system from that of the conventional power market, shall be created. This is called the green certificate market. The trading mechanism of green certificate not only opens up a sales channel for green power, but also ensures its optimized allocation and reasonable supply.

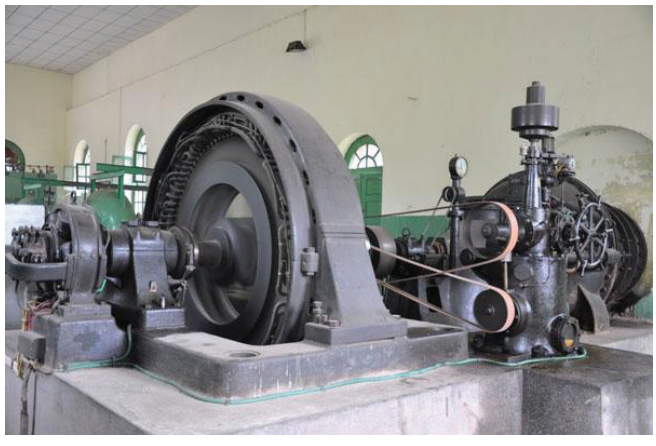


Figure 1. Shilongba SHP in Kunming, Yunnan Province
Note: China's first SHP, with installed capacity of 240 kW, is still operating.

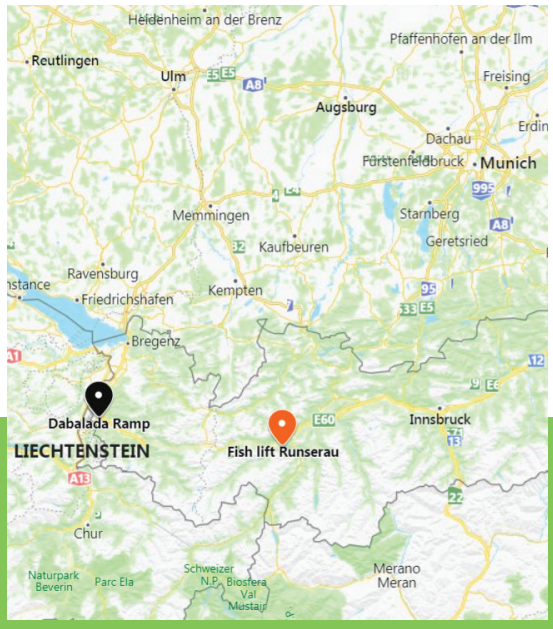
Figure 2. Qingxi SHP in Guizhou

Figure 3. Jinkeng Ling SHP in Zhejiang (1,250 kW)

Figure 4. Hengjin First Cascade in Zhejiang Province (9,750 kW)

Figure 5. Anming First Cascade in Songyang, Zhejiang Province
Note: Total capacity is 2 x 6.3 MW, reservoir storage capacity is 3.32 million m3, an 80 cm pipe was installed at the bottom of the reservoir for ecological flow discharge.

6.2 GREEN SMALL HYDROPOWER IN AUSTRIA IN THE CONTEXT OF THE EU WATER FRAMEWORK DIRECTIVE



Source: Google Maps

Cui Zhenhua, Xu Jincai; Hangzhou Regional Center (Asia-Pacific) for Small Hydro Power/ National Research Institute for Rural Electrification

Small hydropower (SHP) as a renewable energy source plays an important role in Austria's energy sector, although balancing the need for hydropower development and river conservation continues to present a considerable challenge. In an attempt to square this circle, Austria has increasingly turned its attention towards green SHP, its policy and practice endorsing effective measures to promote ecological flow and river restoration, in particular.

The backbone of the Austrian energy mix, hydropower, accounts for over 60 per cent of Austria's electricity generation. Moreover, Austria has more than 3,000 existing hydropower plants with a catchment area larger than 100 km^2. Despite the fact that the country's hydropower potential is already developed to 68 per cent, the current Austrian Climate and Energy Strategy aims to further increase hydropower production based on the EU Renewable Energy Directive.

One potential consequence of such development is that hydropower initiatives may have a negative impact on river ecosystems, in turn hindering the accomplishment of the aims of the EU Water Framework Directive (WFD) and the Habitats Directive. WFD takes a pioneering approach to protecting natural geographical formations, such as, river basins. Overall WFD requires EU member states to reach 'good status' objectives for waterbodies based on a six-year cycle. For surface water, it consists of a general requirement for ecological protection ('Good Ecological Status' or GES) and a low level of chemical pollution ('Good Chemical Status' or GCS). GES is defined in terms of the quality of the biological community, the hydromorphological characteristics and the chemical and physicochemical characteristics.

Hydromorphological alterations (changes in the natural flow regime and structure of surface water) due to hydropower are among the top pressures emerging from the WFD analysis. In an attempt to balance both the hydropower development and the environment conservation, Austria has taken effective measures to guide the new development and ecological restoration of rivers impacted by existing hydropower plants. The specific successful practices employed by Austria, which may be of relevance to stakeholders in other countries facing similar or related issues, are discussed next.

Ecological flows policies for SHP with legal binding

Ecological flows (Eflows) as a hydrological regime consistent with GES shall ensure the good functioning of the ecosystem according to river type-specific biological conditions. The Austrian Water Act of 1990 requires that water abstraction has to be restricted so that an ecological minimum flow to achieve GES is guaranteed. In 2010, the Eflows to achieve good status (base flow and dynamic aspect) were defined in the ordinance on quality objectives for rivers and lakes. Requirements covering ecological minimum flow, ecological continuity (fish pass) and hydro-peaking are stipulated in the ordinance in detail with legal binding.

Figure 1. Dabalada ramp offering possibility of ascent for fish

Moreover, the Austrian National River Basin Management Plan stipulates that an ecological minimum flow must also be restored in existing hydropower plants that were awarded permits before 1990. Restoration will be undertaken incrementally until 2027 via an ecological prioritization approach.

The Austrian Water Act 2011 also stipulates that it is obligatory to guarantee ecological continuity at all the barriers, for example, hydropower plants or obstacles due to flood protection measures. Fish passes are, therefore, required for all hydropower plants that are situated in rivers with natural fish habitats. This also means that flow conditions have to allow fish migration (regulations for minimum depth and minimum flow velocity). Standards for the construction of fish passes, necessary for GES, have been developed and were published in 2012.

Implementation via an orderly prioritization approach

In Austria, the first National River Basin Management Plan (2009) prioritizes river stretches with middle-distance migratory fish. Furthermore, in 2011, the Governor of Upper Austria issued an ordinance for mitigation measures in the priority river reaches – and this ordinance enforces the establishment of river continuity at 310 barriers, 100 of which are hydropower plant barriers. Permit holders were obliged

Box 1. Requirements for a good hydromorphological status of a waterbody

Indicators	Requirements	
Minimum flow	Natural mean annual flow ‹1 m³/s	Natural mean annual flow ›1 m³/s
	›natural lowest daily minimum flow	
	›50 per cent mean annual low flow	›33 per cent mean annual low flow
Dynamic flow	20 per cent of actual flow (recommended)	
	Seasonal character of the natural bed-sediment relocation and thus a substrate composition is ensured	
	Sufficient current/flow is ensured in times of spawning migrations	
	Different habitat demands of individual age classes of key organisms are considered during different times of the year	
Water depth and flow velocity	Minimum water depth and minimum flow velocity in the natural fish habitat	
Hydro-peaking	For large rivers, anthropogenic fluctuations in water flow shall be assessed on a case-by-case basis. For all other waterbodies, they shall not exceed a ratio of 1 to 3 between downsurge and surge, and the water covering of the riverbed shall, during downsurge, account for at least 80 per cent of the riverbed surface covered in times of surge.	
Fish migration	Anthropogenic migration barriers occurring in the natural fish habitat must be passable for fish all year long	

Figure 2. Fish lift in Runserau

Figure 3. Fish pass and residual turbine at the Opponitz hydropower plant

to submit projects related to river continuity and ecological minimum flow, and the measures had to be licensed and implemented according to strict timelines.

Meanwhile, a technical paper addressing barriers in the Danube River Basin has been issued to the countries through which the Danube River flows. The paper outlines existing technical solutions to restoring river connectivity for fish migration, summarizes measures for ensuring fish migration at transversal structures and provides a rough orientation for the construction of fish passes.

It also evaluates types of fish passes, and covers upstream and downstream migration. Measures to restore the river continuum are classified as removal of the barriers, rough ramps or river bottom sills, nature-like bypass channels or nature-like pool-type fish passes, technical fish passes and special constructions (e.g., fish locks, fish lifts). Two approaches for the assessment of fish pass functionality are also discussed – evaluation based on indirect parameters (abiotic) and evaluation based on ecological investigations into the ecological impact on fish. Based on the evaluation of the waterbody condition, measures are also stipulated in the National Water Management Plan (NGP) that are required in NGP I in the priority waterbodies (catchment area greater than 100 km^2).

Specific measures

Until 2013, the Dabalada dam was an impassable hurdle for fish upstream of the entry to the Ill River into the Rhine River and it was the only migration obstacle before the subsequent renaturation stretch. To create connectivity, the previous Dabalada dam was replaced by a riverbed ramp in the trough-step-pool system, which covers the entire width of the waterbody. With this ramp, fish can now travel upstream unrestricted (Figure 1).

Moroever, a fish lift is used as a fish pass at the existing Runserau weir on the Inn River due to the lack of space and the extremely variable headwater levels. The downstream waterside is connected to the Inn by means of a vertical slot fish pass system and the head pond side is connected by a fish return pipeline (Figure 2). Two entrances in the tailwater and conventional vertical slot passes ensure that the fish can find the pass. A total of 1,393 fish were transported by the lift fish pass in 2016 and 719 in 2017. All in all, four different

fish species were transported: brown trout, rainbow trout, grayling and bullhead.

Similarly, the construction of the fish pass (Figure 3) at the Opponitz power plant established access for fish from the downstream side of the Göstling dam to the upstream side. A vertical slot pass was built on the left bank of the Ybbs River. The downstream entrance of the fish pass is located directly below the outlet of the residual water turbine, a constant attraction flow is ensured, securing the findability of the fish pass. The overall length of the fish pass is around 150 metres and the maximum altitude difference to be bridged is 6.2 metres. Moreover, ecological flow was increased from 0.25 m^3/s to 1.2 m^3/s.

Incentives for ecological restoration of SHP

In Upper Austria, an Energy Agency is responsible for awareness-raising and management of an advisory programme, which oversees consultations of plant owners, trainings and awareness campaigns. Overall 790 of the Upper Austrian hydropower plants are smaller than 0.5 MW, so the advisory service has a strong focus on SHPs. SHP owners can ask for preliminary advice about the optimization potential, technical and ecological requirements (best available technique including river continuity) and funding and incentive schemes. Since 2007, a total of 338 one- or two-day consultations have been undertaken by independent experts. Costs are met entirely by the programme.

Moreover, scientific research activities are supported by many stakeholders to deepen the scientific basis of specific fields. For instance, a HyTEC (Hydromorphological and Temperature Experiment Channel) test facility (Figure 4) was established to develop causal relationships with regard to the reaction of aquatic organisms to surging and sinking phenomena by means of experimental approaches under controlled conditions. The project and the pilot plant are financed by the Austrian Ministry of Economy as well as by hydropower plant companies.

Lessons for future SHP development

Lesson 1: There is a need for a common understanding of ecological flow

A unified common understanding of ecological flow is essential for the proper implementation of Eflows policy. The understanding of Eflows should not only refer to the minimum flow but also specific requirements on dynamic flow, water depth and flow velocity, which are critical to river habitats.

Lesson 2: An orderly approach is needed to promote the sustainable development of SHPs

To restore the ecological impacts of existing SHPs, an orderly prioritization approach is needed. The ecological and economic effects should be balanced to promote the sustainable development of SHPs and the conservation of river ecosystems. Mitigation measures should be taken on a site-specific basis.

Lesson 3: Green SHP development requires incentives

Incentives are needed to guide the development of green SHP. Scientific findings and cost-effective technologies play an important role in accelerating the restoration of riverine reaches impacted by SHP development.

Figure 4. Research facility hydromorphological and temperature experiment channel

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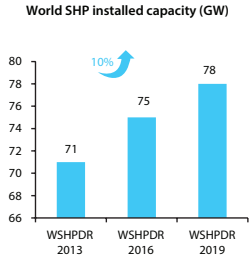
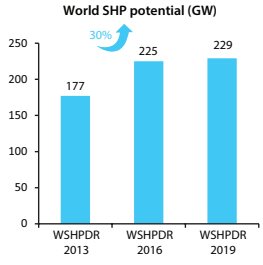
World Small Hydropower Development Report

The World Small Hydropower Development Report (WSHPDR) 2019 is an update of the Report's first two editions in 2013 and 2016. The WSHPDR 2019 contains **166** national reports and **20** regional reports, with 21 new countries added since its first edition.





A special report with **Case Studies** is added to the WSHPDR 2019, showing the different roles small hydropower can play in achieving the SDGs.

- SHP for productive use
- SHP for social and community development
- SHP financing
- Technology, innovation and smart SHP
- Incentive policies for SHP development
- Green SHP

- The Report is available on **www.smallhydroworld.org**;
- More than 230 experts and organizations have been involved;
- Every country report provides information on:
  a. Electricity sector;
  b. Small hydropower sector;
  c. Renewable energy policy and;
  d. Barriers to small hydropower development.

Small hydropower for a better world

Contributing organizations

European Bank for Reconstruction and Development

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HRC Small Hydro

HYCON GmbH

Asociacion de Trabajadores de Desarrollo Rural – Benjamin Linder (ATDER-BL)

Der Wasserwirt

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Smart Hydro Power

Sarhad Rural Support Programme

Turbulent

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Zhaoheng Hydropower Group

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