IRENA
International Renewable Energy Agency

# RENEWABLE ENERGY BENEFITS

## LEVERAGING LOCAL CAPACITY FOR SMALL-SCALE HYDROPOWER

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## ABBREVIATIONS

| | |
|---|---|
| **APRODELBO** | Association for the Development of Bocay Electric Service |
| **ATDER-BL** | Association of Rural Development Workers Benjamin Linder (ATDER-BL) |
| **AKDN** | Aga Khan Development Network |
| **AKRSP** | Aga Khan Rural Support Programme |
| **BoM** | bill of material |
| **BoQ** | bill of quantity |
| **MW** | megawatts |
| **NGO** | non-governmental organisation |
| **VEC** | village electrification committee |


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# ABOUT THE IRENA LEVERAGING LOCAL CAPACITY SERIES

Renewable energy development can drive economic growth, create new jobs and enhance human health and welfare. The IRENA *Leveraging local capacity* series examines the kinds of job created and suggests ways to build on existing capacities to maximise the benefits of renewable energy development. Each study focuses on a technology and outlines the requirements along the entire value chain, particularly in terms of human resources and skills, to produce, install and operate plants or facilities. The series intends to support assessment of potential for local value creation and leveraging of domestic capabilities.

To date, studies have been released for utility-scale and decentralised renewable energy solutions. On the former, analyses for solar photovoltaic (2016), onshore wind (2017) and offshore wind (2018) have been produced. On the latter, in addition to the present report on small-scale hydropower, an analysis has been completed for solar water heaters (2021). Studies covering additional technologies, including concentrated solar power, and updates of previous analyses are in preparation or planned.

The objective of the series is to inform feasibility assessments of procuring the necessary components and services domestically by leveraging local capabilities and capacities. The studies can help decision makers identify ways to maximise domestic value creation opportunities for various energy transition solutions and reap socio-economic benefits. In the context of this report, value creation from small-scale hydropower deployment is closely linked to supporting local livelihoods, strengthening watersheds and building climate resilience.

The series is part of IRENA's extensive analytical work, ongoing since 2011, assessing the socio-economic impacts of a renewables-based energy transition. The initial focus on employment creation and skills was subsequently extended to cover other socio-economic elements such as gross domestic product, broader measures of welfare, local economic value creation, improved livelihoods and gender-differentiated impacts.

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## ANALYSES OF LOCAL CAPACITIES

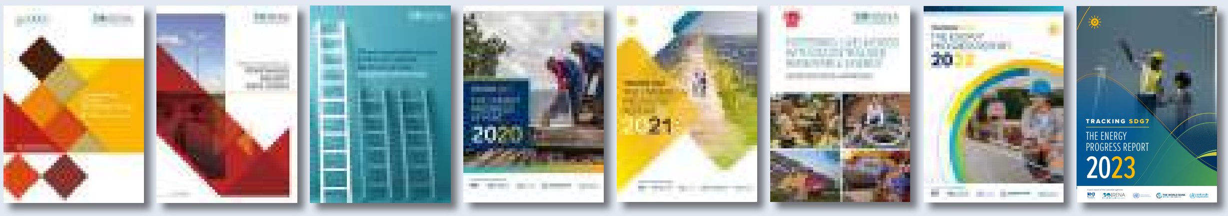
2016 | 2017 | 2018 | 2021 | 2023 | 2023


## ASSESING GENDER EQUALTY IN RENEWABLE ENERGY

2017 | 2019 | 2020 | 2022

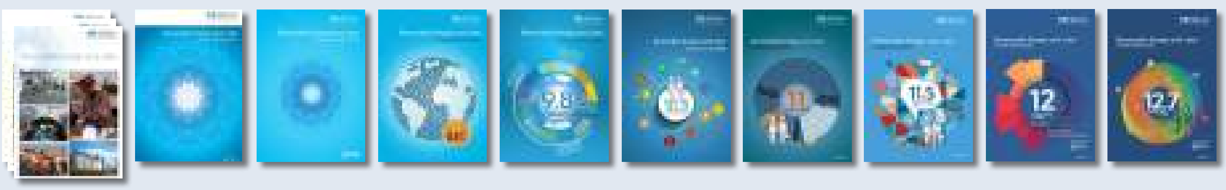

## STUDIES OF ACCESS CONTEXT

2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023




## ANNUAL REVIEWS OF EMPLOYMENT IN RENEWABLES

2011-2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022



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# KEY FINDINGS

- Small-scale hydropower systems, or hydro mini-grids (< 1 MW), offer benefits including irrigation services and can connect communities to the central grid, even allowing for the sale of excess power. Additionally, community-based hydro mini-grids can be a nature-based solution for climate adaptation and mitigation, incentivising local communities to restore and maintain surrounding watersheds.
- Small-scale hydropower presents opportunities for socio-economic value creation through local employment and livelihoods. Plenty of job opportunities are created in the implementation value chain. Additional opportunities for employment are derived from productive uses (utilisation value chain) and from the infrastructure investments needed in watershed conservation to ensure the community and the hydro mini-grid are are resilient against droughts and floods (climate adaptation value chain).
- The implementation value chain generally consists of six segments: feasibility, planning and procurement, manufacturing, installation and connection, and operation and maintenance, followed by decommissioning once the lifetime of the facility is reached.
- The implementation of a small-scale hydropower plant requires more than 17 000 person-days for a pico hydro plant (averaging 5 kW), around 64 000 person-days for a micro hydro facility (50 kW) and over 160 000 person-days for a mini hydro system (500 kW).
- Operation and maintenance work, which is needed throughout the lifetime of a system, represents the largest chunk of the labour required (94%, 87%, and 78% of total person-days, respectively, for pico, micro and mini hydro facilities).
- The majority of labour required for the project involves low- to medium-level technical skills, with percentages ranging from 79% of total person-days for a 500 kW project to 93% for a 5 kW project. These skills are generally readily available in a country's workforce or can be developed through certification programmes or vocational training centres. These skills are transferable and in high demand for other rural infrastructure development jobs.
- Connecting renewable energy supply with income-generating activities (productive end uses) across sectors has the potential to boost productivity, enhance incomes, create local employment and catalyse rural economies. Translating energy access into livelihood improvements requires investing in a social ecosystem that can foster technology solutions tailored to livelihood needs and deliver the financing, capacity and skills training; market access; and cross-sector policy support to realise the full benefits of decentralised renewable energy solutions.


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- Small-scale hydro systems in remote locations are often operated under social asset only models, resulting in low revenue and minimal socio-economic benefits. However, transitioning to an inclusive social enterprise model, where the community or members own and manage the mini-grid, can lead to maximum utilisation of the system, generating benefits for local energy use and socio-economic development. This approach incentivises electricity use for income generation and promotes sustainable energy access through financial viability of the mini-grid.
- Among the different distributed renewable energy solutions suitable for improving energy access, small-scale hydropower not only provides the most opportunities to develop local capacity but is the most reliant on local capacity development to be successful.
- Small-scale hydropower hardware can be manufactured locally, representing an opportunity to impart local skills, create jobs and foster enterprise development. However, costly international standards make it difficult for local developers to compete for small-scale hydropower projects. Therefore, international programmes funded by donors need to encourage the use of local experts, instead of relying on foreign service providers, to maximise the benefits of engaging local talent.
- The lack of access to modern energy affects women and children disproportionately. Small-scale hydro can help in the advancement of gender equality and the empowerment of rural women as leaders and economic agents of change, thereby transforming local economies and generating inclusive growth.
- To fully realise the benefits of small-scale hydropower and maximise domestic value creation, policies and measures need to focus on enhancing community capacity along the value chain and promoting social acceptance. Investment in a social ecosystem is critical for the deployment of small-scale hydropower, which should encourage customised technical solutions and provide funding, capacity building, market access and policy support. This will enable the benefits of decentralised renewable energy to be realised.

# 1.INTRODUCTION

More than 733 million people throughout the world still do not have access to electricity, and at the current pace of electrification, nearly 670 million are expected to remain without access by 2030 (IEA *et al.*, 2022). Extending national grids to remote rural areas with low-density settlements presents significant challenges in terms of technical complexity, high costs and limited economic viability due to low consumption and subsequent low return on investment. These difficulties are often compounded by additional factors, such as poor governance, inadequate access roads, harsh winters and the constant threat of natural disasters (UNIDO and ICSHP, 2019). As a result, the endeavour of establishing power infrastructure in these localities remains a daunting and financially unfeasible task.

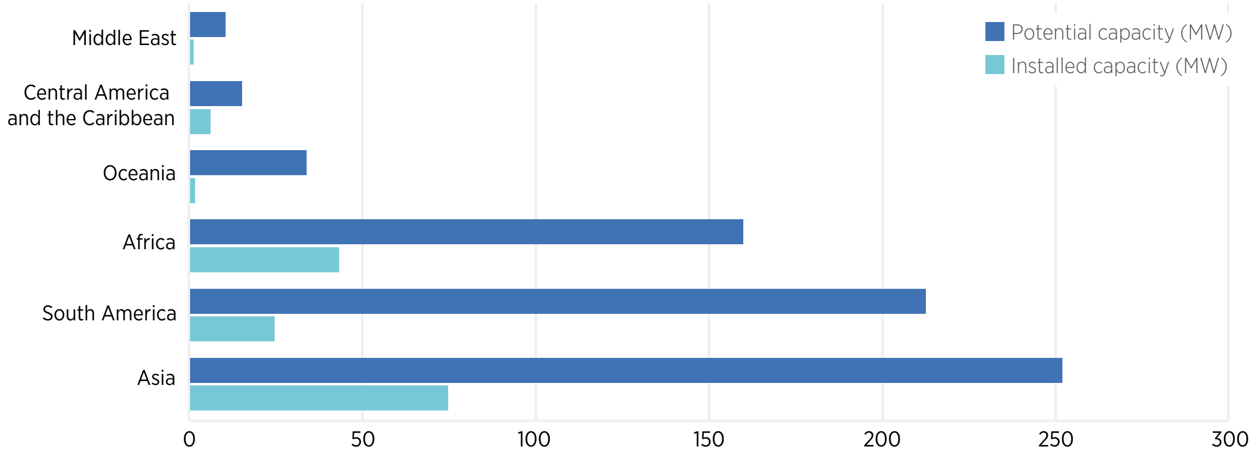
Decentralised mini-grids or stand-alone solutions are increasingly being deployed to expand electricity access for households and public services and to support livelihoods critical for rural development (IRENA and SELCO Foundation, 2022). Among these solutions, small-scale hydropower has the longest track record of adoption globally, with tens of thousands of systems installed since the 1980s (ESMAP, 2022) to meet diverse community energy needs such as health care, education, access to water, entertainment, and safety (*e.g.* streetlights), as well as to stimulate rural economies through household and commercial income generation and job creation.

Hydropower has played a variety of roles in infrastructure development, from large-scale systems[1] that are vital in some countries to meet urban and major industrial demand, to smaller-scale facilities, which can deliver access in off-grid communities but also connect to the central grid in some cases and which frequently provide a range of non-energy benefits, including irrigation services (see Annex A). The inherent benefits of small-scale hydropower systems, also called hydro mini-grids, enable bridging of community-scale and utility-scale contexts, such as when communities sell excess power to the central grid utility (UNIDO and ICSHP, 2019).

Small-scale hydropower is widely used mini-grid technology, often for delivering energy to off-grid villages. IRENA estimates that the number of people connected to hydropower-based mini-grids rose from 5.7 million in 2012 to nearly 7.2 million in 2021, the majority of them in Asia (IRENA, 2023a). Asia remains the leader in installed capacity but also has the largest untapped potential in the world, followed by South America and Africa (IRENA, 2023a) (see Figure 1). Sub-Saharan Africa has the highest untapped potential for small-scale hydropower, notably in countries that have less than 5-10% rural electrification rates (Korkovelos *et al.*, 2018; Water and Energy for Food, n.d.).

1 The classification of the scale of a hydropower plant relates to the electricity production capacity expressed in kilowatts (kW) or megawatts (MW). However, specific classifications vary from country to country as there is currently no consensus among countries and hydropower associations on the upper limit of what constitutes small-scale capacity (see Annex A for further details). For the purposes of this report, the cut-off is 1 MW.

Figure 1 **Regional installed and potential small-scale hydropower capacities up to 1 MW in 2019**



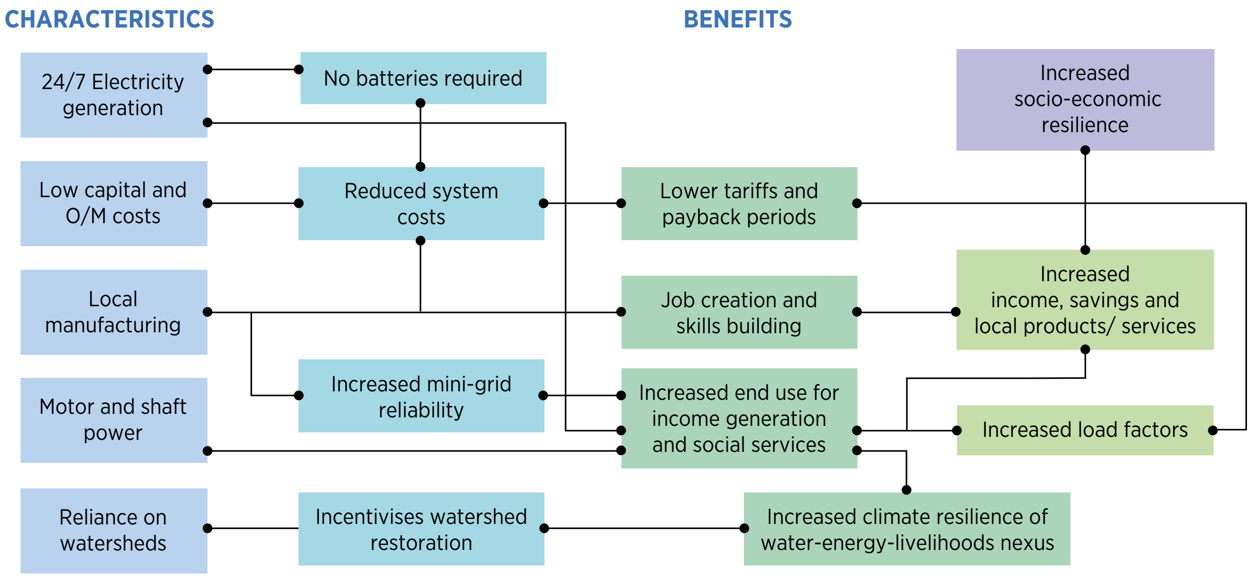

Source: Based on: IRENA, 2023a; IRENA, 2023b; TU-Delf, 2017.

Where the requisite natural resources exist, small-scale hydropower can produce electricity with a low levelised cost of energy. Its techno-economic characteristics, including reliability, affordable upfront capital, and affordable operation and maintenance costs, allow for economic viability with highly positive social and environmental impacts (see Figure 2). These advantages enable lower tariffs for off-grid households, higher tiers of electricity service, extensive productive end uses, market-based scalability and financially viable grid interconnection.

Among other benefits, community-based hydro mini-grids (< 1 megawatts [MW]) can be a nature-based solution for climate adaptation and mitigation. The energy access afforded by small hydro incentivises local communities to restore and maintain surrounding watersheds,[2] as otherwise electricity generation will be interrupted by droughts and severe rain. Nature-based solutions generate extensive jobs (WWF and ILO, 2020) and strengthen the water-energy-food-livelihoods nexus. In off-grid, high-altitude regions of northern Pakistan, the experiences of the Aga Khan Development Network (AKDN) show that community-based micro and mini hydropower can provide an alternative energy source to the majority of households that use fuelwood for heating and cooking collected from the small patches of available natural forest or fruit trees, adversely impacting an already fragile ecosystem (AKDN, 2014).

2 Watershed strengthening treatments include restoration (planting forests) and conservation (protecting forests). The protection ensures climate resilience not only for the hydro system but also for any other usage of water (drinking water, irrigation, *etc.*) as the same watershed provides a reservoir for all these uses. At the core of climate adaptation in rural areas of the Global South is the climate resilience of the water-energy-food nexus, in which hydro mini-grids and their watersheds play a critical role as nature-based solutions.

Figure 2 ■ **Overview and characteristics of small-scale hydropower (< 1 MW)**




Source: HPNET and ATDER-BL, 2021.
Note: 24/7 = 24 hours/7 days a week.

Because the equipment needed can be manufactured and maintained locally, small-scale hydro development can increase local skills, jobs and enterprise development. The skills required for implementation can be transferred from other infrastructure work: construction of concrete structures, fabrication of electromechanical systems, installation of transmission and distributions lines, and so on. Further, as hydro mini-grids generate electricity 24 hours per day, they require no batteries and provide on-tap electricity. The quality of power can be similar to that of the central grid, offering low-cost electricity during off-peak hours, ideally at or below grid tariffs, to power a range of productive end uses, including motorised loads for agro-processing and livestock cottage industries (*e.g.* poultry farming), a critical need in rural and semi-urban areas in developing countries.

To ensure sustainable socio-economic growth in rural communities, special attention needs to be given to the development and strengthening of local capacities, particularly of local technical service providers, as well as community stakeholders (*e.g.* women, youth). Further, communities that have an opportunity to self-organise and play an active role in the planning, implementation and management of small-scale hydropower projects can develop social cohesion that enables them to achieve additional community-centric aspirations.

This report analyses the way in which jobs and local livelihood creation can be leveraged through small-scale hydro systems, differentiating between value chains (*i.e.* implementation, [3] utilisation and climate adaptation). It considers each segment of the relevant value chain more closely, focusing on the human resources, skills and materials required (Section 2). This is followed by a qualitative overview of the socio-economic value created from the deployment of small-scale hydropower units in terms of community enterprise, local jobs and social capital (Section 3). Finally, the report offers conclusions and policy recommendations (Section 4).

The scope of the analysis is global but includes country and regional experiences, with particular focus on developing countries. Data were obtained through surveys and interviews with local experts and internationally recognised and specialised institutions involved in small-scale hydropower.[4] The report aims to deepen policy makers' understanding of the steps needed to develop a local market for small-scale hydropower and of the existing capabilities that can be leveraged to do so.

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3 In some sectors the term implementation refers only to the design, planning and construction of a project. In this study, it includes all steps of the development of a project, including its feasibility analysis and day-to-day operations.

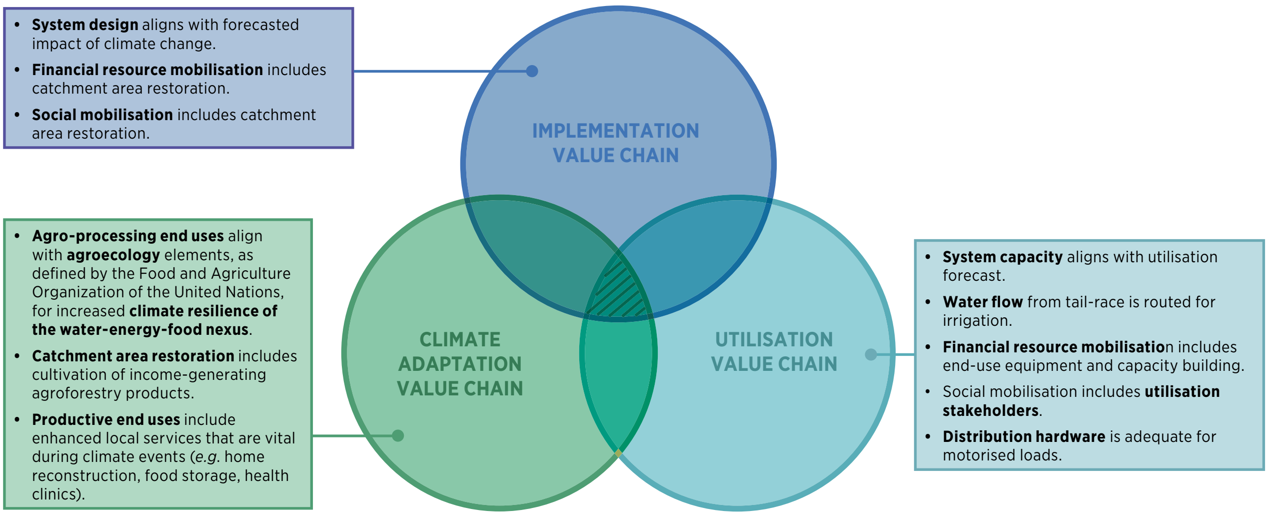
4 A large number of stakeholders were interviewed and/or responded to questionnaires regarding the requirements for developing local capacity around small-scale hydropower. These stakeholders included project developers; component manufacturers; service providers; energy authorities; and representatives of communities and of national and global associations dedicated to small-scale hydropower or renewable energy in general. The study also draws on the public reports of relevant organisations.

# 2. REQUIREMENTS FOR SMALL-SCALE HYDROPOWER

Small-scale hydropower presents opportunities for socio-economic value creation through local employment and livelihood enhancement during the implementation stages, as well as through productive uses during the operation phase.

Job opportunities arise throughout the development phases of small hydropower projects. These jobs are part of what is called the implementation value chain. Additional opportunities for employment are derived from productive uses (the utilisation value chain) and from the infrastructure investments needed in watershed conservation to ensure the community is resilient against droughts and floods (the climate adaptation value chain).[5] These three value chains are interdependent in terms of ensuring the long-term sustainability of the hydro mini-grid, as well as strengthening the water-energy-food-livelihoods nexus of the rural community (see Figure 3).

Figure 3 **Integration of hydro mini-grid value chains for implementation, utilisation and climate adaptation**




The following subsections discuss the different value chains derived from the deployment of small-scale hydropower facilities (implementation, utilisation and climate adaptation). First, for each of the segments of the implementation value chain, there is an evaluation of the materials, equipment and labour needed (2.1). Second, a qualitative analysis of the productive end use of electricity is provided: the utilisation value chain (2.2). Last, the implications of climate adaptation are examined (2.3).

This study uses quantitative analysis to examine the potential for small-scale hydropower projects with capacities below 1 MW, including pico, micro and mini hydropower capacities (see Box 1 and further details in Annex A). The primary objective is to identify opportunities for local value creation and synergies with existing industries. This analysis also seeks to identify ways in which the existing capabilities of the local industry can be leveraged to support the development of small hydropower projects.

5 Up to now, the *Leveraging Local Capacity* report series has focused on the implementation value chain, assessing the jobs, occupation, materials and equipment required from the inception of a project (planning) to its decommissioning. The current report, given the decentralised nature of the technology, also explores, in a qualitative manner, the climate adaptation and utilisation value chains.

**Box 1 ■ Classification of small hydropower according to capacity**

Pico hydropower systems typically have a capacity of up to 5 kW. They are designed to provide electricity to individual households or small communities. Pico hydropower systems usually rely on small turbines that can be installed in streams or small rivers. These systems are relatively simple and inexpensive.

Micro hydropower systems typically have a capacity of between 5 kW and 100 kW. They are designed to provide electricity to small communities or commercial enterprises, such as farms or small factories. Micro hydropower systems can be installed in larger streams or rivers and require a larger investment than pico systems. However, they can provide a more reliable source of electricity and can be used to power more energy-intensive activities.

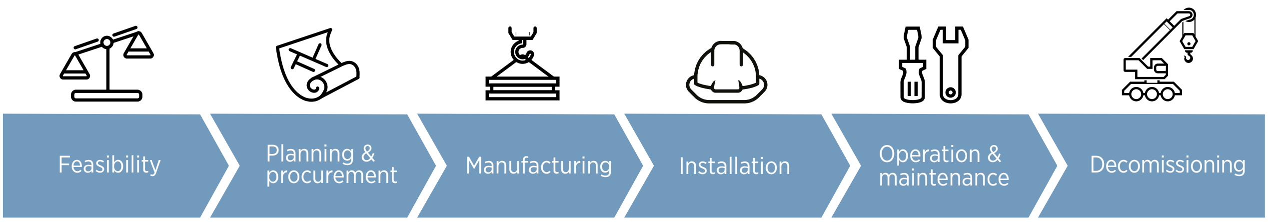
Mini hydropower systems typically have a capacity of between 100 kW and 10 MW. They are designed to provide electricity to larger communities or commercial enterprises, such as large factories or municipalities. Mini hydropower systems usually require a significant investment and may require the construction of dams or other infrastructure. However, they can provide a reliable source of electricity and can be used to power a wide range of activities. For the purpose of this study, mini hydropower systems of 1 MW and below are considered.

## 2.1 Implementation value chain

On the basis of existing installations, estimates suggest that every 1 MW of community-owned hydropower installed generates ten full-time equivalent jobs in every year of its operation. This is significantly more than other generation technologies, including the next-best performer, community-owned solar photovoltaics at around three full-time jobs per 1 MW installed (Bere, Jones and Jones, 2015).

The small-scale hydropower implementation value chain mainly consists of six segments: feasibility, planning and procurement, manufacturing, installation and connection, and operation and maintenance, followed by decommissioning once the lifetime of the facility is reached. These segments cover all processes along the supply chain from the procurement of raw materials and equipment to the final product. A brief overview of the value chain for small-scale hydropower is presented in Figure 4. Additional details on the average duration of each segment, together with project-specific factors impacting duration can be found in Annex B.

Figure 4 ■ **Implementation value chain of small-scale hydropower**




Findings are presented first for the total labour inputs in person-days (see Box 2) needed for 5 kilowatt (kW), 50 kW and 500 kW hydro plants. Each segment of the value chain is then discussed.

Box 2 ■ **Measuring employment**

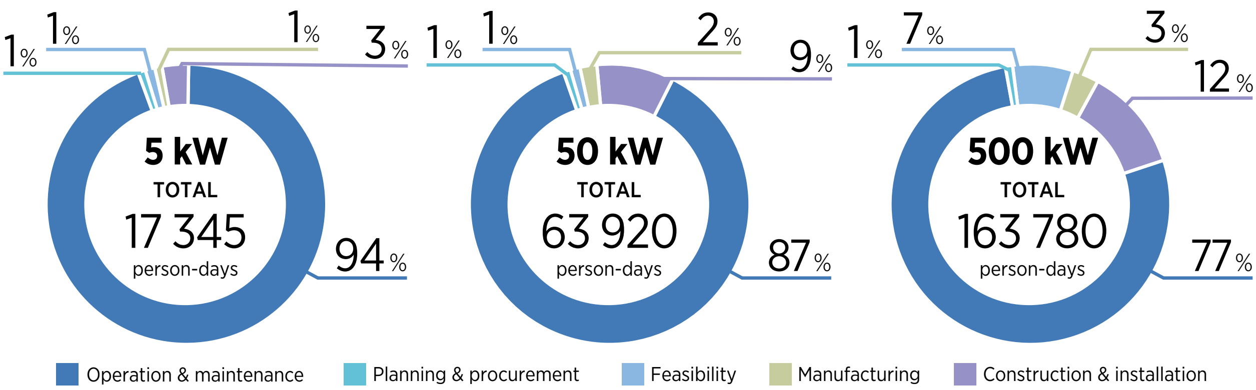
The deployment of renewable energy leads to employment in different sectors, with different levels of qualification and duration. We can distinguish between **direct, indirect and induced jobs**. Direct employment refers to employment generated directly by core activities (implementation value chain). Indirect employment includes jobs in upstream industries that supply and support core activities for sustainability (*e.g.* in this case, the climate adaptation value chain, which must happen on the sidelines of the deployment of the small-scale hydropower system). Induced employment (generated by productive end uses) encompasses jobs resulting from additional income being spent on goods and services in the broader economy, such as food, clothing, transportation and entertainment (utilisation value chain).

Employment can be measured in different ways. **Full-time equivalent jobs** are equal to one person working full-time over the course of a year. **Person-days** reflect the amount of work done by one person working full-time for one day.

## Labour requirements along the implementation supply chain

Together, the feasibility, planning and procurement, manufacturing, installation and connection, operation and maintenance, and decommissioning of a small-scale hydropower plant require more than 17 000 person-days for a pico hydro plant (average 5 kW), around 64 000 person-days for a micro hydro facility (50 kW) and over 160 000 person-days for a mini hydro system (500 kW).[6] The labour requirements vary across the value chain. Operation and maintenance work is needed throughout the lifetime of a system – estimated at around 40 years – and therefore represents a large chunk of the labour required (94%, 87% and 78% of total person-days respectively for pico, micro and mini hydro facilities).[7] As illustrated in Figure 5, installation and connection and manufacturing are the next-largest shares (up to 4%, 11% and 15%, for pico, micro and mini hydro facilities, respectively). Decommissioning is included, but its share is negligible.

Figure 5 ■ **Distribution of human resources required along the value chain for pico, micro and mini hydro plants**




Note: The figures presented in this report have been rounded for clarity and ease of comprehension. As a result, there might be slight discrepancies in the totals, and they may not precisely add up to the overall total. However, these rounding adjustments do not significantly impact the overall findings and conclusions drawn from the data.

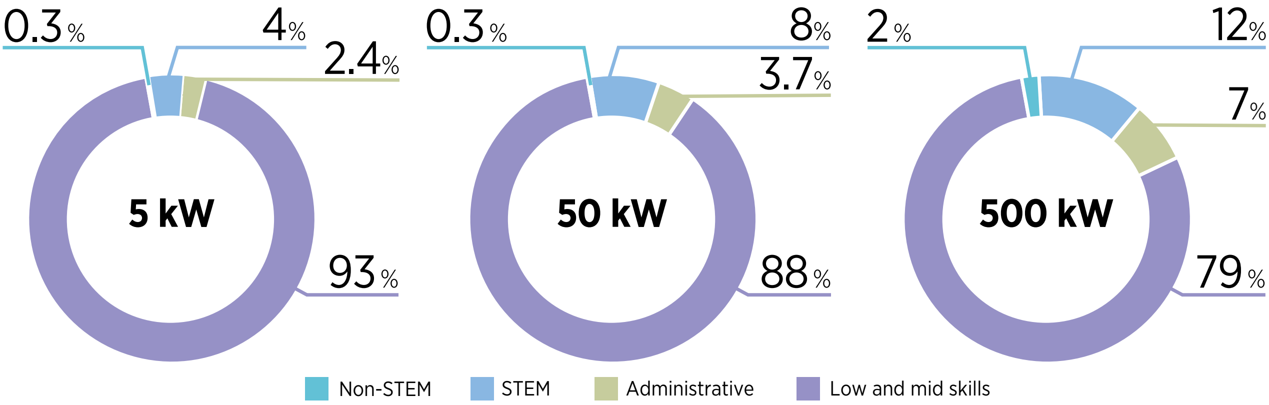
6 That is, direct jobs required throughout the lifetime of a pico, micro and mini hydro system (from manufacturing to decommissioning). Indirect and induced jobs are not included.

7 The person-days required for the annual operation and maintenance of a pico, micro and mini hydro plant are estimated to be 636, 1 038 and 1 299 person-days, respectively. Over a period of 40 years (considered the average life expectancy of these systems), the cumulative total is 25 428, 41 538 and 51 951 person-days, respectively, for pico, micro and mini hydro.

## Skills requirements along the implementation supply chain

Countries that do not manufacture equipment domestically can achieve job creation in other segments of the value chain, especially in installation and connection and in operation and maintenance. The bulk of the labour needed involves low- to medium-level technical skills, which may be available in any country's workforce or could be developed through certifications or vocational training centres (see Figure 6).

Figure 6 ■ **Distribution of skills required for pico, micro and mini hydro plants**




Note: STEM = science, technology, engineering and mathematics.

Note: The figures presented in this report have been rounded for clarity and ease of comprehension. As a result, there might be slight discrepancies in the totals, and they may not precisely add up to the overall total. However, these rounding adjustments do not significantly impact the overall findings and conclusions drawn from the data.

The discussion below highlights the labour and equipment requirements for different segments of the small hydro implementation value chain, from project feasibility studies all the way to the decommissioning of projects that have reached the end of their useful life.

### *2.1.1 Feasibility*

Typically, the value chain for any renewable energy project begins with a **feasibility** analysis, including the technical and financial aspects. Activities in this phase include the following:

- **Site identification:** Because small-scale hydro sites require flowing water, prior to conducting a feasibility study, potential sites are identified using topographic maps and interviewing community members. Often, after visiting already operational systems, potential beneficiaries better understand the required type of water flow and terrain, enabling them to identify a potential site in their community and then invite an experienced developer to conduct a pre-feasibility study.
- **Feasibility study of the site:** After potential site identification, a detailed feasibility study is carried out to determine the precise head, flow, location and size of the civil engineering structures required and the anticipated demand from household, commercial and public end users. For plants that are 300 kW to 1000 kW in eco-fragile regions, a two- to four-year assessment of hydrology is critical. The estimated demand is then used to determine whether the expected power generation will be sufficient across various seasonal cycles. Consumer-related aspects of financial viability (*e.g.* productive end use, willingness to pay) are also assessed during this period, including tariff structures and connection fees. Extensive community engagement is likely to take place during this stage to ensure buy-in and to arrive at a common value proposition for the development of the small hydro infrastructure and to define the role of community in the various stages of the project. Such engagement would involve the participation of community mobilisers, comprising local champions and social scientists, and the use of tools that can support community-level data collection (see Box 3).

- **Engineering design, bill of material and bill of quantity:** If the feasibility study determines the site is viable, detailed engineering designs for the civil works, electromechanical system, and transmission and distribution line are developed to generate the bill of material (BoM)[8] and the bill of quantity (BoQ)[9] and determine the project budget.
- **Financial and socio-economic viability analyses:** After the project budget is determined, a targeted plan for financial viability is created based on available financing (*e.g.* grants, subsidies, loans, shares, in-kind contributions), as well as the specific enterprise model (*e.g.*,households, agriculture, other end-use consumers) and the anticipated revenue of the mini-grid from connection fees and tariffs. Tools can be used by communities to assess the feasibility stage of mini-grids (see Box 3).
- **Access-to-finance processes:** Considerable effort is dedicated to obtaining the financing to implement the project. Without funds in place, the next phases of the project typically cannot be completed. Some activities of procurement and construction can be initiated if the community or other stakeholders make in-kind contributions (*e.g.* labour, raw material).

Box 3 ■ **Software for site-specific data analyses for mini-grid feasibility**

Software-based tools can optimise socio-economic data collection, analyses and stakeholder engagement during the feasibility stage of mini-grid design, such as the Community Energy Toolkit (COMET) for community-level data collection and the Village Data Analytics (VIDA) tool for multi-thematic analysis across multiple communities and sectors.

**Community Energy Toolkit (COMET)**

Communities play a central role in the operations and sustainability of mini-grids; therefore, community engagement during the feasibility stage is critical. COMET is a role-playing software tool built around a representation of a mini-grid system, intended to be used as an educational and collaborative planning tool in designing a community-sized mini-grid system. The tool is designed to be used within a process that explores mini-grid planning and operational decisions, including demand estimation. Networked users come together to play out household consumption and make important energy choices, like purchasing appliances, setting energy tariffs and managing finances to pay their bills on time. Users' individual behaviour, like switching appliances on and off, or failing to make a payment, are immediately visible to everyone else. The graphic-based tool facilitates collaboration among community members, enabling them to collectively decide on an appropriately sized system and a tariff that pays for system costs, as well as allowing users to simulate energy consumption within the mini-grid's limited capacity.

**Village Data Analytics (VIDA)**

Financial and socio-economic viability requires insight on how the electrification of a specific community will impact the subregion, and vice versa, across rural development interventions. VIDA is a map-based software to help reach the Sustainable Development Goals. Allowing its users in the fields of electrification, health care and agriculture to channel investments, run projects and measure impact, VIDA integrates different data streams – such as satellite imagery, survey data and sensor data – predicts outcomes and allows teams to collaborate. The visual presentation features of the tool are especially useful in communicating potential socio-economic impact to diverse stakeholders, including government agencies, the private sector and community-based organisations.

Source: ENACT, n.d.; VIDA, n.d.

8 A BoM is a comprehensive list of the raw materials, components, subassemblies and other items required to build a product. It is an essential document used in manufacturing, engineering and supply chain management. A BoM typically includes the names of the parts and materials, their quantities, and a description of their specific use in the finished product.

9 A BoQ is a document used in construction projects that provides a detailed list of all the materials, labour and equipment required to complete a specific construction project. It typically includes a description of the work to be done, the quantity of each item required and the unit price for each item. The BoQ is used to estimate the cost of a project, as well as to manage and track the project's progress.

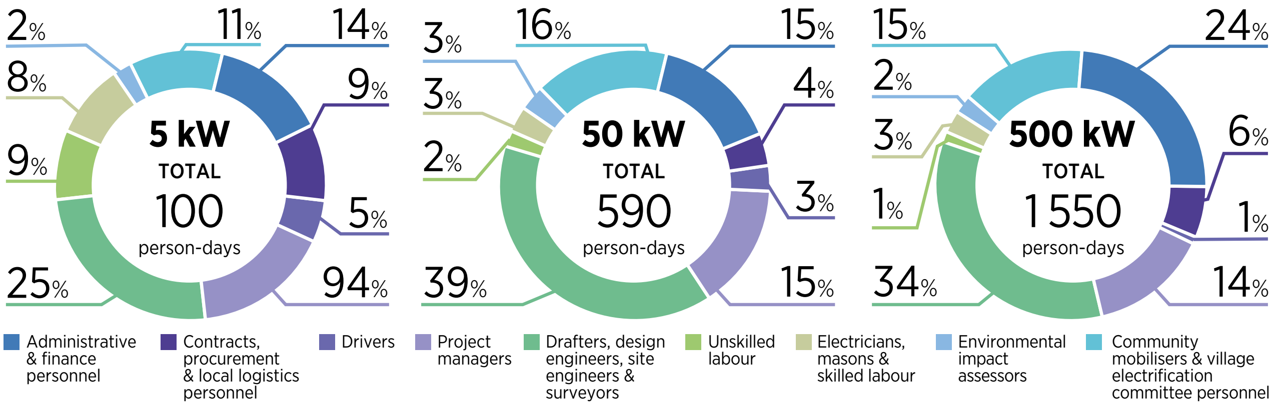
**Labour requirements.** During the project feasibility stage of a 5 kW, 50 kW and 500 kW plant, roughly 100, 600 and 1 500 person-days of labour, respectively, are required, with various levels of technical knowledge and skills. Table 1 represents a breakdown of the workforce needed, by occupation (Annex C lists the different roles included in each group).

Table 1 **Human resources required for assessing the feasibility of a 5 kW, 50 kW and 500 kW plant (person-days)**

| Occupation | 5 kW | 50 kW | 500 kW |
|---|---|---|---|
| Administrative and finance personnel | 13 | 86 | 377 |
| Contracts and procurement personnel | 6 | 15 | 80 |
| Drivers | 5 | 15 | 20 |
| Project managers | 15 | 90 | 211 |
| Design engineers | 9 | 85 | 195 |
| Drafters | 3 | 15 | 40 |
| Site engineers | 7 | 100 | 204 |
| Surveyors | 5 | 28 | 80 |
| Electricians | 3 | 10 | 20 |
| Unskilled labour | 8 | 10 | 20 |
| Masons and skilled labour | 6 | 10 | 20 |
| Community mobilisers | 6 | 26 | 53 |
| Environmental impact assessors | 2 | 15 | 30 |
| Village electrification committee | 5 | 70 | 179 |
| Local logistics personnel | 3 | 10 | 20 |
| **TOTAL** | **96** | **585** | **1 549** |
| **TOTAL (as % of the total requirements)** | **0.60%** | **0.90%** | **0.90%** |

The initial activities (site identification, pre-feasibility study and feasibility study) focus on collecting information from the site and therefore involve field-focused personnel, supervised by the project manager and supported by technical experts for specialised guidance. The remaining efforts focus on analysing the information collected from the site to determine costs and overall financial viability. These efforts include BoM, BoQ and budget preparation. Therefore the roles in this phase are predominantly for engineers, drafters, designers and surveyors (who average nearly one-quarter of the total personnel required during the feasibility phase for pico, micro and mini facilities), followed by administrative and finance personnel (14–24%), and project management (14-16%) (see Figure 7).

Figure 7 ■ **Human resources required for project feasibility activities for a 5 kW, 50 kW and 500 kW plant, by occupation**




Note: The figures presented in this report have been rounded for clarity and ease of comprehension. As a result, there might be slight discrepancies in the totals, and they may not precisely add up to the overall total. However, these rounding adjustments do not significantly impact the overall findings and conclusions drawn from the data.

Overall, the feasibility phase requires unskilled labour, administrative personnel, drivers and surveyors who would benefit from local expertise and therefore offers considerable opportunities for domestic employment.

**Equipment requirements.** The main equipment in the feasibility phase is needed to characterise the site's terrain, including the head measurement from the civil works to the powerhouse, and to measure the water flow. For all projects, the head can be measured using an altimeter; however, for pico and micro hydro capacities, use of a mason's pipe and metre rule is required for sufficient accuracy. The terrain is then mapped using a total station, consisting of an electronic theodolite and electronic distance meter to measure the vertical and horizontal variations needed to determine the ideal penstock path from the civil works to the powerhouse. Depending on the site, the flow can be triangulated using a flow meter, a salt conductivity meter, year-round rainfall data, and/or any available online flow data sources. A low-cost v-notch or square-notch made from locally available material (*e.g.* wood) can be installed if persons based near the site can routinely record the water level.

### *2.1.2 Planning and procurement*

After the project is deemed feasible and funding is secured, it enters the planning and procurement phase, consisting of activities that establish the processes for achieving full project implementation. Planning and procurement can include distinct steps; however, the majority of planning tasks are linked to procurement, and therefore often the same team anchors both. Some planning aspects continue throughout the implementation, such as co-ordination of transportation and accommodation. In remotely located projects that do not have a site-based team and instead depend on experienced persons in the community, the implementation team visits the site at least monthly.

Activities in this phase include the following:

- **Hiring:** Personnel are needed to advertise positions, review applications, conduct interviews and co-ordinate hiring processes.
- **Tendering and service contracts:** For components that are customised to each site (*e.g.* turbine assembly) and components that are less costly when manufactured locally (*e.g.* metal penstock), tenders are developed to contract local manufacturers, who also do the installation and commissioning. Depending on the scale and funding source, tenders may be required for the civil construction of the weir, channel, forebay tank and powerhouse.

- **Purchase orders (by developer):** Procurement of raw material, off-the-shelf components and customised components involves identifying vendors, obtaining quotations, selecting final vendors, creating purchase contracts and co-ordinating payments. Some components may be procured by the service provider (*e.g.* metal for the turbine is purchased by the turbine manufacturer); in other cases, they are procured by the overall developer (*e.g.* cement for civil works).
- **Cash flow planning and accounting:** The manufacturing and construction phases are done in parallel, requiring procurement of raw material, off-the-shelf components and customised components. With extensive purchases and payments involved simultaneously, funds must be made available on time. In addition, meticulous accounting is required for the donor to approve future payments.
- **Monitoring and evaluation:** All funding sources require monitoring and evaluation reports before they will release funding instalments. While the content of the reports can be provided by the field implementation team, the writing of the report to meet the funder's standards requires appropriately skilled persons.
- **Transportation to the site:** Project sites are often in remote areas with minimal road access, requiring skilled driving on gravel and/or mud roads in appropriate vehicles and often motorbiking or walking towards the end, if there is no motorable road. Throughout the project implementation, transportation must be arranged for personnel, raw materials and components to reach the site.
- **Accommodation at the site:** At remote sites, all meals and overnight stays are arranged at individual households or lodges at the beneficiary village. In most cases, items for meals also have to be brought in for all project personnel.
- **Social governance system:** As implementation activities move from desk work to site work, facilitating the formation of a social governance system within the beneficiary community is critical for both implementation and utilisation of the project. Using the same governance system during implementation that will subsequently be used during utilisation of the facility enables gaps to be addressed prior to the commissioning of the project.

Based on the social governance and economic disparity data collected during the feasibility study, discussions are held with community members who represent all socio-economic factions in order to develop community consensus on whether any existing governance structures will be used or a new framework will be developed. A plan is made to operationalise the decision.

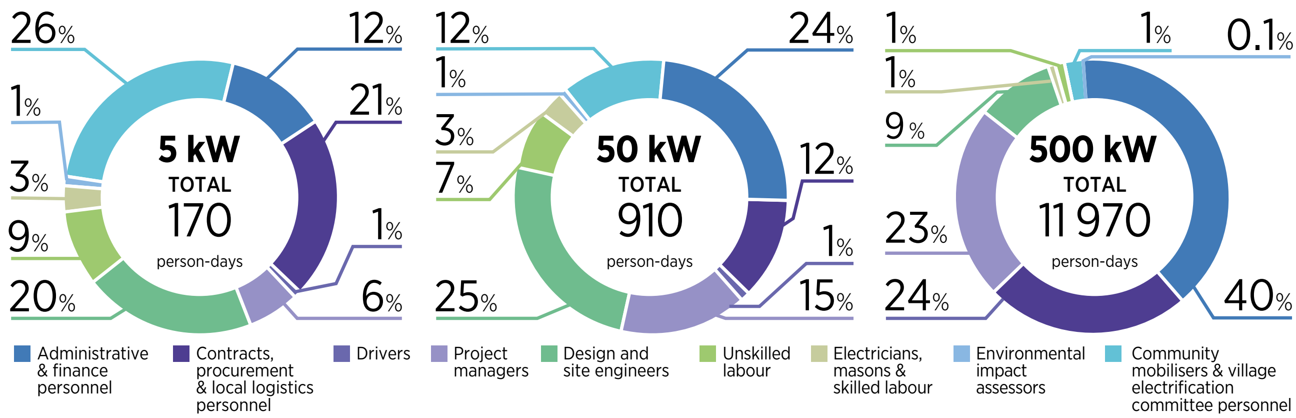
**Labour requirements.** Planning and procurement of a 5 kW, 50 kW or 500 kW plant requires approximately 170, 900 and 12 000 person-days of labour, respectively, with various levels of technical knowledge and skills. Table 2 represents a breakdown of the total workforce needed in the planning and procurement phase by occupation.

Table 2 **Human resources required for the planning and procurement of a 5 kW, 50 kW and 500 kW plant (person-days)**

| Occupation | 5 kW | 50 kW | 500 kW |
|---|---|---|---|
| Administrative and finance personnel | 20 | 215 | 4 732 |
| Contracts and procurement personnel | 15 | 82 | 2 857 |
| Drivers | 2 | 5 | 7 |
| Project manager | 10 | 140 | 2 785 |
| Design engineers | 8 | 92 | 559 |
| Site engineers | 26 | 136 | 500 |
| Electricians | 5 | 30 | 100 |
| Unskilled labour | 15 | 62 | 100 |
| Community mobilisers | 23 | 48 | 62 |
| Environmental impact assessors | 2 | 7 | 15 |
| Village electrification committee | 20 | 60 | 200 |
| Local logistics personnel | 20 | 30 | 50 |
| **TOTAL** | **166** | **907** | **11 967** |
| **TOTAL (as % of the total requirements)** | **1%** | **1%** | **7%** |

Human resources for the planning and procurement phase are distributed such that the roles of administrative and finance, logistics, and contracts and procurement personnel, and of project managers altogether form the majority of the required person-days for the segment in all the capacities, as they are responsible for nearly all the activities in this phase. The person-days for these roles in mini hydro capacities is much higher than in other segments of the value chain, because the civil works are larger and take longer to build. Raw material for civil works is procured as structures are built, and as such the procurement positions are required for a longer period. The remaining requirements mostly comprise technical roles, such as design and site engineers, whose inputs are needed as planning and procurement decisions and processes are established (see Figure 8).

Figure 8 **Human resources required for planning and procurement activities for a 5 kW, 50 kW and 500 kW plant, by occupation**




Note: The figures presented in this report have been rounded for clarity and ease of comprehension. As a result, there might be slight discrepancies in the totals, and they may not precisely add up to the overall total. However, these rounding adjustments do not significantly impact the overall findings and conclusions drawn from the data.

**Material and equipment requirements.** In terms of material and equipment for the planning and procurement phase, for the desk-based roles, IT equipment and applications are needed for finance-related tasks and internal communication. Appropriate types and numbers of vehicles are required to accommodate the travel of personnel to the site and the transport of raw material and components.

### *2.1.3 Manufacturing*

The manufacturing stage refers to the fabrication of components that require custom design and/or components that are less costly to fabricate locally than to procure off the shelf.

Components that are typically procured as ready-made parts include:

- Electromechanical system: generator, electronic components of the load controller, bearings, and valves
- Transmission and distribution line components: accessories, cable and wires
- House wiring components: meters and miniature circuit breakers

Such off-the-shelf components are typically not manufactured locally and instead are supplied by national or international suppliers in the planning and procurement phase. For example, in Pakistan, multiple local companies produce wires and cables, while generators are being built in India.

Components that require site-specific, customised design and that can be locally manufactured include the following:

- Civil works components: gates for the weir and channel, penstock support, penstock expansion joints, and powerhouse doors and windows;
- Electromechanical system components: turbine assembly (including the base, manifold, joints, runner and shaft), generator base frame, housing for electronic load controller, ballast load, grounding element, and accessories;
- Transmission and distribution line components: poles and transformers;
- House wiring components: protective boxes for meters and miniature circuit breakers.

There are also components that can be built by customising off-the-shelf parts for use in pico, micro or mini hydro systems, such as induction motors, which can be locally converted to induction generators.

Formal and informal technology transfer has led to increasing localisation of the above components, specifically with the dissemination of licensed and open-source technology development for turbines and load controllers (see Box 4).

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Box 4 ■ **Licensed versus open-source technology for local manufacturing**

Licensed technology refers to designs that require payment to the licence owner for application of the design, either per unit or a one-time licence fee. The fees help return the investment made by the design owner to develop the technology, typically taking several years. Open-source technology is distributed publicly free of cost. The availability of licensed and open-source technology has helped to accelerate local turbine and load controller manufacturers in the Global South.

**Local manufacturing of turbines**

The type of turbine for any hydropower site depends on the specific head and flow conditions available at the site throughout the year. Turbine types can be classified by various factors, including the energy exchange between the water and machine (*e.g.* reaction or impulse turbines), the direction of flow in the machine (*e.g.* radial, tangential, axial or mixed flow), the hydraulic pressure operating range (*e.g.* low, medium or high head) and the turbine speed (Linquip, 2021).

The following licensed and open-source turbine designs have enabled local manufacturing even in the most rural locations, helping to lower costs, increase reliability and promote innovation for robustness in local conditions. In some contexts where local capacity building has not been provided, local manufacturers have been able to access ready-made turbines and reverse-engineer for local manufacturing of various sizes and configurations.

***Pelton turbines (high head):*** First developed in the United States in the 1870s, Pelton turbines require cast metal buckets for their runners,[10] assembled using fasteners and/or welding. In developing regions where customised metal casting is available, Pelton turbines are prolifically used for high-head pico, micro and mini hydro sites. The Intermediate Technology Development Group, now called Practical Action, along with other international development organisations, helped disseminate open-source designs of the Pelton turbine in the 1990s, and since then nearly all developing contexts with high head have local Pelton manufacturers. Today, the Hydro Empowerment Network (HPNET) facilitates technology transfer of local manufacturing of the Pelton from South Asia to Sub-Saharan Africa.

***Crossflow turbines (medium head):*** The earliest known crossflow designs were developed in the early 1900s by Australian, German and Hungarian designers, and were known as the Mitchell-Banki turbine designs (JLA Hydro, n.d.). From the mid-1970s to the mid-1990s, the Government of Switzerland commissioned the Swiss Centre for Appropriate Technology to support Nepal's pioneering local manufacturers in improving existing crossflow designs for ease of local manufacturing (*e.g.* not requiring cast metal components, and addressing Nepal-specific needs to upgrade wooden watermills to mechanised mills).[11] The revised designs were known as the T1-T8 crossflow turbines and were available as open-source designs through formal training (Nakarmi *et al.*, 1993). As demand for electricity generation grew, starting in 1995 the University of Stuttgart in Germany and its Indonesian partners developed sophisticated designs for higher efficiency, resulting in the T12 series of crossflow turbines, tested at Hong Kong Polytechnic University and available to anyone free of cost through formal training. In the early 2000s, the Swiss company Entec AG, with partners in Indonesia, developed a more advanced crossflow with higher guaranteed efficiency, known as the T14 (< 300 mm runner diameter) and T15 (< 500 mm runner diameter) models, both of which are licensed designs requiring formal training by Pt Entec Indonesia (Entec, 2012).

10 The runner of the turbine refers to the wheel-like component that spins.

11 The United Mission to Nepal supported the parallel development of crossflow turbines for direct-drive milling and electricity production in the industrial town of Butwal (further details can be found in the following section).

***Turgo turbines (medium to high head):*** In Nepal, Mr Akkal Man Nakarmi redesigned the traditional water wheel (*ghatta*) used for grinding maize and wheat, replacing the wooden runner with a Turgo design using metal buckets, creating a more powerful and versatile multi-purpose power unit to expand the turbines' application to rice milling and electricity generation.[12] In recent years, a collaboration between Nepal Yantra Shala Energy, the University of Bristol, the People, Energy & Environment Development Association, Kathmandu University, and HPNET resulted in an open-source Turgo turbine design and e-learning module, available free of cost to anyone, as a part of an ongoing collaborative design process to continue advancing Turgo turbines. The design requires the availability of 3D printing for the turbine buckets, and thus efforts are being made by HPNET to distribute patterns to locations that do not have access to 3D printing. Prior to this recent collaboration, practitioners in remote contexts had reverse-engineered Turgo turbines to develop local designs.

***Propeller, Kaplan and Francis turbines (low head):*** Low-head turbines are the most difficult to manufacture, requiring sophistication in the turbine design as well as the civil works. Low-head turbines have not been included in technology transfer activities funded by international donors, and therefore few local, rural-based manufacturers for propeller, Kaplan and Francis turbines can be identified. However, in Afghanistan and Myanmar, local manufacturers have been able to reverse-engineer low-head turbines to develop their own designs, albeit with limited quality. There is an increasing demand for Kaplan and Francis turbines because they can also be used for medium-head sites with greater efficiency than crossflow turbines. As such, Kathmandu University now has a dedicated effort for the development of Francis turbines, and HPNET is addressing the low-head turbine needs of local practitioners through South-South technology transfer.

**Local manufacturing of load controllers**

Any hydro mini-grid must be able to technically adjust for load variation (*e.g.* users turning lights and appliances off and on), and load controllers are the recommended solution. However, in rare contexts, such as Myanmar, where load controller technology is not available and yet nearly 6 000 small-scale hydro systems are installed, local manufacturers have been able to manage load variation, albeit with loss of efficiency. In most cases, especially those supported by donors and government funding, either mechanical flow controllers or electronic load controllers are used.

Mechanical governors have an intuitive mechanical design (*e.g.* fly wheel) and as such have been easily localised. However, more sophisticated governors require automatic flow control technology that must be imported.

In the case of electronic load controllers (ELCs), many different electronic components are required, most of which have to be imported. Since the 1990s, local electronics experts in Colombia, India, Indonesia, Nepal, Nicaragua and Sri Lanka, among others, have developed and locally manufactured their own control mechanism and circuit designs, while importing the specific resistors and other electronic parts required for the design. The presence of local ELC manufacturers in Asia-Pacific and Latin America occurred thanks to the perseverance of local entrepreneurs in developing their own ELCs, at times supported by foreign designers and donors, such as Practical Action, the German Agency for International Cooperation, the German Technical Cooperation, and EnDev. Currently, HPNET and the Skat Foundation are enabling technology transfer of ELC manufacturing from Asia-Pacific to Sub-Saharan Africa.

Source: Interviews with practitioners in South and Southeast Asia.

12 *www.linkedin.com/pulse/obituary-memory-akkal-man-nakarmi-who-designed-ground-kandel.*

The following steps are involved in locally manufacturing components that will be used in the civil works structures, the electromechanical system, and the transmission and distribution lines:

- **Site visits:** Although site measurements were taken during the feasibility phase, the manufacturer's engineers will visit the site to verify the measurements. If there are disparities, a review process is conducted by both the developer and the manufacturer to reach consensus.
- **Drawings for fabrication and assembly process:** With verified site measurements, the engineering design drawings developed during the feasibility stage are refined for specific components to include details of the fabrication and assembly process.
- **Fabrication BoM, BoQ and work plan for the fabrication process:** Once the component design, along with the fabrication and assembly processes, are finalised, a fabrication-specific BoM, BoQ and work plan are developed. This includes processes that require outsourcing (*e.g.* casting for Pelton turbine buckets, and laser-cutting for crossflow turbine runners). Typically, the machinist is working on multiple projects, and so specific human resources must be scheduled for each step of the fabrication (*e.g.* booking the time of the lathe machine operator).
- **Purchase orders (by manufacturer):** Based on the BoM and BoQ, raw metal is ordered from raw metal shops and transported to the manufacturing workshop. Off-the-shelf parts, namely pipe, valves, bearings, bearing housings, pulleys and belts, are ordered from vendors who deliver on time and provide adequate warranties.
- **Machining of components:** Most of the custom-designed components are machined from raw metal, using welding, drilling, and other such procedures. For high-head sites, runner components (*e.g.* Pelton runner buckets) need to be cast. The type of metal and the facility required to cast and machine it depends on the type and size of the runner. Aluminium, bronze and brass can be cast by small local artisans, while cast iron requires a more established facility, and stainless steel buckets are rarely used for small-scale hydro systems.
- **Assembly and testing:** Before the components are put through final aesthetic steps, a quality check is done and, when appropriate, assembly and testing are conducted to verify the quality of design and machining.
- **Finishing and painting:** The final step of manufacturing is the finishing and painting, which depend on the component and level of quality, primarily to prevent rusting.

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**Labour requirements.** The vast majority of the human resources required for the manufacturing phase are technical roles such as machinists, engineers and drafters. Administrative and finance personnel is the second largest requirement (11–15%) of the manufacturing person-days. Projects that do not use locally manufactured components forgo local job creation of approximately 200, 1100 and 4 000 person-days for a 5 kW, 50 kW and 500 kW plant, respectively (see Table 3).[13]

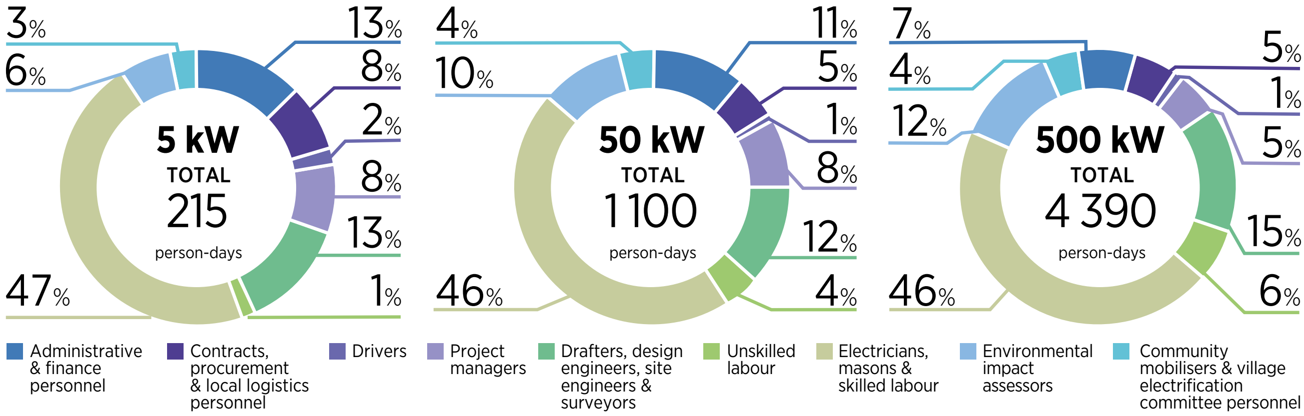
Table 3 **Human resources required to manufacture the main components of a 5 kW, 50 kW and 500 kW plant (person-days)**

| Occupation | 5 kW | 50 kW | 500 kW |
|---|---|---|---|
| Administrative and finance personnel | 27 | 126 | 300 |
| Contracts and procurement personnel | 10 | 20 | 51 |
| Drivers | 5 | 10 | 40 |
| Project managers | 17 | 90 | 205 |
| Design engineers | 22 | 100 | 533 |
| Drafters | 5 | 20 | 90 |
| Site engineers | 2 | 10 | 30 |
| Electricians | 2 | 10 | 30 |
| Unskilled labour | 2 | 40 | 242 |
| Machinists | 100 | 500 | 2 026 |
| Technicians | 10 | 100 | 513 |
| Community mobilisers | 2 | 10 | 40 |
| Village electrification committee | 4 | 30 | 114 |
| Local logistics personnel | 7 | 30 | 171 |
| **TOTAL** | **215** | **1 096** | **4 386** |
| **TOTAL (as % of the total requirements)** | **1.2%** | **1.7%** | **2.7%** |

13 The estimations do not include the human resources required to manufacture off-the-shelf components, such as generators, bearings, valves, cables, electronic components and circuit breakers, also known as *ready-made components*. Such components are produced in large-scale facilities, some of which only assemble components and procure parts from other manufacturers. For example, a generator is made up of many components, and a generator manufacturer may fabricate the generator housing and do the overall assembly but procure the magnet and bearings from others.

Machinists represent the bulk of jobs in the manufacturing section, accounting for roughly half the total requirements. Design engineers, site engineers and drafters follow, requiring altogether between 12% and 15% of the total (see Figure 9).

Figure 9 **Human resources required for manufacturing activities for a 5 kW, 50 kW and 500 kW plant, by occupation**

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**Equipment requirements.** The equipment required for metalworks fabrication includes a drill, a welding machine, a lathe and a cutting machine. The metal required for the turbine runner, shaft, blades (or buckets) or nozzles is either bronze, mild steel or cast iron, depending on the type of turbine, the kilowatt capacity and the targeted quality. For assembly and testing, other structures are required. The ready-made material required for locally manufactured components includes mild steel pipes of different diameters and thickness, metal sheets, angles, and bars.

### *2.1.4 Installation and connection*

The installation and connection phase, which is typically the phase with the second-longest duration in the implementation value chain (the operations and maintenance phase being the longest), encompasses the on-site civil construction of concrete structures and the installation of prefabricated equipment. During this phase, the primary focus is on executing the physical construction and assembly processes meticulously, ensuring that the required infrastructure is built to specifications and that the designated equipment is correctly installed at the site.

- **Training of village-based stakeholders:** Because sites are typically located in remote locations, skilled and unskilled labour is often provided by local communities, requiring extensive on-the-job training for masons, operators, linesmen and others throughout the installation and connection activities. The trainers (*e.g.* site engineers) are typically drawn from the nearest urban or semi-urban centre and/or from the nearby communities that have already implemented small-scale hydro or similar infrastructure, thus involving village-to-village mentorship.
- **Construction of concrete structures:** Concrete structures are required throughout the system, namely for the weir, channel and forebay tank in the upstream civil works; the anchor block of the penstock; the powerhouse foundation and walls; and the poles used for the transmission and distribution lines. Similar steps are used for the construction of any concrete structure; however, the exact process (*e.g.* mixing ratios, application, curing times) will depend on the strength requirements.

- **Installation of all components:** After the concrete structures are built, the prefabricated components can be installed, namely the gates of the weir and forebay tank accessories in the upstream civil works; the penstock pipes, joints and air valves; the turbine assembly (manifold, base frame, valves, runner, bearings, housing); the generator assembly (base frame, generator, bearings, drive system); the load controller system; and the electrical protection systems for the powerhouse, for the transmission and distribution lines, and within homes.
- **Testing and commissioning of the full system:** The final activity of the installation and connection phase is the testing and commissioning of the full system, including the upstream civil works structures and components, the electromechanical system in the powerhouse, the transmission and distribution lines, and the house wiring, in that order. The first test is to release the water from the weir into the channel and forebay tank to test for any leaks. Next, the water is released from the forebay tank to the penstock, again to check for leaks. Finally, the valves in the powerhouse are opened, allowing the water to flow into the turbine to check for smooth rotation. Thereafter, the turbine is engaged with the generator to check for generation output power. The electricity is then released into the transmission line, where voltage is measured at critical points. Soon after, the electricity is released into the distribution lines and into each connected building.

At each step of testing and commissioning, a multitude of safety procedures are required, including safety training for each household, which can also involve the signing of an agreement with the household on usage protocols related to safety. Further, at each step of the testing, various measurements and observations are documented and reviewed before proceeding to the next step.

Training centres in Asia-Pacific have provided extensive opportunity for installation and post-installation training, as well as design and manufacturing (see Box 5).

Box 5 ■ **Training centres for small-scale hydro development**

Training and manufacturing centres in the Global South, particularly those located in subregions with small-scale hydro sites, have significantly contributed to the localisation of the small-scale hydro implementation value chain and the scale-up of skilled human resources.

***Asia-Pacific:*** Centres in Asia supported by the United Nations Industrial Development Organization (UNIDO) include the International Centre for Small Hydro-Power in Hangzhou, China, and the Regional Centre for Small Hydro Power in Trivandrum, India (UNIDO, n.d.). The ASEAN Hydropower Competence Centre in Indonesia, initiated by the ASEAN German Mini Hydro Power Project and the ASEAN Centre for Energy, provides capacity building across the Association of Southeast Asian Nations (ASEAN) region with support from international, national and local governments and the private sector.

The region also has grassroots, non-government, non-profit capacity-building centres, including the People-Centered Business and Economic Institute in Indonesia, the Tonibung Center for Renewable Energy and Appropriate Technology in Malaysia, the SIBAT Center for Renewable Energy and Appropriate Technology in Luzon, Philippines, and the Yamog Renewable and Sustainable Energy Technologies Center in Mindanao, Philippines.

Further, associations for local practitioners and users, such as the Nepal Micro Hydropower Development Association, the Federation of Electricity Consumer Societies in Sri Lanka, and Hydropower for Community Empowerment in Myanmar, have provided opportunities for local capacity building (HPNET, n.d.). In addition, private manufacturers in Nepal and in Pakistan, such as the Hydrolink Engineering Equipment Company, have initiated sector-wide capacity building.

***Latin America:*** Practical Action established the Demonstration and Training Centre in Appropriate Technologies in Peru, equipped with a demonstration pico hydro site for micro hydro design and operations training (Escobar *et al.*, 2012). Based in Colombia, APROTEC Energías Alternativas has supported small-scale hydro design, manufacturing, operation and maintenance capacity building in various regions of Central and South America, including Honduras and Nicaragua (APROTEC, n.d.). Local practitioner organisations, such Asofenix and ATDER-BL[14] in Nicaragua, also provide local capacity building to operators, community leaders and local government.

***Sub-Saharan Africa:*** Various capacity-building initiatives, centres and experts have advanced the sector in African contexts for several decades, starting with missionary organisations; however, most have not been well documented. UNIDO has a prominent centre in Nigeria called the Regional Centre for Small Hydro Power, while grassroots efforts in recent decades have resulted in remotely located centres, such as the Mzuzu Institute for Technology and Innovation in Malawi. Practical Action, EnDev, and Energy4Impact are among several donor and implementing organisations that have enabled local capacity-building activities in Ethiopia, Kenya, Rwanda and the United Republic of Tanzania, among others.

14 Association of Rural Development Workers Benjamin Linder, a company operating mainly in the electric power sector.

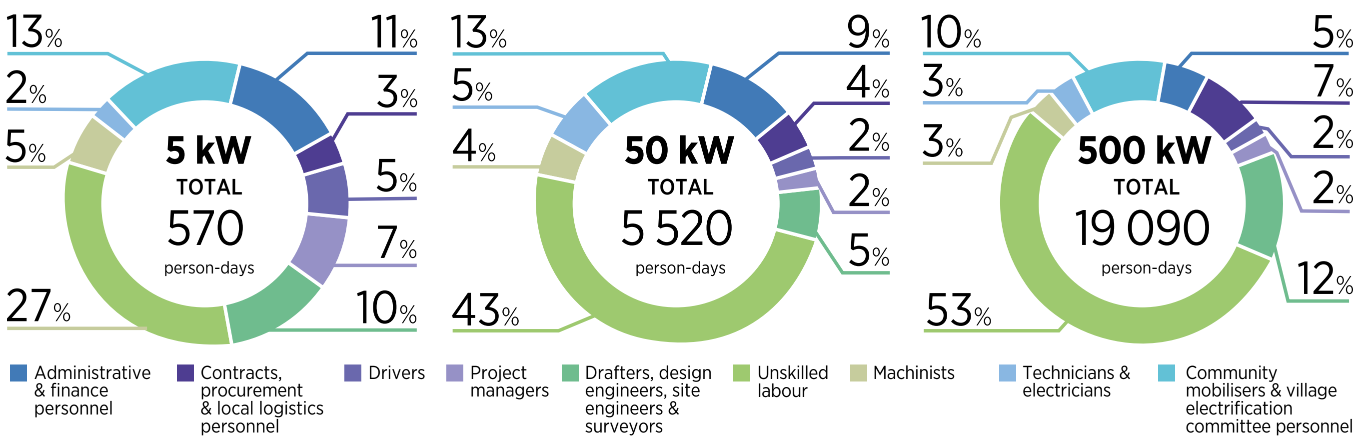
**Labour requirements.** The activities for the installation and connection phase involve nearly the full range of occupational roles. For a 5 kW, 50 kW or 500 kW plant, the person-days required for installation and connection are approximately 600, 5 500, and 19 000, respectively, as seen in Table 4. Unskilled labour has the largest number of person-days, with its share increasing with project capacity (26% to 50%). Person-days for the village electrification committee (VEC) are comparatively greater in pico and micro hydro capacities since those projects tend to be community led, while mini hydro construction is managed by the developer (see Figure 10).

Trained operators have a high rate of attrition because their micro hydro skills open up new employment prospects for them. Because of this, some programmes train a greater number of operators than required during the installation.

Table 4 ■ **Human resources required for installation and connection of a 5 kW, 50 kW and 500 kW plant (person-days)**

| Occupation | 5 kW | 50 kW | 500 kW |
|---|---|---|---|
| Administrative and finance personnel | 60 | 490 | 846 |
| Contracts and procurement personnel | 3 | 18 | 150 |
| Drivers | 30 | 120 | 350 |
| Project managers | 42 | 120 | 439 |
| Design engineers | 5 | 76 | 884 |
| Electricians | 51 | 188 | 1 351 |
| Site engineers | 30 | 200 | 500 |
| Unskilled labour | 150 | 2 400 | 9 600 |
| Machinists | 4 | 31 | 206 |
| Technicians | 12 | 300 | 600 |
| Masons and skilled labour | 70 | 720 | 1 549 |
| Operators | 14 | 203 | 1 155 |
| Community mobilisers | 30 | 456 | 1 080 |
| Environmental impact assessor | 3 | 20 | 50 |
| Village electrification committee | 60 | 162 | 277 |
| Local logistics personnel | 5 | 15 | 50 |
| **TOTAL** | **569** | **5 519** | **19 088** |
| **TOTAL (as % of the total requirements)** | **3%** | **9%** | **12%** |

Figure 10 ■ **Human resources required for installation and connection activities for a 5 kW, 50 kW and 500 kW plant, by occupation**




Note: The figures presented in this report have been rounded for clarity and ease of comprehension. As a result, there might be slight discrepancies in the totals, and they may not precisely add up to the overall total. However, these rounding adjustments do not significantly impact the overall findings and conclusions drawn from the data.

**Material requirements.** The raw material required for the construction of concrete structures includes cement, sand, aggregate and water. Reinforcing bars of different diameters are also required. The curing process for the concrete requires metal or wooden moulds. The installation of prefabricated components requires a full set of mechanical tools (*e.g.* spanner set, hex key set) and electrical tools (*e.g.* multi-meter, tachometer). Depending on whether the penstock is made from HDPE rubber, PVC plastic or metal, its installation requires special tools and material for sealing the joints.

### *2.1.5 Operation and maintenance*

The **operation and maintenance** phase of 5 kW, 50 kW and 500 kW plants covers the operation of the system for the average expected lifetime of 40 years, and therefore accounts for a large percentage of required human resources. Pico, micro and mini hydro plants do not require cost-intensive technical maintenance but benefit from safe operations, routine preventive monitoring and immediate corrective maintenance to avoid the need for major repairs. This phase also involves the social and financial aspects of distributing electricity, including door-to-door checking of load points (in the case of flat tariff), meter readings (in the case of metered tariff), tariff collection, financial management and community mobilisation for technical maintenance.

Activities in this phase include the following:

- **Daily operation:** The operator turns the system on by releasing water into the turbine using a valve in the powerhouse.[15] If the readings for voltage and frequency are stable and sufficient, the electricity generated is released to the village distribution line, and then readings are continually monitored for stability. During the walk to the powerhouse, the operators will check the distribution lines.
- **Routine monitoring:** The distribution line, penstock and forebay trash rack are checked on a weekly basis, if not daily. Electrical connections in the powerhouse are also checked.
- **Preventive maintenance:** Leaks in the concrete structure are best repaired when they are small. Penstock joints, depending on whether they are metal, PVC or HDPE material, are maintained. Rubber packing in the turbine manifold is replaced. Bearings are greased.
- **Troubleshooting and small repairs:** If the water level is abnormal, the operator walks along the penstock to the weir and forebay tank, inspecting all the infrastructure for leakage.
- **Major rehabilitation:** Mudslides can significantly damage the concrete structures and require reconstruction. Flooding in the powerhouse can require replacement of the generator and controller electronics.
- **Door-to-door verification:** In mini-grids that use flat tariffs, limiting the number of load points, the VEC (or other governing body) periodically verifies the number of light points and plug points with visits to each household. In systems that use meters, the VEC delegates persons to read meters, record the data and submit the data to the bookkeeper. Mini-grids that use prepaid smart meters or dedicated distribution lines (*e.g.* enterprises during off-peak hours at reduced tariffs) do not require such monitoring.
- **Tariff collection:** Tariff collection methods can range from door-to-door collection or collection at a central point, depending on the number of households connected to the mini-grid, user willingness to pay, type of tariff system (*e.g.* flat, tiered, dynamic), type of meters, type of user (*e.g.* household, enterprise), the funding available to hire persons or upgrade meters, and the type of mini-grid enterprise model. The governing body is able to consistently collect monthly tariffs and new user connection fees, enabling the mini-grid to generate revenue for its sustainability.

15 Whether the generation system is turned on and off daily depends on whether the governing body has opted to generate and distribute electricity 24/7 or only at certain times of the day. In the case of 24/7 operation, although valve operation will not be daily (since the water release valves will be kept open for long periods), the operator will still need to monitor voltage and frequency readings multiple times a day and be on-call to address any issues on the transmission and distribution lines.

- **Financial management:** Depending on the type of enterprise model, accounts management requires bookkeeping of tariffs owed by and collected from each consumer; provision of compensation to operators, meter readers and other services involved in operation and maintenance; budgeting for preventive maintenance; and preparation of accounting reports for the governing body and shareholders.
- **Community mobilisation:** Systems that are remotely located rely on community members to provide the labour required for maintenance, since the number of powerhouse operators is typically not enough. Tasks include cleaning debris in the weir and forebay tank, maintaining the penstock path to prevent mudslides during rains and fires during droughts, moving boulders at risk of damaging the powerhouse during rains, and trimming vegetation away from transmission and distribution lines. The VEC co-ordinates the maintenance schedules and mobilises community members to support these activities.

**Labour requirements.** The person-days per year required for operation and maintenance activities are estimated at around 400 for a 5 kW plant, almost 1 400 for a 50 kW plant and over 3 100 for a 500 kW plant (see Table 5). Operators have the most important role in this phase (40-45%), followed by the VEC (up to 20%) (see Figure 11).

The total percentage of person-days for this phase is inversely proportional to the output capacity. This is because pico and micro hydro systems are typically not run 24/7 and therefore require operators to start and stop the system daily, while mini hydro systems are usually run 24/7, and therefore less time is required of the operator. In all other phases, such as the installation and connection phase (the phase with the next highest total person-days), human resources increase with capacity because of the more involved processes required for each phase in micro and mini hydro projects.

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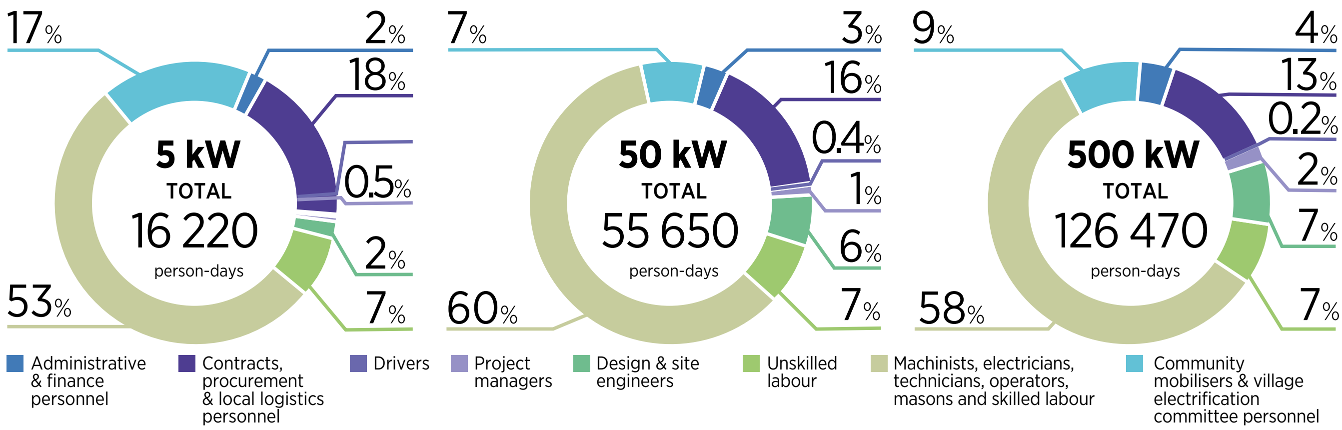
Table 5 **Human resources required for operation and maintenance of a 5 kW, 50 kW and 500 kW plant (person-days, per year)**

| Occupation | 5 kW | 50 kW | 500 kW |
|---|---|---|---|
| Administrative and finance personnel | 7 | 36 | 120 |
| Contracts and procurement personnel | 0 | 1 | 2 |
| Drivers | 2 | 5 | 5 |
| Project managers | 2 | 8 | 64 |
| Design engineers | 2 | 16 | 75 |
| Site engineers | 6 | 70 | 153 |
| Electricians | 18 | 203 | 257 |
| Unskilled labour | 28 | 100 | 210 |
| Machinists | 1 | 12 | 41 |
| Technicians | 3 | 15 | 30 |
| Masons and skilled labour | 12 | 60 | 150 |
| Operators | 183 | 548 | 1 369 |
| Community mobilisers | 68 | 91 | 274 |
| Village electrification committee | 74 | 227 | 412 |
| Local logistics personnel | 2 | 4 | 8 |
| **TOTAL** | **407** | **1 395** | **3 170** |
| **TOTAL (as % of the total requirements)** | **94%** | **87%** | **78%** |

Figure 11 **Human resources required for operation and maintenance of a 5 kW, 50 kW and 500 kW plant, by occupation (40-year lifetime)**




Note: Based on cumulative operation and maintenance requirements over a facility lifetime of 40 years.

### *2.1.6 Decommissioning*

Depending on their use, larger hydro projects are often decommissioned when an alternative power source or irrigation infrastructure is available. However, in the case of pico, micro and mini hydro projects, the systems are developed as community assets and, as such, never decommissioned. In most cases in which the main grid has subsequently arrived in the area, the mini-grid – if operating without technical issues – has continued to be used alongside the main grid (IHA *et al.*, 202217). Even if there is no longer a need for the system, the plant is typically kept intact but not operated. In cases where the system has become non-operational due to technical and financial issues, the community may still choose not to disassemble the system.

The costliest components of a small-scale hydro system, namely the upstream civil works structures made from concrete, cannot be dismantled and then reassembled for use elsewhere; the only way they can be removed is to demolish them. The penstock and electromechanical system can be disassembled and reassembled. However, because the system design is custom to a specific head and flow, it is typically a challenge to find a site that meets the exact specifications to reuse components. In short, there are no financial advantages to decommissioning a plant, and therefore it is usually not done.

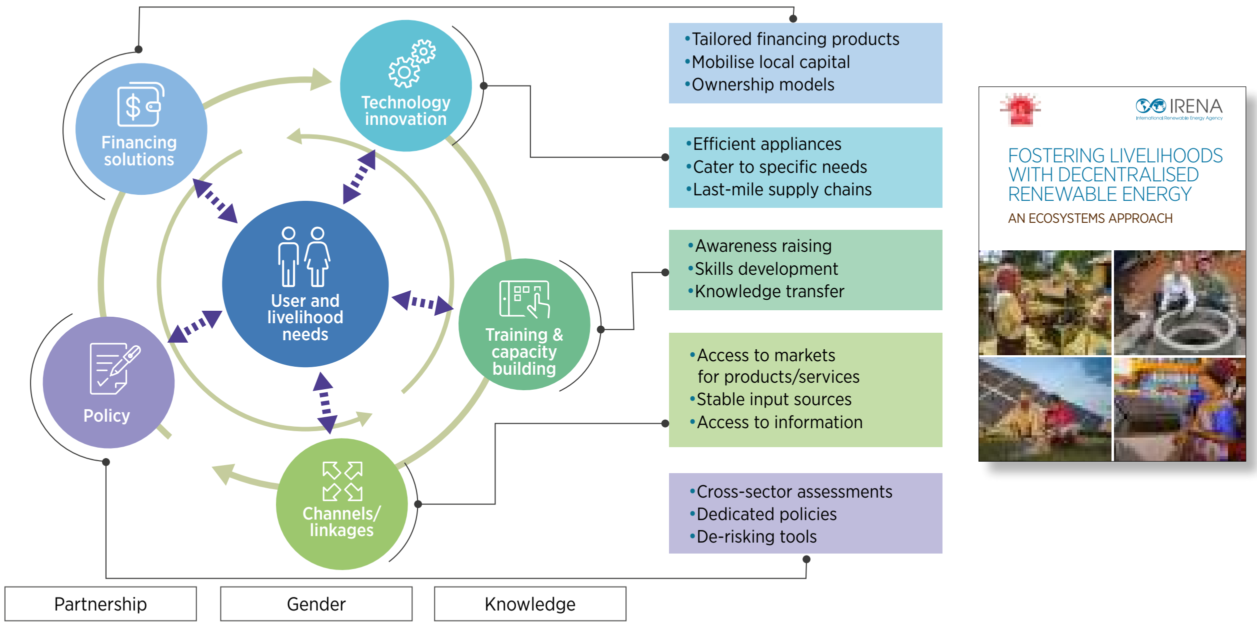
As such, there are no empirical data on jobs and duration for decommissioning pico, micro and mini hydro plants. Theoretically, we can assume that decommissioning involves de-installation of the prefabricated components, destruction of the civil structures, safe removal of the debris and salvaging of any components that can be used in another project. The human resources required would be skilled labour for removing the prefabricated components for use elsewhere and unskilled labour for removing the concrete structures. In terms of equipment, the same tools that were used to install the prefabricated components would be used to remove them. For the removal of the civil structures, tools that can quickly destroy concrete structures and can be taken to the upstream location by foot are required (*e.g.* sledgehammer).

## 2.2 Utilisation value chain: Productive end use of electricity

Connecting renewable energy supply with income-generating activities across sectors has the potential to boost productivity, enhance incomes, create local employment and catalyse rural economies. In Ethiopia, for example, installing decentralised renewable solutions for horticulture, wheat and dairy industries may result in the creation of around 190 000 employments throughout value chains by increasing production capacity and reducing losses (Ethiopia Jobs Creation Commission, 2021). In many developing countries, the transition to improved energy access through decentralised renewables has large-scale implications for livelihoods. Several examples from Kenya and Nigeria show that productivity gains and productive uses in rural enterprises ranging from retail and other services to agricultural processing businesses create up to five times more employment than the direct jobs created in delivering renewable-based energy solutions (Shirley, 2020).

Translating energy access into livelihood improvements requires investing in an ecosystem that can foster technology solutions tailored to livelihood needs and deliver the financing, capacity, skills training, market access, and cross-sector policy support to realise the full benefits of distributed renewable energy solutions (Figure 12). Targeted efforts to link renewables with livelihoods are well aligned with the ongoing objective of building back better from the COVID-19 pandemic and with the Sustainable Development Goals (IRENA, 2020). Achieving both these objectives requires co-ordination within governments to assess existing and new livelihood opportunities across sectors that stand to gain from improved access to modern energy services. Beyond technology deployment, efforts are also needed to raise awareness of productive end-use applications and to improve access to markets for new products and services.

Figure 12 ■ **Ecosystem needs for livelihood-centric approach**




Source: IRENA and SELCO Foundation, 2022.

The availability of small-scale hydropower units in communities otherwise not connected to the grid makes it possible to create new employment through productive end uses,[16] which could encourage more inclusive growth within the communities. Such uses are typically household-based, community-owned or externally owned enterprises. Some examples can be seen in Table 6.

16 Although it generally refers to the utilisation of electricity, the term productive uses of energy is used differently across the literature. For the purpose of this study, productive uses will be classified based on public services, household-based livelihoods and enterprises that can benefit from energy access, as shown in Table 6 with examples.

Table 6 ■ **Classification and examples of productive end uses of mini-grids for the purpose of this study**

| Public services | Household-based livelihoods | | | Enterprises | |
|---|---|---|---|---|---|
| **Social welfare & community services** | **Product making** | **Service provision** | **Hybrid** | **Villager-owned enterprise** | **Externally owned enterprise** |
| Facilities that do not directly contribute to income generation and offer services for maintaining social welfare and well-being | Making products at home and selling them | Selling a service from home | Selling products and services from home | Separate from a household connection and owned by village entrepreneurs to manufacture and sell services and products | Facilities that generate profit and are not owned by someone in the village |
| • Health clinics<br>• Community centres<br>• Training centres<br>• Place of worship<br>• Schools<br>• Local markets<br>• Street lights | Producing:<br>• Brooms<br>• Chopsticks<br>• Leaf plates<br>• Silkworm breeding<br>• Daily goods shop<br>• Lime baking<br>• Wine making | • Cold storage<br>• Phone charging<br>• Printing<br>• Washing or ironing clothes<br>• Small-scale milling<br>• Water heating | • Carpentry (e.g. sell products, build homes)<br>• Tailoring<br>• Weaving<br>• Restaurants & catering | • Community-scale agri-processing<br>• Bakery<br>• Fabrication workshop<br>• Convenience store<br>• Brick making<br>• Cash crop farming (e.g. cashews)<br>• Vehicle repair and rental<br>• Rice hulling<br>• Corn threshing | • Petrol/gas pump<br>• Telecom tower<br>• Large-scale agri-processing<br>• Agri-plantations<br>• Poultry farm |

Hydro mini-grids offer opportunities to support communities in different ways:

- The sector's well-established local manufacturing enterprises, some of which are also small-scale hydro project developers and manufacturers, have been able to support communities with enterprise mentorship, locally fabricated utilisation equipment, and seed finance – all of which stimulates energy demand and increased utilisation (see Box 6).
- Small-scale hydropower can be used to directly operate agri-milling equipment, through the use of a belt drive connecting the shaft of the mills to the shaft of the hydro turbines, without the need to generate electricity. In fact, the small-scale hydro sector in Nepal was scaled up because of tens of thousands of households accessed loans from the Agricultural Development Bank to upgrade their waterwheel mills to more efficient micro hydro mills, helping to finance the capacity building resulting from the BYS (Balaju Yantra Shala) and SATA partnership, ultimately leading to local skills for developing advanced systems that also include electricity generation.
- Without reliable access to 24-hour power, many enterprises will not find it feasible to invest in power intensive equipment. Hydro mini-grids offer that access and thus can encourage investment into productive end uses by entrepreneurs and banks, particularly if they are equipped to avoid damaging voltage fluctuations. Availability of 24-hour power also makes it possible for mini hydropower installations to offer lower tariffs for productive end uses during off-peak hours, increasing their profitability. Examples are bakeries which can fire up electric ovens starting very early in the morning and grain mills that can operate during the day. Applications such as cell towers will be prepared to pay high tariffs but need reliable power 24 hours a day.

**Box 6 ■ Energy demand stimulation: The role of local manufacturers**

Productive end uses that generate local income and/or reduce physical drudgery require machinery such as grain mills, oil presses, water pumps, brick-making machines, and induction furnaces for metal casting. However, machinery that is aligned in size to the mini-grid (and affordable) is often not available, since most is designed with unlimited electricity supply from central grids in mind. Further, communities that are not versed in enterprise-based end uses may not have individuals who can establish and operate end-use enterprises.

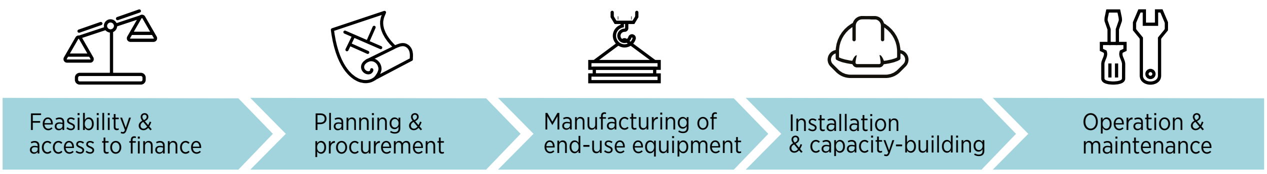
Small-scale hydro developers have overcome these challenges and successfully achieved high load factors incorporating agri-processing and local industry loads by locally manufacturing the end-use appliances and providing training and mentoring to local youth groups, women's groups, and individuals with a natural sense of entrepreneurship. Typically, the local manufacturers of small-scale hydro equipment are also the key resources to fabricate local end-use equipment and can apply their entrepreneurial experience and skills to mentor community members and enable them to initiate financially viable end uses. Examples of such local manufacturers include (a) Hydropower for Community Empowerment in Myanmar, supporting micro and mini hydro co-operatives with ideas, equipment, mentorship and finance to establish anchor loads that generate high revenue for the co-operative, such that household use can be subsidised, and (b) Mzuzu Institute for Technology and Innovation in Malawi, providing equipment and training to women's groups to transition from high drudgery manual corn milling to mechanised milling.

Source: Interviews with local practitioners.

Use of small-scale hydro systems has the potential for extensive productive end use because electricity is produced 24 hours, making these systems more cost-effective than battery-dependent mini-grids. As such, after or in parallel with the installation of the mini-grid, the project and its beneficiaries will benefit from entering from the utilisation value chain.

The dedicated value chain for productive uses derived from the deployment of hydro mini-grids is shown in Figure 13. The utilisation value chain will differ based on the approaches of the stakeholders involved, however minimally it will involve the following: feasibility and securing finance, planning and procurement, manufacturing of equipment not available in the market, installation and capacity building, and operation and maintenance.

Figure 13 ■ **Utilisation value chain for small-scale hydropower**




***Feasibility phase:*** A participatory demand assessment for productive end use is conducted with households, social service providers, and enterprises, with facilitation support from the VEC. The power consumption for the ideal scenario is forecasted and compared with various technical aspects of the generation capacity and quality of power output of the proposed hydro mini-grid. Final productive end uses for households, social service providers, and enterprises are prioritised based on an effective load management strategy, the availability of end-use equipment and appliances, the availability of funding to procure the equipment and appliances, local capacities to properly use the equipment and appliances, access to markets, and financial viability.

***Planning and procurement phase:*** Plans are made to integrate productive end uses into the mini-grid, (*e.g.* replacing flat tariffs with metered tariffs). Policies and processes are developed to address overloading and any grievances caused by the use of larger loads. Financial and logistical arrangements for procurement are made. For social and public services, the process involves interfacing with local government.

***Manufacturing phase:*** For certain end uses, the equipment can be designed and fabricated locally (*e.g.* concrete brick-making machines). Some end uses (*e.g.* a community rice mill) may require a new building or sheltering structure. As the equipment is procured, it is tested before being transported to the village. In other cases, both the equipment and structure already exist, and the preparation is to ensure the wiring is appropriately sized for the anticipated current and voltage. During this period, members of the community receive any needed capacity building to operate the end-use equipment, as well as to develop and manage electricity-based enterprises.

***Installation and capacity-building phase:*** After the mini-grid is commissioned, the end-use equipment has been procured, and necessary trainings have been completed, the end-use equipment is installed and initiated.

***Operation and maintenance phase:*** The end-use equipment is operated and maintained as per instructions provided by the equipment supplier.

**Labour requirements.** While the pre-installation activities and person-days will vary with the type of organisation leading the utilisation value chain and the approach used, the human resources typically required are for project management, administrative, finance, specialist, skilled labour, and unskilled labour roles. Required specialists include persons who can identify income-generating activities that are home based and enterprise based, having a keen sense of which goods and services are both high in demand and will become increasingly viable when produced with electricity. Employees responsible at social services facilities, such as health clinics and schools, are also required to integrate electricity use into the services they provide.

The installation and capacity-building phase entails roles for project management, administration, specialists, skilled labour, and unskilled labour. Required specialists include those recommended by the suppliers of the end-use equipment for quality installation and those providing training of equipment operators.

In post-installation activities, each social service, home-based livelihood and enterprise will have its own value chain. Trends to note include:

- In end uses that existed prior to the hydro mini-grid, jobs may increase if facilities are being expanded. New facilities for productive end uses established after the provision of electricity will offer new jobs. Assuming there is ongoing demand, finance and human resources, and ample electricity, the jobs will be available indefinitely and likely increase in number, based on examples of villages that have transformed into small towns after electricity access.
- Integrating agri-processing and agroecology with hydro mini-grids raises the need for human resources and increases socio-economic benefits from electricity access. A country can be a leading producer of raw materials but lack of rural electrification results in minimal processing and thus limits local income generation. For example, Myanmar is one of the top sesame producers globally, yet due to lack of electricity harvested sesame must be transported for processing, which has led to excessive loss of the produce. When electricity access is linked with the local agri-processing needs of smallholder farmers, the chance of local income generation in agriculture value chains increases without the need for intermediary trade.
- In coastal and island communities, electricity access for seafood production and trade (*e.g.* fish farming, cold room facilities, ice makers and electric boats) have high demand.
- The enhancement of electricity access enables improvements in the livelihoods of rural women. In turn, women leaders bring their experience to bear on ways to improve the utilisation value chains.

Maximising utilisation of hydro mini-grids and solutions to meet the full energy demand of the productive end-use facility leads to improved local socio-economic conditions through income generation and livelihood enhancement, and improved social well-being through the provision of social services – all requiring extensive human resources. However, higher capacity mini-grids do not automatically translate into greater human resource need. In fact, with less electricity there is more reliance on manual processes, which in fact require more human resources than mechanised processes. These jobs, however, are typically harsh and badly paid.

**Material requirements.** The material required for the utilisation value chain includes building construction material for new facilities, such as tin roofing, bricks and cement. It also includes raw material to produce end-use equipment that may not be available off the shelf due to the required smaller power consumption (*e.g.* rice mills that can run on small motors) or because there is no demand for it in urban areas (*e.g.* locally fabricated machine to produce cement bricks). Finally, material requirements include raw material and supplies required for the myriad of end uses (*e.g.* clinic supplies, school furniture, agroforestry enterprise inputs).

## 2.3 Climate adaptation value chain

Rural communities are bearing the brunt of climate change, partly due to a lack of adequate housing, water and energy infrastructure resilient against droughts and floods. Food security also becomes an issue with longer dry seasons and intense wet seasons, which impact both agriculture and access to markets.

Hydropower requires a consistent water supply to generate electricity year round. Seasonal fluctuations in stream flow, as well as topography and changes in forest cover, all impact a system's energy output, making some systems more vulnerable than others. When the forest above hydropower intake is logged, the retention capacity of the soil and stream flow is altered. Such conditions are exacerbated during extreme temperatures and weather events caused by climate change. The consequences are large variability between wet and dry season flow rates and increased risk of floods and landslides, which could damage hydropower structures. Increased siltation can also clog intakes and wear down turbine runners, incurring additional maintenance costs. Distribution and transmission lines are prone to damage by storms and other climatic events with strong winds.

Within the context of increasing the climate resilience of the water-energy-food-livelihoods nexus through adaptation, community-scale hydro can generate nature-based, technical and socio-economic solutions and draw benefits from them.

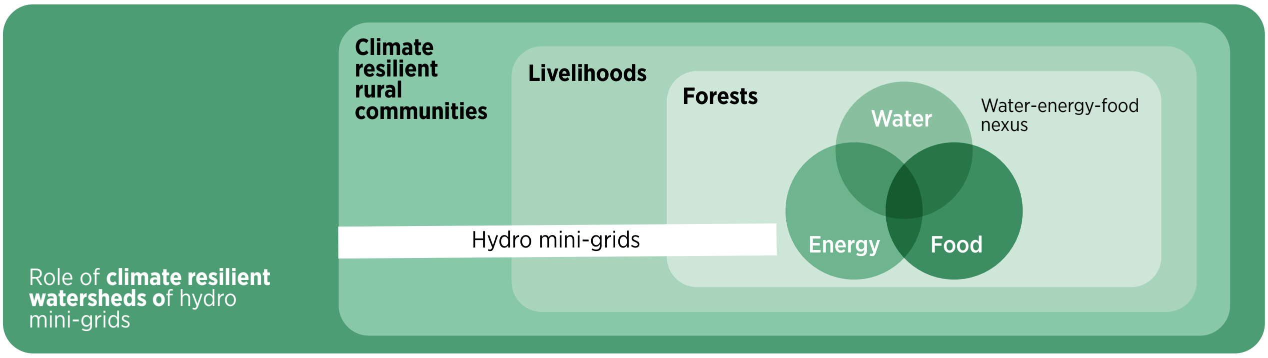
***Nature-based solutions:*** The terrain and forests of the watershed form the catchment area that harnesses natural water sources for the operation of the small-scale hydro system. Maintaining and establishing mature forest cover and using methods to minimise rainwater run-off alleviates the impacts of seasonal variability in flow, reduces landslide risks and can help build resilience against the impacts of climate change. Such nature-based solutions[17] offer extensive job creation (WWF and ILO, 2020). Access to reliable electricity provides communities that have small-scale hydropower an added incentive to protect their watersheds, as do the socio-economic co-benefits of watershed restoration, securing of clean drinking water and water for irrigation, forest resources for enhancing local livelihoods, and electricity utilisation for income generation.

17 Nature-based solutions, such as restorative forestry, wetlands and agriculture (Institute for Carbon Removal Law and Policy, 2020) are practices that leverage ecological systems to meet societal goals, including infrastructure development and climate resilience, while also restoring or strengthening the natural processes themselves. Areas of impact include water resource management, disaster risk reduction and green infrastructure (WWF, 2022).

***Technical solutions:*** In addition to catchment area restoration, the technical design and engineering of the hydro mini-grid components can be adapted to withstand climate change impacts. For example, adjusting the location and dimensions of the civil structures and powerhouse, as well as considering underground cables for the transmission line, can mitigate impact during climate events.

***Socio-economic solutions:*** As reflected in Figure 14, the climate adaptation value chain can benefit from, and create benefits for, the utilisation value chain. Productive end uses designed to provide vital services during climate events and other disasters, such as earthquakes, accelerate the community's recovery and rehabilitation. Conversely, catchment area restoration inclusive of agroforestry and benefits for water uses that impact livelihoods and health build the climate resilience of the socio-economic aspects of the community, as well generate jobs and strengthen existing livelihoods.

Figure 14 ■ **Links between watersheds of hydro mini-grids and the water-food-energy nexus**



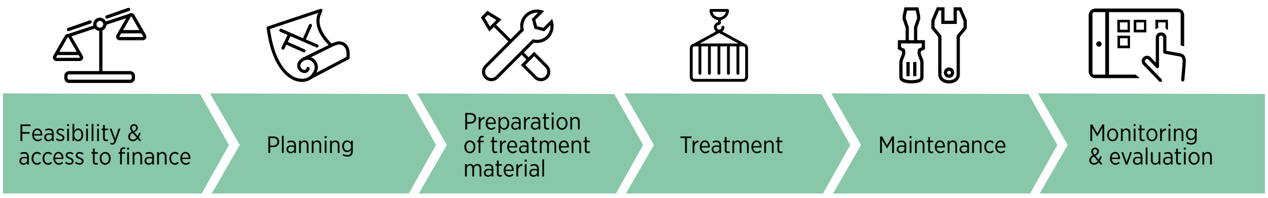

Source: HPNET-SEEED, 2022.

Funding for small-scale hydropower typically does not include funds for building climate resilience (*e.g.* watershed restoration), and so the intensive labour required is typically not compensated. Although in some cases forest conservation programmes enable employment for similar activities, dedicated funding for climate adaptation in small-scale hydropower generates significant direct and induced employment, especially for women in rural areas.

Among the activities that require human resources are mapping the watersheds and spring sheds, monitoring seasonal and climatic changes to water flow, identifying and prioritising areas for restoration, implementing restoration activities, maintaining tree nurseries, conserving existing and restored forests, and monitoring results.

Climate adaptation is a vital component of small-scale hydropower implementation, ensuring sustainable electricity generation during droughts and floods, as well as building climate resilience in other water usages that impact the water-energy-food-livelihoods nexus (*e.g.* irrigation and drinking water). As previously shown in Figure 14, the value chains of hydro mini-grid implementation, utilisation and climate adaptation are distinct yet interdependent. A dedicated value chain for integrating climate resilience in hydro mini-grids is required. The **phases for climate adaptation** (see Figure 15) in hydro mini-grids include the following:

Figure 15 ■ **Climate adaptation value chain for small-scale hydropower**



***Feasibility phase:*** The baseline conditions of the watershed are assessed using various methods. In parallel, a watershed governance body is identified to facilitate the community in collectively developing a long-term strategy with near-term measurable goals, initial community protocols for watershed stewardship, stakeholder roles, activity milestones, rough budget, potential funders, and impact indicators – all of which may be iterated in later phases. Goals set in the feasibility phase can focus on restoration and rehabilitation processes, as well as conservation, and on measures to prevent or mitigate damage from negative external activity such as logging, mining and degenerative agroforestry. The feasibility phase concludes with the process of securing funding and/or in-kind resources for near-term goals and activities, including developing proposals.

***Planning phase:*** This phase's activities entail planning of the preparation and treatment phases for specific projects (or treatments) after funding and/or in-kind resources are secured. The proposals established in the feasibility phase are used to develop a detailed work plan that integrates logistical steps, such as transportation, procurement, and liaison with external actors, including local government and watershed specialists. Based on the work plan, the objectives, protocols, roles and impact metrics proposed in the feasibility phase can be refined.

***Preparation phase:*** This phase includes preparation of the material, equipment and/or facilities required for the specific watershed treatment, such as nature-based, technical and/or socio-economic treatments. For example, preparation for watershed restoration treatment might include seed collection, seedbed preparation, seed propagation and the construction of a nursery.

***Treatment phase:*** The actual climate adaptation activity is carried out, as per the work plan developed in the planning phase and using the materials prepared during the preparation phase. Treatment activities (see Table 7) can be passive or active. Passive nature-based treatments focus on conservation methods, where the existing forest landscape is relatively healthy and therefore protected or where natural generation can result in sufficient rehabilitation. Conversely, active nature-based treatments focus on restoring the ecological integrity of severely degenerated watersheds, where restoration is done through activities such as planting seedlings to restore forests or applying earthwork techniques to reduce erosion. A middle path between the two is where communities support the landscape to naturally restore itself, based on their generations of knowledge of the land (WRI, 2022). Treatment also includes technical design or retrofitting so that the hydro mini-grid civil and transmission structures can withstand climate change impacts. Finally, the treatment phase can include the initial steps of establishing new or strengthening existing livelihoods dependent on the watershed.

***Maintenance phase:*** Activities in this phase focus on maintaining the specific treatment, such as weeding, watering, replanting to replace seedlings that did not survive, and applying organic fertilisers.

***Monitoring and evaluation phase:*** Broadly, the progress of the long-term strategy developed during the feasibility phase is tracked in this phase based on the milestones set. More specifically, the results of the solutions, treatments or projects carried out in the planning, preparation and treatment phases are monitored using the impact metrics set during the planning phase.

In Nicaragua (see Box 7), India, Malaysia and the Philippines (HPNET YouTube Channel, 2021), catchment area restoration has been integrated with the implementation of micro and mini hydro systems.

**Box 7 ■ Energy demand stimulation: The role of local manufacturers**

Since 1987, the partnership of ATDER-BL and APRODELBO[18] has been developing small-scale hydro projects in conjunction with the conservation of the watersheds that provide water to the natural systems. Because catchment area restoration efforts bear results over several years, ATDER-BL and APRODELBO's restoration activities spanning over several decades provide an evidence-based perspective on impact.

Early on in the 190 kW Bocay mini hydro and the 914 kW El Bote mini hydro case studied by the United Nations Industrial Development Organization (UNIDO and ICSHP, 2019), ATDER-BL monitored the conditions of the forest and other resources of the mini hydro catchment area. Over six years, accelerated forest loss was observed due to the advancement of the agrarian frontier, itself driven by rising acute rural poverty. Although highly labour intensive, low yielding and destructive to the forests, subsistence farming became the default for most families, and led to intense erosion during rains, exacerbating socio-economic conditions.

To alleviate the situation, a two-prong restoration approach was established: acquire the forest land for preservation and support families to improve agrarian practices for increased income and preservation of soil. The initial two years of activities included a soft loan for families to grow basic grains and coffee, provision of an agronomist to ensure the loan was used effectively, and simple reforestation methods starting with seeds. The results were mixed, however: due to lack of awareness and know-how, there was no uptake of the loan, the part-time agronomist was insufficient, and the seeds sourced from another region did not take root.

Based on the lessons learnt, the programme was revised to focus on payment for ecosystem services, along with improved capacity building. The results were positive, including the increase of household income through sustainable agriculture and new crops; identification and rehabilitation of severe erosion locations; social activities to promote environmental practices; increased wildlife and strengthened local ecological through forest regrowth; and a women-centric approach to restoration where women are key contributors and beneficiaries of the watershed and the mini hydro system through sustainable agriculture products.

Source: HPNET and ATDER-BL, 2021.

18 Association for the Development of Bocay Electric Service.

**Labour requirements.** The human resource requirement for climate adaptation of small-scale hydro systems is substantial and depends on the specific climate vulnerabilities and adaptation opportunities present in a given catchment area. In northern Pakistan, where climate change is causing water sources to diminish, the Aga Khan Rural Support Programme (AKRSP) has mandated hazard and vulnerability risk assessment as a part of feasibility studies of small-scale hydro projects. Some projects built eight to ten years ago lack sufficient water to operate at full capacity and have catchment areas that can be rehabilitated with natural treatment. The initial phases of these efforts require climate change experts who can design small-scale hydro plants with climate-resilient methods for fragile regions. Plausible treatments to address certain climate impacts have varying time frames for results (see Table 7) depending on the field labour required. The longer the time frame to generate results, the more person-days are required.

Table 7 ■ **Range of watershed restoration treatments for climate adaptation in hydro mini-grids**

| | POTENTIAL TREATMENTS FOR HYDRO MINI-GRID WATERSHED STRENGTHENING* | | | |
|---|---|---|---|---|
| **Climate change adversity, impact or risk** | **Restorative agroforestry for degraded areas** | **Agri-tech (agricultural contouring, terracing, *etc.*)** | **Built structures (check dams, weirs, levees, culverts / channels / drainage structures, penstock, impoundment / forebay tank, gabions, riprap)** | **Afforestation (active) + Reforestation (passive or active)** |
| Mudslides | Time-intensive | Time-intensive | Quick | Time-intensive |
| Flooding | Time-intensive | Medium-term | Quick | Time-intensive |
| Sedimentation & deteriorated water quality | Time-intensive | Time-intensive | Quick | Time-intensive |
| Soil nutrient depletion | Time-intensive | Time-intensive | Medium-term | Time-intensive |
| Stream flow fluctuation | Medium-term | | Medium-term | Time-intensive |
| Reduced biodiversity | Time-intensive | | Medium-term | Time-intensive |
| Shifting species / climate migration | Time-intensive | | | Time-intensive |
| Change or fluctuations in water and air temperatures | Time-intensive | | Quick | Time-intensive |
| Reduced water level / flow (surface or groundwater) | Medium-term | | Quick | Medium-term |

*Treatment is specific to each watershed and designed after conducting and analysing a baseline assessment.

Legend for time frame for results:**

| Quick results (6 months - 5 years) | Medium-term results (5-10 years) | Time-intensive results (10-20+ years) |
|---|---|---|

***Exact time frame of results varies with each catchment area and treatment scenario.

Source: HPNET-SEEED, 2022.

Furthermore, if climate adaptation is done in parallel with the implementation of the hydro mini-grid, overlapping phases can be leveraged to save costs and time (see Figure 16).

Figure 16 ■ **Benefits from phase interlinkages when hydro mini-grid implementation and adaptation are done in parallel**

| HYDRO MINI-GRID IMPLEMENTATION PHASES | | CLIMATE ACTION PHASES |
|---|---|---|
| Feasibility | Potential ecological impact of both optimised | Feasibility |
| Planning & procurement<br>Manufacturing | • Potential overlap between site locations<br>• Collaboration between governing bodies of both<br>• Skilled & unskilled labor prioritised for both<br>• Sharing vehicles for raw material transportation | Planning<br>Preparation |
| Construction & installation | • Potential overlap between site locations<br>• Collaboration between governing bodies of both | Treatment |
| Operation & maintenance | Same team for civil structure & treatment maintenance | Maintenance |
| Utilisation | Agri-processing intergrated with watershed restoration | Monitoring & evaluation |

Source: HPNET-SEEED, 2022.

However, in smaller communities most local stakeholders (*e.g.* social mobilisers, governance bodies, households (see Figure 17) may not have enough bandwidth to pursue mini-grid implementation and climate adaptation in parallel.

Figure 17 ■ **Stakeholder links between hydro mini-grids and watershed management for climate adaptation**

| HYDRO MINI-GRID IMPLEMENTATION STAKEHOLDERS | | CLIMATE ADAPTATION STAKEHOLDERS |
|---|---|---|
| Developer | MANAGMENT | Watershed Governance Body or external organisation |
| Government donors, specialists | FUNDS / APPROVAL | Local government, donors, households |
| End-use & environmental impact specialists | ACCOUNTS / PROCUREMENT | Watershed Governance Body, NGOs, CSOs |
| Developer | SPECIALISTS | Treatment specialists, NGOs, CSOs |
| Manufacturers & developer's teams of engineers, hydrologists, surveyor, technicians, operators | TECHNICAL ROLES | Foresters and agronomists |
| Village Electrification Committee, CSO, NGO | SOCIAL MOBILISERS | Project committees |
| Village Electrification Committee | GOVERNING BODY | Watershed Governance Body |
| | COMMUNITY MEMBERS | |

Source: HPNET-SEEED, 2022.

Note: CSO = civil society organisation; NGO = non-governmental organisation.

Although impossible to generally quantify due to differences among specific sites, the roles are similar across nature-based, technical and socio-economic methods. All require project management, administrative, finance, specialist, skilled labour and unskilled labour roles. However, the specialists' roles will vary depending on the method.

For nature-based solutions such as regenerative agroforestry, afforestation and reforestation, foresters and agroeconomists are required, with varying job intensity depending on the specific treatment (WWF and ILO, 2020). For technical solutions, roles are similar to those presented in the installation and connection phase of the implementation value chain since activities focus on built structures. For socio-economic solutions, persons experienced in themes that connect catchment area restoration with agri-processing (*i.e.* agroecology) are required. Women provide invaluable contributions to all methods and role types.

**Material requirements.** The material required for the climate adaptation value chain also depends on the type of treatment. Nature-based solutions require material and tools to construct temporary shelters based on the input required for each treatment (*e.g.* nursery for seedlings, storage for organic fertiliser). The construction material is typically locally sourced (*e.g.* bamboo) and reused from other project (*e.g.* cement bags). Other material inputs include seeds, containers and items to cultivate the seedlings. Technical solutions require material and tools to build and/or reinforce components of the hydro mini-grids, such as mild steel rods, cement, aggregate and sand for concrete structures. The material required for socio-economic methods will depend on the community's specific vulnerabilities to climate change (*e.g.* equipment for building reconstruction in a post-disaster scenario).

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# 3. SOCIO-ECONOMIC VALUE CREATION: COMMUNITY ENTERPRISE, LOCAL JOBS AND SOCIAL CAPITAL

The previous section discussed in detail the human resources, equipment and materials required to implement small hydro systems. However, additional value is derived from steps taken to ensure that local communities are resilient against droughts and floods after the installation is completed. Small-scale hydropower is a mature technology, and therefore, local manufacturers – often small to medium enterprises – can produce, install and maintain most of the elements required. In this way, a stream of new jobs can be provided in rural areas, which can have a transformative effect on economic and social development, and encourage investments to build a climate-resilient water-energy-food nexus, such as watershed protection. Particularly in remote mountainous regions, such as Nepal or parts of Pakistan, these advantages strengthen a primary source of local income, sustainable tourism, where guesthouses and homestays can offer enhanced services with access to electricity and reliable water sources.

Successful implementation and consistent operation of the value chains of pico, micro and mini hydro systems require a cohesive community. Working effectively together during the project implementation generates extensive social capital, which strengthens the sustainability and utilisation of the systems. This includes community participation in planning and feasibility assessments, design, planning, ground preparation, collection of raw material, construction of infrastructure, commissioning, and training. Community-based ownership can incentivise cohesion and self-organisation in less homogenous communities or a cluster of communities to operate mini-grids inclusively for shared socio-economic benefits.

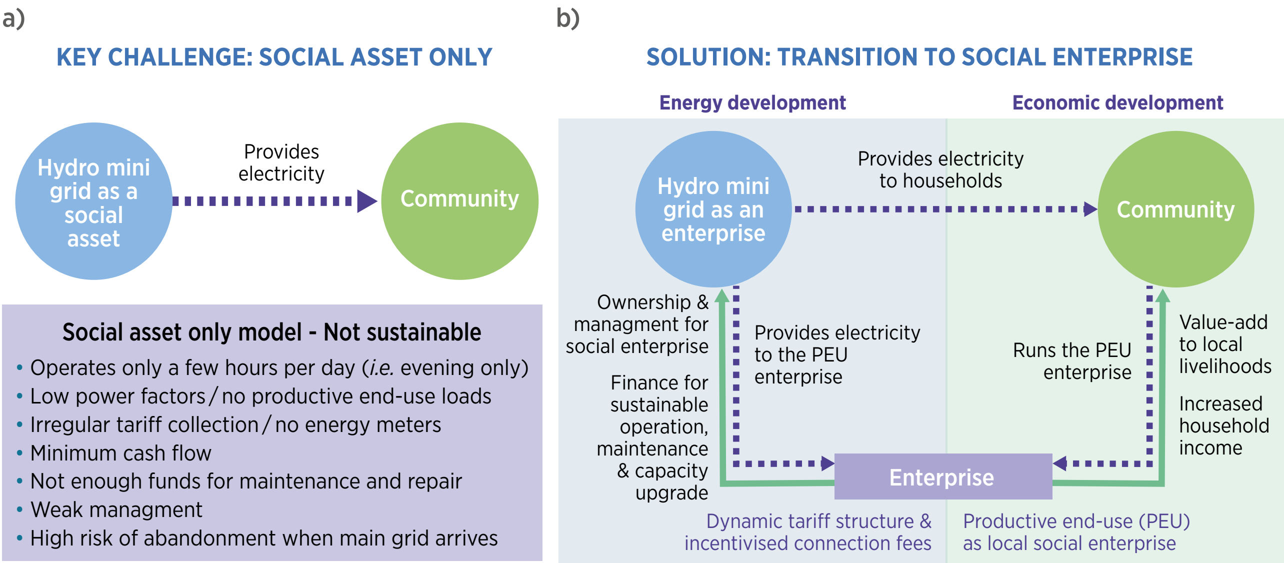
Further, for a community adopting small-scale hydropower, the potential to generate income and create jobs during the installation and post-installation phases depends on the extent to which it can leverage existing local skills and economic activities or create new ones. The expertise required to design and build the major technical components (see Annex D) can typically be found or established locally. The potential to create post-installation value principally lies in the maintenance and operation of the facility. Additionally, induced jobs result from the conservation of the area and from the productive uses that can be generated after the renewable energy facility is up and running. Experience suggests that approaches that leverage women-centric processes result in more robust governance, utilisation and technical sustainability of the hydro system.

Mechanisms for optimal and inclusive socio-economic impact are discussed in the following sections, which cover the types of community enterprise model and the factors for their sustainability (3.1), support for local service providers and job creation (3.2), and application of a gender lens to ensure benefits reach women (3.3).

## 3.1 Community enterprise models

Small-scale hydro systems are often located in remote locations and are operated under a “social asset only” model, whereby communities operate the system for only a few hours per day to meet basic needs, even though electricity can potentially be generated 24 hours. This practice results in low load factors with less revenue and minimum cash flow; it does not optimally generate socio-economic benefits, and maintenance is challenging as usually there are insufficient funds to sustain these systems (see Figure 18[a]). However, the management of a system can be transitioned from a social asset only to an “inclusive social enterprise”, where the mini-grid is managed as an enterprise owned by the community or members of the community. By creating management structures that incentivise maximum utilisation of small hydro systems, the community social enterprise approach generates multiple benefits for energy and socio-economic development, including financial viability of the mini-grid, and therefore sustainable energy access, as well as incentivisation of electricity use for income generation (see Figure 18[b]).

Figure 18 ■ **Social asset only model (a); and social enterprise model for hydro mini-grids (b)**




Source: HPNET, 2020.

Community enterprise models used for hydro mini-grids include user group, co-operative, public limited company and private limited company. They differ in terms of stakeholder roles, plant ownership, decision-making processes and profit-sharing arrangements (see Table 8).

- In the ***user group model***, all or a majority of households in a community join together to establish and manage their mini-grid. The group is facilitated by a representative supervisory body: the VEC. Because user groups are founded on the values of inclusivity and equity, they can generate high levels of community participation, especially at the start of implementation; however, after commissioning there is often the free-rider issue of households not paying a tariff but still receiving electricity. User groups can be seen as subpar compared with other enterprise models because they are not legal entities that require external financial audits. However, they are recognised by local institutions, such as in Pakistan where micro hydro user groups, known as village organisations, are acknowledged by the government as owners of the mini-grids. Most grant- or subsidy-funded projects start as user group models. In recent years, some user groups have transitioned to enterprises to resolve pitfalls. In Nepal, the Alternative Energy Promotion Centre and United Nations Development Programme's Renewable Energy for Rural Livelihood initiative has facilitated fledgling projects governed by user groups to adopt community-private partnerships, where the plant is leased out to a private entrepreneur who is able to cultivate financial viability (HPNET-SEEED, 2021).
- The ***co-operative model*** refers to a situation where the mini-grid is owned and managed by a legally registered co-operative, as a jointly owned and democratically controlled enterprise. A co-operative is an autonomous association of individuals united voluntarily to meet their common economic, social and cultural needs and aspirations. In the case of mini-grids, the co-operative members share the costs, risks and responsibilities of establishing and running a mini-grid to provide sustainable electricity. Co-operatives are governed by a democratically elected body that usually delegates the management of the mini-grid to a qualified and paid group of persons from within the community. In the absence of such local capability, co-operatives can resort to hiring external staff for the short or long run. Co-operative owned hydro mini-grids in Myanmar and Nicaragua have been instrumental in enabling local communities to achieve goals beyond energy access. In Myanmar, the

Lin Yuang Chi mini hydro co-operative also owns productive end-use enterprises, providing additional services to the community. In Nicaragua, a mini hydro co-operative established by ATDER-BL (Rural Development Workers Association – Benjamin Linder) has restored many acres of watersheds, resulting in climate resilience of the hydro mini-grids, improved rural livelihood and mitigation of greenhouse gas with healthier forests (HPNET-SEEED, 2021).

- In the ***public limited company*** model, the mini-grid is jointly owned and managed by a large group of individuals, as a legally registered entity as per the rules and regulations of a public limited company. The number of minimum shareholders varies from country to country, with a minimum range of 50-70 individuals. An example of the public limited company model that is inclusive to all the mini-grid beneficiaries is the approach developed by the AKRSP in Pakistan for its mini hydro projects, known as the community utility company model. It enables the participation of women as the primary shareholders of the project and productive end-use enterprises (HPNET-SEEED, 2021).
- In the ***private limited company*** model, the mini-grid is owned and managed by an individual or a small group of individuals, as a legally registered entity as per the rules and regulations of a private limited company. The maximum number of investors varies from country to country but is typically fewer than 30. Because the sustainability of small-scale hydro systems is inherently dependent on the role of the beneficiary community, projects owned by a private limited company work best when the enterprise is owned by someone from the community itself or already has rapport with the community. An example of such an owner is Mr Bir Bahadur Ghale in Nepal, the managing director of Hydro Concern Pvt. Ltd. The first of the more than 200 hydro mini-grids he has developed was for his own community of Barpak in rural Nepal. Because he is part of and trusted by the community, he has been able to coach households and enterprises to establish extensive productive end uses, which have played a major role in post-earthquake rehabilitation, as well as upgrading the project to generate more electricity (HPNET-SEEED, 2021).

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Table 8 ■ **Community enterprise models for hydro mini-grids and characteristics for differentiation**

| Characteristic | User group | Co-operative | Public limited company | Private limited company |
|---|---|---|---|---|
| **Social enterprise stakeholders** | | | | |
| Mini-grid beneficiaries | All households are invited to connect to the mini-grid at no or minimal cost | All households are invited to connect to the mini-grid for a connection fee | | |
| General governing body | All households connected to the mini-grid, called users | Anyone who buys shares is a member. Custom to each co-operative: • Who can buy shares and how many • Partial shares for affordability | Anyone who buys shares is a *shareholder*. Custom to each public limited company: • Who can buy shares and how many • Mechanisms for affordability | Anyone who buys shares is an *investor*. Custom to each private limited company: • Who can buy shares and how many • Partial shares for affordability |
| Supervisory body | Village electrification committee (VEC) | Board of Directors | Board of Directors | Individual owner or Board of Directors |
| Mini-grid management | VEC (unpaid) + technicians (paid) | Board or hired staff | Hired staff | Hired staff |
| **Ownership processes** | | | | |
| Legal owner | No legal registration but recognised locally | Registered co-operative | Registered public limited company | Registered private limited company |
| Decision making | Representative consensus-building | One vote, regardless of numbers of shares | Votes can depend on number of shares | Owner makes decisions with investor inputs |
| Profit sharing | Communal needs are prioritised | Among all members, as per country-specific bylaws | Among all shareholders, as per country-specific bylaws | Among owners |

These community enterprise models, along with hybrid versions, can significantly enhance the long-term financial viability of small-scale hydro systems and the resulting socio-economic impacts. They help shift the mindset of communities towards maximising the utilisation of their pico, micro and mini hydro systems to sell electricity as well as increasing electricity-based services and products.

In addition to stand-alone operations, there are opportunities for community enterprises to benefit from connecting their small-scale hydro projects to the main grid and/or to each other. This may take place in situations where the main grid is being extended and/or where local demand has outgrown the capacity of a particular small-scale hydro system.

- ***Interconnection*** to the main grid is possible where appropriate government regulation exists for feed-in-tariffs. In such settings, several things may happen. In cases where electricity from the central grid is reliable and more affordable than electricity from the local mini-grid, generation plants have been abandoned, or the transmission and distribution lines are extended to communities that do not have access to the main grid but can afford to pay the tariff for electricity from the small-scale hydro system. In cases where the central grid is not reliable, communities tend to use both the central grid and the mini-grid. When the central grid is not affordable, communities typically continue the use of the small-scale hydro system. Yet another variant is the community distributing power to its own consumers before feeding into the main grid. In all cases, the sale of electricity to the utility generates income for the community, which can contribute to community funds for social welfare expenses (*e.g.* teachers' salaries, funeral expenses, climate adaptation). Small-scale hydro feeding into the main grid has been successful in Indonesia, Nepal and Sri Lanka (see Box 8).

- ***Project-to-project interconnection*** is when the transmission and distribution lines of multiple small-scale hydro projects are integrated into a single network for systems with excess power to sell electricity to meet the needs of systems that have been overloaded. The practice has been effectively implemented in Nepal, with up to seven mini-grids interconnected and sharing electricity to ensure 24-hour demand is met. The practice has also met with success in Malaysia and Nicaragua and is currently being developed for valley-scale hydro mini-grids in Pakistan.
- ***Project-to-project interconnection feeding*** into the main grid is the combined option of the above, where the transmission lines of multiple small-scale hydro projects are interconnected to form a larger mini-grid that is interconnected to the central grid run by the national or state utility. This practice has been successful in Nicaragua, while in Nepal and Pakistan technology for controlling the rate of power injected from each interconnected project into the main is being explored.

In all the above scenarios, community enterprise and grid interconnection are complementary in that most regulatory frameworks require mini-grids owned by user groups to convert to legal entities, such as registered co-operatives, public limited companies or private companies, in order to interconnect and sell electricity to the central grid or to neighbouring mini-grids.

**Box 8 ■ Practice to policy: Accelerating grid interconnection in South and Southeast Asia**

The arrival of the central grid poses a dilemma for mini-grid investors, including policy makers, project developers and beneficiary communities.

Grid interconnection was first piloted in the South and Southeast Asia region in Indonesia, by the People-Centered Business and Economic Institute (IBEKA). Over the last two decades, IBEKA has facilitated the interconnection of several community-owned projects, including the Cinta Mekar project in collaboration with the United Nations Economic and Social Commission for Asia and the Pacific using the Pro-Poor Public-Private Partnership (5P) approach (ESCAP, n.d.). In Sri Lanka, several micro hydro projects have been successfully interconnected to the main grid as part of a corporate social responsibility partnership between the utility, the communities and the NGO Energy Forum. In spite of the demonstrated success in these efforts, regulatory and financing challenges have prevented them from been scaled beyond several projects (Tenenbaum, Greacen and Vaghela, 2018).

During a South-South practice-to-policy exchange (HPNET, 2018), the key policy and technical actors of the piloted efforts, along with developers and government actors from contexts in need of grid interconnection regulations, were brought together in Sri Lanka, where the participants were able to visit an 18 kW community-owned micro hydro project that was generating community income thanks to the utility interconnecting to the main grid. The event inspired key actors from Nepal to move forward with their own commitment in 2014 to interconnect micro hydro projects to the main grid, followed by the development of a power purchase agreement in 2016 and the first interconnection of a micro hydro system to the central grid in 2018.

The pilot interconnection of a 23 kW community-owned micro hydro plant resulted in significant benefits both for the mini-grid and the central grid. The financial sustainability of the micro hydro plant drastically improved because by selling electricity to the central grid the micro hydro plant load factor rose from 25% to 77%. The reliability of the central grid increased.

With such measurable results, efforts thereafter have scaled to several interconnections under a new policy of the Nepal Electricity Authority allowing the interconnection of all micro hydro projects to the national grid (Mallik, 2018). At the time of writing, the Alternative Energy Promotion Centre (AEPC) and the Nepal Electricity Authority were jointly preparing the Integrated Master Plan for Minigrids, which has ranked 2 353 potential small-scale hydro projects on their functional status, plant capacity, age of plan, potential benefit to the utility, and socio-economic benefits, among other metrics.

With 10% of Nepal's 3 000 micro and mini hydro projects faced with the arrival of the main grid and/or power shortage as communities grow, main grid interconnection and cluster interconnection are now proven solutions to sustain the operations of the community-owned systems (Mallik, 2018). The efforts are being co-ordinated by the Renewable Energy for Rural Livelihoods (RERL) initiative at the Alternative Energy Promotion Centre, in partnership with the United Nations Development Programme. RERL's success in Nepal is an example for others in the region to use a multi-actor approach to push for demonstration and then scale-up of grid interconnection of small-scale hydro projects.

## 3.2 Enabling local service providers through affordable and reliable energy access

Small-scale hydro is a mature and fairly simple technology (IRENA and IEA-ETSAP, 2015), and unlike large-scale facilities that rely mostly on external material imports and expertise, such installations require a close knowledge of local geography and suppliers. Further, the implementation skills required are closely related to, and can be carried forward to, other infrastructure work; for example, the design and construction of hydrological structures built for micro hydro may be similar to design and construction used for irrigation services, and the design and upkeep of micro hydro electromechanical components are similar to the design and upkeep required in many other sectors that rely on motors and generators.

Because hardware can be manufactured locally (within a country, or even a city or village) and maintained by local actors, the development of projects represents an opportunity to enhance local skills, jobs and enterprise development. Policies and programmes that have prioritised capacity building to advance local expertise and to manufacture equipment locally in Indonesia, Nepal (see Box 9), Pakistan and Sri Lanka have not only resulted in accelerated rural electrification but have also enabled:

- local innovation for adapting equipment to local contexts, ensuring long-term technical sustainability of small-scale hydro systems;
- local manufacturing to achieve international quality standards, allowing them to increase profit by accessing foreign customers; and
- local job creation from a growing small-scale hydro sector, the injection of skilled human resources into related sectors, and local technical enterprise development – all directly benefiting local economies.

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Box 9 ■ **What went right: Sustainability versus dependence in Nepal's hydropower development**

Hydropower accounts for almost 100% of the electricity generated in Nepal and meets over 70% of the country's power needs, with the remainder imported from India. Nepal also has over 3 000 micro hydropower mini-grids supplying off-grid communities. Around half the hydropower on the grid is generated by independent power producers. The ecosystem of professionally skilled hydropower practitioners in the private sector, for both on- and off-grid systems, largely traces its origins to two pioneering centres. One, based in Butwal, started with the Butwal Technical Institute,[19] a vocational training school, and eventually developed into a complex of three complementary companies: Butwal Power Company, Himal Hydro, and Nepal Hydro and Electric. The other centre is at the BYS (Balaju Yantra Shala Pvt. Ltd.)[20] in Kathmandu, which provides both vocational training and installations of micro and small hydropower projects.

Established in the 1960s with technical capacity building from European expertise, BYS and the Butwal Technical Institute triggered the development of Nepal's homegrown hydropower manufacturing sector. They produced the country's first crossflow and Pelton turbines, which currently account for an estimated 80% of turbines in Nepal. Over the course of five decades, these institutions built power projects while producing or catalysing thousands of competent engineers and technicians, over a hundred active independent power producers, and dozens of construction and manufacturing companies and engineering consultancy firms. The key factors that accelerated the establishment and success of both organisations were a high demand for hydropower technology addressed by local capacity building and local finance.

Source: Gautam, 2020; Liechty, 2022.

19 The Butwal Technical Institute was established in 1963 by the United Mission to Nepal and was accelerated by the Butwal Power Company, which was established for development and operation of large hydropower (BTI, n.d.).

20 BYS was the first turbine manufacturer in Nepal, established in 1959 as a joint venture between the Swiss Association for Technical Assistance and the Nepal Industrial Development Cooperation. With support from the Swiss Association for Technical Assistance, BYS started with a focus on upgrading wooden waterwheels with efficient water mills, made possible with the use of micro hydro crossflow turbines. With milling a basic necessity, there was great demand for the efficient mills. BYS's efficient mills were in great demand and strengthened the company's financial resources to further innovate and build its capacity to add electricity generation to the milling sites. As BYS's capacity to develop hydro mini-grids accelerated so did its workforce number, many of whom later started their own small-scale hydro enterprises addressing specific niches to scale up the local sector's value chain (BYS, n.d.).


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Box 10 ■ **Facilitating South-South knowledge exchange**

The Hydro Empowerment Network (HPNET) is a knowledge exchange and advocacy platform to advance small-scale hydropower (< 1 MW) for climate-resilient and equitable rural development in marginalised regions of Asia-Pacific, Latin America and Sub-Saharan Africa. With over 150 members, the HPNET Secretariat facilitates a four-step approach to South-South exchange, as part of its accelerator programme Social Enterprise for Energy, Ecological and Economic Development:

***Collating best practices***. By documenting and collating local knowledge and experiences, HPNET has identified factors for sustainability and best practices from high-impact, long-lived hydro mini-grids to support all local practitioners and communities to maximise long-term, technical, environmental, institutional and financial sustainability of their hydro mini-grids.

***Ground truthing.*** HPNET is mapping stakeholder ecosystems in countries with low electrification rates and high potential for community-based hydro, identifying and assessing the work of local practitioners by means of in situ observations rather than remotely.

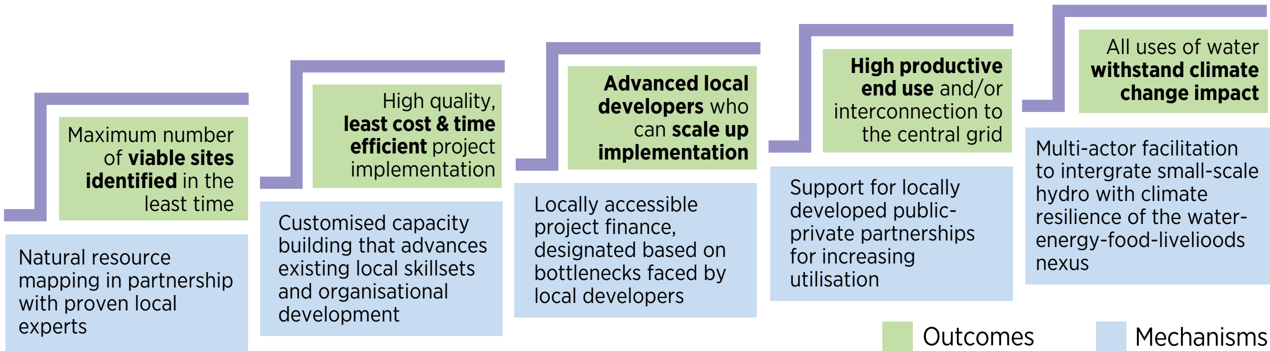
***Knowledge exchange.*** Technical and thematic capacity building is offered to localise large segments of the micro hydro value chain, including local manufacturing, and thereby improving sustainability and benefits for livelihood promotion. Peer-to-peer exchange among regions or common stakeholders is also offered. Impact-focused, customised capacity building is offered to especially promising local practitioners.

***Strategic advocacy.*** Gaps and opportunities for resource mobilisation are being identified for high-potential, high-need contexts, towards facilitating partnerships between local practitioners and decision makers to achieve access to finance for project implementation, productive end-use application, and solutions for climate resilience, such as watershed strengthening through catchment area restoration to reduce the impact of droughts and floods on hydro mini-grid infrastructure.

Source: HPNET, n.d.

When development programmes integrate local technical capacity building with natural resource mapping, local multi-actor ecosystem development and locally accessible financing for project implementation, utilisation and catchment area restoration, the result is accelerated deployment with lower costs, higher reliability, greater local job creation and optimal socio-economic benefits, as in the case of Nepal (see Figure 19).

Figure 19 ■ **Mechanisms to enable and scale up local practitioners in small-scale hydro development**



## 3.3 Gender-sensitive approaches

The lack of access to modern energy affects women and children disproportionately. Depending on the choices made, the availability of resources from small-scale hydro watersheds can decrease women's burdens and vulnerabilities. For instance, availability of electricity, irrigation, drinking water and food have a significant impact on women, due to their traditional roles of cooking, carrying water and fuelwood, working in the fields and hills, and caring for other family members (IRENA, 2016).

Small-scale hydro can help in the advancement of gender equality and the empowerment of rural women as leaders and economic agents of change, thereby transforming local economies and generating inclusive growth. Across South and Southeast Asia, hydro mini-grids have enabled a reduction in women's physical drudgery, increased their time for rest and leisure, provided new opportunities for income generation, and offered improved health and safety. In Pakistan, the AKDN has observed how girls and women in communities electrified with mini hydro are able to study at night, since during the day they have household responsibilities.

Household cooking with firewood has been replaced with electric cooking. The AKDN has provided 110 girls schools that are powered by small-scale hydro with satellite-based internet, providing strategic gender empowerment in remote areas of northern Pakistan (AKDN, 2014). In Indonesia, Myanmar and Nepal, hydro mini-grids have enabled rural health facilities to provide infant delivery services in the community, alleviating the need for pregnant women to travel long distances. Such benefits for women can be generated using gender-sensitive approaches to small-scale hydro implementation, utilisation and climate adaptation, which in turn benefit the sustainability and effectiveness of the project (see Table 9).

Table 9 **Differences between typical and women-centric approaches to small-scale hydro**

| | | Typical approach | Women-centric approach with benefits for the project |
|---|---|---|---|
| Implementation | Feasibility | There is a minority representation of women in the project governing body. | All women are invited to feasibility activities and provided an equal voice in decision making.<br>» Leads to accelerated cohesion of the community required for the project. |
| | Planning & procurement | Women are not consulted in planning of implementation milestones (*e.g.* scheduling of construction activities). | Representatives of women from all social groups provide strategic inputs in planning.<br>» Leads to timely milestone achievements. |
| | Installation & connection | Women provide physical labour but are not aware of how the system works. | Women's expertise is prioritised for skilled roles (*e.g.* surveyors, masons) and facilitated to provide all women in the community working knowledge on how the hydro system works.<br>» Leads to more women supporting the project installation. |
| | Operation & maintenance | Because women do not know the basic components of a system and key aspects of troubleshooting, yet are heavily impacted by power cuts, they create pressure for the governance body to maintain the system. | Women are able to understand how the technical system works, contribute to management of financial accounts and other governing aspects by having an equal or majority women-men ratio in the governing body.<br>» Leads to women supporting troubleshooting and governance aspects for reliable operation. |
| Utilisation | | Women are not involved in the demand assessment for productive end uses and not provided capacity building to use electricity for existing and new livelihoods. | Starting from project feasibility, women are prominently involved in envisioning the utilisation of the project and the potential socio-economic impact at the household level, including load estimation, contribution, payment plan, and tariff decision and collection.<br>» Leads to women purchasing machines to use with existing productive end uses and requesting training to learn new end uses, thereby increasing the plant load factor and financial viability. |
| Climate adaptation | | The community is not motivated to undertake climate adaptation activities, resulting in reduced water flows and limited operation of the plant. | The connection of rural women to forests is leveraged by understanding women's viewpoints on solutions to ensure water flows remain consistent with climate change.<br>» Leads to women mobilising the community for forest restoration activities and playing a leading role in protecting existing forests. |

In terms of implementation, especially in larger communities, women from different social groups play an important role in unifying the community. Yet in terms of implementation decision making and governance, women from the beneficiary community are often excluded and limited to providing labour. A large pay gap is well known to exist in the engineering roles across the sector (IRENA, 2019). The gender imbalance in the sector needs to be redressed, such as through partnerships between hydropower companies and universities, mentoring schemes with other women in the sector, and promotion of gender-sensitive workplace practices, such as parental leave.

In terms of utilisation, women can be trained and educated in the use and maintenance of electricity services, since they are the ones who most frequently use electricity in the household. The AKRSP in Pakistan has enabled women to become the primary shareholders of the project and productive end-use enterprises (see Box 11). In addition, community-based organisations, NGOs and relevant government organisations that support small- and medium -sized enterprise can join the project from the start of its development to enable existing and potential women-empowering businesses.

Box 11 ■ **Women-centric mini hydro utilities in northern Pakistan**

Since initiating small-scale hydro projects in rural Pakistan in the 1980s, the Aga Khan Rural Support Programme (AKRSP) has iterated its approach to increase the technical and economic sustainability of hydro mini-grids, as well as the socio-economic benefits generated by the projects. The AKRSP's micro hydro projects provide electricity to one or a few villages, while its mini hydro projects electrify entire valleys with many villages in the remote region of Chitral in northwest Pakistan, with up to 1 500 households per system.

Central to the AKRSP's mini hydro approach is the community utility company model (see Section 3.1), in which each electricity generation and distribution enterprise is registered as a public limited company under the 1984 Companies Ordinance of the Securities and Exchange Commission of Pakistan. Each community utility is established with all beneficiary households as shareholders (typically 1 000 to 1 500), with the AKRSP and international development partners as co-investors for seed funding. The enterprise has a Board of Directors for governance and a management body led by a CEO for day-to-day management.

The AKRSP facilitates each community utility to set commercial and social objectives, including enabling women beneficiaries to lead and earn by being Board members, shareholders, operations staff and/or productive end users of the mini hydro enterprise. As Board members women develop governance policies, including tariff setting, and as shareholders they directly earn dividends. Women also make significant contributions as operations staff, managing tariff collection and raising awareness on increasing end use. The AKRSP provides frequent training and seed funding opportunities for women consumers to use the mini hydro for income generation, including carpentry training, craft development and other commercial end uses. The AKRSP has established over 200 micro and mini hydro systems providing electricity to 33 000 households, of which seven are community utilities with 8 300 connections.

Source: HPNET-SEEED, 2021; Khan, 2019.

In terms of catchment area restoration for climate adaptation, the knowledge and experience of indigenous women often extend to a range of watershed management and agriculture-related work and practices. Community hydro watershed efforts show that watershed management is most effective when women are leading and co-ordinating the process. Their knowledge of soil, plant and pest management, seed preparation, and post-harvest processing and storage has contributed to the development of sustainable traditional farming systems in many regions, while providing subsistence to their families and the community.

Designing policies to maximise local benefits from the deployment of small-scale hydropower requires a deep understanding of the input requirements. The following section provides a detailed assessment of the different value chains derived from the deployment of small-scale facilities (implementation, climate adaptation and utilisation). It provides a detailed assessment of the requirements in terms of labour, skills, materials and equipment for different capacities (*i.e.* pico, micro and mini). The assessment focuses on the core segments of the value chain – feasibility, planning and procurement, manufacturing, installation and connection, operation and maintenance, and decommissioning of small-scale hydropower – but also provides an overview of what would also be required for the utilisation and climate adaptation value chains, and what benefits they would bring to communities.

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# 4. CONCLUSIONS AND POLICY RECOMMENDATIONS

Renewable sources of energy are key for the unfolding energy transition, not only in supporting climate goals and other environmental protection objectives but also in increasing energy security, reducing reliance on fossil fuels and, more crucially in the case of small-scale hydropower, enabling energy access to communities. Greater energy access can improve livelihoods, community economic growth, employment opportunities and human welfare. Domestic value creation can be maximised by leveraging and enhancing capabilities in existing industries along the value chain or developing such capabilities.

In parts of the world where hydrological and topographic conditions are suitable, generally mountainous and hilly regions with reliable rainfall, mini-grids powered by small-scale hydropower are particularly well suited to provide energy access to communities in remote rural areas to improve their resilience to climate change and increase livelihood opportunities. Among the different distributed renewable energy solutions suitable for improving energy access, small-scale hydropower provides opportunities to develop local capacity and relies on local capacity development to be successful.

## 4.1 Opportunities for local capacity development and job creation

Small hydropower presents opportunities for local job creation at every stage of its development. Compared with solar energy and wind power, small hydropower requires the largest share of on-site civil works construction, and many of its key electrical and mechanical components can often be manufactured locally, even in countries with only basic industrial infrastructure. Civil works require local capacity for site surveying, design and construction of the intake, de-silting and water conveyance structures, installation of the penstock pipe, and construction of the powerhouse. Civil works also provide communities with opportunities to contribute in-kind labour for transportation of construction materials and masonry. In-country manufacturing of sluice gates, penstock pipes, manifolds and water turbines requires leveraging and building the capacity of local metal workshops. On the electrical side, while generators might need to be imported in many countries, there are opportunities for workshops to manufacture control panels and electronic load controllers in-country. This report has outlined the person-hours of local skilled and unskilled labour required at each step to properly design, construct and operate small hydropower projects of a range of sizes.

In countries with national capacity for design, manufacturing and construction, small hydropower projects are often able to provide electricity at prices comparable to the grid or lower. Small hydropower can operate without battery storage. Without the need to amortise the cost of chemical batteries, the operation of small hydropower facilities is almost free. The ability to operate 24 hours a day results in the production of a large amount of energy, which may be able to be sold during off-peak hours at lower tariff. Affordable tariffs are key to the feasibility of a range of productive uses, which have the potential to significantly improve livelihoods and generate employment in rural areas. At the same time, additional energy sold increases the income of the power plant without significantly increasing operational costs. Small hydropower projects thus have both the opportunity and a very clear incentive to actively promote productive uses and increase their own utilisation factor through the provision of flexible tariffs. This report outlines the local capacities that can be leveraged both from inside the communities supplied by small hydropower and from outside to invest in and operate enterprises that can be powered by small hydropower projects.

The sustainable operation of all hydropower projects depends on the conservation of the watershed that supplies them. In the case of small-scale hydropower projects, the community also depends on the same watershed for many other services such as community drinking water, irrigation, fuel and fodder, and livelihoods related to non-timber forest products. By themselves investing in the protection of watersheds and mobilising the community to do the same, small-scale hydropower projects become an important nature-based solution for both climate mitigation and adaptation. This investment leverages the capacity of the community and generates jobs as well as contributing to strengthening communities' resilience to climate change.

## 4.2 Need for local capacity development

Small-scale hydropower can rely on in-country capacity development for its success more than other renewable energy technologies, such as solar and wind. The examples provided in this report show that small-scale hydropower has been successful in countries such as Afghanistan, Indonesia, Nepal, Nicaragua, Pakistan, Peru and the Philippines, where significant investment has been made over the past four to five decades to develop local capacity in all aspects of small hydropower development. The resulting capacity in survey, design, installation and manufacturing of components is responsible for these countries being able to install and operate thousands of small-scale hydropower projects. Myanmar is an exception in that the capacity was generated by practitioners from within, given the relative isolation of the country in this time period. The small-scale hydropower projects in these countries power agri-processing and other productive end uses and, in many cases, have been able to mobilise the communities they serve to contribute to protecting the watersheds.

Attempts at expansion of the small-scale hydropower sector to new geographies, such as Sub-Saharan Africa, have often been unsuccessful when they do not incorporate the need to invest in local capacity development. Bringing in expertise from outside the country to survey, design and install individual projects, along with importing key components such as turbines, penstock pipes and electronic load controllers, has resulted in expensive projects and has lost the advantages of small-scale hydropower generating jobs in its development and promoting a range of productive end uses. It is critical to provide resources for training local experts and transferring expertise to in-country workshops for local manufacturing of turbines, electronic load controllers and other components.

Therefore, to maximise the domestic value created in the development of small-scale hydropower, policies and measures are needed to first stimulate social acceptance and to then enhance community capacity along the value chain. For the deployment of small-scale hydropower, it is critical to invest in a social ecosystem that can encourage technical solutions customised to livelihood requirements while also providing funding, capacity and skills, market access, and policy support to fully realise the benefits of decentralised renewable energy. Some key actions to achieve this are:

- **Gather up-to-date data:** Data gathering on the potential of small-scale hydropower to supply the energy needs of communities is key to attracting investment. Climate change also poses a threat to the reliability of small-scale projects; therefore, proper data are needed to ensure the plants will be able to run efficiently and mitigate the impacts of climate change. Available data on the economic and exploitable potential are scarce and do not always account for current policy frameworks, technological advancements and the possibility to engage communities in the process.

- **Promote public awareness, acceptance and community commitment:** The social and environmental costs of large-scale hydropower may colour perceptions of small-scale hydropower, thus limiting its appeal. It is important to highlight the advantages of small-scale hydropower as a solution to community electrification and inclusive sustainable industrial development. Measures to enhance community awareness of the benefits of small-scale hydropower are key to overcoming non-economic barriers. Local practitioners and government can jointly promote the benefits of small-scale hydropower through information and awareness campaigns and seek community engagement.
- **Encourage stakeholder engagement:** An effective social ecosystem can only be created with the participation of key stakeholders, including local or national governments; financing institutions ranging from international donors to intermediaries and local banks; businesses focused on energy and other livelihood areas; and NGOs to act as incubators, advocates and so on. For that, planning should include a mapping of stakeholders across livelihood value chains and establish partnerships to support the integration of small-scale hydropower and enable access to markets, new skills and capacity to maximise benefits for local enterprises.
- **Support small hydropower development through policies, regulations and incentives:** Although many countries have renewable energy policies, financial incentives and targets, they sometimes favour other technologies and do not apply to small-scale hydropower. The policy framework should give more attention to and protect the development of small-scale hydropower, which is often located in remote areas without access to the local grids. National electrification plans need to more fairly consider how small hydro offers solutions in terms of costs compared with other solutions, the higher tiers of access small hydro can provide, the existing ecosystems available in certain countries (*e.g.* developers, turbine manufactures), and the non-energy benefits. Incentive policies tailored to a country's specific needs increase banking institutions' and facilitators' confidence, which may result in more significant investments. Additionally, there is a need to simplify bureaucratic procedures. Long, complicated administrative permit processes are costly, difficult to navigate for untrained actors, and can result in significant delays during project implementation and discourage investors and communities.
- **Mobilise financing mechanisms for local service providers:** Despite the benefits outweighing the initial costs, small-scale hydropower is still often perceived as high risk by private investors. As a result, the deployment is limited in some cases to grants or soft loans from multilateral or bilateral donors, which does not represent a sustainable financing model. There is a need to facilitate the access to early-stage high-risk financing and platforms for experience and knowledge sharing. Additionally, a broad mix of policies and measures are needed to ensure the competitiveness of domestic firms. These include efforts towards industrial upgrading and supplier development as well as the creation of associations and networks among importers, producers and sellers.
- **Expand local capabilities and skills development:** Education, training and retraining initiatives are needed to meet the occupational and skills requirements of small-scale hydropower. Vocational training centres, especially in rural areas, could play a critical role in skilling workers to overcome local skills gaps that may exist. Prospects for local employment would be boosted by training programmes and certification schemes for required occupations, as well as by productive end-use activities. Moreover, involving women and men equally in the employment opportunities along the various segments of the value chain would leverage an opportunity for gender empowerment and improve livelihoods.

- **Facilitate South-South, peer-to-peer learning:** While developing contexts of South and Southeast Asia, Sub-Saharan Africa, and Latin America have all had small-scale hydro development for several decades, the scale-up and mainstreaming of the sector has varied in the last two decades. Due to extensive donor investments in local capacity building, the sectors in South and Southeast Asia have had success in scaled-up implementation, while in Sub-Saharan Africa and Latin America the number of initiatives remains small, with opportunities nascent or not yet identified. There is extensive demand for South-South exchange between Asia-Pacific and Sub-Saharan Africa practitioners. There is also much to learn from the Latin American contexts, as the level of documentation and South-South engagement there has been minimal.
- **Empower women and youth:** The lack of access to modern energy affects women and children disproportionately. Small-scale hydro can help in the advancement of gender equality and the empowerment of women as economic agents of change and leaders, thereby transforming economies and generating inclusive growth. Integrating a gender lens can help remove barriers for women participating in the deployment of small-scale hydropower or in productive end uses. In that context, it is critical to facilitate access to finance and to develop skills and mentorship programmes for women. The success of women-owned enterprises could be a role model for other women, who would be encouraged to become entrepreneurs. Similarly, the involvement and capacity building of community youth to become local practitioners of small-scale hydro can lead to accelerated implementation and technical sustainability.

The various measures presented here need to be tailored to each context, reflecting specific circumstances (*e.g.* policy and regulatory frameworks, financing landscape, skills and capacity, existing plans to facilitate access to grid). Poorly selected and structured measures can set back small-scale hydropower development. An assessment of existing resources including labour, materials and equipment should be mapped against the requirements in each segment of the value chain. Based on such analysis, opportunities for leveraging local labour markets and existing industries can be identified and policies and measures can be introduced to strengthen local capacities and maximise domestic value. The detailed look at value creation opportunities presented in this report can serve as a starting point for designing policies appropriate for each case.

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# ANNEXES

## Annex A. Classification of hydropower according to capacity

The classification of the scale of a hydropower plant simply relates to the electricity production capacity expressed in megawatts (MW). However, specific classifications vary from country to country as there is currently no consensus among countries and hydropower associations regarding the upper limit of what constitutes small-scale capacity. For instance, some European Union countries like Belgium, Greece, Ireland, Portugal and Spain accept 10 MW as the threshold between small and large systems, while others place the maximum capacity from 3 to 1.5 MW. Outside the European Union, this limit can be much higher, as in the United States (30 MW) and India (25 MW).[21] For the purposes of this report, the cut-off is 10 MW.

Below that threshold, small-scale hydropower can be broken into subcategories of pico, micro, mini and small hydropower (see Table A.1).

Table A1 ■ **Applicability depending on power output**

| Type | Capacity | Applicability |
|---|---|---|
| Large | > 10 MW | Large urban populations |
| Small | > 1 and < 10 MW | Small communities with the possibility of supplying electricity to the national grid |
| Mini | > 100 kW and < 1 MW | Small factory or isolated community |
| Micro | > 5 kW and < 100 kW | Small isolated community |
| Pico* | < 5 kW | Few to several households, depending on load per household (see Table A.2) |

* For the purpose of this publication, the analysis dives into pico, micro and mini hydro capacities, as they have particular merit in leveraging local c apacities; pico hydro is considered as ≤ 5 kilowatts.

Source: Adapted from Carrasco, Pain and Spuhler, 2019.

This report focuses on capacities below 1 MW. To help contextualise, Table A.2 provides possible scenarios on maximum numbers of households for each capacity, assuming simultaneous usage of loads.

Table A2 ■ **Illustrating consumption and system capacities of different load scenarios for small hydro**

| Simultaneous load scenarios | Pico hydro ≤ 5 kW | Micro hydro > 5 kW and < 100 kW | Mini hydro > 100 kW and < 1 MW |
|---|---|---|---|
| | Maximum number of households for simultaneous use | | |
| **Basic household use**<br>100 Watts<br>3 LED points, cell phone, small TV | 50 | 1 000 | 10 000 |
| **Household use with electric cooking**<br>1 500 Watts<br>3 LED points, cell phone, TV, rice cooker | 3 | 66 | 66 |
| **Household use with electric cooking & small appliances**<br>2 500 Watts<br>LED points, cell phone, TV, rice cooker, blender | 2 | 40 | 400 |
| **Household use with electric cooking, small appliances, and productive end use**<br>5 000 Watts<br>LED points, cell phone, TV, rice cooker, blender, carpenter's saw | 1 | 20 | 200 |

21 Carrasco, J.L., A. Pain and D. Spuhler (2019), "Hydropower (small-scale)", Sustainable Sanitation and Water Management, https://sswm.info/water-nutrient-cycle/water-distribution/hardwares/water-network-distribution/hydropower-%28small-scale%29

# Annex B. Implementation value chain: Factors for variation in duration and costs

Table B1 ■ **Small-scale hydropower implementation phases, average duration and project-specific factors impacting duration, person-days and costs**

| Implementation phase, activities and average duration | Factors impacting duration |
|---|---|
| **Phase 1: Feasibility,** 5 kW (0.5 months); 50 kW (6 months); 500 kW (12 months) | |
| a Site identification<br>b Pre-feasibility study of the site<br>c Feasibility study of the site<br>d Technical design, bill of material, bill of quantity, work plan and budget<br>e Financial and socio-economic viability analyses<br>f Securing finance | • Ease of access to the site for feasibility study<br>• Availability of reliable rainfall data, topographic map, and multiple spot measurements<br>• Size of the catchment area<br>• Options for civil structure locations<br>• Availability of skilled personnel<br>• Ease of access to finance<br>• Interest of the beneficiary community to commit |
| **Phase 2: Planning & procurement:** Ongoing through installation and connection | |
| a Human resource hiring<br>b Tenders and service contracts<br>c Purchase orders (by developer)<br>d Cash flow planning and accounting<br>e Monitoring and evaluation<br>f Transportation to the site<br>g Accommodation at the site<br>h Social governance framework | • Ease of access to the site for transporting raw material and equipment<br>• Timeline alignment between funder payments and procurement milestones<br>• Availability and cost of raw material and off-the-shelf components, vehicles and drivers for transporting supplies over dirt roads, and unskilled labour in remote locations for unloading equipment<br>• Mobilisation of the beneficiary community |
| **Phase 3: Manufacturing of custom components:** 5 kW (0.5 months); 50 kW (3 months); 500 kW (6 months) | |
| For the local fabrication of custom components required for the civil works, electromechanical system, turbine assembly, controller system, transmission and distribution lines, and house wiring components:<br>a Site visits<br>b Drawings for fabrication and assembly process<br>c Fabrication bill of material, bill of quantity, and work plan<br>d Purchase orders (by local manufacturer)<br>e Machining of components<br>f Assembly and testing<br>g Finishing and painting | • Ease of access to the site to collect design measurements<br>• Availability of raw material<br>• Capacity of the fabrication facility<br>• Consistent availability of machinists<br>• Whether any fabrication processes require outsourcing |

| **Phase 4: Construction & installation:** 5 kW (1 month); 50 kW (6 months); 500 kW (12 months) | |
|---|---|
| On the site:<br>a Capacity building of village-based stakeholders (unskilled labour, masons, operators, linesmen, governance body, *etc.*)<br>b Construction of civil work structures (*i.e.* weir, channel, forebay tank, penstock anchor blocks, powerhouse, and transmission and distribution poles)<br>c Installation of all components, (*i.e.* penstock, manifold-valves-turbine-generator system, load controller, electrical protection, transmission and distribution lines, and wiring)<br>d Testing and commissioning of the full system | • Ease of access to the site for transporting raw material and equipment<br>• Extent of manual labour required for material transport<br>• Width of the weir<br>• Length of the channel<br>• Penstock length and whether it will be buried<br>• Size of the powerhouse<br>• Turbine selection impact on powerhouse design<br>• Whether households are scattered or densely located<br>• Professional and effective management of installation and connection<br>• Self-co-ordination of the community to provide unskilled and skilled labour, including masons<br>• Possibilities of social conflict related to construction aspects<br>• Availability of experienced persons to train operators and to test and commission the system<br>• Whether management team is managing a single project or multiple projects in parallel |
| **Phase 5: Operation & maintenance:** Ongoing through project utilisation | |
| a Operation of the system<br>b Maintenance<br>c Troubleshooting | • Ease of access to the powerhouse, including after nightfall<br>• Quality of the design and installation for reliable system operation<br>• Operation and maintenance of the specific turbine type<br>• Extent of operational issues (*e.g.* short repairs or extensive troubleshooting and rehabilitation)<br>• Frequency of required repairs |

# Annex C. Role categories

Table C1 ■ **Role category disaggregation**

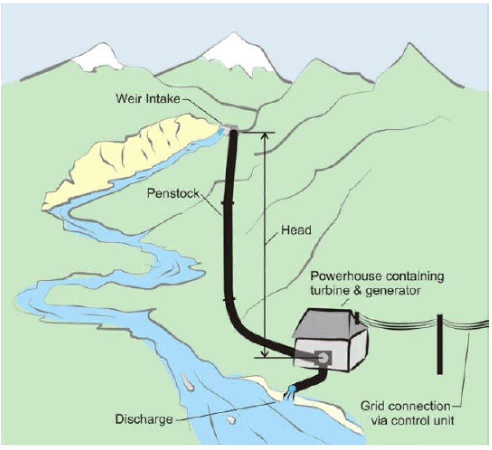
| | |
|---|---|
| **Administrative and finance personnel** | Accountant |
| | Administrative personnel |
| | Finance co-ordinator |
| **Contracts and procurement personnel** | Contracts co-ordinator |
| | Procurement co-ordinator |
| **Drivers** | Driver – heavy vehicle |
| | Driver – light vehicle |
| **Project manager** | Project manager |
| **Design engineers** | Design engineer – civil works |
| | Design engineer – electromechanical system |
| **Drafters** | Drafter for engineering drawings |
| **Site engineers** | Site engineer for civil works |
| | Site engineer for electromechanical system |
| | Site engineer – manufactured components for civil works |
| **Surveyors** | Topographic surveyor |
| **Electricians** | Electrician |
| **Unskilled labour** | Labour for lifting / loading and construction |
| **Machinists / fabricators** | Machinist – gas cutter |
| | Machinist – drill operator |
| | Machinist – general |
| | Machinist – grinder operator |
| | Machinist – lathe operator |
| | Machinist – PCB fabrication (skilled labour) |
| | Machinist – roller operator |
| | Machinist – special skilled persons |
| | Machinist – welder |
| | Machinist – spray painter for electromechanical components |
| **Technicians** | Penstock technician |
| | Technical helper |
| **Masons and skilled labour** | Masons |
| | Skilled labour – miscellaneous |
| **Operators** | Micro hydro operator |
| **Agronomists** | Agronomist |
| **Community mobilisers** | Community mobiliser |
| **Environmental impact assessor** | Environmental impact assessor |
| **Village electrification committee** | Includes manager, accountant, meter reader, secretary |
| **Local logistics personnel** | Village lodging person (cook, cleaner, *etc.*) |

## Annex D. Technical overview and components of small-scale hydropower

Small-scale hydropower systems can use one of three solutions for generating power from water: diversion channel type, hydro kinetic, and vortex systems. Diversional channel type systems use small civil structures to divert the flow of stream at sufficient head into the penstock connected to the turbine. The tailrace is placed such that the water flows back into the original source (see Figure D.1). These systems have the highest generation potential and not surprisingly are the most implemented. Hydro kinetic systems are those placed in large water sources, such as tidal hydro systems. They are typically low head and the have the least generation potential. Vortex systems are modular and can be submerged or suspended over the vortex; however, they require special site conditions and are not as common. This publication focuses on the **diversion channel type** used for pico, micro and mini hydro.

**Built infrastructure components** of the diversion channel type system (see Figures D.1 and D.2) include:

Figure D1 ■ **Diversion channel type micro hydro**




Source: *www.gov.scot/publications/report-small-scale-hydro-plant-machinery-review/pages/4/*

Figure D2 ■ **Components of a sustainable hydro mini-grid**


- Upstream civil structures, including the weir (or intake) that diverts the stream into a channel (or canal) connected to the forebay tank, and accessories (*e.g.* gates and valves)
- Penstock to route the water from the forebay tank to the manifold of the turbine assembly
- Power generation equipment in the powerhouse: the turbine assembly (including manifold, valves runner, shaft, housing, and accessories), generator, drive assembly (connecting generator and turbine), and load controller
- Power distribution: transmission, distribution, and house wiring equipment

The upstream civil structures and penstock alone can be used for water irrigation and management purposes. The entire system, including the civil structures, penstock, power generation system and power distribution network, is referred to as a hydro mini-grid.

In additional to the built infrastructure, the technical function of a small-scale hydro system is dependent on the natural environmental features at the specific site, particularly the watershed and the hydro mini-grid catchment area. As precipitation occurs over a land area, the watershed in the terrain drains off the water into rivers, streams, lakes and/or underground water sources (see Figure D.3).

The catchment area is a part of the watershed located between its upper boundary and a specific point of interest in the watershed, such as the weir of a hydro mini-grid, an irrigation system or drinking water infrastructure. The concept of a catchment area is critical to hydro mini-grids because it is where the flow of water required to generate electricity is sourced.

Because the power output of any hydro mini-grid depends on the head and flow defined by a specific catchment area, the design and installation of the civil works, penstock, power generation system and distribution network must be customised, making local knowledge and local capacities critical throughout implementation and operation.

Figure D3 **Precipitation absorbed by the watershed, through specific catchment areas**


Source: Berks Country Conservation District, 2023.

The ability of the catchment area to either absorb precipitation or produce run-off depends on the structural resilience of its terrain, which greatly benefits from the presence of healthy forests. Forested watersheds sustain stream flow during the dry seasons, ensuring consistent power generation from the hydro mini-grid, as well as a reliable water source for irrigation, sanitation and other rural needs. During wet seasons, dense forests prevent erosion and mudslides, known to devastate rural infrastructure. Further, sustainable forests can allow for forest-based food security and rural livelihoods that enable additional income, jobs and enterprise from access to electricity (*e.g.* local processing of agri-forest products for a higher selling price). Finally, strengthening forests is a primary solution to capturing greenhouse emissions and prevents emissions caused by deforestation. In these ways, small-scale hydropower is a nature-based solution that can produce co-benefits for climate-resilient rural development.

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