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Sub-Saharan Africa: Quality Infrastructure for Renewable Energies in the Context of Climate Change

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On behalf of

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On behalf of the Federal Government of Germany, the Physikalisch-Technische Bundesanstalt promotes the improvement of the framework conditions for economic, social and environmentally friendly action and thus supports the development of quality infrastructure.

Demand for Quality Infrastructure Services for Climate Change Mitigation and Adaptation to Climate Change in Sub-Saharan Africa

1. Current trends in the sector in times of climate change (global and regional)

Renewable energies play a key role in climate change mitigation efforts worldwide and can support a country's energy self-sufficiency (IRENA 2013:9). This is particularly important in developing and emerging countries which have a growing population, increasing electricity needs and low electrification rates. Moreover, some renewable energy technologies such as solar photovoltaic, solar thermal and mini-hydropower installations are well adapted for distributed generation and can support the electrification of rural areas (Agostinelli 2017).

Energy demand in Africa has grown by over 45 % since the year 2000 and electrification efforts in many countries cannot keep up with population growth. Energy supply thus remains low, despite the wealth of energy sources available on the continent. The main issues in Africa's energy sector are the insufficient capacity and low access to electricity, the poor reliability of the electricity grid and high costs (Agostinelli 2017). It is expected that energy demand will increase substantially in the coming decades as a result of megatrends such as urban population growth and economic development (EUEI PDF 2017).

Sub-Saharan Africa has great potential for renewable energies. As early as 2010, 60 % of energy was generated with hydropower plants in the region and several countries have conducted resource assessments and identified potential for solar power, additional hydropower installations, wind energy, biomass and, in Eastern Africa, geothermal energy (IRENA 2013:6-9). In many countries, renewable energies are also competitive in financial terms. In Kenya and Tanzania, for example, the generation costs of solar photovoltaic and biogas are similar to electricity costs from the public grid for commercial and industrial use, and are considerably lower than electricity generated with diesel (Kaiser 2017).

There is also support on the political level. Internationally, the Paris Agreement provides a policy framework for the advancement of renewable energies and fosters technical assistance and investments in African countries to support climate change mitigation measures. Within the framework of the Agreement, national governments submitted climate action plans along with regions and cities in Sub-Saharan African countries. These plans include the expansion of renewable energies (Munang and Mgendi 2016; EUEI PDF 2017:6). As early as mid-2015, before the Paris Agreement was signed, 35 Sub-Saharan African countries had introduced national renewable energy targets in at least one of the following areas: primary energy supply, final energy consumption, electricity, heating and cooling, and transport (IRENA 2015d).

Furthermore, the Africa Renewable Energy Initiative (AREI) was established to accelerate the expansion of renewable energy capacities across the continent under the mandate of the African Union. The aim of the initiative is to install 10 GW of renewable energy capacities by 2020 and generate 300 GW from renewable sources by 2030 (AREI 2017).

The achievement of the national and regional targets is challenging because, in most Sub-Saharan African countries, a favorable policy and an economic and institutional framework still need to be created; at the same time, the different stakeholders need to coordinate and commit to the targets to enable the expansion of renewable energy capacities (Interview 1). Moreover, at present, administrative hurdles, corruption and aspects such as unclear property titles make the expansion of renewable energies difficult. These circumstances delay the development of renewable energies and can result in considerable deadline pressure once the implementation is underway; this, in combination with cost pressure, can compromise the quality of renewable energy installations, especially if experience with renewable technologies is still limited. The development of solar photovoltaic, for example, is recent in many countries in the region. For this reason, qualified service providers are lacking and services need to be improved. This leads to quality and safety issues – for example, in the installation of rooftop photovoltaic systems. As has been experienced in other developing and emerging economies, the fast development of the technologies in the global market makes it difficult for local industries to keep up. At the same time, capacities to effectively control the quality of imported renewable energy technologies are often lacking. Some countries decide to protect their local industries through local content laws or customs duties, thus creating trade barriers and a national market with limited incentives to be competitive concerning quality (Telfser et al. 2016). Negative experiences with new technologies can damage their reputation and make investors reluctant to support further projects (IRENA 2015b:8).

2. Significance of quality infrastructure services

As mentioned above, the achievement of national targets is jeopardized by lacking quality due to insufficient coordination between different stakeholders, by lacking quality assurance, capabilities and capacities of the local industry and service providers, and by time constraints. The establishment of a functioning quality infrastructure is thus essential if the expectations of policy makers, investors and consumers are to be met. Quality infrastructure services help to increase the quality and safety of renewable energy installations and provide consumers with confidence in this technology. Quality assurance and support services are necessary throughout the value chain.

The International Renewable Energy Agency (IRENA) has identified several benefits of a functioning quality infrastructure for policy makers, manufacturers, professionals and end users. For policy makers, quality infrastructure enables the detection of low-quality products, which allows growing markets to be protected and strengthened and economic growth to be stimulated. Moreover, it helps provide assurance that the renewable energy installations will perform according to expectations, thus supporting the financial viability of the technologies and increasing the return on investment, including that of public incentives for renewable energies. For manufacturers, quality infrastructure can open new markets if locally provided quality infrastructure services are internationally recognized and prove the quality of local products. Through testing and certification, as well as through the implementation of a quality management system in accordance with international standards, products and manufacturing quality can be improved. For the renewable energy industry, certification (for instance, of installers) facilitates hiring processes and improves the competitiveness of service providers. This, in turn, results in higher wages and more mobility for professionals and attracts talent to the industry. Finally, for end users, a functioning quality infrastructure creates confidence in products and allows products to be compared based on trustworthy third-party information on performance and durability. Quality infrastructure also increases confidence of financial organizations and investors in technology, making more financial resources available for the sector (IRENA 2015b:8-13).

3. Identification of sub-sectors relevant in Sub-Saharan Africa

The selection of renewable energy types for this study is based on an evaluation of their relevance for the energy supply in Sub-Saharan Africa at present and in the future, the relevance of quality infrastructure services for the technology throughout the value chain and their relevance for socio-economic development.[1]

Solar photovoltaic is starting to be developed across Africa, with some countries including South Africa and Kenya making sizable investments in this technology. According to projections by the International Renewable Energy Agency, this technology is poised to grow considerably: Its application in solar home systems and mini-hybrid grids makes solar photovoltaic an interesting option for rural electrification. Photovoltaic power plants themselves, as well as their manufacturing, installation and maintenance, have important positive socio-economic impacts. Quality infrastructure services are essential throughout the value chain. All solar photovoltaic technologies and installations of all sizes, including grid-connected ground-mounted and rooftop plants, as well as small-scale off-grid systems are considered in the study.

Hydropower is currently one of the main renewable energy sources in Sub-Saharan Africa, yet only a fraction of its existing potential is in use. The possibility of installing large-scale as well as mini- and micro-hydropower plants makes it an interesting option for urban as well as rural electrification. Quality infrastructure services are relevant in manufacturing, planning, construction and operation of the plants. This study considers hydropower installations of all sizes and designs.

Solar thermal power is applied to a limited extent at the moment, but is projected to gain in importance in the future for application in both buildings and industry. Manufacturing and installation require low technology investments, creating development opportunities for local small and medium enterprises. This energy type depends on quality infrastructure services primarily with regard to correct manufacturing, planning and installation. The focus of this study lies on solar water heating systems of all sizes. Electricity generation with solar thermal energy and Concentrated Solar Power (CSP) are not considered, due to their limited relevance in Sub-Saharan Africa.

Wind power is currently of limited importance in Sub-Saharan Africa. Although its share in the energy mix is projected to grow, its importance in the energy mix will remain relatively low. The technology requires considerable investments and is not easily accessible for local small and medium enterprises. Wind power is therefore not considered in this study.

Biogas is mainly used in rural areas at present, providing an alternative energy source used principally for cooking in Sub-Saharan Africa. The contributions to sustainable development are positive, especially due to the substitution of fire wood. However, acceptance of this technology is frequently low, and maintenance is not ensured. Considering the projections of rural electrification based on photovoltaic, its importance in the total energy mix is expected to decrease. Biogas is therefore not considered in this study.

Geothermal energy is mainly important in Eastern Africa (e.g. Kenya and Ethiopia). Due to its lacking relevance for other Sub-Saharan African countries, as well as its relatively low impact on sustainable development because of the high investments needed, it is not included in this study.

4. Demand for quality infrastructure services in Sub-Saharan Africa for the sub-sectors identified

Solar photovoltaic and solar thermal water heating

The study focusses on two technologies which are powered by the sun: solar photovoltaic and solar thermal water heating. Although the two technologies are substantially different in the way they convert sunlight into energy, risks occur at similar stages and for similar reasons along the value chain, resulting in similar demand for quality infrastructure services in order to ensure quality. Quality gaps can occur along the respective value chain and can have a substantial impact on the long-term performance of the plant.

Assurance of product quality is crucial for all components of solar photovoltaic and solar thermal systems. In many countries, quality control of imported products is lacking and the market is exposed to low-quality imports (Interview 1). Maintaining quality controls for solar photovoltaic components, solar thermal components and complete thermal systems is further complicated by the large number of component providers active on the global market (Interviews 2 & 3).

1 Evaluation by the authors based on: IRENA (2015a) Africa 2030: Roadmap for a Renewable Energy Future.

Regarding the manufacturing of components, the situation is different for solar photovoltaic compared to solar thermal. Within the framework of this study, only one South African company could be identified which produced photovoltaic cells in Sub-Saharan Africa (Barbee 2016), and there are only a small number of photovoltaic module manufacturers in the region. Furthermore, inverters for grid-connected solar photovoltaic installations are mainly imported. The development of quality infrastructure services for quality assurance in photovoltaic module and inverter manufacturing is thus less urgent at present (it is expected that it will be more important in the future). In contrast, in several countries in Sub-Saharan Africa, solar thermal systems are being manufactured (Interviews 1, 2 & 3). Quality assurance for manufacturing – from raw material to product – is thus very important for this technology.

For planning and site selection, the availability of reliable irradiation data is of utmost importance for both technology types, as it determines the performance potential of the plant (IRENA 2015c; Telfser et al. 2016). Often, imprecise satellite data and estimations are used, resulting in unrealistic performance predictions. For photovoltaic power plants, considerable know-how is needed to successfully plan a plant, as a variety of factors need to be taken into consideration, including orientation, shading, wind conditions, seismic information and, in the case of rooftop installations, building and rooftop conditions. Moreover, the choice of the correct components is crucial. The chosen technology needs to be matched to the local climatic conditions; for on-grid installations, the inverter needs to be adequate for the system which is being built (Telfser et al. 2016). Furthermore, for solar thermal installations, choosing the right technology is of key importance. In addition, the orientation of the installation is a determining factor for the performance of solar water heaters (Interview 2).

Problems also arise due to installers lacking know-how and experience (Interview 1; IRENA 2015c; Telfser et al. 2016). Installation faults are very common in photovoltaic plants worldwide. A study by TÜV Rheinland identified that, throughout the world, installation faults were the cause of more than 50% of serious defects in photovoltaic plants (TÜV Rheinland 2015). Incorrect installation, often due to minor errors such as loose screws or incorrectly inserted connectors, can thus have devastating effects on plant performance and financial returns. According to a study of the Solar Bankability project of the European Union, improper installation has the highest financial impact among the most common issues related to modules and inverters (Solar Bankability 2016:61-63). Despite solar thermal technology being comparatively less complex, the installation of solar thermal systems requires solid knowledge and can result in complete failure of the system if carried out incorrectly. Unfortunately, many countries worldwide have had negative experiences with solar thermal water heaters (IRENA 2015c:22). A common issue caused by erroneous installation is leakages which result in water entering houses through the roof (Interviews 2 & 3).

Finally, during operations and maintenance, correct monitoring is essential for both solar photovoltaic and solar thermal installations to detect underperformance and take measures accordingly. Moreover, during this phase, cleaning is important for ensuring that the performance potential of the technology installed is not compromised (Telfser et al. 2016).

Table 1 below summarizes the quality issues along the value chains of solar photovoltaic and solar thermal and indicates which quality infrastructure services are relevant for each technology. The relevant quality infrastructure services are explained in more detail in the following sections. Regulation needs and other transversal aspects are summarized at the end of the chapter.

Metrology

Metrological services are of great importance for the sound development of solar energy technologies and are relevant throughout their value chains. For the manufacturing and assembly of components for solar photovoltaic and solar thermal systems, manufacturers should conduct incoming and outgoing product control; at customs, the quality of imported products and material needs to be ensured. Manufacturers and authorities need to regularly calibrate their testing equipment in order to provide reliable results and identify insufficient quality. For solar photovoltaic, the calibration of reference cells is also an important service a national metrology institute should offer to enable local industries to improve the quality of locally produced or assembled photovoltaic modules.

For the planning of solar energy installations (both solar photovoltaic and solar thermal), the calibration of pyranometers is important for ensuring the reliability of data on solar irradiance. Only with accurate information on irradiance can the potential performance of a plant be determined realistically. Moreover, metrological services are relevant for testing equipment for other important information used as a basis for planning. This includes the calibration of testing equipment such as anemometers to determine wind conditions or the conditions of a building and rooftop where a solar photovoltaic or solar thermal plant should be installed.

Finally, the calibration of testing equipment is also important for the commissioning of solar photovoltaic and solar thermal plants as well as during operations and maintenance, when – depending on the size of the installation – regular performance checks or continuous performance monitoring should be carried out in order to be able to detect underperformance and take necessary measures. For solar thermal installations, for example, calibration of flow meters and thermometers is required.

Standardization

Standards of the IEC are available for each step of the photovoltaic value chain. For components, the standards define safety and design requirements and how the components should be tested, for example. Other IEC standards define requirements for solar photovoltaic systems, including their design, monitoring, capacity and energy evaluation. Additionally, a set of recommendations and guidance documents are available (IEC 2017). A full list of IEC standards related to solar photovoltaic can be found on the following website:[2] *https://webstore.iec.ch/searchform&ComNumber=82#*

International standards for solar thermal technologies have been developed by the ISO. They define test methods for solar thermal collectors, specific components and complete systems. A list of available standards can be found on the website of ISO technical committee 180 for solar energy: *https://www.iso.org/committee/54018/x/catalogue/*

Moreover, ISO standards available for the implementation of quality management systems can help to ensure high product quality on manufacturing sites (Solar Bankability 2016) or correct operation and maintenance of large-scale solar energy installations.

2 The IEC standards for solar photovoltaic are currently being revised.

The national standards body has an important role in adopting the relevant international standards or adapting them to the local conditions, if necessary. In the case of solar photovoltaic, adaptation of the standards to local climatic conditions may be needed. A hail test for solar photovoltaic modules, for example, might not be relevant in a tropical country, while testing for salt mist might be more important in coastal areas, and exposure to sand and dust is an issue which needs consideration in and near deserts. In order to have the Sub-Saharan African perspective better reflected in international standards, the participation of delegates from the region in the respective IEC working groups is important. Additionally, the coordination of standardization activities on the level of the African Organisation for Standardisation (ARSO) and organizations on the sub-regional level like the East African Community (EAC) is important. This is especially true if adaptations of existing international standards to meet the requirements of the African stakeholders or new regional standards are needed.

Testing, certification and inspection

Testing services are important for component manufacturing, transport, planning, operation and maintenance. Quality tests can be carried out upon the arrival of materials and components for solar energy systems (both solar photovoltaic and solar thermal), as well as at different stages of the production and assembly process of components. International standards define testing methods and specific requirements for different components. As mentioned above, local manufacturing of solar photovoltaic modules and inverters is very limited in Sub-Saharan Africa. Nevertheless, testing capabilities are important for verifying the quality of imported photovoltaic components, protecting the market from low-quality products and detecting fake certificates.

For photovoltaic modules, it is particularly important to be able to test their quality upon arrival, as modules can easily be damaged during transport. If transport damage is not detected and damaged modules are installed, the performance of the photovoltaic power plant can be considerably affected (Solar Bankability 2016).

For the planning of solar photovoltaic and solar thermal plants, long-term data on solar irradiance at potential plant locations is needed. Weather stations and other testing facilities which gather solar irradiance data over long periods play an important role here (IRENA 2015c, Telfser et al. 2016). Finally, once the solar photovoltaic or solar thermal installation is in operation, regular performance tests should be carried out to monitor the correct functioning of the plant and to detect underperformance.

Certification is available for photovoltaic components and solar thermal collectors according to international standards. Moreover, certification schemes for engineering, procurement and construction (EPC) contractors which implement large-scale renewable energy projects, as well as for trained installers who carry out the installation of smaller solar photovoltaic or thermal plants or work for EPCs, can be very valuable for both solar energy technologies. Planning, procurement and installation are crucial for the final performance and safety of photovoltaic and solar thermal plants, and certification can provide confidence in the know-how of a particular service provider (IRENA 2015c; Solar Bankability 2016:20). Moreover, the availability of certification schemes can have positive effects on industry development, as it can result in higher wages for certified installers and in market growth thanks to increased confidence in the technology (IRENA 2015b).

Inspection services are relevant for component production, where buyers can require inspection of production facilities before delivery in order to be sure that the manufacturer has the necessary processes in place to ensure product quality (Solar Bankability 2016:19). A commissioning committee, including third party inspectors, should commission larger-scale solar energy plants once they are installed. Regular inspections can also be carried out during the operations and maintenance phase of solar photovoltaic and solar thermal installations in order to ensure correct functioning of the plant (IRENA 2015c; Telfser et al. 2016).

Accreditation

Accreditation services relevant for solar energy include accreditation of testing and calibration laboratories in accordance with ISO/IEC 17025 (ISO 2005), accreditation of certification bodies in accordance with ISO/IEC 17065 (ISO 2012b) and accreditation of inspection bodies in accordance with ISO/IEC 17020 (ISO 2012a). The availability of internationally accredited conformity assessment bodies for solar energy can help to strengthen the development of industry. Locally or regionally available services are generally more affordable than accreditation services from institutions based from locations further away on the continent or in Europe. Accreditation can improve the investment climate of a country if trustworthy services are locally available and facilitate investments based on reliable information. Moreover, it can support the export of locally manufactured products, such as solar thermal systems.

Hydropower

For hydropower projects, the assurance of quality and safety is most important during planning, installation and operation of the plant. For some aspects, a distinction between different sizes of installations needs to be made. Generally, hydropower is a mature technology and manufacturing of components does not pose major difficulties. Nevertheless, the quality of materials and components used needs to be ensured.

During the planning phase, the greatest challenges lie in selecting an adequate site and minimizing the environmental and social impacts of the plant. Detailed studies need to be carried out. Given the potential impacts of hydropower installations – especially large-scale ones – relevant stakeholders should be involved in decision-making processes (International Rivers 2014). Because assessments and plant design require considerable expertise and experience, all important factors are taken into consideration for site selection, plant optimization and minimization of possible negative impacts. For large-scale as well as small-scale hydropower plants, sufficient water flow and water quantity throughout the year are crucial factors (IEA Small Hydro 2017). Correct determination of the water line is important in this context (Interview 4). Water availability may be subject to great variation in the coming years due to climate change-induced changes in precipitation patterns, increased temperatures and more extreme weather events such as droughts and floods. Therefore, for site selection, historical meteorological data should be considered alongside future predictions (International Rivers 2014:51) (see section 2.3. on meteorology). Lacking or not sufficiently accurate hydrological data considerably increases uncertainties for planning (Interview 4).

For the installation of hydropower plants, the quality and safety of the established infrastructure, – for example, dams – are indispensable. In a worst-case scenario, quality shortcomings in hydropower plants can cause a dam to burst, with potentially devastating effects on the surrounding communities and ecosystems in the case of large-scale hydropower plants. Smaller construction and installation errors can have negative economic impacts – for example, due to lower long-term performance or the repairs needed. Additionally, they may compromise the safety of employees and surrounding ecosystems.

Quality aspects are also important during operation and maintenance of hydropower plants. This is highly relevant in Sub-Saharan Africa, where more than half of the region's energy is generated via hydropower (IRENA 2013:6-9). However, maintenance and monitoring are often neglected (Interview 4). In addition to the long-term functioning of the technology, water quality upstream and downstream of the plant needs to be monitored in order to detect possible negative impacts on the environment (such as altered levels of dissolved oxygen) and take timely measures (Fondriest Environmental Inc. 2016). Moreover, reservoir management is relevant in the context of climate change in order to limit greenhouse gas emissions (Deemer et al. 2016).

Table 2 summarizes the quality and safety issues along the value chain of hydropower plants and indicates which quality infrastructure services are important in order to respond to these issues. The relevant quality infrastructure services are explained in more detail below. Regulation needs and other transversal aspects are addressed in the last part of this section.

Metrology
Metrological services are important for the quality and safety assurance of hydropower plants throughout the value chain from component manufacturing to operation. The testing equipment used for manufacturing should be calibrated regularly. For site selection, it is important to calibrate the equipment used to determine the water line, flow and quality, to monitor precipitation and to test the soil and foundation. For water quality tests, the national metrology institute can also provide reference material and act as a proficiency test provider as part of their services in chemical metrology. Calibration is also relevant for the testing equipment used for quality control during construction and installation as well as for the monitoring and testing devices used during operation and maintenance (e.g. flow meters, extensometers). Monitoring may include the performance of the plant, the infrastructure, and environmental impacts such as effects on ecosystems and greenhouse gas emissions from the reservoir.

Standardization
Relevant standards for hydropower include technical standards for components such as turbines and electrical generators, for plant design and for the installation, commissioning and control of power plants. Specific standards and guidance documents for hydropower are developed by the Institute of Electrical and Electronics Engineers (IEEE) (ANSI 2017). Some relevant standards have also been developed by IEC and ISO. In order to limit the negative environmental impacts of existing hydropower installations, relevant standards from the ISO 14000 family on environmental management as well as guidance documents for the Environmental Impact Assessment can be applied.

Several international organizations, such as the World Commission on Dams and the International Hydropower Association, are involved in the development of guidance documents and additional tools for the assessment of social and environmental impacts and the systematic integration of sustainability aspects in hydropower development (Scanlon et al. 2004, Interview 4).

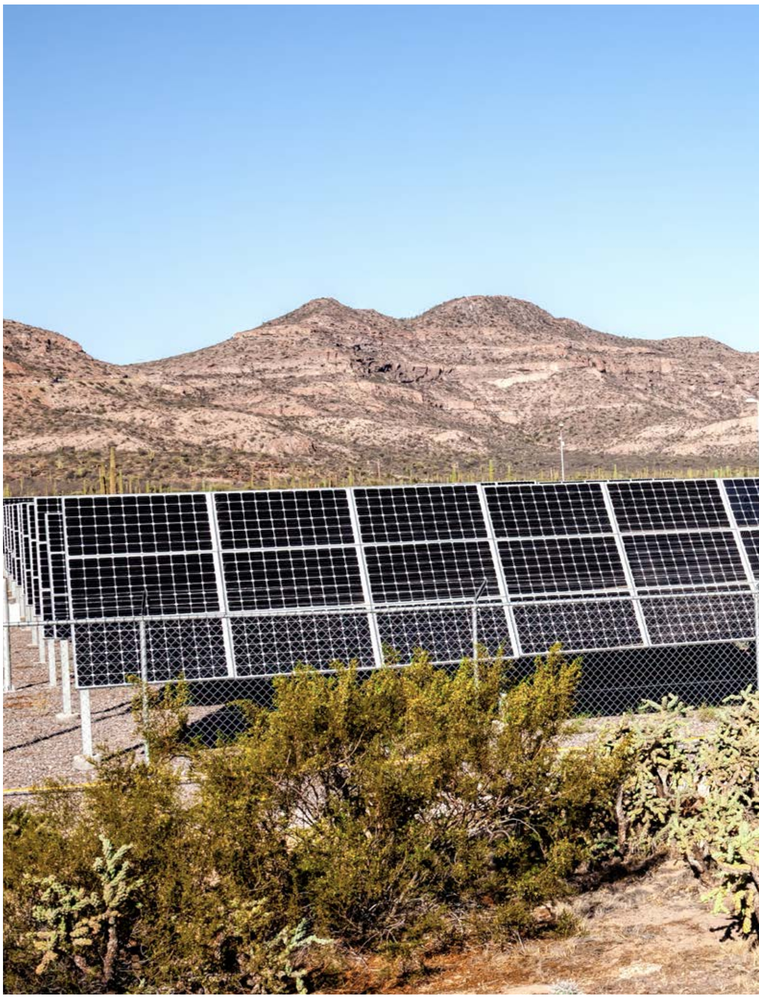
Testing, certification and inspection
Testing services are important throughout the hydropower value chain. Tests can be conducted to ensure the quality of materials and components from the raw material to the finished product. For the planning phase, tests of on-site water conditions need to be carried out. The water line, flow and quality should be analysed (IEA Small Hydro 2017). Long-term precipitation and temperature data, as well as information about extreme weather events which is usually generated by weather stations and meteorological laboratories, provide important information about the viability of a hydropower plant in a potential location. Furthermore, tests have to be conducted during construction and installation to detect possible faults. In order to monitor the composition of concrete throughout the construction process, testing capacities need to be available locally. For large-scale hydropower projects, on-site laboratories may be set up for this task (Interview 4). During commissioning, the plant has to be tested for safety and correct functioning. Once the plant is in operation, monitoring of water pressure, flow and quality is important in order to be able to detect potential risks for plant performance and negative impacts on the environment and take measures accordingly. Infrastructure monitoring is also necessary: The established volume should be regularly checked for changes in length with an extensometer (Interview 4).

Personnel certification can be relevant for specific service providers such as welders (Bureau Veritas Group 2017). Certification for components helps to select quality inputs for the power plant. In some countries, certification schemes exist for environmentally friendly hydropower plants and ecological power generation. In the United States, for example, the Low Impact Hydropower Institute provides certification for hydropower installations (LIHI 2017), while in Switzerland, the *naturemade* label certifies eco-friendly power generation from hydropower plants, among other sources (Naturemade 2017). However, such certifications are not yet widely used (Interview 4). No information about the application of such labels in Sub-Saharan African countries could be retrieved.

Inspections have to be carried out during the construction and installation of a hydropower plant. Moreover, inspection services are relevant for commissioning – both after the installation has been completed and during operation and maintenance – to ensure that the plant functions correctly.

Accreditation

As explained for solar energy above, accreditation services relevant for hydropower include accreditation of testing and calibration laboratories in accordance with ISO/IEC 17025 (ISO 2005), accreditation of certification bodies in accordance with ISO/IEC 17065 (ISO 2012b) and accreditation of inspection bodies in accordance with ISO/IEC 17020 (ISO 2012a). In the Sub-Saharan African context, accredited laboratory services are important in order to generate accurate information and ensure the reliability of the information needed for planning and monitoring of hydropower projects. Accredited inspection bodies can also ensure quality during installation and carry out competent commissioning of installed plants. As mentioned above, the availability of accreditation services nationally or regionally can considerably reduce the cost of the services.



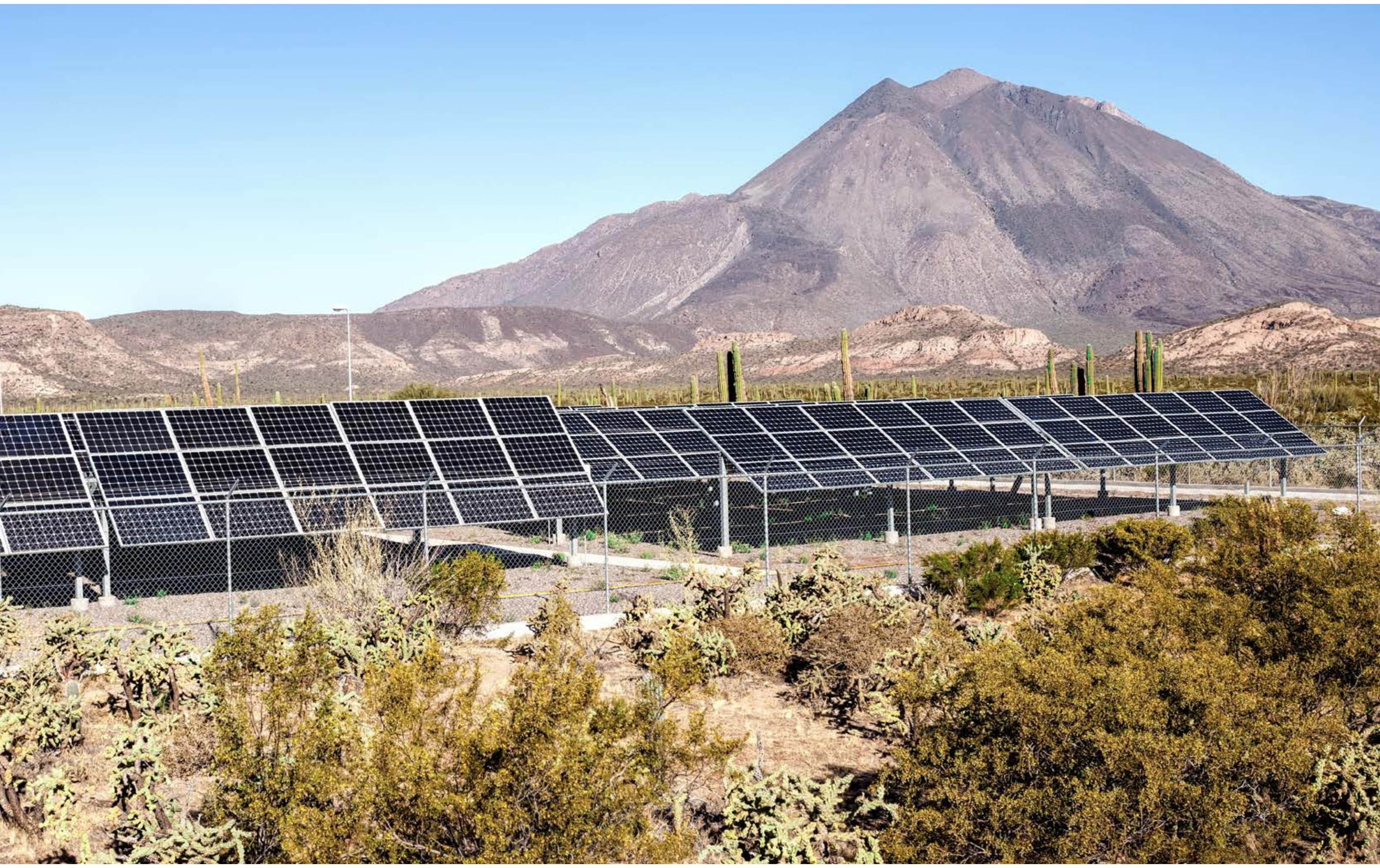
Transversal needs for quality and safety assurance

For the development of renewable energy technologies, support from local authorities is required. This can be achieved via awareness-raising events and initiatives concerning the need for quality and safety in renewable energies, as well as related risks addressed to stakeholders along the value chain, including end users and investors. Moreover, training programmes for EPCs and installers can be supported in order to improve the capabilities of local service providers.

The authorities also have an important role in regulating the development of the renewable energies sector. Commissioning procedures should be established for the different technologies, and regular or continuous monitoring should be required once the power plant is in operation.

The inclusion of quality and safety criteria in tenders for renewable energy installations is an important step toward promoting quality in the sector, which in turn will foster confidence in new technologies. At the same time, it generates demand for quality infrastructure services and allows national quality infrastructure institutions to sustainably develop additional quality assurance services for renewable energies (Telfser et al. 2016).

Finally, the grid needs to be appropriate for the successful expansion of renewable energies, and grid codes need to be available to ensure secure, safe and economically proper functioning of the electric system. This is particularly relevant for solar photovoltaic, as electricity generation is not constant; here, the grid needs to be sufficiently flexible to allow for the use of renewable energy when it is available.



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Quality infra-structure services/ value chain	Quality challenges	Metrology	Standardization
Maintenance/ monitoring	■ Monitoring of performance ■ Correct maintenance, e.g. cleaning	■ Calibration of performance testing devices	■ Procedures and implementation of management systems
Installation	■ Correct installation ■ Complete system documentation	■ Calibration of testing devices	■ Technical installation ■ Documentation
Planning	■ Site selection: ■ Reliable irradiation data ■ Consideration of all relevant information (e.g. orien-tation, shading, wind and other climatic conditions, seismic information, condition of the foundation and/or building and roof)	■ Equipment calibration	■ System design ■ Site selection
Transport	■ Prevention and detection of photovoltaic module/ ■ component damages		■ Criteria for correct transportation
Manufacturing	■ Component quality (national and imported)		■ Component quality ■ Production processes

Table 1: Quality issues and necessary services of quality infrastructure along the value chains of solar photovoltaic and solar thermal water heating

Quality infra-structure services/ value chain	Quality challenges	Metrology	Standardization
Maintenance/ monitoring	■ Correct long-term functioning ■ Water quality upstream/downstream ■ Environmental management of water quality upstream, downstream and reservoir	■ Equipment cali-bration ■ Chemical metrology	■ Maintenance procedures ■ Testing procedures for water quality ■ Management systems for upstream, downstream and reservoir water quality
Installation/ construction	■ Infrastructure safety, e.g. dams ■ Correct installation of turbines	■ Equipment cali-bration	■ Infrastructure safety ■ Commissioning
Planning	■ Appropriate site selection	■ Equipment cali-bration ■ Water quality	■ Plant design ■ Social and environmental impact assessment
Manufacturing	■ Production of high quality components	■ Equipment cali-bration	■ Quality criteria for components ■ Quality management systems

Table 2: Quality issues and necessary services of quality infrastructure along the hydropower value chain

	Testing	**Certification**	**Inspection**	**Accreditation**	**Regulation/ transversal aspects**
	■ Regular performance and safety tests	■ Quality management systems (e.g. ISO 9001)	■ Regular inspections of large-scale power plants	■ Accreditation of laboratories (testing/calibration), certification and inspection bodies	
	■ Initial performance and safety tests	■ Training and certification of installers	■ Commissioning		■ Commissioning criteria and procedures
	■ Long-term solar irradiance data and data on environmental conditions (e.g. wind speed and precipitation)		■ Building structure (e.g. for rooftop installations)		■ Training and awareness raising about quality issues
	■ Performance tests ■ Infrared and electroluminescence tests for photovoltaic modules	■ Transport procedures / systems			
	■ Component quality, e.g. performance and durability	■ Certification of product quality and management systems	■ Inspection of production facilities		■ Quality requirements

	Testing	**Certification**	**Inspection**	**Accreditation**	**Regulation/ transversal aspects**
	■ Water pressure on turbines ■ Water flow ■ Water quality		■ Regular plant inspections	■ Accreditation of laboratories (testing/calibration), certification and inspection bodies	■ Safety requirements for infrastructure
	■ Quality parameters of materials used	■ Construction material	■ Infrastructure safety ■ Commissioning		■ Safety requirements for infrastructure ■ Quality and safety criteria for commissioning
	■ Water quality, flow etc. ■ Precipitation in water catchment ■ Quality of foundation		■ Plan acceptance		
	■ Component quality	■ Component quality			

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