Sustainable Energy Fund for Africa

Africa Hydropower Modernisation Programme

Continent-wide mapping of hydropower rehabilitation candidates

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Contents

Acronyms

US$	United States dollar
US$m	United States dollar million
°C	Celsius degree
AAR	Alkali-Aggregate Reaction
AC	Alternate current
AFD	Agence française de développement
AfDB	African Development Bank
AHMP	Africa Hydropower Modernisation Programme
BPA	Bui Power Authority
CAPEX	Capital expenses
CAPP	Central Africa Power Pool
CSP	Concentrated solar power
DC	Direct current
DRC	Democratic Republic of the Congo
E&S	Environmental and sustainability
EAPP	Eastern Africa Power Pool
EOI	Expression of Interest
EM	Electromechanical
EPC	Engineering, Procurement and Construction
ESIA	Environmental and social impact assessments
FPV	Floating photovoltaic
GERD	Grand Ethiopian Renaissance Dam
GHG	Greenhouse gas
GW	Giga watt
HDPE	High Density Poly Ethene
HESG	Hydropower Sustainability Environmental, Social and Governance Gap
HGIIP	Hydropower Sustainability Guidelines on Good International Industry Practice
HPP	Hydropower plant
HSH	Hydro-solar PV hybrid
HVDC	High voltage Direct Current line
IEA	International Energy Association
IFI	International Financial Institution
IHA	International Hydropower Association
IPP	Independent Power Producer
km2	Square kilometer
kW	Kilo watt
kWh	Kilo watt hour
LCOE	Levelised cost of electricity
LEC	Liberia Electricity Corporation
m	Meter
m2	Square meter
m3	Cubic meter
MVA	Mega Volt Ampere
MW	Mega watt
N	No
NITS	National Interconnected Transmission System
O&M	Operation and maintenance
OEM	Original Equipment Manufacturer
ONEE	Office National de L'Electricite
OPEX	Operating expenses
PSH	Pump storage hydropower
PV	Photovoltaic
Q1	Quartile 1
Q3	Quartile 3
s	Second
SAPP	Southern Africa Power Pool
TWh	Terawatt Hour
UEGCL	Uganda Electricity Generation Company Ltd.
VRA	Volta River Authority
WAPP	Western Africa Power Pool
y	Year
Y	Yes

Executive summary

This high-level screening study, commissioned by the African Development Bank (AfDB) through its Sustainable Energy Fund for Africa (SEFA) funded Africa Hydropower Modernisation Programme (AHMP), presents the results of a 12-month continent-wide mapping of hydropower facilities eligible for modernisation carried out by the International Hydropower Association (IHA).

Regarding energy supply and global development, Africa is one of the continents that will face the most difficult challenges over the coming decades. African countries will need to progressively increase their domestic power supply to meet the demand for power required to develop their economy and provide electricity for millions of people to improve their living standards. In doing so, this energy transition will need to be done sustainably. Even though Africa currently is only responsible for 4% of global greenhouse gas emissions, the worldwide challenge of mitigating climate change will impose limits on future emissions. Hydropower can offer a valuable contribution to ensuring that this twofold challenge is met in the most sustainable, economical, and secure way.

In 2019 Africa's gross generating capacity of all forms of energy was in excess of 245 GW.[1] Hydropower in Africa currently contributes to 16% of the total capacity and is today the most mature and flexible source of renewable electricity at scale. It accounts for 80% of the renewable energy generated on the continent.[2] As of 2022, the installed hydropower capacity was 40 GW, and of these, over 60% is more than 20 years old.[3]

Currently, electricity consumption in Africa has reached 732 TWh, which is expected to increase by 61%, to 1,180 TWh, by 2030.[4] In 2020, out of 1.3 billion people living in the continent, over 580 million, around 44% of the total, had no electricity. The situation is even worse in rural areas as 74%[5] of these populations are without access. Of these 87 candidate stations, 21 plants with a total capacity of 4.6 GW were categorised to be in urgent need of modernisation (or high demand), and an additional 31 stations with a total installed capacity of 10.1 GW will likely require investment over the next decade (medium need category).

Table 01 shows a regional breakdown of the modernisation needs identified by the study. All plants classified in high need of modernisation were in Sub-Saharan Africa, and in terms of installed capacity, close to 80% is located across West (2.1 GW) and Central Africa (1.6 GW), with the remaining in East (0.6 GW) and Southern Africa (0.3 GW). All regions had additional capacity in medium need, particularly Southern Africa (5 GW) and North Africa (3 GW).

Table 01. Regional overview of modernisation needs by number of stations and installed capacity

Regions	Low need		Medium need		High need	
	No. stations	**Capacity (MW)**	**No. stations**	**Capacity (MW)**	**No. stations**	**Capacity (MW)**
North Africa	0	0	7	3,094	0	0
West Africa	3	1,268	3	430	4	2,103
East Africa	6	538	6	938	7	625
Central Africa	5	923	5	666	3	1,557
Southern Africa	16	6,800	15	4,961	7	337
TOTALS	**30**	**9,529**	**36**	**10,089**	**21**	**4,621**

The study has identified the ageing of the electromechanical components, lack of access to spare parts and the need for maintenance on the civil structures as the main trigger for modernisation projects. Numerous plants classified in the high-need category are operating with legacy technology, often at derated capacity, with units operating in a state of disrepair or entirely out of service.

In order to secure reliable, efficient, and safe electricity generation from the plants in the high-need category, IHA estimates that approximately US$2.1 billion will need to be invested. In comparison, an additional US$4.7 billion may be required by the plants in medium need.

Table 02. Overall estimates of investment need for total capacity assessed in the study with high and medium needs for modernisation

	High need	Medium need
Installed capacity assessed in in the mapping*	4.6 GW	10.1 GW
% of overall African hydropower fleet (38.5 GW)[6]	12%	26%
Estimated investment need based IHA benchmark modernisation cost**	Approx. US$2.1 billion	Approx. US$4.7 billion
Indicative capacity upgrade associated with complete modernisation project[7]	0.23 GW – 0.53 GW	0.51 GW - 1.17 GW

* This total includes power plants for which data were received directly from the owners and plants for which only secondary data were available.
** The cost figures shown in this table are high level estimates to provide a relative sense of the magnitude of modernisation costs but would be subject to a more stringent and detailed cost estimating process if a project is to proceed to the next phase.

From a capital requirement perspective, modernisations are less intense than greenfields projects.[8] This level of investment would not only secure the availability of over 14.7 GW installed capacity, enhance plant flexibility, reduce maintenance costs, enhance water management and enable safer operations of the existing fleet but would also increase the existing generating capacity. The replacement of outdated, deteriorated, or damaged electromechanical components could increase the installed capacity of the fleet between 740 MW and 1,700 MW, thanks to the improved efficiency and increased power capability of modernised systems.

Investments are, therefore, fundamental to securing these plants' ongoing productivity over the following decades and should be seen as an immediate priority to achieve decarbonised economic development and secure a resilient fleet capable of operating under more extreme weather conditions triggered by climate change. A modern and efficient hydropower fleet will provide clean and reliable electricity and offer grid stability and flexibility services, which are necessary to enable the expected large-scale deployment of wind and solar energy.

From an environmental & social perspective, modernisation to increase efficiencies, replace equipment, and rectify ageing infrastructure issues would not instigate an adverse change in the project's impacts. In fact, these projects are often a great opportunity to implement measures that can improve the E&S footprint of the plant and its operations. Examples of these measures are the introduction of fish ladders, the adoption of improved turbine seals which eliminate lubricant leakage and a general improvement of the health and safety condition of the personnel working in the plant.

An additional and important benefit that hydropower plants could provide within the development of the African power systems is the opportunity to introduce floating solar photovoltaic (FPV) panels for deployment in existing hydropower reservoirs, where it may be feasible and economically viable to do so as has been demonstrated by numerous international projects[9]. Floating solar technology located on hydropower plant reservoirs can be successfully implemented, taking advantage of existing grid infrastructure to reduce costs, whilst complementing the energy production of plants.

During the mapping exercise data, were gathered for 26 hydro reservoirs to assess potential suitability for floating solar PV (FPV). This led to identifying 11 candidate sites where floating solar hybrids could be developed. Introducing a solar-hybrid system could help support generation shortfalls during drought conditions and provide a 'quick win' given their relatively short deployment timescales.

The result of this study represents a valuable starting point on which the AfDB can build a comprehensive project to modernise the African hydropower fleet. The recommended next step is to further intensify the dialogue with the owners, particularly in those high-need plants where IHA's assessment serves as a pre-feasibility study. These are plants in urgent need of modernisation where the owners or the concessioners have demonstrated interest in the opportunity to cooperate with the AfDB in the near future through their collaboration with the IHA during the course of the study.

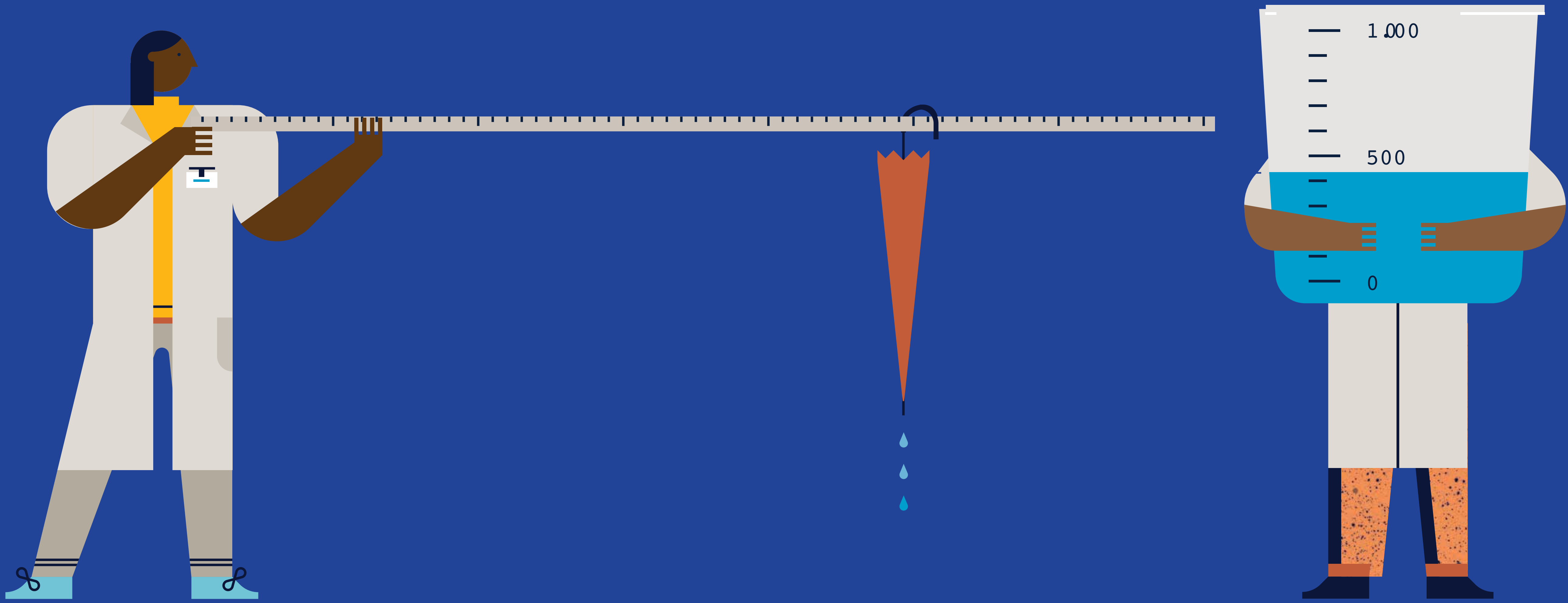
The goal of this dialogue should be to understand the scope of works further. The feasibility and the financial needs for the selected projects, also consider any potential additional barriers (e.g. financing or environmental & sustainability (E&S)) as well as other opportunities that could be included in a proposed modernisation.

Report structure

The report is structured as follows:

Part 01

General modernisation background information

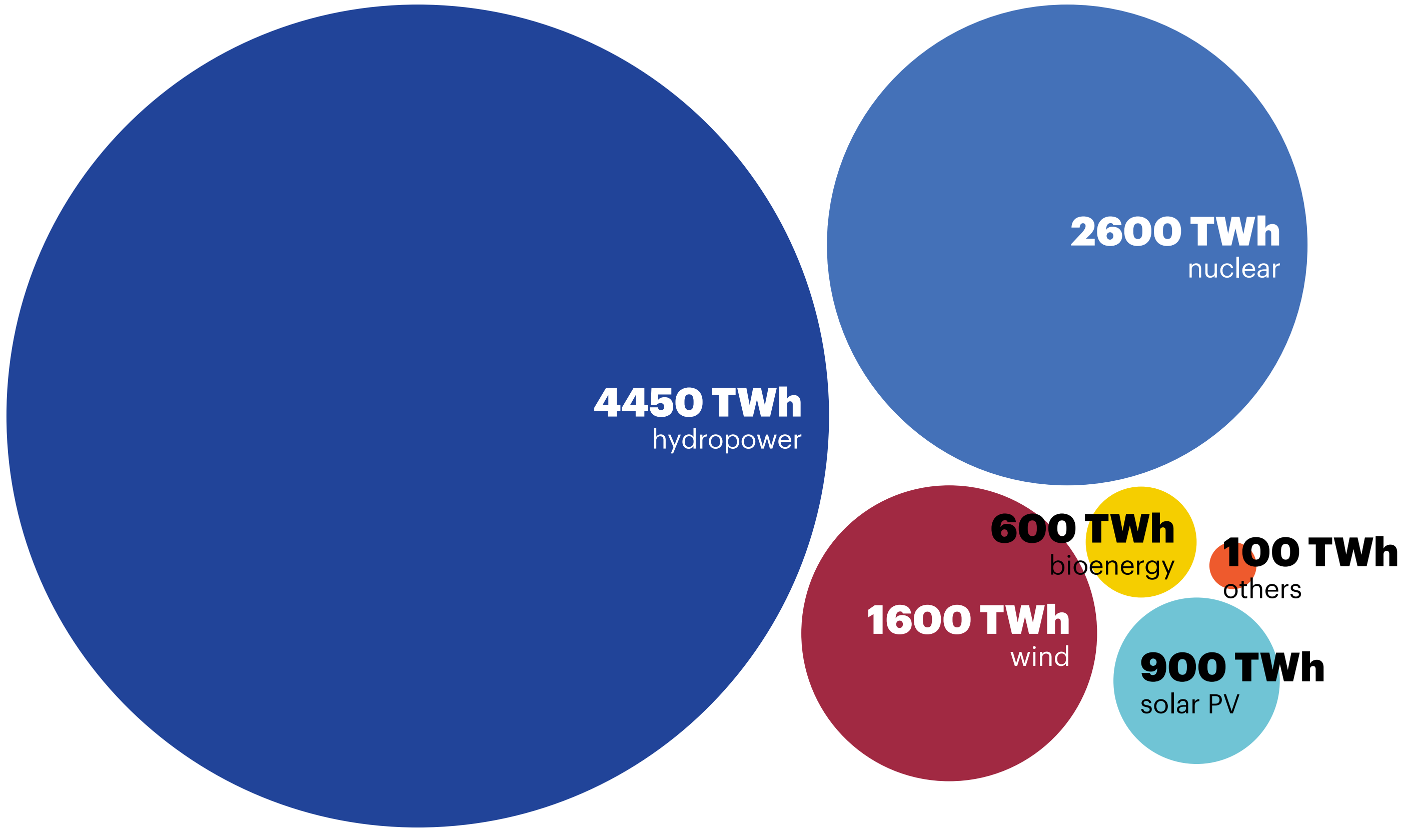


Section 01
background information

01.1 | Overview of the hydropower sector

Hydropower is globally the backbone of low-carbon electricity generation and remains the single largest source of renewable electricity. In 2021, it accounted for 16% of all electricity generated across the globe, providing an overall contribution 55% higher than nuclear and more significant than all other renewables combined (Figure 01). However, while most of the finances are globally directed towards unlocking new developments, there is also a rapidly increasing need to modernise and optimise the current fleet of ageing assets. Indeed, as of today, circa 40% of the global fleet is at least 40 years old.[10] This will ensure that the vital role played by hydropower is sustained and enhanced.

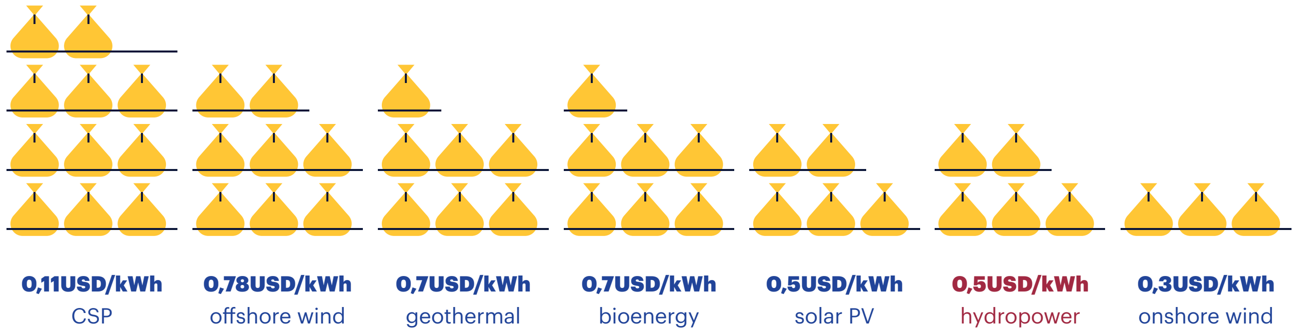
Figure 01. Global electricity generation from low-carbon technologies (2021)



SOURCE IEA

Hydropower remains one of the most competitive energy sources available. According to the International Renewable Energy Agency (IRENA), the cost of electricity from new hydropower projects remains amongst the cheapest renewable energy sources with an average levelised cost of energy (LCOE) in 2021 of 0.048 US$/kWh (Figure 02), well below offshore wind, geothermal, bioenergy and concentrated solar power.

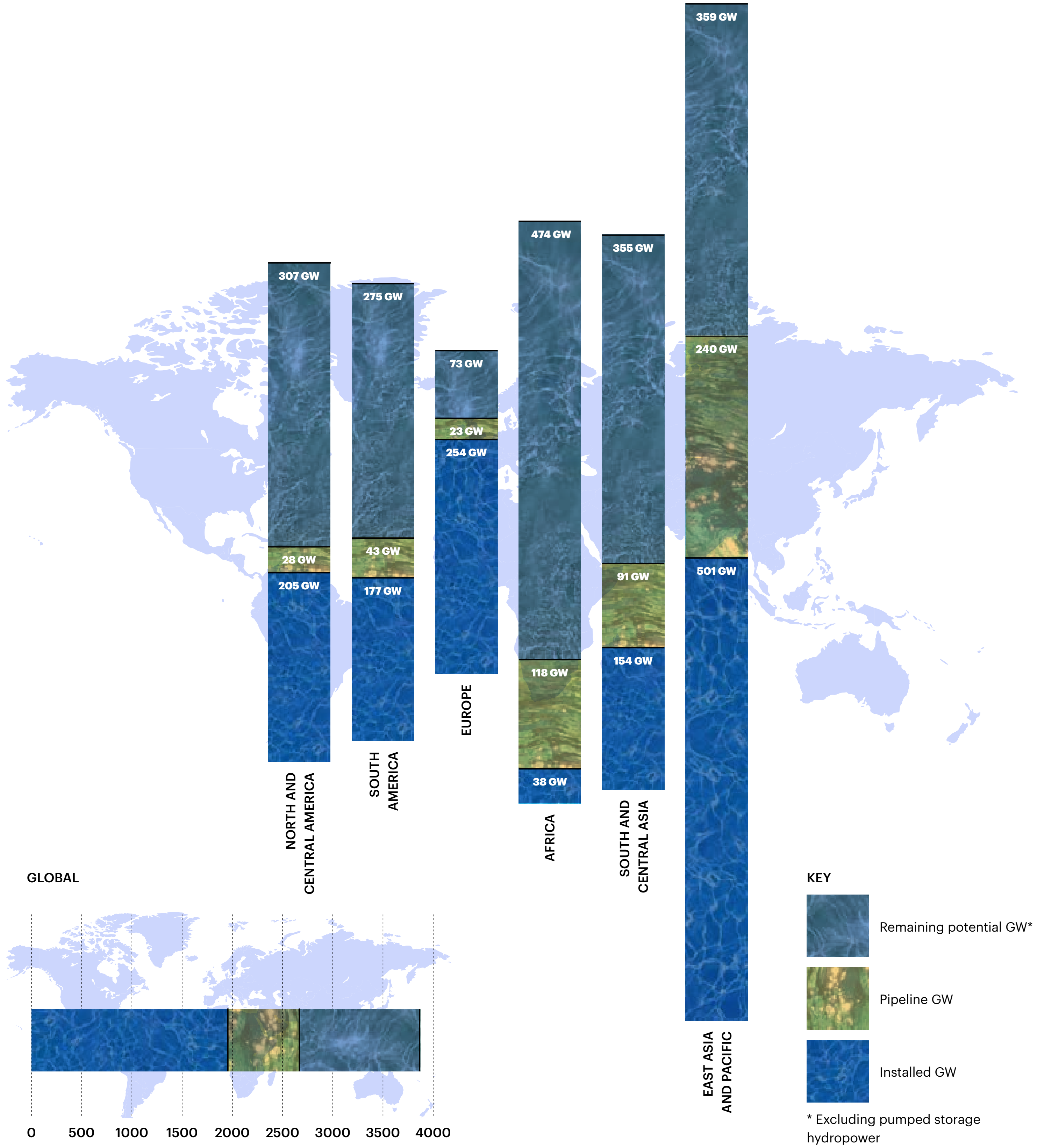
Figure 02. Levelised cost of electricity of renewable energy sources (2021)



SOURCE IRENA and IHA analysis (CSP refers to concentrated solar power)

The remaining potential for the development of new greenfield hydropower projects is substantial. Without including off-river pump storage hydro, circa 2,000 GW of potential sites are left untapped, not including 550 GW currently under development. The International Energy Agency and the International Renewable Energy Agency agree that to keep global warming below two °C, the most cost-effective pathway would see at least 850 GW of new hydropower capacity developed over the next 30 years. The numbers are even more significant for the more ambitious Net Zero target (limiting temperature rise to below 1.5°C), with a total installed capacity required in excess of 2,500 GW (almost twice today's installed capacity).

Figure 03. Hydropower potential capacity



SOURCE IHA – Hydropower Status Report 2022

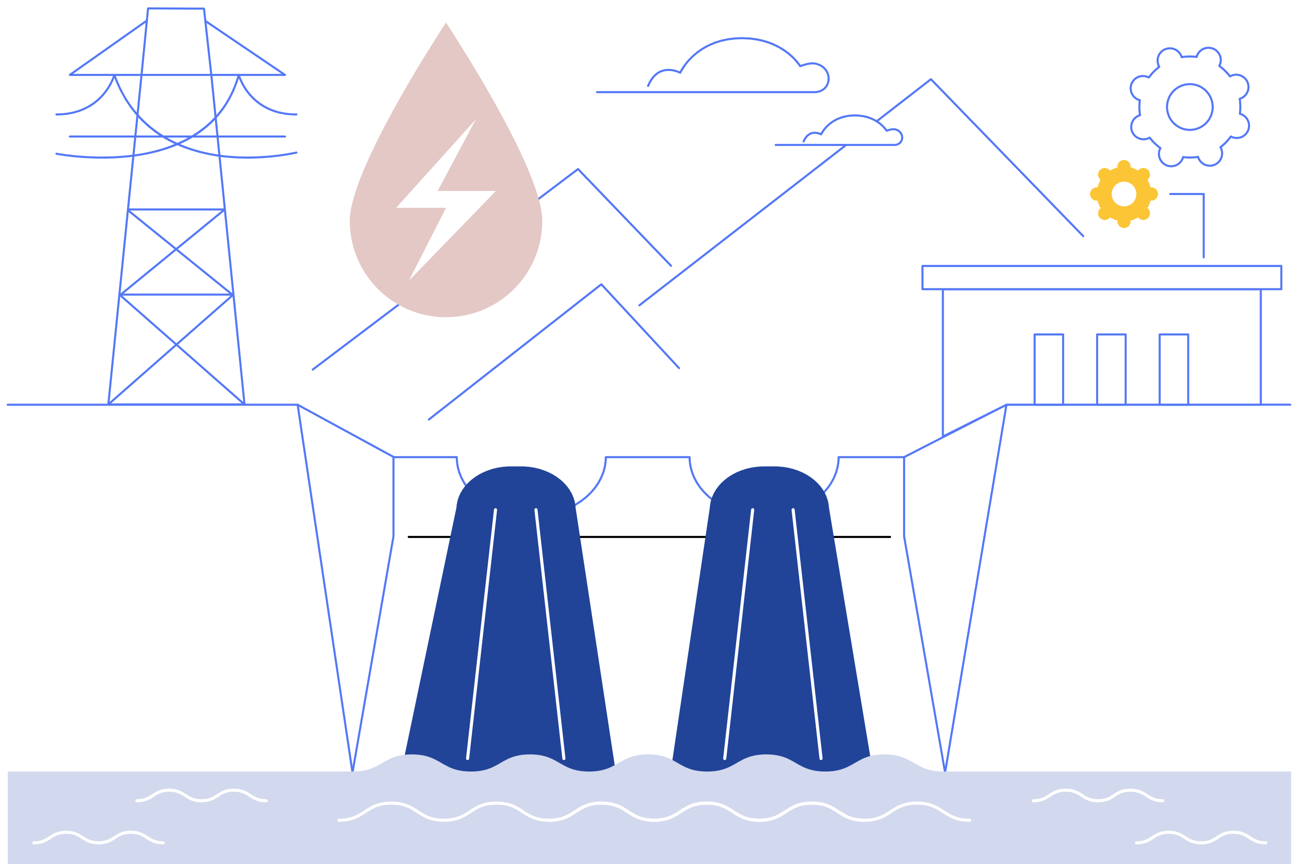
The challenges faced to achieve a net-zero economy involve not only the development of new greenfield projects but also substantial efforts in modernising the existing fleet. Indeed, according to the IEA, 166 GW of new hydropower capacity is expected to come from the modernisation of the current fleet over the next decade. It is also reported that if the business case for modernisation is made more attractive and if there will be sufficient water resources available to increase turbine size, this potential could be substantially higher, closer to 400 GW[11].

Nonetheless, despite these promising figures, global investment in modernisation remains well below the required level. Indeed, the IEA figure shows that planned and announced modernisation projects are estimated to cost a total of USD 127 billion by 2030, while the minimum required investment to replace ageing components and maintain plants availability is estimated in the order of US$ 300 billion, or 2.4x higher.[12]

01.2 | References to global modernisation efforts

Previous continental studies that were conducted by the IHA on modernisation of hydropower fleet include:

- Hydropower Modernisation Needs in Asia; developed in association with the Asian Infrastructure Investment Bank (AIIB), 2020.
- IHA Summary
- AIIB Working Paper
- Modernization of Hydropower Plants in Latin America and Caribbean – Identification and prioritisation of investment needs; developed in cooperation with the Inter-American Development Bank (IDB), 2020.
- Modernisation of hydropower in Latin America and the Caribbean: Investment needs and challenges; IDB article based on IHA research, 2020.
- XFLEX HYDRO – This project currently brings together 19 institutional partners with internationally-recognised expertise (including IHA) to study and demonstrate advanced technological solutions to extend the flexibility of existing hydropower plant and increase hydraulic components lifespan, using advanced software solutions and modest technological upgrades.



Section 02

drivers and opportunities of modernisation

02.1 | Overview

The modernisation of hydropower stations is driven by numerous and often interrelated factors, from ageing equipment to improving energy performance, operating strategies, environmental impacts and broader policy changes. In all cases, specific components of a generating station will need to be replaced, refurbished or upgraded to ensure that it can continue to operate reliably, at least until the end of the life of the asset.

Beyond extending the lifetime of these assets, modernisation represents a key opportunity for existing hydropower infrastructure to provide benefits such as optimised power production through improved efficiency or capacity additions, optimised operations and maintenance (O&M), enhanced flexibility and water services at multipurpose hydropower sites. Modernisation projects have capital requirements which are much less significant than greenfield projects and generally have modest or negligible E&S impacts.

Projects to modernise hydropower plants go further than business-as-usual O&M and involve a more significant re-investment in an existing asset. Although the type of modernisation will vary on a case-by-case basis, depending on the needs and options available for a given site, strategies will generally fall into the following types:

Life extension
projects look to extend the life of the station with repairs or replacements of existing key electro-mechanical components to maintain the existing operation of the units or, in some cases, restore derated units back to their design capacity, often improving performance. A case study is presented in case study 1 in section 2.4.

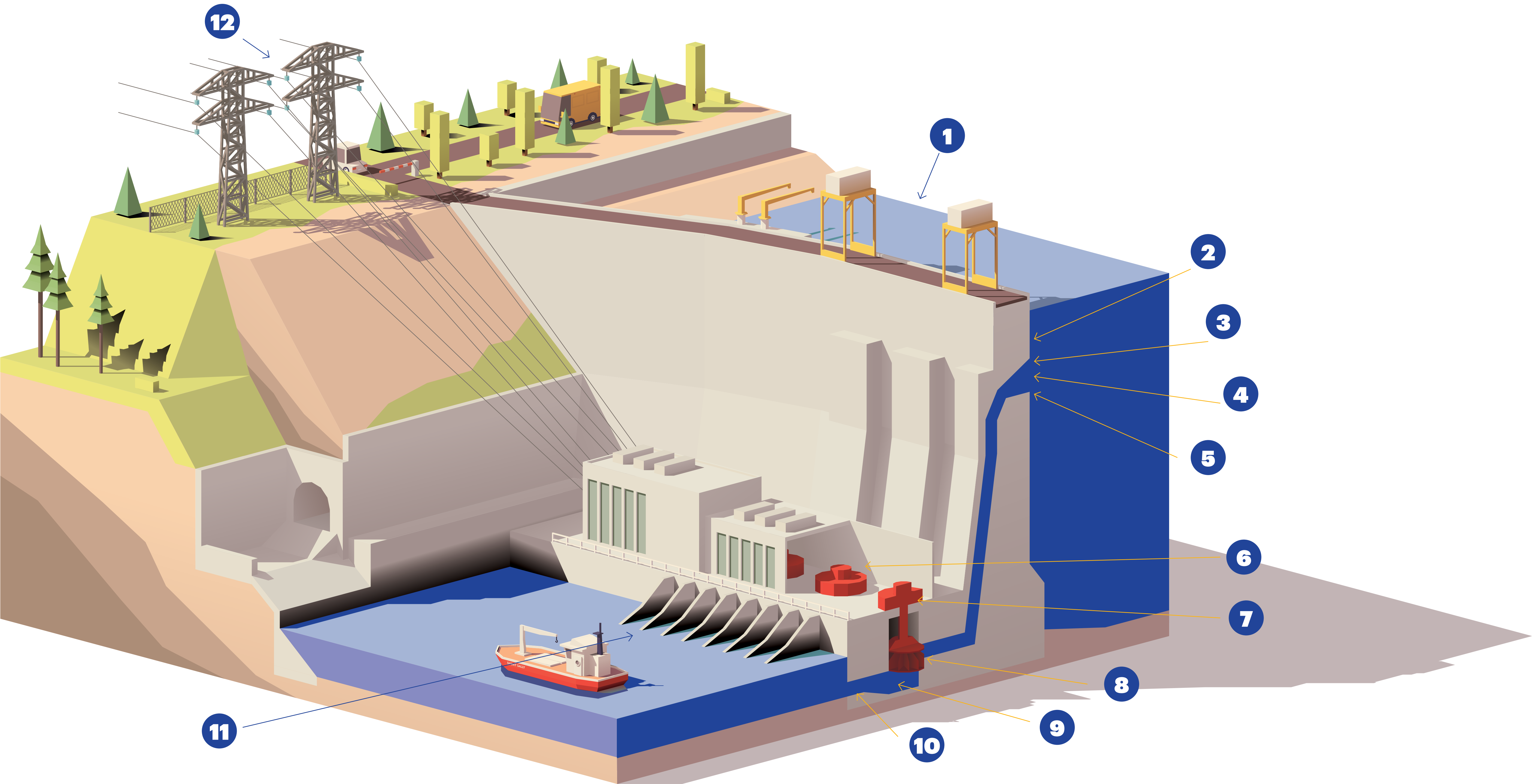
Major upgrade/uprate
projects aim to improve services by increasing generating efficiency, uprating installed power capacity, expanding the operating regime or re-equipping a site with new technologies, e.g. to operate under more extreme variations in streamflow or to accommodate greater penetration of variable renewable technologies into the energy mix; while also extending the life of the station. Case study 2 in section 2.4 shows an example profile.

Total redevelopment
projects involve larger-scale station overhauls, rebuilds or plant expansion schemes, including significant civil works to modernise and, in some cases, replace the existing station either in-situ or by adding a new powerhouse in a new location. Repurposing hydropower dams and reservoir sites with pumped storage capability is another example. A case study for a station rebuild is given in case study 3 in section 2.5.

Digitalisation
can also play a central role in any modernisation scheme and be integrated within any of the listed categories. Such projects focus on updating control systems, monitoring and communication systems, and introducing state-of-the-art digital analytics to optimise operations and provide preventative maintenance.

With different types and scales of projects, there can be many reasons for modernising an existing hydropower station. This review looks to introduce the main drivers and opportunities for modernisation projects.

Figure 04. Diagram of a hydropower station displaying key features



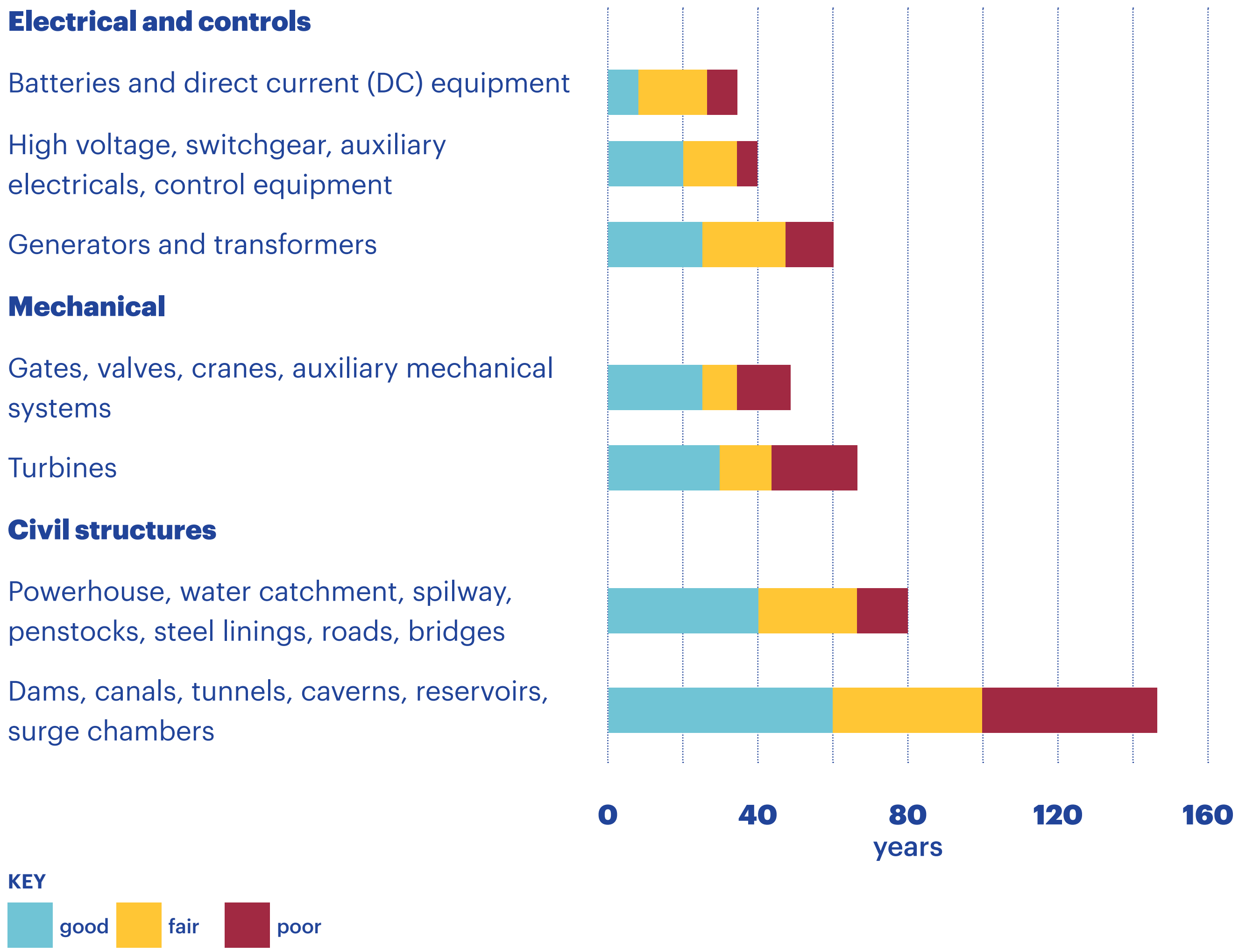
KEY
1 Reservoir
2 Control gate
3 Trash rack
4 Intake
5 Penstock
6 Powerhouse
7 Generator
8 Turbine
9 Draft tube
10 Outflow
11 Spil way
12 Transmission

02.2 | Plant ageing

All hydropower stations age over time, causing a degradation in reliability and performance. Hydraulic generating units all undergo some degree of mechanical degradation over years of operation; typically, the unit's generator is the first major component to exhibit signs of wear and tear from high thermal or mechanical stresses (rotors and windings), generally followed by the turbines (rotating blades, guide vanes, etc.) and eventually civil structures will show signs of degradation over longer timeframes, sometimes introducing issues with the safety of the facility. Studies published by International Financial Institutions (IFI)s, Original Equipment Manufacturers (OEMs) and research organisations describe the physical processes which lead to degradation as well as remedial measures taken in modernisations in more detail.[13,14,15,16,17,18]

Figure 5 presents the lifespans of the major systems of a hydropower station based on assessments applied in a World Bank study. The blue bars show the years each type of system is in good working condition after entering service; the dark red bars show subsequent years of fair performance; and above this threshold, the systems are expected to be in poor condition, shown in yellow.

Figure 05. Indicative average lifespans of major systems in a hydropower station



SOURCE based on data from a World Bank study by Goldberg and Espeseth, 2011

As shown, the electrical auxiliary and control systems are typically replaced or updated first, often due to obsolescence. The major electro-mechanical drivetrain components such as hydraulic turbines, generators and transformers generally are modernised 30 to 45 years after the original commissioning date depending on several factors, including the original materials used in manufacturing components, operating conditions and site conditions. Degradation rates can be accelerated for different reasons:

- Improper equipment maintenance, either through lack of training on O&M practices or resources, will accelerate the end of life of hydropower facilities.
- High sediment loads will lead to accelerated plant degradation, particularly in the turbines.
- Changes in modes of operation, such as when machines are more extensively used for peaking or the provision of grid support services, can also cause higher stresses on rotating machinery and electrical systems, therefore reducing their lifetime.
- More extreme weather events such as cyclones or floods or damage caused by social unrest.

Finally, the civil structures and associated features, including the powerhouse, spillway gates, underground assets, dam, and reservoir, typically last longer, with overall plant lifetimes anywhere from 60 to 100 years and even higher in some cases. Condition assessments of the main structures are usually carried out periodically to assess structural integrity and any need for repairs.

02.3 | Performance recovery

As described above, the general ageing of key electro-mechanical components, along with other factors such as operational changes or lack of maintenance, will almost certainly lead to reduced performance over time. This, in turn, will result in longer and more frequent maintenance outages, with an increased incidence of forced outages, loss of efficiency, and losses in energy production.

This can increase business risk and, depending on the owner's appetite for risk over time, determine when modernisation is required. Moreover, as hydropower is commonly the lowest marginal cost unit in a power pool in many markets, failing to modernise assets adequately can have detrimental impacts. Suppose the station is operating significantly below rated capacity for long periods. In that case, the shortfall in electricity supply may be replaced by more expensive thermal alternatives resulting in increased

greenhouse gas (GHG) emissions and costs for the utilities and customers.

Modernisation can mitigate this risk by repairing and replacing old equipment to reduce outages, improve availability and, in some cases, increase power output. A study undertaken by an OEM showed that life extension projects where turbine runners are replaced could increase or recover overall plant efficiency by 3 per cent and potentially up to 6 per cent or more; while larger projects involving the upgrade of turbine-generator units can increase installed capacity by up to 40 per cent.[19]

02.4 | Capacity and technology upgrades

In some cases, opportunities may exist to expand or update existing facilities' installed capacity and overall efficiency. In these cases, installed capacity (MW) may be increased by replacing turbine runners with higher capacity units and optimised systems.[20] Technology developments are a key factor in hydropower modernisations. Old systems can be replaced with state-of-the-art equipment, bringing benefits for operators.[21, 22] From turbine generators to spillway gates, equipment installed over 30 to 40 years ago can be retrofitted with new components optimised for improved efficiency and reduced environmental impact, thanks to advanced manufacturing and materials.[23,24,25,26] Technology upgrades can also bring forward the decision to modernise a project.

Finally, because of the lower capital costs associated with modernisation[27], a potential project associated with increased installed capacity could represents a substantial and cost-effective improvement to the energy systems at a much lower investment than a green field project. In several cases, the associated capacity upgrade can be quite substantial.[28]

Case study 01. Kpong, Ghana

Type of modernisation
Life extension

Year of completion
2020

Type of facility
160 MW run-of-river plant

Age of facility when modernised
Commissioned in 1982; approx. 38 years.

Owner
Volta River Authority (VRA)

Picture
ANDRITZ.com, © VRA.

Having operated the plant for about 30 years, the Volta River Authority decided to undertake a significant retrofit to extend the plant's life and increase its availability. The modernised plant will provide Ghana with a reliable and clean energy supply for another 30 years, contributing 4.3% of the country's total electricity mix.

CHARACTERISTICS

1. All four turbine generators and associated systems were modernised by Andritz Hydro, including turbines & governors, generators, intake gates, excitation, protection & control systems, and power station service facilities.
2. The units were completed sequentially in 2016, 2017, 2019 and 2020.
3. Installed capacity of the plant was maintained as before at 160 MW.
4. Plant availability recovered to an average of about 96% following completion in 2021, compared to the 2014 average availability of about 92% just before the retrofit works – minimising plant downtime for maintenance and forced outages.[a]
5. Annual generation: 986 GWh in 2021.
6. The project was supported by an Agence française de développement (AFD) loan.[b]
7. Benefits: improved availability and reliability of electricity supply, reduced plant failures, life extension, optimised operations, and improved VRA's competitive position in national and international markets.[c]

References
[a] Information provided by VRA; [b] https://www.afd.fr/fr/carte-des-projets/rehabilitation-de-la-centrale-hydroelectrique-de-kpong; [c] https://www.andritz.com/hydro-en/hydronews/hn34/kpong-ghana

Case study 02. Nalubaale, Uganda

Type of modernisation
major upgrade

Year of completion
2000

Type of facility
180 MW run-of-river plant

Age of facility when modernised
Commissioned in 1954; approx. 46 years.

Owner
Uganda Electricity Generation Company Ltd. (UEGCL)

Picture
© UEGCL.com

In the 1990s, the Nalubaale station was refurbished to repair concrete issues caused by Alkali-Aggregate Reaction (AAR) in the powerhouse and main dam and to address accumulated wear from a decade of civil disorder. During the repairs, the output power of all ten generators was increased, bringing the Nalubaale Power Complex's generating capacity to 180 MW. The station is adjacent to the 200 MW Kiira hydropower plant built in 2003, and together the Nalubaale-Kiira complex supplies a third of Uganda's electricity.c

CHARACTERISTICS

1. From 1990 to 2000, each of the ten 15 MW Kaplan turbine units was upgraded to 18 MW; increasing total installed capacity by 20% from 150 MW to 180 MW.a
2. Sinohydro Corporation oversaw the refurbishment of the concrete dam and powerhouse in 2018-21.
3. Since 2003, upgrades have been periodically undertaken on the electrical components, typically due to systems becoming obsolete; some works have also been done on mechanical and civil structures.
4. Full environmental and social impact assessments (ESIA) carried out to ensure compliance.[b]
5. Annual generation: 724 GWh in 2021.[a]
6. Eskom Uganda Ltd. has operated the Nalubaale-Kiira complex under a 20-year concession, which is nearing the end of its term.[d]
7. Benefits: Increasing power capacity by 30 MW, life extension of components, reduced

environmental impact, increased availability, higher annual output & reduced O&M costs.
8. The plant is coming up for its subsequent rehabilitation and optimisation, with feasibility studies completed and project implementation planned from 2025. The program aims to continue to address the long-term effects of AAR on the dam, refurbishment of electromechanical equipment, and structural enhancements for flood mitigation.[a]
9. There had been no spilling since 2000 following the upgrades. However, recent flooding events in 2020 have raised concerns about the capacity of the spillway as well as the safety of the dam.
10. UEGCL is studying the feasibility of installing floating solar PV on its hydro reservoirs, including Nalubaale.
11. Find further details on the operations & maintenance (O&M) strategy, issues and modernisation in a report prepared by IHA for the World Bank's O&M Handbook for Hydropower published in 2020.[d]

References
a Information provided by UEGCL; b https://tractebel-engie.com/en/references/nalubaale-and-kiira-hydropower-plants
c https://allafrica.com/stories/201208060974.html ; d https://openknowledge.worldbank.org/bitstream/handle/10986/33313/Six-Case-Studies.pdf?sequence=4&isAllowed=y

There are many other examples of hydropower upgrade programs in Africa, such as Akosombo, Upper Kafue Gorge and Kariba North Bank in Zambia, where major turbine retrofits increased capacity.[29] Other projects include the Roseires hydropower plant in Sudan where measures were implemented to enhance sediment handling capacity by increasing the height of the dam by 10 m to raise its storage capacity from 3 to 7.4 billion m3 and thereby increasing energy generation by 50 per cent.[30]

02.5 | Policy and markets

The decision to extend the life and potentially upgrade a hydropower station will typically be influenced strongly by the overall project economics, which is primarily driven by modernisation costs, electricity prices and market design. At the national level, where there is a risk of decommissioning old hydropower stations and potentially losing reliable, renewable generation capacity, governments may also develop enabling policies to encourage re-investment. Typical cost benchmarks for hydropower modernisation projects are discussed in section 6.1.

In Africa, cross-border power trading has been taking place for many decades, with bilateral power trading arrangements dating back to the 1950s and 1960s. During the 1990s, energy sector reform and liberalisation of national grids were undertaken in many African countries and set the stage for the development of power pools, beginning with the Southern Africa Power Pool (SAPP), followed by the development of Central (CAPP), Western (WAPP) and Eastern power pools (EAPP); all with similar objectives[31]:

- promote and increase investments in electricity production, transmission and distribution infrastructure;
- create a regional regulatory framework for pooling energy resources, including the establishment of common standards, rules and monitoring mechanisms;
- coordinate the long-term energy development in the region.

While these power pools have been functioning successfully for some time, specific challenges in Africa have developed over time. Whilst the SAPP has been the dominant player, led by well-established markets in South Africa, the lack of a champion in the WAPP and EAPP appears to have significantly limited their progress. This is evident in Sub-Saharan Africa, where existing hydropower is dominant and future growth in new hydropower is underway, but a well-established power trading market is still evolving.[32]

The table 03 summarises those countries within each power pool with over 100 MW of hydropower capacity considered under the Continental Mapping study; and comments on some key trends that have evolved relative to their respective energy markets and major hydro suppliers.

Case study 03. Mount Coffee, Liberia

Type of modernisation
total redevelopment

Year of completion
2017

Costs
US$ 357m

Type of facility
88 MW run-of-river plant

Age of facility when modernised
Originally commissioned in 1966; approx. 51 years.

Owner
Liberia Electricity Corporation

Picture
openknowledge.worldbank.org b, ©Hydro Operation International (HOI)

After being destroyed in the Liberian Civil War in 1990, a complete rebuild of the Mount Coffee Hydropower station was completed in 2017, increasing its pre-war 64 MW capacity to 88 MW following the modernisation. The restoration brought much-needed power online, providing 1 million people with a stable electricity supply, replacing fossil-fuel diesel generators and helping reduce electricity prices in Liberia.[c]

CHARACTERISTICS

1. Rebuilding dams and associated civil works, rehabilitation of the spillway and gates, intake structure, and powerhouse civil structure & replaced the electromechanical equipment.
2. The rehabilitation of the dam began in 2012, though with the Ebola virus in 2014 and local access challenges with poor road infrastructure, works were delayed by a year. Following partial completion of the intake and spillway structures, commissioning of the four 22 MW Francis units was done in 2016-2017, supplied by Voith Hydro. [d]
3. As the facility was rendered inoperable for years, the original owner (LEC) lost its in-house expertise in operating the hydropower plant. In 2016, a contract was assigned to an outside agency (HOI) to operate and maintain the plant while carrying out theoretical and hands-on training to qualify O&M staff. Further information on the O&M model was published in 2020.[c]
4. Annual generation: 223 GWh in 2020.[a]
5. Funded by the Liberian and Norwegian governments, European Investment Bank, German development bank KfW, and the Millennium Challenge Corporation; at a total cost of US$357m.[c]
6. Benefits: Improved efficiency and capacity by restoring 88 MW, optimised operations, life extension, training on O&M practices, and improving climate resilience.[a]
7. Safety: mitigation of upstream and downstream flood impacts
8. Although the plant is now operating well, there is a ten-year plan to add two more units, which would expand installed capacity from the current 88 MW to 132 MW. There are other plans under consideration for a second hydropower plant. a Furthermore, a 90 MW solar farm is planned in Liberia, of which 20 MW will be built at the Mount Coffee hydropower plant expected by 2024.[a]

References
a Information provided by LEC (Mount Coffee); b https://openknowledge.worldbank.org/bitstream/handle/10986/33313/Six-Case-Studies.pdf?sequence=4
c https://www.ft.com/partnercontent/voith/mount-coffee-hydropower-plant-raised-from-the-ruins.html ; d https://voith.com/hydro-in-africa-en/mount-coffee.html

Table 03. African regional power pools and key hydropower trends

Regional Power Pool	Linked countries with >100 MW of ageing hydropower in scope	Key trends & hydropower plants (HPPs)
Southern Africa (SAPP)	Zambia, South Africa, Mozambique, Zimbabwe, Namibia *Planned members: Angola, Malawi, Tanzania	Hydro plants in the Zambezi river basin have undergone or are undergoing major modernisations or expansions, e.g. at the Kariba, Kafue Gorge & Tedzani Falls HPPs[33]
		Cahora Bassa HPP in Mozambique generates significant energy for the SAPP and has facilities due for modernisation
		HPPs in South Africa also play a critical role, including Drakensberg pumped storage scheme which helps provide back-up reserve to the network; recently with units modernised[34,35]
		Angola, Malawi and Tanzania are not yet integrated and efforts are at an advanced stage to link the three countries into the power pool[36,37]
		In Malawi, modernisation will be needed to allow existing HPPs to interface with a new interconnector being constructed to Mozambique
East Africa (EAPP)	Egypt, Ethiopia, Kenya, Sudan, Uganda	Ethiopia has a number of existing hydro facilities in need of modernisation that play a major role in the EAPP.[38]
		Recently, the World Bank financed a 667 km HVDC line from Kenya through Tanzania to Zambia; to link EAPP & SAPP[39]
		In Egypt, the major Aswan HPPs are coming up for modernisation[40]
West Africa (WAPP)	Nigeria, Ghana, Côte D'Ivoire	The Kainji & Jebba HPPs are key to the success of power trading in Nigeria, which has low electrification rates (<50%). The 'North Core' transmission project soon to be completed will link Nigeria-Niger-Benin-Burkina Faso[41]
		Ghana and Côte d'Ivoire are key drivers of integration because of their regional ambitions & central location in the region.
		Kpong & Akosombo HPPs in Ghana were upgraded; while plans for Kossou, Buyo & Taabo HPPs in Côte D'Ivoire are underway
Central Africa (CAPP)	DRC, Cameroon, Gabon	Modernisation & expansion of the Inga HPPs in DRC will play a strong role in the regional pools (CAPP, SAPP)
		HPPs in Gabon are due for rehabilitation, and works progressed in Cameroon (Edéa, Lagdo, Songloulou HPPs[42]
		Angola's location could also trade supply into CAPP
North Africa (COMELEC)	Morocco	As the primary source of renewable energy in Morocco, the existing hydropower assets are due for modernisation

In all regions and countries of Africa where existing hydropower plays a key role, such as Ethiopia, Nigeria and Uganda, the success of those markets will be tied firmly to the maintenance of existing hydropower capacity and the continued development of new hydropower where feasible, to ensure that these regions can generate an energy surplus, along with ensuring that adequate transmission is in place for cross-border power trading.

Electricity markets can therefore act as a key driver for modernisation decisions, whether heavily liberalised or, as is more common in an African context, still mainly driven by national-level decisions. Ongoing reforms in many markets will have to recognise better and remunerate the essential role hydropower plays in supporting grids and offering balancing services to the system. In parts of both North and South America, Europe and Australia, hydropower units are already moving away from traditional baseload generation to modes of operation which accommodate and support a changing energy mix.[43] This continues to make use of hydropower's unique characteristics as a dispatchable power source, but can also lead to higher operating costs and the need to re-invest in plants.[44]

Broader policy changes can also have a direct or indirect impact, particularly regarding climate policy. For example, nearly all African countries have committed to action on climate change in ratified Nationally Determined Contributions under the Paris Agreement, agreeing to reduce their greenhouse gas emissions and build resilience. Such policy commitments will lead to an increased emphasis on low carbon generation, which can be directly supplied by hydropower or, in the case of variable solar or wind, enabled by hydropower's flexible characteristics, which can be further enhanced through modernisation (see section 2.6).

Similarly, a policy aimed at increasing access to electricity can, in part, act as a driver for modernisation as such projects can secure existing levels of access and provide enhanced availability through additional capacity and more reliable operations.

02.6 | Power flexibility, energy storage and variable renewable energies deployment

As electricity markets and transmission grids evolve[45], power flexibility and energy storage are becoming increasingly essential and strongly support the need for hydropower modernisation. According to IRENA projections, by 2050, the fleet of wind and solar plants in Africa and the Middle East may reach the record-breaking level of 1220 GW of installed capacity, 36x more than today[46]. It is, therefore, natural that, as of today, many generators and transmission system operators are looking for ways to improve frequency control and other ancillary services to support the electricity grid; this can require hydropower units to operate over an extended range, requiring quicker response ramping capability, part-load and fast stop/start capabilities amongst other improvements. If existing stations were not originally designed for these services, components may need to be re-engineered and replaced.

Existing and future pumped hydropower storage projects continue to be integral in Africa. In South Africa, Eskom's 40-year-old 1000 MW Drakensberg pumped storage facility was recently modernised, with upgrades to all three units, to ensure reliable operation for the next 40 years.[47] Another example is in Morocco, where the Office National de L'Electricite (ONEE) has commissioned a study of the 465 MW Afourer hydropower complex, aimed at optimising operation in both the pumped storage and conventional hydropower mode of the complex.[48] The International Forum on Pumped Storage Hydropower (PSH) provided global recommendations to support the increased deployment of PSH.[49]

Innovative generating systems can also be implemented in modernisation projects, such as those being demonstrated in the EU-funded XFLEX HYDRO programme.[50] Variable speed hydroelectric technologies can increase the power flexibility and efficiency of pumped storage, especially in markets where network stability is influenced by asynchronous wind, solar and battery technologies. Battery hybrids can also improve energy storage services at existing hydropower stations, whereby the battery provides fast frequency response over short timescales (2 seconds or less). In turn, hydro-generators provide network regulation & ramping services over longer timeframes. Using battery electronics for frequency control can also relieve control requirements and mechanical wear and tear on hydro machinery.

These strategies add to the range of options available for hydropower. They can also give access to revenue streams that are offered (or may be offered in the future) for power balancing services, thus helping to harness hydropower's full potential. When planning modernisation projects, both the benefits and added costs of flexibility technologies will need to be increasingly considered and weighed against alternative approaches.[51,52]

02.7 | Digitalisation of systems

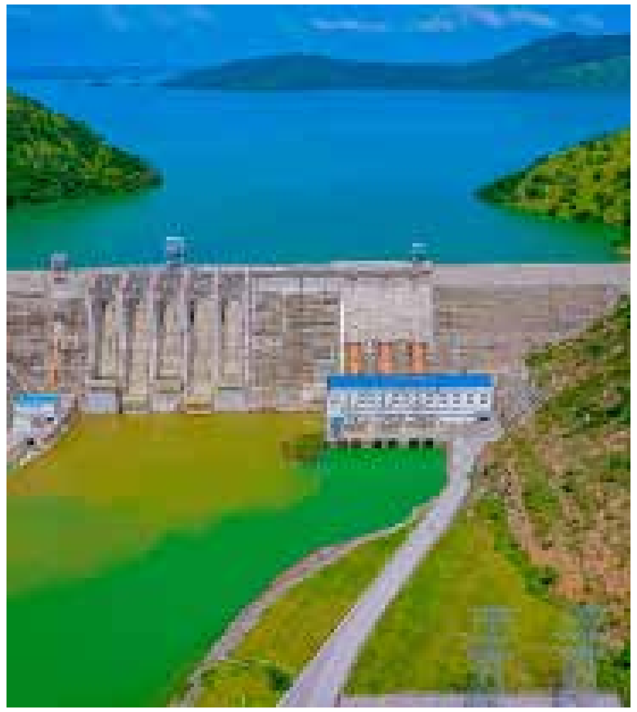
The digitalisation of hydropower technologies and operation and maintenance practices is well established in many more mature energy markets and has become a key feature of modernisation programmes. Projects now include installing new digital controls, intelligent condition monitoring systems, remotely operated systems, and supervisory control and data acquisition systems to digitalise the operation and management of existing stations.

A recent publication by the Policy Center for the New South indicates that digitalisation will be key to unlocking Africa's renewable energy potential to address the meager electrification rates across the continent. Existing hydropower assets that are designated for modernisation will need to embrace digitalisation into their project designs to ensure that these projects are optimised.[53]

02.8 | Hybridisation of hydropower plants

Hybrid concepts are gaining interest, whereby different renewable technologies complement each other and work more efficiently. Installing FPV onto existing reservoirs, in particular, provides additional renewable generation that is low carbon and cost. FPV systems can use existing infrastructure at the hydropower site, reducing land acquisition and grid connection costs otherwise incurred in greenfield solar projects. Integrating the FPV and hydropower control systems can also provide a win-win solution; because generating units can be run flexibly and used to back up solar output fluctuations, thus feeding a more stable power profile into the grid network. The added solar output can also reduce requirements on hydro generation in daylight hours and can help to preserve reservoir storage levels during dry periods.

Case study 04. Floating solar PV, Bui Dam in Ghana



Project
Solar hybrid at Bui Hydro Generating Station

Year of completion
2020

Type of facility
404 MW storage hydro plant, with 1 MW floating PV, plus 4 MW under construction and plans for >50MW.

Age of facility
Hydro commissioned in 2013; Floating PV in 2020

Owner
Bui Power Authority (BPA)

Pictures
© Bui Power Authoritya

With the government of Ghana's commitment to increase penetration of renewables by 10% by 2030, BPA expanded the existing switchyard at its Bui hydropower plant to accommodate 250 MW of solar PV – for the creation of a hydro-solar PV hybrid (HSH) system within the Bui enclave. In 2020, a pilot 1 MW floating PV array was installed on the reservoir alongside a 50 MW land-based solar PV, which was also commissioned. When complete, the HSH system aims to augment and preserve the Bui reservoir by generating solar power.

KEY COMPONENTS

Panels
2,500 PV panel units for the 1 MW floating PV pilot, to be upscaled to 10,000 units (Bi-Facial Mono-crystalline PV module); the rating per unit is 405 W with surface area of $2m^2$ and 30kg weight.

Inverters
4x 250kW size

Transformer
1 MVA size to be upgraded to 6.3 MVA upon completion of the 5 MW plant.

Floats
High Density Poly Ethene (HDPE).

KEY BENEFITS

1 MW floating solar pilot had a footprint of 1.7 acres (6880 m2), which is around a 50% saving on space compared to an equivalent 1 MW of land-based solar array.

Reduced dust accumulation on the floating panels compared to land-based, reducing the regularity of cleaning and lower maintenance cost.

Higher efficiency and output: Average monthly generation for the 1 MW floating PV is 176 MWh compared to 148 MWh of land-based PV (19% increase). The higher efficiency is primarily due to the cooling effect of the water on the solar panels.

Water is also conserved for larger arrays due to reduced evaporation from the reservoir.

IMPLEMENTATION

Phase 1 pilot commissioned in 2020;
Phase 2 expansion to 5 MW floating PV expected complete by end of of 2022;
Phase 3 subject to a successful implementation of the 5 MW system, BPA aims to upscale to >50MW.

Project model

1. Engineering, Procurement and Construction (EPC) + financing
2. Installation was done by in-house staff at BuiPower.
3. Power is transmitted via the Bui switchyard to Ghana's National Interconnected Transmission System (NITS).
4. BuiPower has broader plans to develop a 250 MW solar PV facility at the site (including the 50 MW co-located system on land) and has also earmarked six other locations for PV projects in the region.

References
a Information provided by LEC (Mount Coffee); b https://openknowledge.worldbank.org/bitstream/handle/10986/33313/Six-Case-Studies.pdf?sequence=4
c https://www.ft.com/partnercontent/voith/mount-coffee-hydropower-plant-raised-from-the-ruins.html ; d https://voith.com/hydro-in-africa-en/mount-coffee.html

02.9 | Climate resilience and hydrology

Climate resilience is a growing concern, with hydrological variability now being considered in hydropower modernisation projects. Greater weather extremes will affect hydropower infrastructure in climate-sensitive regions and may require investment in adaptive measures. For example, southern Africa is likely to experience a drier climate with more frequent incidences of low precipitation, while east Africa is projected to experience a wetter climate with more frequent heavy rainfall.[54]

Climate change impacts on existing and future hydropower projects in Africa will unquestionably result in the need for additional resilience measures, which could range from enhanced flood protection to sediment management strategies, improved dam safety measures, including early warning systems, and structural improvements to river and reservoir areas.[55] Hydropower facilities may also provide increased protection for communities via modern and well-maintained hydropower dams and facilities which can offer important flood protection or water storage services during extreme meteorological events. Climate change may also result in the potential for increased generation in some regions. A recent study on the Landscape of Climate Finance in Africa by the Climate Policy Initiative identified that hydropower systems in the eastern Nile, Niger and Volta basins could experience potential revenue increases of 20-140% if climate change scenarios are integrated into design and building.[56]

Other specific examples include sediment management strategies applied at the 280 MW Roseires hydropower plant in Sudan and as well at the 130 MW Kapachira facility in Malawi.[57,58,59]

Box 01. Hydropower Sector Climate Resilience Guide

To facilitate the development of hydropower infrastructure that can withstand the risks of variable climatic conditions, the Hydropower Sector Climate Resilience Guide was developed and launched in May 2019. It is the first sector-specific climate resilience guide providing a practical and helpful approach for identifying, assessing and managing climate risks to enhance the climate change resilience of new and existing hydropower projects.

The six-phase methodology can be applied to projects of all types, scales and geographies and looks at climate risk screening, data analysis, climate stress testing, climate risk management, monitoring, evaluation and reporting.

For further information on the Hydropower Sector Climate Resilience Guide, please see here: https://www.hydropower.org/publications/hydropower-sector-climate-resilience-guide

More generally, the magnitude and variability of river inflows affect water availability for electricity production, sometimes requiring remedial measures to be taken. Long-term changes in hydrology may justify the need for more extensive redesign at an existing site for reservoir storage and run-of-river hydropower projects.

For example, suppose the long-term average river flow is declining. In that case, station modernisation may be required to optimise water use by changing the turbine design to adapt to lower minimum flows or potentially decommissioning older units. Conversely, plant modernisation would consider upgrades to increase unit capacity where possible or even additional units if flows are growing. In other cases, dam, reservoir and spillway upgrades may be required if average river flows have changed significantly over the decades and there is a greater risk of extreme flood events in the future.

In a special report prepared by the International Energy Agency (IEA), projections were made about the impacts of climate change on hydropower projects in various regions of Africa. Under a range of scenarios, the regional mean hydropower capacity factor[60] is projected to decrease by the end of the century due to climate change. The analysis indicated significant spatial variation in climate change impacts regionally in Africa. For example, the hydropower capacity factor in Morocco is projected to decrease slightly; while it increases slightly for projects located in the Nile basin (including Egypt, Sudan, Kenya, and Ethiopia) under a scenario that assumes global warming of less than two°C by 2100.[61]

In some regions, climate change is already showing strong indications of impacting water availability and season inflow variability, with declining hydro output in Morocco in recent years and droughts in parts of Angola. The data and tools available to accurately model hydrological impacts vary by country and region. The World Meteorological Organization's 2022 State of Climate Services: Energy[62] report set out several approaches by different National Meteorological and Hydrological Services providers, including, for example, Tajik Hydromet in Tajikistan. With support from several international agencies, Tajik Hydromet can now apply new techniques to provide more targeted information to Tajikistan's state-owned power utility to support the safe and efficient operation of hydropower plants.

02.10 | Socio-environmental impacts

Sustainability and environmental and social impact can be key drivers for modernisation, particularly in large-scale redevelopments. New environmental technologies are also being increasingly adopted to improve natural habitats, water quality, fish management and reduce detrimental impacts on ecology upstream and downstream of hydropower sites.[63]

For existing multipurpose hydropower schemes in Africa, water services can potentially be improved as due to modernisation by increasing reservoir capacity or by adding or improving existing irrigation services, flood management and downstream flow regimes. Hydropower sites and their operations can also impact a region's public water resources, meaning changes expected from modernisation projects must be considered at the planning stage and in collaboration with the water authority.

For example, in the case of the modernisation of the Nalubaale and Kiira hydropower plants in Uganda, Environmental Social Impact (ESIA) / Compliance Assessment and Environmental & Social Risk Screening/ Initial Impact Assessments were considered for all possible options.[64] Similarly, the ongoing modernisation of the Kainji-Jebba complex in Nigeria involves full consideration of environmental & social impacts and benefits from the recovery and rehabilitation of these facilities.[65]

Box 02. Hydropower sustainability standard & tools

Developed through a multi-stakeholder process, hydropower operators and developers can now demonstrate their projects' environmental, social and governance (ESG) performance using the Hydropower Sustainability Standard.

Projects can be certified against defined international goods and best practices using Hydropower Sustainability Tools. The tools provide a common language for governments, civil society, financial institutions and the hydropower sector to discuss and evaluate sustainability issues in hydropower projects. There are three complementary tools:

- The Hydropower Sustainability Guidelines on Good International Industry Practice (HGIIP) define processes and outcomes that constitute good international industry practice. Performance can be measured through two complementary tools:
- The Hydropower Sustainability Assessment Protocol (HSAP) considers 26 guideline topics and comprehensively enables projects to benchmark performance against defined good practices.
- The Hydropower Sustainability Environmental, Social and Governance Gap Analysis Tool (HESG) checks for gaps against the good practice on key topics and includes a gap management plan.

For further information on the Hydropower Sustainability Tools, please see here: https://www.hydrosustainability.org/hydropower-sustainability-tools

02.11 | Contractual limits and regulations

Many large-scale hydropower facilities operate under long-term concession agreements held with a local authority or power off-taker and sell the electricity generated to a third-party buyer via a power purchase agreement (PPA).[66] The expiry of an existing concession or a PPA can be a key driver for re-investing in an existing asset. For a station nearing the end of its life, renewal of the concession agreement may be a key factor to make sure that the current operator is sufficiently incentivised to start a modernisation project.[67]

Regulatory risks affect decisions around modernisation projects across several areas, notably:

Electricity sector legislation
can guide re-licensing requirements for power stations; grid network rules can affect operating and dispatch requirements; and typical market structures and public-private models implemented in the power sector (PPAs, concessions, etc.). Governments may also support re-investment and modernisation, mainly where hydropower plays a significant role, as in Norway and Switzerland. Furthermore, in the case of FPV hybrid, there may be additional regulatory factors to consider.[68]

Water laws and policies
can affect the usage of water resources. Water authorities must often be consulted to license any changes resulting from hydropower modernisation.

Environmental legislation
requirements can come into force or be updated, obligating owners to refurbish existing hydropower sites to meet stricter limits.

An Investors Guide to Hydropower in Africa, published in 2021 by international law firm Addleshaw Goddard with support from IHA, gives an overview of these areas and related legal issues. Country profiles are included on Ethiopia, Nigeria, Malawi, Zambia, Uganda, Morocco, Mozambique, Cameroon, Ghana, and Rwanda – many of which have ageing hydropower stations and modernisation needs.[69] The World Bank's Operation and Maintenance Strategies for Hydropower, published in 2020 with support from IHA, also provides further information on O&M models.[70]

Section 03

E&S implications associated with modernisation projects

03.1 | Introduction

The focus of this section is to discuss the main environmental and social (E&S) implications associated with modernisation projects. Hydropower projects provide an interface between society and the environment. Modernisation projects are no different. They aim to protect people from natural hazards, like droughts or floods. They also allow people to benefit from what nature offers – renewable and clean electricity that drives socio-economic development and enables wind and solar power with storage services – by maximising the output of existing infrastructure.

But such projects inevitably influence the environment by harming or improving existing conditions. It is essential to recognise and address these impacts to increase hydropower potential for development, avoiding/mitigating the negative and maximising the positive.

The Hydropower Sustainability (HS) Standard offers the leading global assessment framework to evaluate the E&S performance of hydropower projects. Based on over two decades of implementation, the HS Standard is a proven and robust methodology to address E&S challenges in hydropower and its framework has already been used to assess the potential E&S impacts of a modernisation project in Sweden.[71] It covers the following 12 sections, which are aligned with the International Finance Corporation's (IFC) Environmental and Social Performance Standards and the World Bank's Environmental and Social Framework:

1. Environmental and Social Assessment and Management
2. Labour and Working Conditions
3. Water Quality and Sediments
4. Community Impacts and Infrastructure Safety
5. Resettlement
6. Biodiversity and Invasive Species
7. Indigenous Peoples
8. Cultural Heritage
9. Communications and Consultation
10. Governance and Procurement
11. Hydrological Resource
12. Climate Change Mitigation and Resilience

03.2 | General considerations about the environmental & social implications of modernisation projects

Hydropower projects can have several sustainability risks and opportunities. These are often site- and project-specific and must be understood in detail to apply best management practices. This applies equally to modernisation projects.

It is known that hydropower projects tend to have an extensive lifetime, with over 60% of the plants in Africa having been in service for more than 20 years. These vast lifetimes are usually accomplished due to modernisation works on electrical, electromechanical and civil components that help ensure the long-term efficiency of the projects. Generally, and in the HS Standard, many E&S considerations around major modernisation exercises or refurbishments for operating hydropower projects are typically assessed using the Preparation Stage and Implementation stage tools. This is because many challenges facing modernisation projects are similar to those in the design and construction stages of a new build facility, such as altered flow regimes, sedimentation and erosion issues, occupational health and safety concerns, and potential legacy issues.

Minor works to increase efficiencies, replace equipment and rectify ageing infrastructure issues could be considered normal asset management practice for operations and usually would result in positive changes in the E&S indicators of the project.

Other examples of E&S impacts associated with rehabilitation works that should receive careful consideration include but are not limited to: the use of land for brief facilities and access roads, the temporary diversion of river waters from river sections, the discharge of pollutant drainage from camps or the discharge of hazardous substance in the surroundings of the plant, noise and safety risks faced by local communities and possible conflicts between workers and local community members.

Beyond mitigating impacts, modernisation projects can enhance pre-project E&S conditions and even address legacy issues that may impact the future perception of hydropower in the country or region. The HS Standard also offers insight into best practices to help guide ambitious project owners in developing projects that positively impact people and the planet. Another positive aspect is that modernisation projects are often associated with increased electricity generation from the target plant. This factor alone has a substantial positive effect in supporting economic development and improving the life quality of local communities.

Table 04 provides a non-exhaustive list of potential E&S impacts of modernisation projects and opportunities for best practices.

Table 04. Overview of the potential physical, biological and social impacts of hydropower projects

Physical	Biological	Social
Alteration to water level around the reservoir and the downstream river	Temporary disturbance of fauna, including nesting, spawning and migration fauna	Safety risk for works during rehabilitation work
Disruption of sediment movement in the river system	-	Safety risk for local communities leaving in the surrounding area of the plant
Conversion of land for disposal of spoil, obsolete components, and disposal of waste	-	Possible conflict between workers and local communities
Temporary use of land for facilities and access roads	-	-
Emission to air (from vehicles)	-	-
Additional noise during project implementation	-	-
Temporary diversion of a river or excessive spilling	-	-

03.3 | Hydropower sustainability guidelines on good international industry practice

Older projects, developed before environmental and social issues were considered at all, often lack adequate environmental documentation and plans. Modernisation projects thus offer an excellent opportunity to implement new and modern environmental and social assessment management approaches, with increased stakeholder engagement and local community buy-in.

In the case of rehabilitation and modernisation projects, it is highly recommended to follow the same steps as for new projects in analysing possible E&S impacts during the preparation and implementation stages. The various steps can be summarised as follows:

Preparation stage

- Scoping and detailed assessment of potential environmental and social impacts of the implementation of the rehabilitation or modernisation project and the ongoing operation of the scheme.
- Detailed stakeholder engagement on impacts and issues of the project, those of ongoing operations, and proposed management measures.
- Planning of avoidance, minimisation, mitigation and compensation measures for implementing rehabilitation, modernisation, and ongoing operation.
- Planning of stakeholder engagement for implementing rehabilitation, modernisation, and ongoing operation.

Implementation stage

- Construction to the required designs to avoid and minimise impacts.
- Mitigation of construction stage impacts, or when mitigation is not feasible, compensation.
- Continuing stakeholder engagement.
- Monitoring and reporting to regulators and stakeholders.

Even though in the case of rehabilitation projects, the risks of noticeable negative E&S impacts are substantially smaller than those associated initially with the plant's original construction, rehabilitation projects, if not properly managed, could trigger unwanted negative E&S consequences and lead to project delays. One important approach to consider when implementing E&S impact assessment and management plans is the principle of proportionality. This principle stipulates that the extent of mitigation required (and the associated budget) is proportional to the nature and scope of the impacts caused by the project.

It is therefore recommended that, as part of the study to be carried out in preparation for rehabilitation or modernisation, all the parties involved (including plant owners, the suppliers, and the financiers) dedicate sufficient time and resources to the identification of possible E&S impacts associated with the execution of the project.

A recent initiative funded by Switzerland's State Secretariat for Economic Affairs (SECO) made available a total of 1 million Swiss Francs (USD 1.02m) to 40 or more hydropower projects between 2020 and 2024 to help developers and operators in Africa, Asia, Europe and the Americas to benchmark and raise their social and environmental performance. This initiative is managed by the International Hydropower Association's sustainability division.[72]

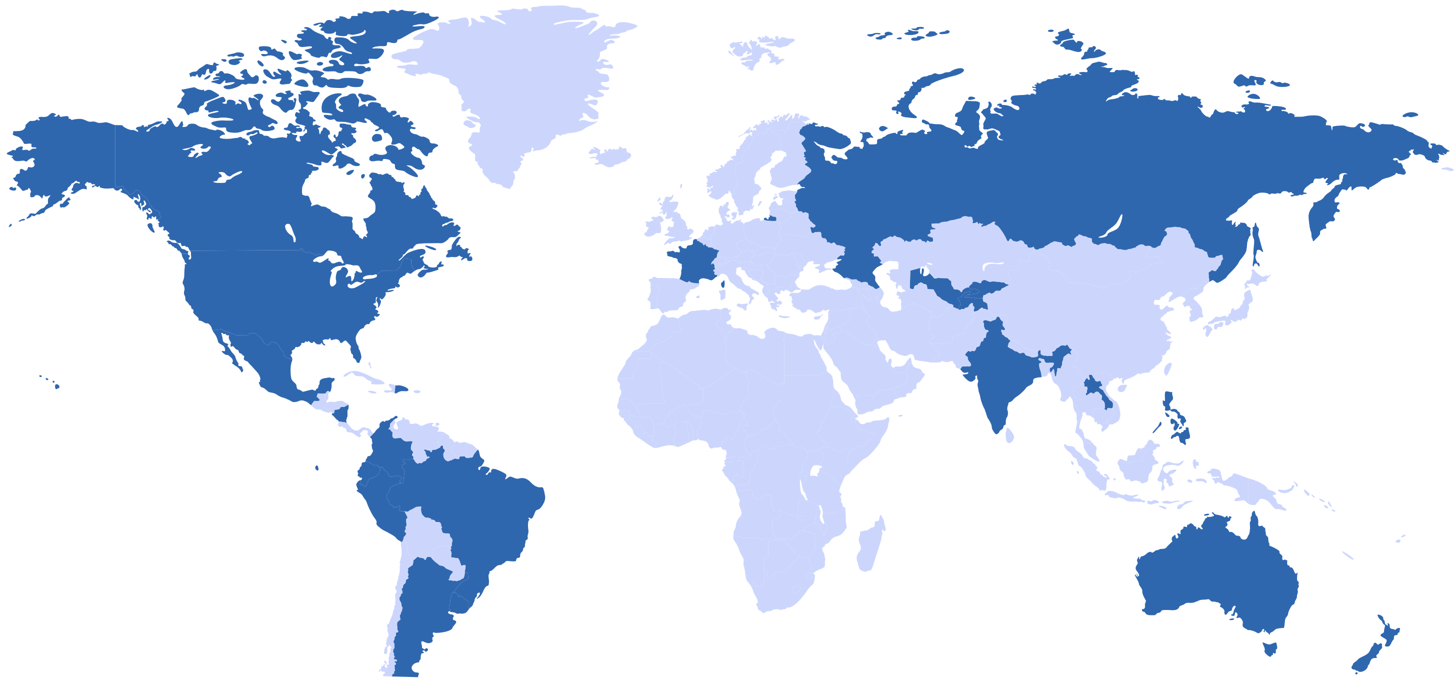
Section 04
Modernisation cost benchmarking

04.1 | World-level cost benchmarks

Much like a greenfield hydropower project, modernisation projects vary from site to site in scope and complexity; therefore, estimating a modernisation project's cost in its very early stages is not always a straightforward activity. Furthermore, there is limited literature on the subject. Modernisation costs can also vary significantly on a global scale due to commodity prices, labour costs, regulatory and licencing policies and availability of parts locally.

IHA undertook a high-level benchmarking exercise in 2020 to help inform understanding of investment cost ranges. The exercise covered 95 data points across 64 stations in 28 countries across the world, focusing on projects greater than 10 MW in installed capacity and undertaken after the year 2000.[73] The cost information was drawn from both publicly available sources (e.g. utilities, equipment suppliers, engineering firms, governments and IFI reports) and cost data supplied directly from station owners or operators. Publicly available information presented some problems; for several projects, cost breakdowns were not reported. In such instances, discretion was used to determine how costs were apportioned, but where sources were deemed unreliable, these projects were discarded.

Figure 06. The location of projects used as part of the cost benchmarking exercise



NOTE Dark blue indicates countries were at least one project considered in the cost benchmarking exercise was located

Firstly, Capex costs were collected, recorded in US$ and divided into three main subsystems of a station:

Electrical installation costs: including transformers, high voltage switchgear, electrical equipment, auxiliary electrical services and electrical control systems.

Electro-mechanical installation costs: including key drivetrain components (i.e. generator, turbines, stators and rotors) and control structures (i.e. gates, valves and cranes).

Civil works costs: including the civil infrastructure of a project such as a dam, intakes, powerhouse, penstocks, tunnels, spillways, roads and bridges.

These three categories are purposely broad due to the lack of detailed information available at a project level. This is

why electrical installation costs have been combined with mechanical installation costs to create electro-mechanical installation costs. While generators are part of the electrical subsystem of a station, the costs associated with turbine-generator sets are typically reported together rather than separately.

If required, costs were converted into US$ and then escalated to obtain actualised costs in 2020 to make them comparable and account for the effect of general inflation.

The following formula was used:

$$\mathbf{CAPEX_n = CAPEX_0 x\ (1+i)^n}$$

$CAPEX_n$ = the actualised capital expenditure at year n;
$CAPEX_0$ = the base capital expenditure at year 0;
i = the escalation rate;
n = the difference between year n and year 0.

In line with a 2018 study which focused on estimating the costs of greenfield projects worldwide, an escalation rate (i) of 3 per cent was adopted.[74] The escalation rate refers to annual increases in prices associated with modernisation projects due to inflation.

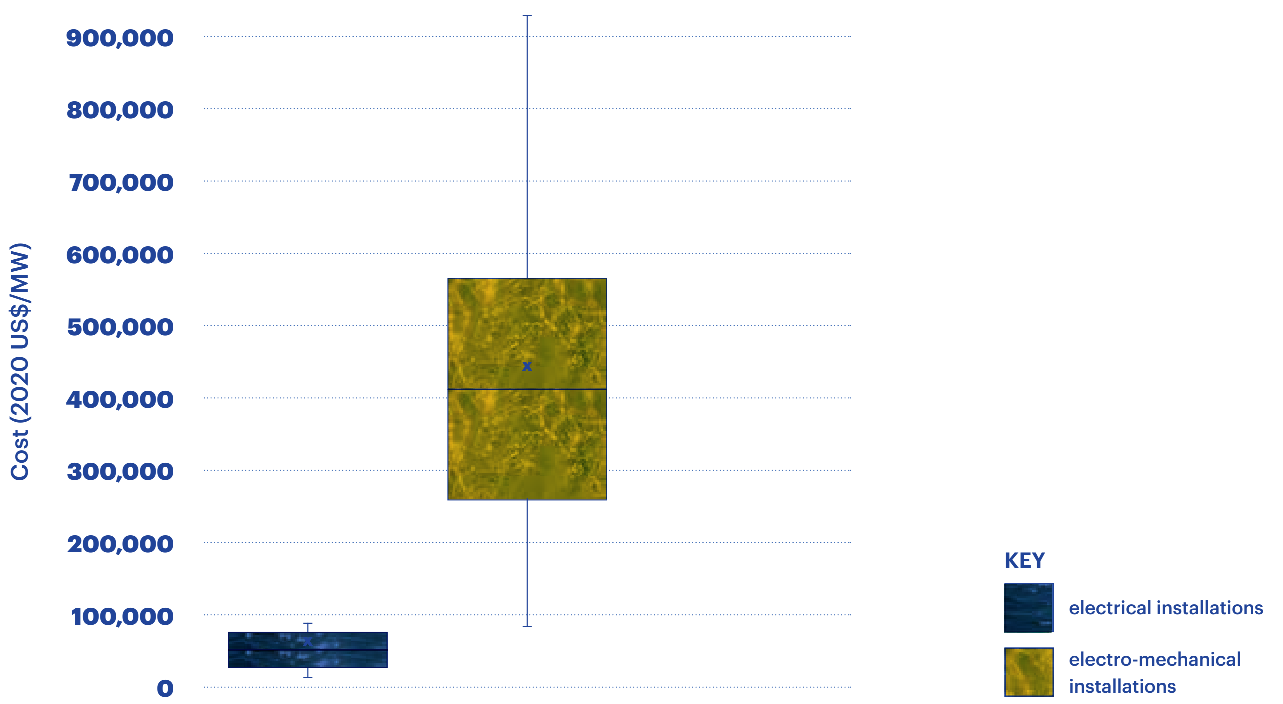
Meanwhile, civil costs bear little relationship with the capacity of a station, reflecting that the scope of civil works can vary widely and is more dependent on the size and conditions of the structure. For example, civil works can range from raising a dam's height to rehabilitating its spillway gates which have significantly different cost implications and are not directly linked to a station's generating capacity. Civil costs can also be greatly influenced by local material and labour costs, making estimating costs on this scale difficult. Figure 8 shows costs as unit values per installed capacity

(US$/MW) for electrical and electromechanical installations . The methodology used for calculating each unit value on a US$/MW basis was:

- Electrical installation cost (US$) / Total capacity of the station.
- Electro-mechanical installation cost (US$) / capacity associated with the number of units impacted.

For electro-mechanical costs, the impacted units' capacity was used as the denominator. Using the entire station's capacity would significantly deflate the cost on a US$/MW basis and not reflect reality.

Figure 07. Boxplot showing the distribution of modernisation cost values for electrical installations and electro-mechanical installations



It illustrates the range containing the minimum, Quartile 1 (Q1), the median, Quartile 3 (Q3), and to the maximum. The mean is marked by 'x'.

Table 05. The range of modernisation costs on a US$/MW basis (2020)

	Electrical installations	Electro-mechanical installations
Minimum	35,00	91,000
Q1	24,000	291,000
Median	39,000	432,000
Q3	53,500	542,000
Maximum	166,000	945,000
Mean	44,000	464,000

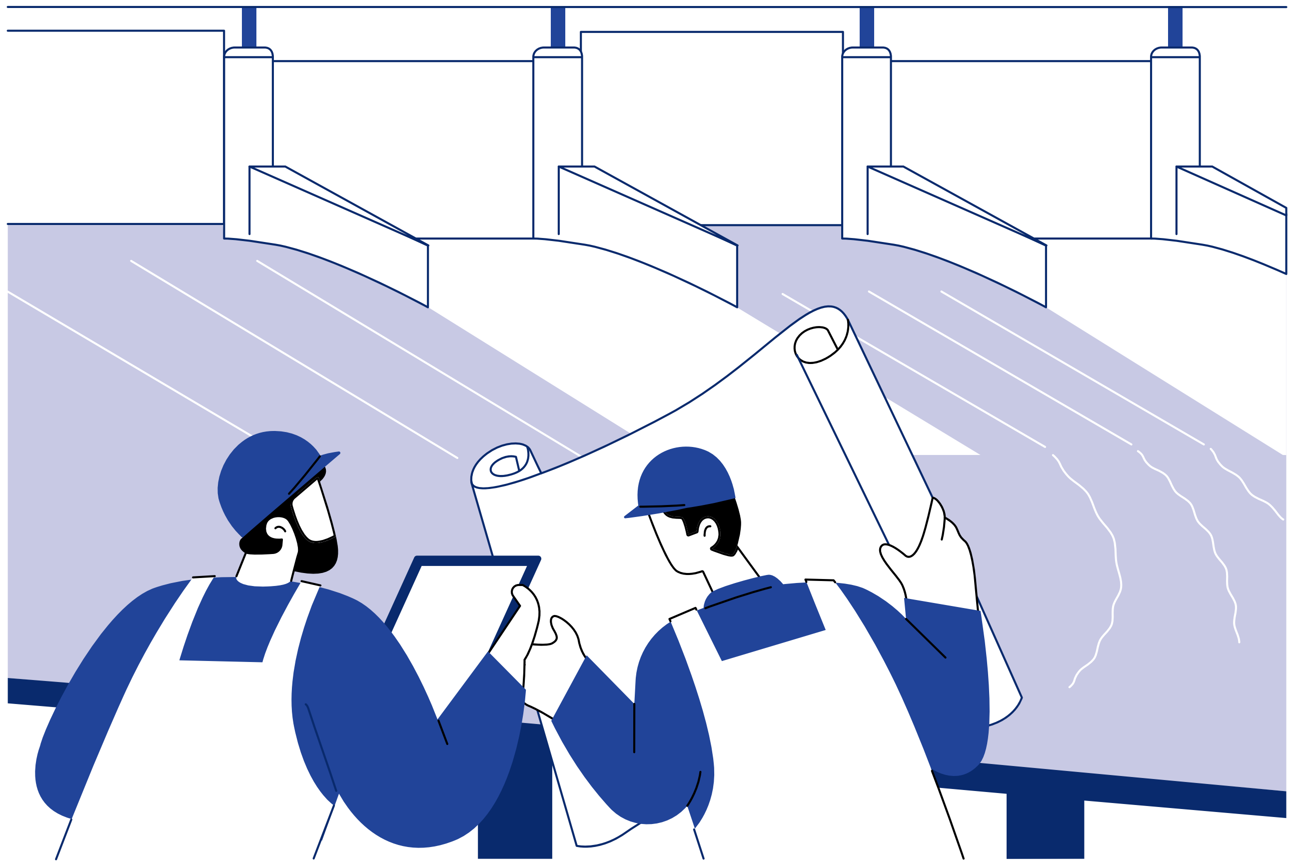
With an average of US$ 44,000/MW, electrical installation costs represent a small percentage of the overall cost associated with more complex electro-mechanical modernisation projects (less than 10%).

Electro-mechanical costs varied by over US$ 250,000/MW between Q1 and Q3. This can, in large part, be explained by the scope of work. Costs at the lower end of this range were generally associated with unit rehabilitation. In contrast, costs of replacing and upgrading the main drivetrain components (stators, rotors, turbines etc.) within the unit were at the higher end. Modernisation projects that involved the rehabilitation of units tended to record average costs of below US$ 400,000/MW, while projects which replaced turbines and associated components incurred costs above US$ 600,000/MW.

Moreover, even modernisation projects similar in scope can vary due to the various other factors influencing costs, including access to units within the powerhouse, availability of replacement parts for non-typical unit designs, variable labour costs by country, upgrades required to undersized overhead cranes, etc.

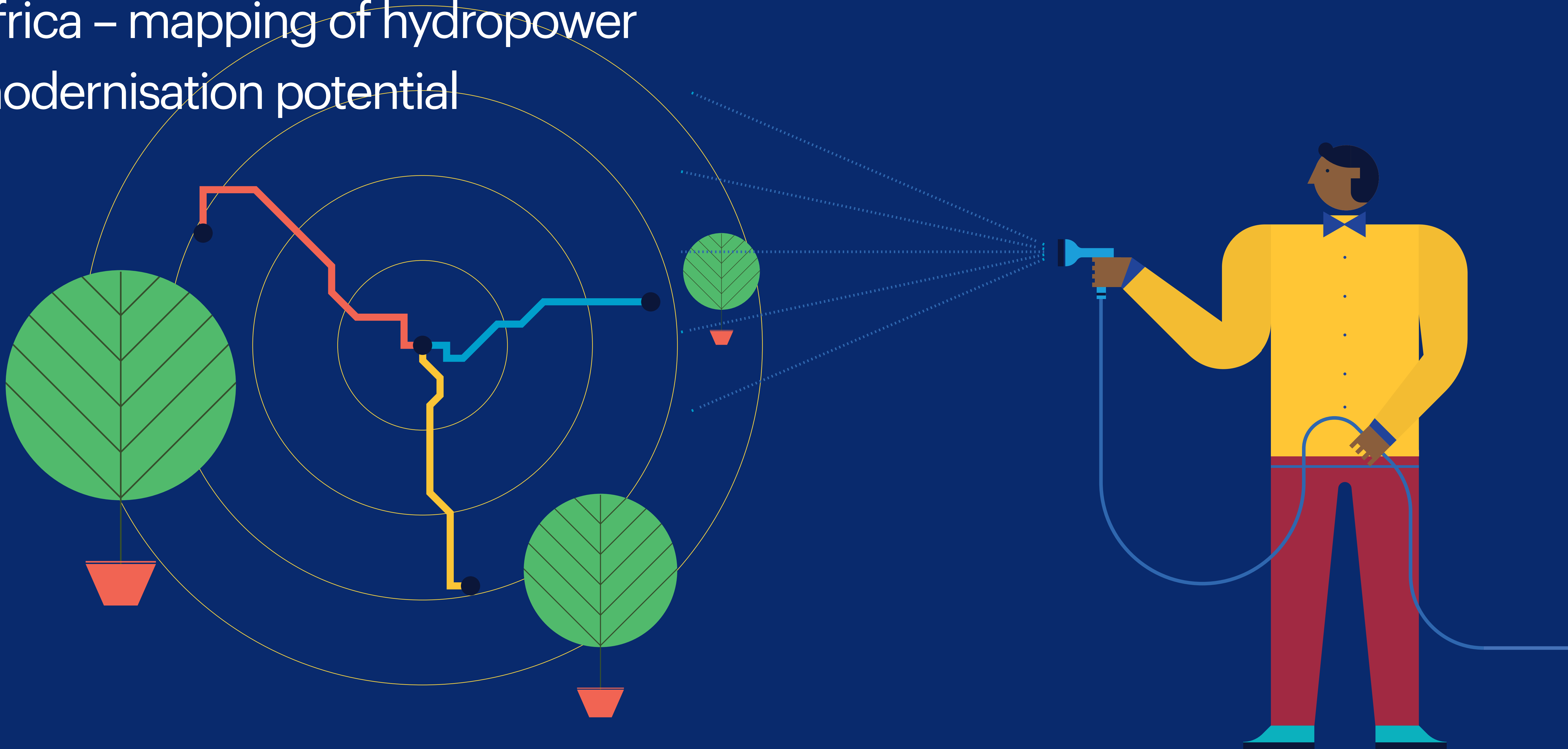
For this level of analysis, detailed costs of the varying components were not provided. More detailed information on specific components within the scope of the modernisation project (sealings, bearings, cooling system, turbine type, rotor and stator specifications, etc.) would allow for a more accurate cost estimate. Still, it would need to be based on more detailed studies, which are planned to be conducted for AHMP pilot projects.

As part of the work in the Africa modernisation mapping project, IHA has confirmed the validity of this modernisation cost benchmarking methodology and figures through consultation with two major hydropower Original Equipment Manufacturers (OEMs). Both OEMs indicated the benchmarks are reasonable and comparable with their market experience.



Part 02

Africa – mapping of hydropower modernisation potential



Section 05

African context

Access to electricity is a crucial factor in enabling Africa's economic growth and social development. With energy demand growing twice as fast as the global average, Africa has the opportunity to be the first continent to develop its economy using mainly renewable energy.

Despite the remarkable progress of African governments in tackling energy poverty, the continent still needs to connect 20 million people to the electricity network every year from now to 2030. According to the IEA, 44% of Africa's population was without access to electricity in 2020, or 584 million residents, with certain countries like DRC, Congo, Malawi, Niger or South Sudan reporting levels above 80%.

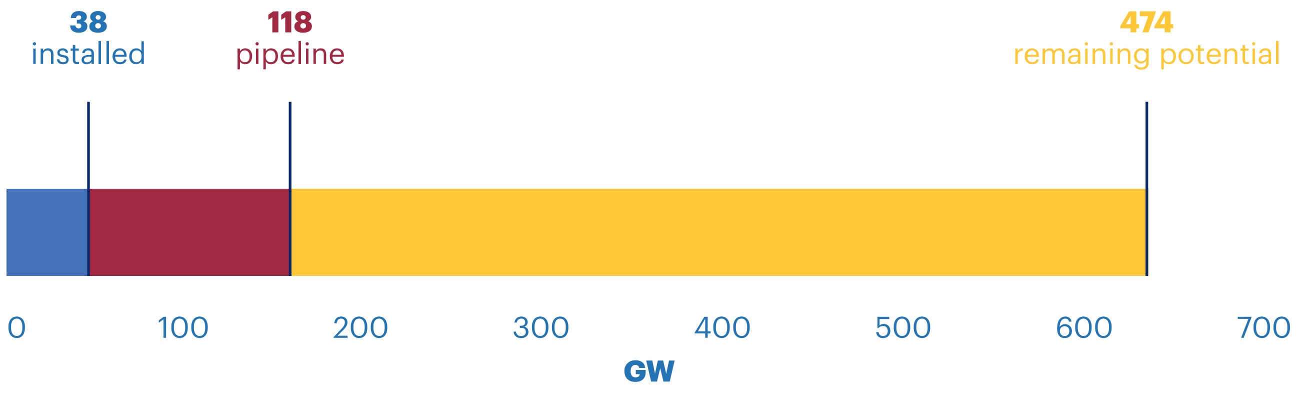
Figure 08. Electricity access in Africa (2020 – % of population)

SOURCE IEA data & IHA analysis

The continent currently houses roughly 40 GW of installed hydropower capacity, making it the leading renewable resource and a primary electricity source alongside coal and gas. Its share of total electricity generation is predicted to increase from 17% in 2021 to over 23% by 2040.[75]

As shown in Figure 09, the current pipeline of hydropower project amounts to 118 GW and the remaining untapped potential is above 470 GW.[76]

Figure 09. Installed, under development, and remaining potential hydropower capacity in Africa (2021)



SOURCE IHA Status Repot 2022

05.1 | Scope

While Africa has the highest percentage of the untapped hydropower potential of any inhabited continent (with circa 10% utilised), 47% of the installed capacity is over 40 years old, and 60% is over 30 years old.[77] Significant opportunities exist to improve the general and specific needs of different assets, countries, and regions as part of a future holistic strategy for a clean, reliable, and sustainable energy system. This report aims to present the results of a continental-wide mapping exercise by the IHA on the current status of the main hydropower facilities in Africa. This work included:

- A screening of the IHA's world hydropower database;
- A webinar with the owners and operators of these plants to describe the intent and the possible outcomes of this work and how it relates to AHMP;
- A station-level data collection to classify the status of the assets reviewed.

Table 06. Hydropower capacity per region

Region	Countries participating	Capacity (MW)	# stations
North Africa	Morocco, Egypt, Sudan. Algeria,	3094	7
West Africa	Côte D'Ivoire, Ghana, Liberia, Nigeria, Mali	3801	10
East Africa	Burundi, Ethiopia, Kenya, Malawi, Mozambique, Tanzania, Uganda, Zambia, Zimbabwe	2101	19
Central Africa	Congo, DRC, Cameroon, Gabon,	3146	13
South Africa	South Africa, Namibia	12098	38

The outcome of this assignment will be a valuable tool in the decision-making process of the AfDB in in developing of their activities under the Africa Hydropower Modernisation Programme.

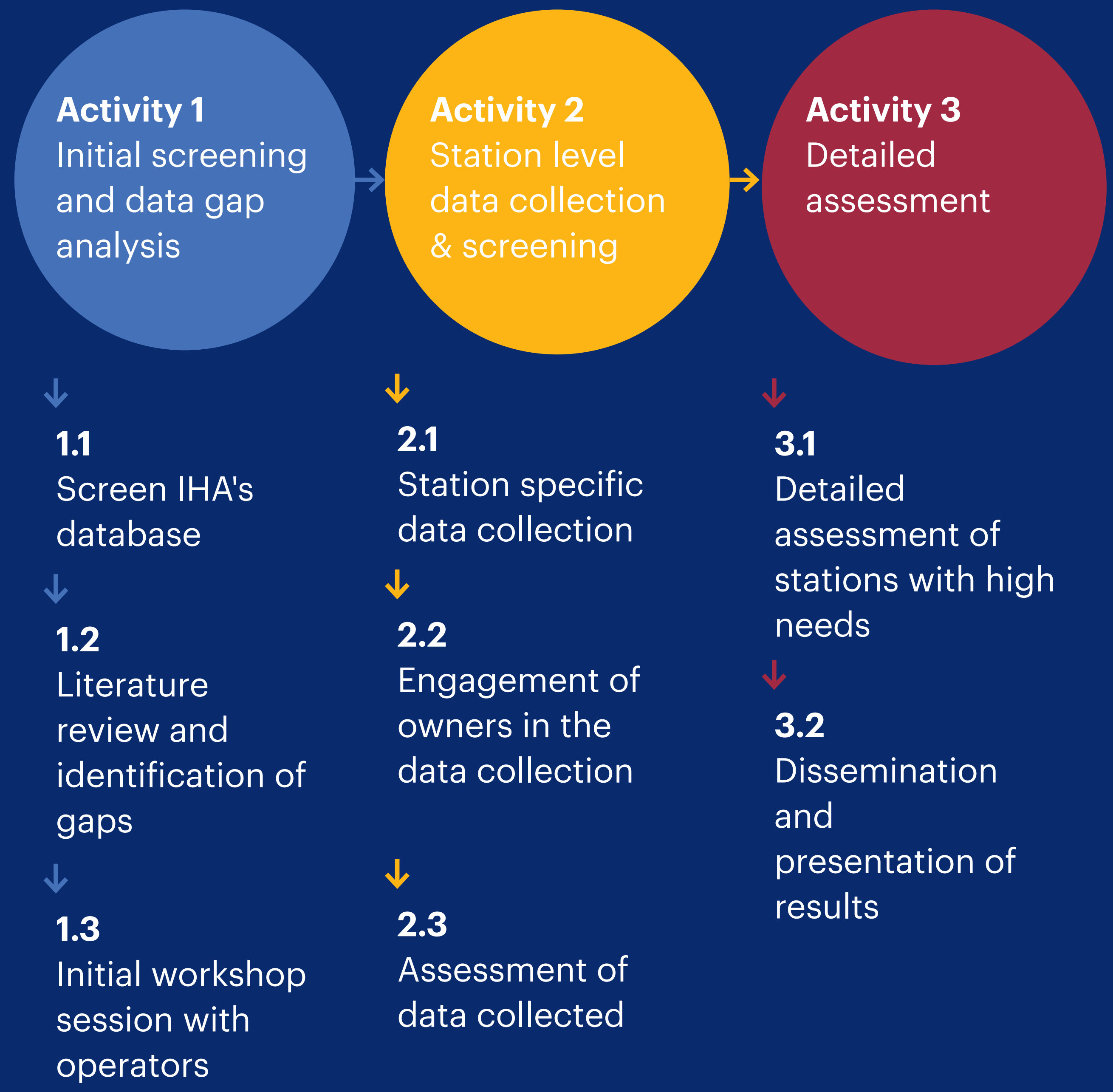
Section 06

Methodology

06.1 | Overview

The overall methodology for the project followed a three-step process which is illustrated in Figure 10. Each step helped narrow down the number of stations needing modernisation through data-based analysis, expert advice, and feedback from station owners.

Figure 10. Overall methodology for the Continental Mapping



The following sections describe the activities carried out in tasks 1.1 to 3.2, as illustrated in Figure 10

06.2 | Activity 1 – initial screening and data gap analysis

6.2.1 Screening IHA's database (Task 1.1)
For the initial screening, the draft database was compiled using station data extracted from IHA's global hydropower database and initially filtered for stations above 50 MW and over 30 years old. This reached a list of 87 stations,[78] totalling 24.2 GW installed capacity (more than 60% of the African hydropower fleet). The primary station characteristics gathered in the database included:

1. Station name
2. Installed capacity (MW)
3. Country
4. Year of commissioning
5. Type of project (storage, pumped storage, or run-of-river)
6. Number of units
7. Province/ state
8. River name
9. Location with latitude and longitude geocoordinates
10. Project status (operational or non-operational)
11. Station owner and classification
12. Annual generation

Figure 11. Location of the 87 plants identified for the study

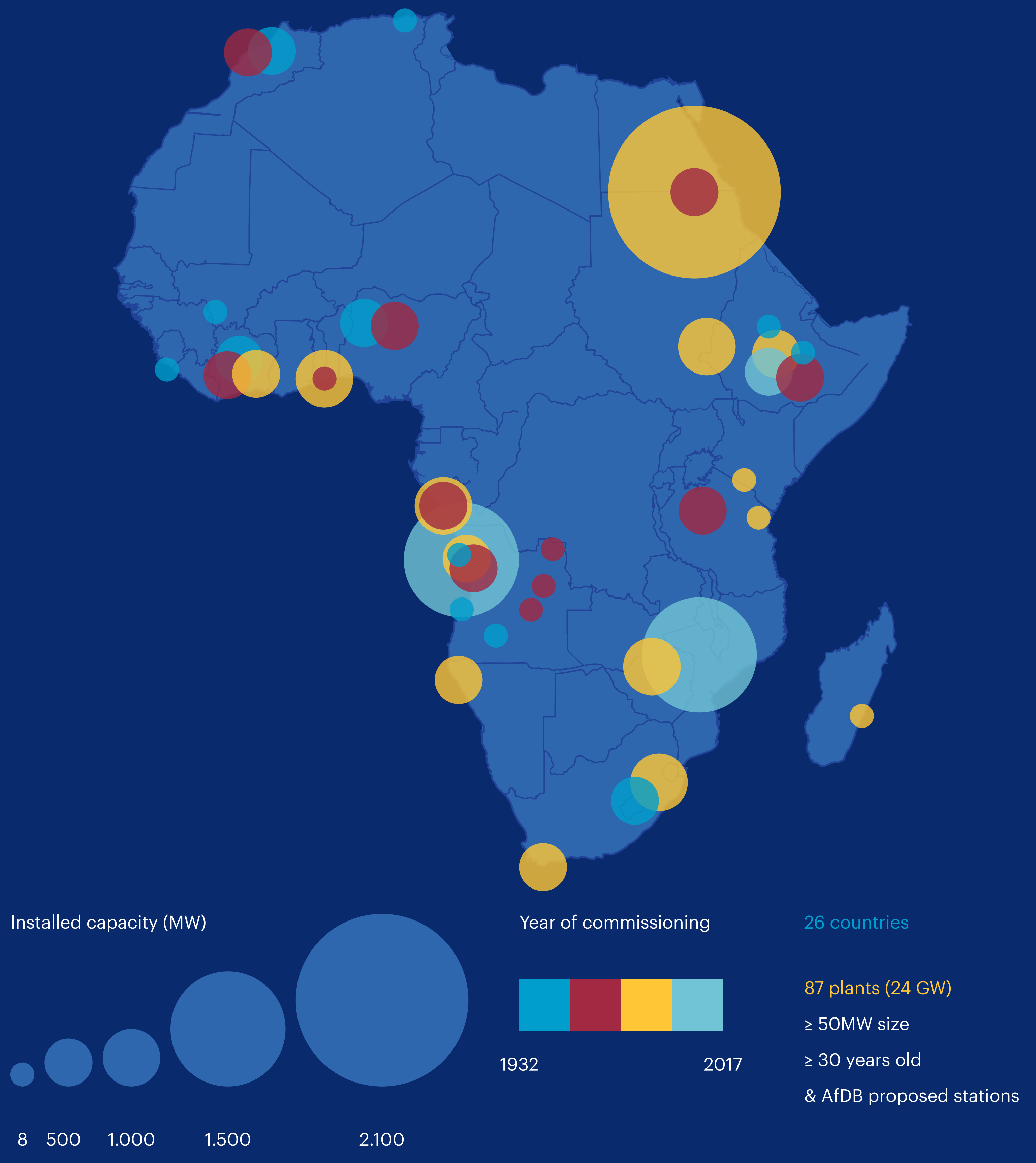
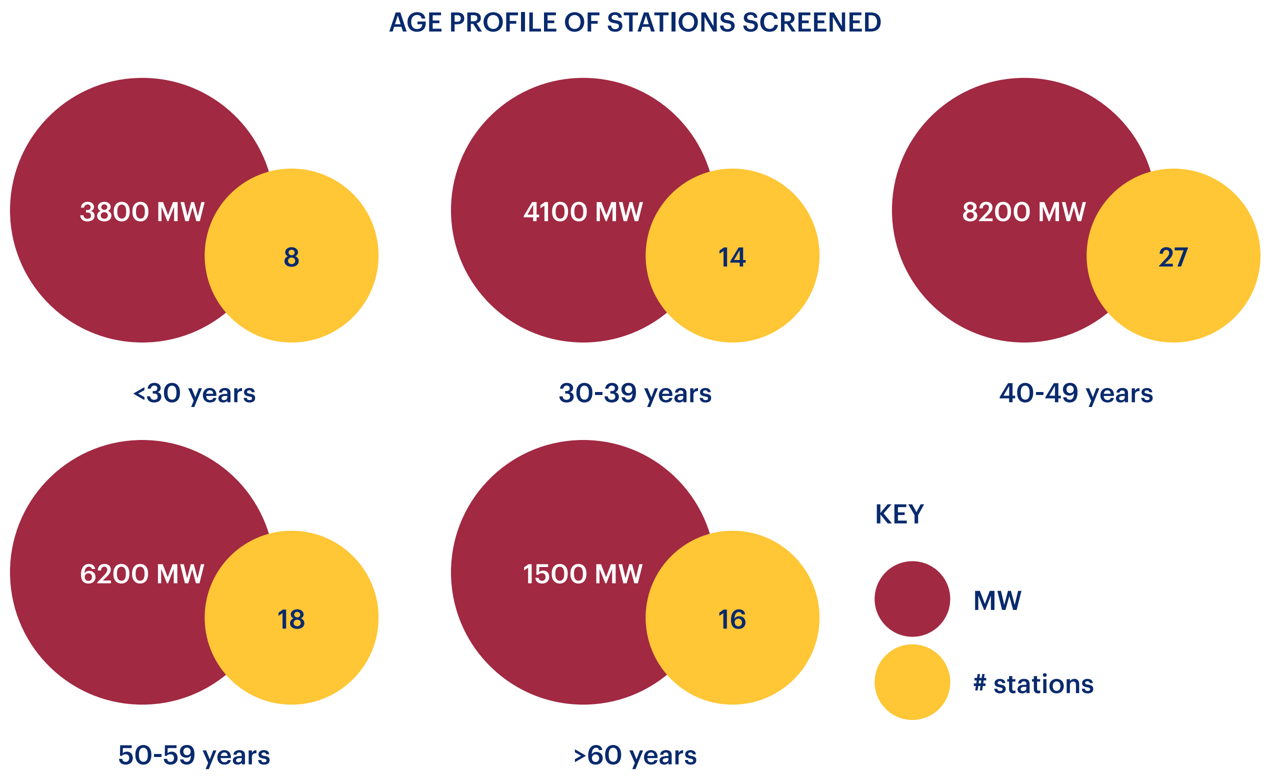


Figure 12 below presents the age profile of the plants, i.e. installed capacity and number of stations within each age range. This illustrates that most stations within the identified dataset were between 40 and 60 years old.

Figure 12. Age profile of the 87 hydro stations & installed capacity



SOURCE IHA database and analysis

6.2.2 Literature review (Task 1.2)

A literature review was undertaken covering three subtasks:

1. **Check the dataset of basic characteristics and close gaps where possible using public information sources, such as other online databases, news articles, and reports;**
2. **Screen past or ongoing rehabilitation programmes that have taken place at the 87 stations; and**
3. **Review the key drivers and opportunities for hydropower modernisation using existing references.**

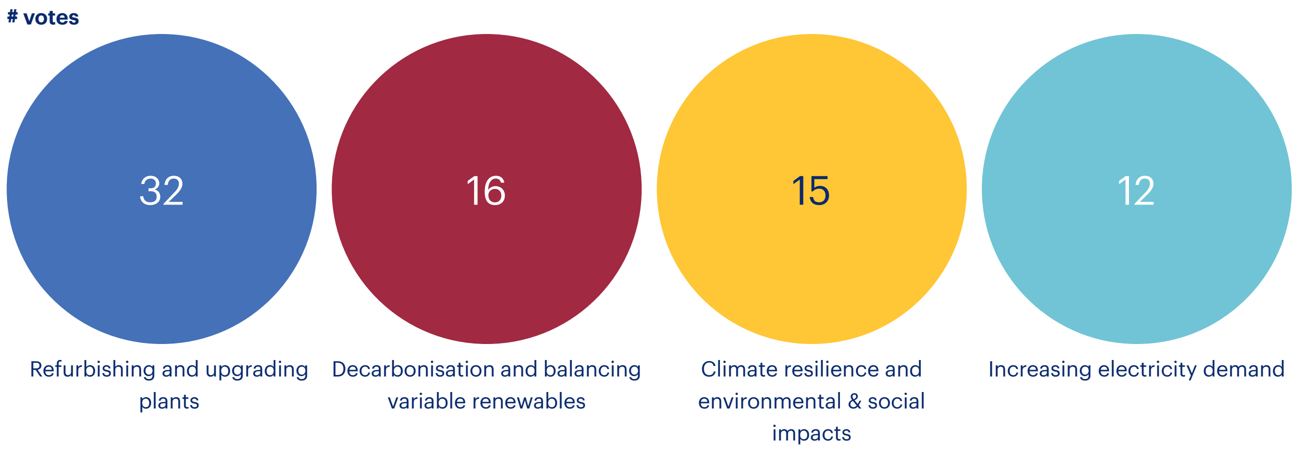
In the review of past or ongoing modernisation programmes, for stations where information was found, the year of the rehabilitation was recorded, along with a note on what type and scope of rehabilitation (e.g. electromechanical units, electrical systems, or complete station rebuild for instance; if this information was available). This review complemented the data collection and owner surveys in activity 2 on the rehabilitation status of plants.

The review of key drivers and opportunities for hydropower modernisation was helpful in better understanding the key factors that determine the need for modernisation, with a particular focus on the African region. This helped contribute primarily to section (Drivers and opportunities of modernisation) and sections 6 & 10 (Summary of findings and detailed assessment of candidate projects).

6.2.3 Webinar with owners (Task 1.3)

In parallel with the literature review, owners of the 87 stations were contacted to participate in the study. Contact details were obtained through the combined IHA and AfDB networks. In total, the 87 stations comprised 30 owners, who were all sent a formal letter from IHA and AfDB explaining the background of the study, together with an invitation to a webinar which took place on 6 April 2022. The objective of the webinar was for IHA to present the background context of hydropower modernisation, the planned methodology for the Continental Mapping Study and for AfDB to present the AHMP. It was also an opportunity to invite the owners to actively participate in the mapping process and encourage participation in the data collection phase following the webinar (activity 2). The invitations also effectively identified the most relevant contact points at each organisation. During the webinar, two live polls were taken on the key drivers and barriers for hydropower modernisation, and questions from participants on various parts of the agenda, as shown below:

What are the key drivers and opportunities for modernisation projects?



What are the major barriers to hydro modernisation projects?

The webinar was very well attended, with over 100 participants, including 75 from African hydropower companies, representing two-thirds of the hydropower companies invited. In addition to building engagement, the webinar presentations and discussion points revealed several key trends:

- Hydropower modernisation will be critical both globally and in Africa
- Modernising hydropower plants goes beyond standard refurbishments
- Initial mapping shows Africa has an ageing fleet and good examples of projects that are suitable for modernisation
- New technology concepts have a key role to play in hydropower modernisation
- Access to financing is essential to move modernisation projects forward
- Other matters discussed during the webinar included financing models, floating solar PV, cascade hydro, staff training, climate resilience, and different hydropower hybrids such as green hydrogen.

06.3 | Activity 2 – Station level data collection and screening

Following the webinar and informed by the literature review in Activity 1, Activity 2 focused on the collection of station-specific data to assess the modernisation needs.

6.3.1 Station specific data collection (Task 2.1)

The data collection was carried out by remote contact with the station owners. Detailed annual performance data is not available from publicly available sources. Therefore the owner surveys were essential for this task.

The station-level template used to collect information included a questionnaire and data form. Along with a template Excel sheet prepared for each of the 87 stations.

The form was divided into six sections:

↓
01
Modernisation history
aiming to gather information about any modernisation activity that may have been undertaken in recent years, the reasons and benefits, and any available information related to the costs of modernisation.

↓
02
Current operating status
gathering insights on the current status of the asset, in terms of operational power and annual generation compared to installed capacity and optimal annual output; rate of forced outages; if there are excessive spills (indicating the asset may not be the right size relative to river flows, and/or occurrence of flood events); recent condition assessments; and if there are any major safety issues.

↓
03
Future modernisation plans
if future modernisations are planned and information on when, what type, the reasons and cost; if there are any environmental or social legacy issues involved; and request on any further details that may impact the station/ modernisation need.

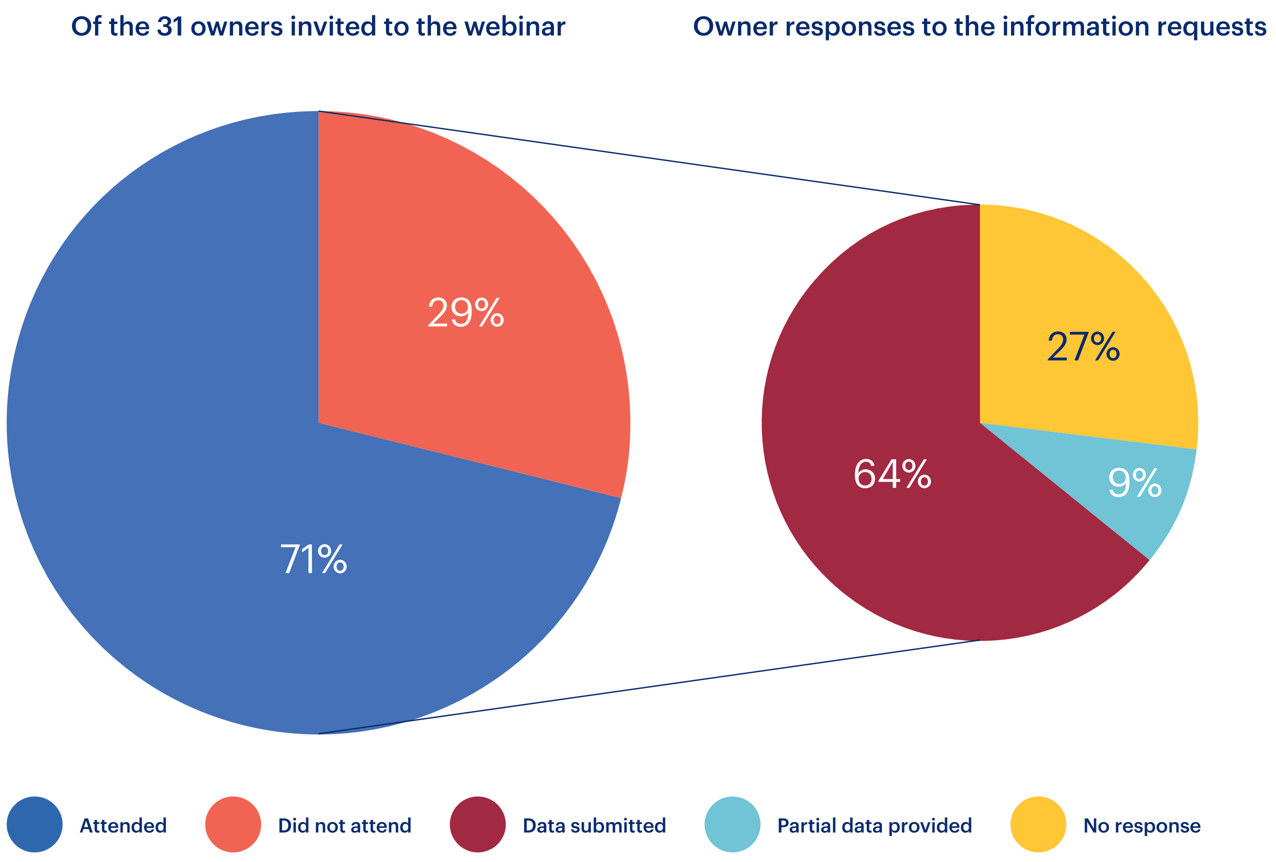
↓
04
Station design data
closing any gaps on the essential characteristics collected in activity 1, and some additional fields on gross & net head (m), turbine type, optimal capacity factor (%) and annual generation (GWh), type of dam, and multipurpose uses of the site/ reservoir.

↓
05
Annual performance data
10-year historical trends on annual powerhouse water discharge (m3/s), annual operational capacity (MW), annual generation (GWh) and capacity factor (%), annual availability (%), planned & forced outage rate (days & %)

↓
06
Floating solar assessment data
Further to the modernisation needs and performance of the hydropower plants, data was requested to assess the potential for floating solar PV at the hydropower reservoirs. These data focused on both the overall characteristics of the reservoirs (size, depth, level variation, wave height and discharge) and the accessibility to the switchyard and the capacity and the condition of the existing transmission line.

6.3.2 Engagement of owners in the data collection (Task 2.2)
The form then was sent to all owners covering the 87 stations in scope, including a number who did not attend the webinar. The response rates for the webinar in Task 1.3 and subsequent data collection Task 2.2 phases are shown in Figure 16.

Figure 13. Response rates



This engagement process provided a dialogue with plant owners and operators to initiate the discussion on modernisation needs, using the information extracted from the datasheets.

6.3.3 Assessment of stations data (Task 2.3)

This task aimed at organising the data gathered via the response to the survey into a consolidated set of information and classifying the rehabilitation need of the 51 plants reviewed.

The assessment of the station data (Task 2.3, Figure 10) was carried out in two steps:

- First, a qualitative judgement was made on each case as to whether it was in high, medium or low need for modernisation, based on general criteria presented in Table 7 below.
- Subsequently, a quantitative assessment was then carried out to score each plant's level of modernisation need based on a set of specified criteria; this step was undertaken on the 51 plants for which sufficiently detailed information was received. The quantitative analysis was done to validate the initial qualitative categorisations and rank projects within each category.

Figure 14. Illustration of the two steps process used in the station assessment (Task 2.3) criteria in an infographic

Step 01
Categorisation

In the first step, the data collected about the power plants were reviewed and reorganised to extract a standardised set of specific information enabling a comprehensive view of the various plants.

Each plant's modernisation needs were then categorised between low, medium and high using a set of general criteria summarised in Table 7. Plants were analysed across several specific parameters extracted from the datasheets, i.e. on modernisation history, current operating status, future modernisation plans, and the annual performance of the plants.

Table 07. General criteria guiding the stations' categorisation

Low need	Medium need	High need
Performances		
Good - high availability, low forced outage rate	Satisfactory - some years with low availability and evidence of forced outage rate	Poor - low availability, high forced outage rate over extended period
Components condition & modernisation status		
Owner outlined not in need of modernisation	Partial modernisation completed or underway	Key components reaching end of life and no recent modernisation completed
Full works completed or underway	Minor works required/scheduled	Owner or government outlined priority for modernisation or expansion
Modernisation to commence shortly – contracts already in place	-	Modernisation plans in place, sometimes pending a complete feasibility study
Criteria used for plants lacking data		
Secondary information indicated works completed or well progressed, & no urgent issues	Secondary reports noted projects or partial rehabilitations undertaken, and/ or if the status was unclear	Secondary sources indicated poor condition & urgent rehabilitation needs/ plans

Plants with good performance or modernisation projects recently completed, underway or commencing shortly were classified as low need.

Conversely, plants running outdated technology[79], with poor performances due to low availability, high forced outage, and/or indication of derated or compromised units were typically classified as high need. Often this judgment was facilitated by some clear indications provided by the owners about one or multiple plants in their fleet requiring imminent modernisation works for which an initial assessment was already carried out.

Finally, hydropower plants relying on units that were not recently installed but still operating reliably, possibly thanks to a good maintenance programme or small rehabilitation works carried out over time, were classified under the medium need category.

Step 02
Scoring process

As illustrated in Figure 14, besides the qualitative assessment (step 1), in the second step of the process, a quantitative assessment was done to assign a score describing the rehabilitation needs of each station. This more quantitative analysis aimed to corroborate the results of the above qualitative categorisation process. Leveraging the data received by the owner, a modernisation need score was calculated for the candidate plants owned by companies that provided sufficient information. The modernisation score was calculated as the sum of individual points associated with some specific criteria describing the condition of the power plant.

For example, on the age of the major electromechanical equipment, a plant with generating units older than 45 years since the last refurbishment was assigned a score of 2, those with units between 31-45 years old scored 1, while those under 30 scored 0. These age boundaries correspond to typical ageing rates of hydro turbine generators, as found in the literature review of modernisation drivers and benefits (see section 4). Other main assessment criteria were also scored, e.g. Is the owner indicating major mechanical issues? (Yes scored 1, whereas No scored 0); Is the owner indicating a need for civil works?; Is a share of the installed capacity out of service?; Is annual generation below expectations?, etc.

All scoring criteria used in calculating the total modernisation need a score for the 51 plants are shown below in Table 8.

Table 08. Criteria used in the scoring process of stations' modernisation needs

Scoring criteria for hydropower modernisation needs
How old is the electromechanical equipment? (0-30y=0, 31-45y=1, 45y+=2)
Is owner indicating major mechanical issues? (Y=1, N=0)
Is owner mentioning need for Civil works? (Y=1, N=0)
Is there power out of service relative to installed MW capacity? (0%=0, 1-50% =1, >50% =2)
Is annual generation in 2020 and 2021 below expectations? (0-50%=2, 50%-90%=1, >90%=0)
Has the owner linked low generation to water level issues? (Y=-1, N=0)
Has the owner linked low generation to low grid demand? (Y=-1, N=0)
Has annual availability in 2020 and 2021 been low? (<80%=2, 80%-90%=1 >90%=0)
Indication of high forced outages? (Y=1, N=0)
Has the owner plans or indications for modernisation? (Y=1, N=0)
Has the plant a substantial role on the grid? (>10% national supply = 1, <10% = 0)
Has the owner indicated safety issues? (Y=1, N=0)
Is there indication of excessive spills? (Y=1, N=0)
Total score

Summing the resulting values associated with each criterion gave a total score for each station out of a maximum of 15. These results were used to validate the qualitative categorisations and prioritise candidates most needing modernisation. In some cases, specific data fields were missing in the responses from owners, reducing the total score possible for those stations.

Floating solar assessment

The main criteria for assessment of sites' potential for floating solar were as follows, based on a screening methodology and literature review of constraints for floating PV at hydropower reservoirs:

Solar irradiance in the reservoir area

in order to assess the level of resource availability

Reservoir geometry (surface area and water depth) and water level variations

to assess the space availability for floating solar PV and constraints on the anchoring and mooring floating structure. Further bathymetric surveys would be required in a feasibility study.

Transmission line utilisation factor and excess capacity

to understand if there is available grid connection capacity at the existing site to evacuate power from the floating PV, and the hydropower facility's generation.

Distance between the reservoir and the switchyard

affects the cable connection cost.

Reservoir uses

to assess constraints if the reservoir is used for other purposes beyond water storage for energy production.

Other data

on maximum wave height, transformer capacity, reservoir discharge ratio, turbine ramping rate – which could further affect suitability for floating PV and hybrid operations.

In total, data was received for 26 hydro reservoir sites from owners for the floating solar assessment. A scoring process was also used to screen the dataset against the criteria specified in Table 09.

Table 09. Criteria used in the scoring process to assess floating solar potential at the hydro/ reservoir site

Scoring criteria for hydropower modernisation needs
Is solar irradiation intensity at the site above 2000 kWh/m2/year? (Y=1, N=0)*
How large is the hydro plant capacity? (0-49MW=0, >50MW=1)
Is the reservoir surface area above 4000 m2? (Y=1, N=0)
Is the maximum reservoir depth below 50m? (Y=1, N=0)
Are the maximum water level variations below 25m? (Y=1, N=0)
Is the reservoir single purpose, for energy production only? (Y=1, N=0)
Is the maximum wave height below 2m? (Y=1, N=0)
Is the distance between the reservoir and switchyard below 3km? (Y=1, N=0)
Is there spare transmission capacity available (above 30MW)? (Y=1, N=0)
Is the turbine type flexible? (Pelton/ Francis=1, otherwise=0)
Total score

*NOTE
solar irradiation data was available from a public database per location (globalsolaratlas.info)

Each station could receive a maximum possible score of 10 (1 point per listed criteria). The total scores were used to rank the hydro sites regarding suitability for floating PV. Note some of the datasheets had missing data fields which reduced the overall score possible for those cases.

A selection of candidate sites was then reviewed in more detail, discussing the various site characteristics and potential constraints according to those screened in Table 9. The potential energy yield from a 50 MW floating solar array was also calculated based on a methodology from a published EU JRC study[80]. FPV yield is calculated by multiplying various input terms and assumptions. These include solar irradiation at the site (kWh/m2/y), % of reservoir surface area covered by FPV (i.e. km2 covered), PV area factor (assumed as 0.1 kW/m2), PV performance ratio accounting for system losses & cooling effects (0.8 assumed), and AC/DC inverter load ratio (1.25 assumed including solar clipping).

06.4 | Activity 3 – detailed assessment

Hydropower stations assessed in high need of modernisation in Activity 2 were carried forward as shortlisted candidates into Activity 3. In this project phase, a more detailed analysis was carried out to understand better the context and the required rehabilitation work for each case.

6.4.1 Detailed assessment of stations with high needs (Task 3.1)

For this task, interviews were set up with each relevant owner to discuss the candidate plants and modernisation needs in more detail. The goal was to produce summaries on each high-need case for a more detailed assessment and prioritisation of candidates covering:

- Hydropower station overview and description (key essential characteristics; categorisation rationale; age & condition of electromechanical units; year of last refurbishment; key modernisation needs – no. of units impacted and if any civil works would be required)
- Role of the plant currently in the power sector and how it could improve after the modernisation (contribution to total national supply; baseload or peaking services; generation profile concerning seasonal hydrological flows; reservoir storage; cascade operations with other plants)
- Annual performance indicators (historical generation and availability trends)
- Operational issues (further detail on ongoing equipment problems, refurbishment needs and/or reasons for low performance)

- Scope of potential modernisation (components and works required; status of the project regarding timeline, studies, funding secured; the magnitude of energy gains from a modernisation, if available)
- Cost estimates of modernisation (either provided directly by the owner where possible and/or using IHA benchmark ranges applied to the capacity impacted) and owners preferred legal structure for modernisation (public, Independent Power Producer or Public Private Partnership)
- Potential for solar PV (with any additional detail on project constraints, the status of studies)
- Further considerations (e.g. sediment management, other local factors)

6.4.2 Dissemination and presentation of results (Task 3.2)

The final task of the project focuses on disseminating and presenting the results. This is mostly covered by the preparation of this report and the participation at several events and webinars to showcase the high-level findings of this work.

06.5 | Environmental & sustainability

As part of the screening activities focusing on assessing the hydropower plant conditions, IHA has attempted to collect information regarding the environmental and sustainability (E&S) impacts of modernisation projects for the plants in the high-need category. However, insufficient information was available at this stage, and further assessment would be needed on a project-by-project basis ahead of modernisation work. IHA has prepared a review of the possible E&S impacts of the modernisation works required by the high-need stations. This was prepared in consultation with the IHA Sustainability Team, and it also includes some general suggestions about Good International Industry Practice (GIIP) to be followed in preparation for rehabilitation and modernisation projects. The results of this review are presented in section 08.

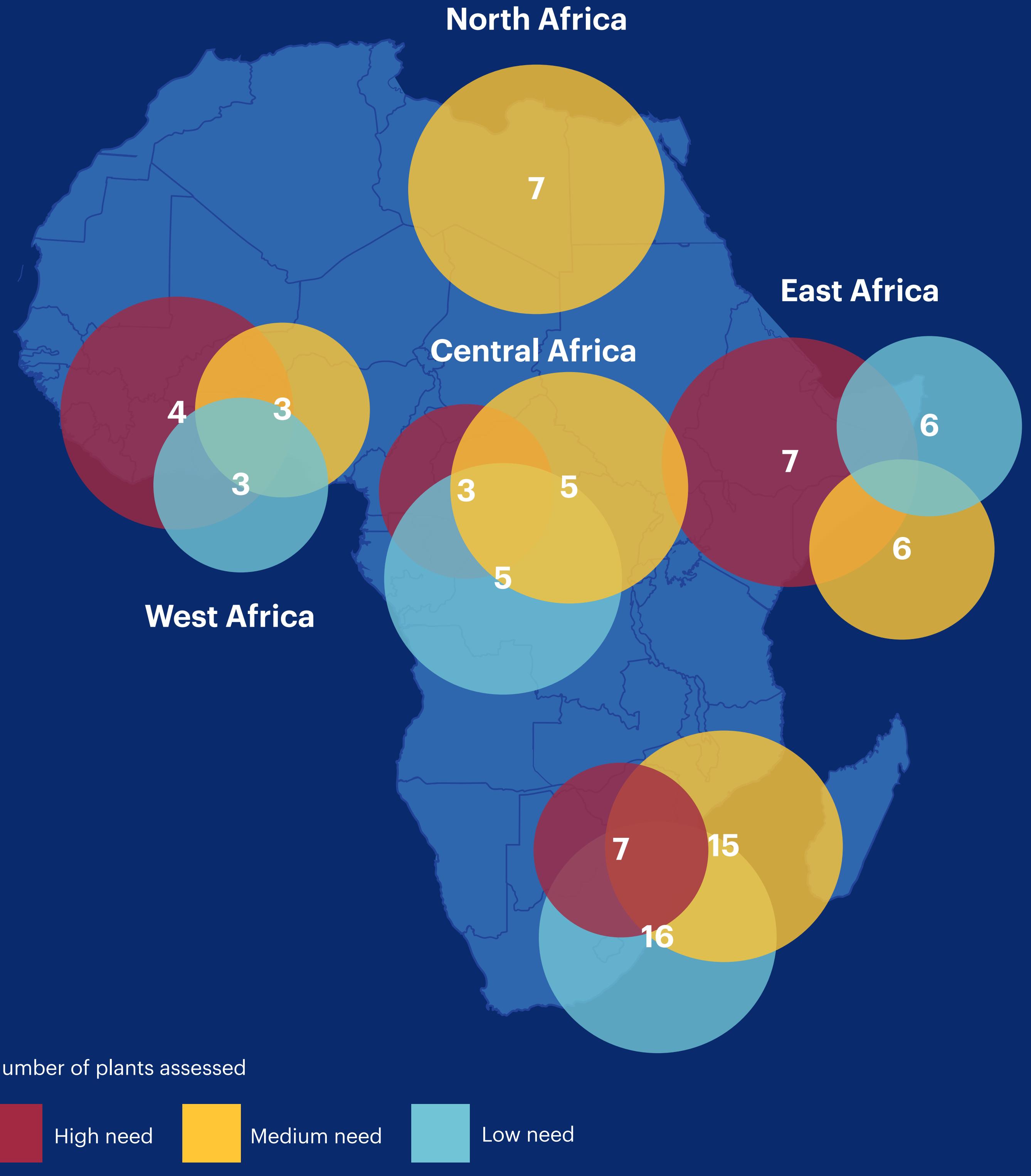
Section 07
Summary of findings

This section presents the results of the mapping exercise carried out by IHA by following the methodology described in section 06.

07.1 | Continent-wide mapping and regional analysis

The findings of the station-level assessments obtained applying the methodology described in sections 6.3.3 and 6.4 for the 87 hydropower plants totalling 24,200 MW across Africa are presented in Figure 18. This shows the number of plants assessed to be in high, medium and low need for modernisation at the regional level, with the results shown in Table 10 alongside the installed capacity in each category.

Figure 15. Number of plants in high, medium, or low need for modernisation by region



Source IHA analysis

Table 10. Regional overview of modernisation needs by number of stations and installed capacity

	Low need		Medium need		High need	
Region	No. stations	Capacity (MW)	No. stations	Capacity (MW)	No. stations	Capacity (MW)
North Africa	0	0	7	3,094	0	0
West Africa	3	1,268	3	430	4	2,103
East Africa	6	538	6	938	7	625
Central Africa	5	923	5	666	3	1,557
Southern Africa	16	6,800	15	4,961	7	337
TOTALS	**30**	**9,529**	**36**	**10,089**	**21**	**4,621**

Overall, 21 plants totalling 4,621 MW – approximately 20% of capacity screened and representing 12% of the total African fleet – were assessed with high modernisation needs; 36 plants equivalent to 10,089 MW (approx. 40% capacity screened) in medium need; and 30 plants totalling 9,529 MW (approx. 40%) were categorised as low need. East and Southern Africa had the highest number of plants with high needs, whereas West and Central Africa had the most significant amount in high demand for installed capacity.

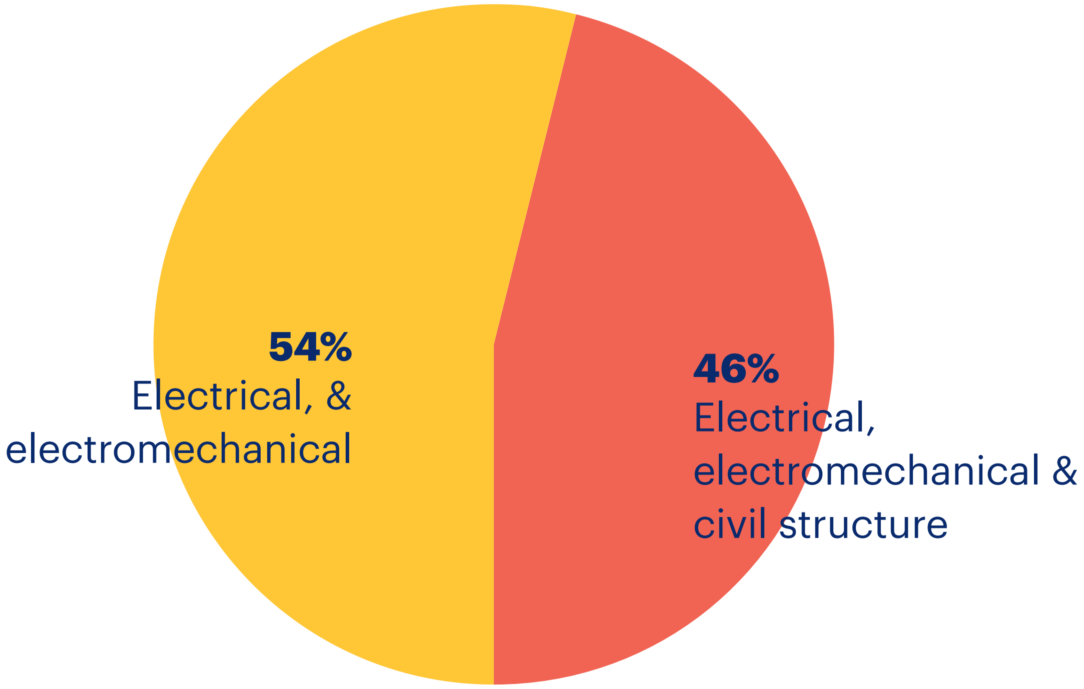
Table 11 describes the archetype cases of the plants identified as a high, medium and low need. These result from the qualitative assessment criteria outlined in the methodology in section 06 describes the condition of the plants that can be found in the three categories.

Table 11. Archetype cases and characteristics of plants classified as high, med or low need

Low need
Plants recently built or refurbished/ upgraded (0-30 years), operate at or near design performance levels and do not report any particular electrical, mechanical or civil issues.
*For those plants lacking data, rehabilitations noted as completed or well progressed, and no indication of urgent issues.
Medium need
Plants are running old technologies but not experiencing major mechanical problems limiting their production.
Plants partially compromised and running at somewhat reduced capacity because of a specific electrical, mechanical or civil issue, regardless of age.
*For those plants lacking data, rehabilitation plans & projects reported due to their age and/or partial rehabilitations undertaken; but the current status is unclear.
High need
Plants running old technology (30y +) and are currently experiencing repetitive outages or mechanical issues limiting their productivity (e.g. unit(s) out of service, safety issues, repetitive forced outages).
Plants severely compromised with several (or all) units out of service and/ or incapable of producing at all, regardless of their age.
*For those plants lacking data, reports identified poor condition due to age and urgent needs for rehabilitation & repairs indicated; many with committed projects.

Figure 16 illustrates the percentage of stations identified as high needs requiring modernisation, categorised by the components of the asset; showing that 54% of the assets necessary modernisation primarily to the electro-mechanical systems (stators, rotors, turbines, etc.), whereas the remaining 46% required work on both the electro-mechanical systems and civil structures.

Figure 16. Percentage split of the number of high need cases depending on the type of work required



Source IHA mapping exercise

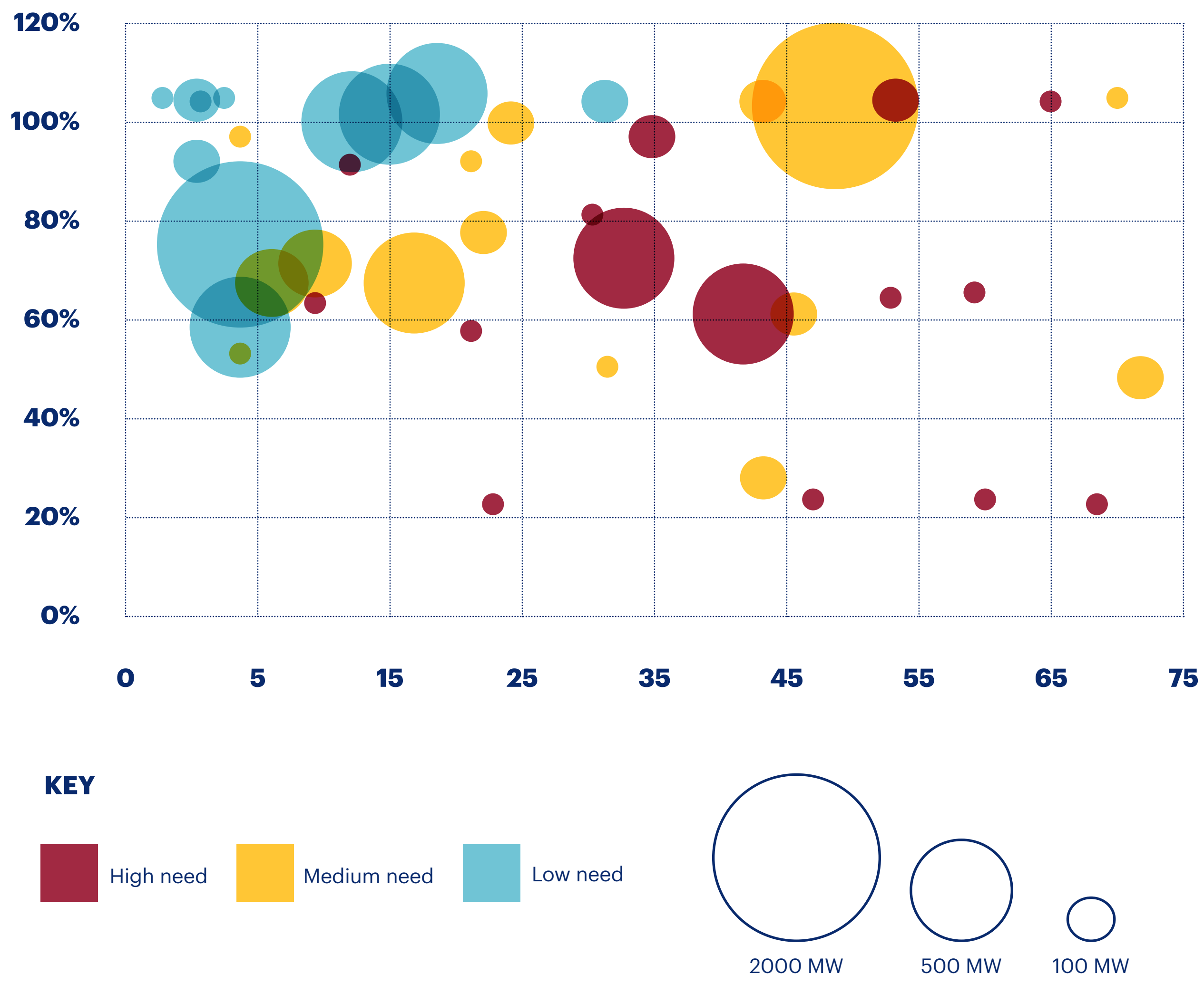
Most stations that were categorised as high need exhibited a range of recurrent problems, which in some cases resulted in derating the plant's design capacity. These issues included:

- high shaft vibration when operating at rated power,
- high temperature in a turbine thrust bearing
- cooling systems malfunctioning
- lack of spare parts, which often triggers cannibalisation process of units out of service.
- in some specific cases, sedimentation was a major driver of the need for modernisation

Figure 17 maps the stations according to age of electromechanical equipment since last major refurbishment (along the X axis, in years) and annual generation/expected generation (along the Y axis, in %). The size of the bubble reflects the size of the installed capacity (MW) of the plant.

The colour indicates if it was classified as low (green), medium (yellow) or high (red) modernisation need.

Figure 17. Mapping of stations by key assessment criteria



Notes Y axis: Actual output in 2020 and 2021 in GWh divided by the optimal output for the plant in GWh.
*X axis: Age is based on the information available about major electromechanical rehabilitation work. If the plant has units of different age the weighted average of the age of the units is considered.
Bubble size: Representing the size of the installed capacity (MW).

Those assessed in low need (blue) showed relatively lower age of equipment (<20 years) and recent annual generation closer to optimal (100%). In contrast, the medium (in yellow) and high need (red) cases were more distributed across the chart. Most showed reduced generation, around or below 65% of expected output, and/or electromechanical components over 30 years old since commissioning or the last major refurbishment. A few outliers with units under 30 years old reported specific ongoing equipment or performance issues. Some data points also sit along the bottom axis at 0% generation, as these plants have been shut down due to aged and damaged equipment.

07.2 | Quantitative assessment

As explained in section 6.3.3, the second step of the station data assessment (Task 2.3) included a quantitative assessment of the plants. For the stations with data received from owners, a scoring process was undertaken to provide a quantitative assessment of the modernisation needs, confirm the initial findings and provide an indicative ranking of the stations classified under the same category.

7.2.1 Ranked list of candidates

The plants were scored against specific criteria using performance indicators and feedback received in the datasheets, as outlined in the methodology. The results of this quantitative assessment confirmed the high-need cases identified in the initial categorisation of plants into high, medium and low-need groups based on qualitative reviews and further provided a ranking of the candidate stations. In summary, the high need cases scored in the 6.5 – 12 range out of a maximum of 15 across the assessment criteria; medium cases scored 2.5 – 5.5; and low need cases scored 0 – 2.5.

07.3 | Cost estimates for modernisation projects in Africa

Additional information was gathered on costs in Africa based on estimates provided by owners and secondary sources. Most of the cost estimates were for the proposed rehabilitation and replacement of electromechanical components; The data collected for each project included installed capacity associated, cost estimate for modernisation, the reference year for the estimate received, and the 2020 actualised cost following the world-level benchmarks methodology, US$/MW calculation.

The statistical distribution of these US$/MW cost estimates was then calculated and compared with the distribution of the IHA world-level benchmark values, as shown in Table 12.

Table 12. Comparison of IHA benchmarks with African modernisation cost estimates (electromechanical installations)

	IHA Benchmark	African Estimates
	US$/MW	US$/MW
Min	90,988	227,132
Q1	290,923	317,950
Median	431,852	413,514
Q3	542,175	514,551
Max	945,427	622,277
Mean	463,815	417,898

In general, the datasets correlate reasonably, and particularly when looking at the median and mean values which are in the same ballpark, in the US$400,000-500,000/MW range.

07.4 | Overall investment needs

An estimation was also made of the total investment needs of installed capacity assessed in high and medium needs in the mapping study. For this calculation, IHA's benchmark cost was assumed to cover the modernisation of electromechanical components (mean value: US$464,000/MW)[81], multiplied by the capacity in each category, with results shown in Table 13.

Table 13. Overall estimates of investment need for total capacity assessed in the study with high and medium needs for modernisation

	High need	Medium need
Installed capacity assessed in in the mapping †	4.6 GW	10.1 GW
% of overall African hydropower fleet in 2021 (38.5 GW)[82]	12%	26%
Estimated investment need based IHA benchmark modernisation cost††	Approx. US$2.1 billion	Approx. US$4.7 billion
Indicative capacity upgrade associated with complete modernisation project[83]	0.23 GW – 0.53 GW	0.51 GW - 1.17 GW

† This total includes power plants for which data were received directly from the owners and plants for which only secondary data were available.
†† The estimated investment figures in the table are exclusively aimed at providing an indication of the order of magnitude of the investment required and should be taken as a general indication only.

The results from this level of investment would be extremely beneficial to the economic and social development of the continent. A comprehensive hydropower plant modernisation programme would secure over 14.7 GW of reliable electricity generation, increase plant flexibility, improve the existing fleet's health and safety operations and boost the actual generation. According to a research paper on the modernisation of hydropower plants published in 2021, the replacement of ageing turbines has the potential to increase system efficiency between 4% and 6% and the installed capacity between 5% and 11.6%.[84] This translates into a total potential capacity gain between 740 MW and 1.700 MW for the 14.7 GW in high and medium need.[85]

07.5 | Floating solar assessment

7.5.1 Screening of candidates

Data was gathered for 26 hydro reservoir sites to assess potential suitability for FPV. Based on the methodology outlined in section 06, the list of sites was scored against a range of screening criteria, receiving a score out of 10 per site, with higher scores indicating higher potential suitability. The screening exercise resulted in a total of 11 candidate sites based on acceptable scores (indicating better likelihood of site suitability), geographic spread (max three sites per country) and completeness of data received.

Reviewing the 11 hydro reservoir sites, the characteristics that were used to select these sites were as follows:

- **Solar irradiance was generally higher than the 2000 kWh/m2/y average for the African continent for most candidate sites (referenced in a European Commission Joint Research Centre (JRC) study)[86].**
- **Reservoir surface area was more significant than 1 km2 in all cases.**
- **Maximum reservoir depth was at or below the 50m screening threshold for 6 of the sites; Deeper reservoirs may add complexity and cost to the mooring and anchoring system for the floating structure; bathymetric survey would need to be carried out to to study design & installation constraints properly.**
- **Reservoir water level variations for several sites exceeded the scoring threshold of 25 m max, another factor impacting anchoring and mooring.**

- Seven reservoirs were single-purpose, suggesting a low likelihood of other reservoirs restricting the use of floating panels. However, most of the multipurpose functions were for flood control and irrigation, which would not necessarily impact use of the floating panels.
- Max wave heights were generally below 1 m, which poses no particular constraint.
- Distance between reservoir and switchyard was below 3 km for most sites. Longer distance would add cabling cost to connect in the floating PV system but would not necessarily preclude projects. In some cases, other tie-in points may also exist nearer the reservoir sites.
- Some extent of spare transmission capacity at the hydropower stations' grid connection was identified for all the listed cases. Most of the 9 cases suggested at least 30-50 MW available, based on reported excess transmission capacity available (in MW), or line utilisation factor (in %), which is lower than 100% suggests spare headroom. There may also be cases where solar generation could enable hydro generation to be reduced during those periods, which may benefit operators in preserving water levels at the reservoir. These aspects would need detailed study and power system studies to assess the capability of the local grid to handle added solar power supply. Capacity constraints would also affect FPV system sizing.
- The last criterion showed most of the hydro stations had Francis turbines which would provide more ramping flexibility to accommodate solar output fluctuations.

7.5.2 Solar energy yield calculation

To represent the potential solar energy yield, annual output from a proposed FPV system was calculated based on various input assumptions; and by comparing the increase in generation achieved at selected hydro sites.

The methodology follows that outlined in Chapter 8 (based on published EU JRC study92), whereby FPV yield is calculated by multiplying various input terms and

assumptions. These include solar irradiation at the site (kWh/m2/y), % of reservoir surface area covered by FPV (i.e. km2 covered), PV area factor (assumed as 0.1 kW/m2), PV performance ratio accounting for system losses & cooling effects (0.8 assumed), and AC/DC inverter load ratio (1.25 assumed including solar clipping).

To review a reasonable scenario, the calculation assumed a 500,000 m2 surface area of reservoir covered by FPV, i.e. a 50 MW system size, which gave a % area covered depending on the reservoir size in each case.

Annual FPV output is in the 100-125 GWh range from the 50 MW system assumed.

The study shows that floating solar hybrids could be a valuable means of improving generation at hydro sites during drought events. They also provide a quick win, given their relatively short deployment timescales.

Section 08

E&S sustainability review of high need plants

08.1 | Introduction

To collect data about the possible E&S implication associated with the modernisation need of the plants in high demand, simplified questionnaires were sent to the plant owners based on the standard's performance requirements and technical criteria. From the results of the questionnaires, it was hoped to provide a detailed E&S review of the potential impacts of the different modernisation projects. Unfortunately, there have been no responses to date. Nonetheless, the following section presents a literature review and desk-based analysis of similar examples of modernisation projects to highlight key trends and flag any high-risk areas.

08.2 | Work required by the high need cases and high-level considerations on the E&S impacts

A high-level summary of the work needed by each of the plants identified in high need is summarised into the following categories:

- **electromechanical systems;**
- **minor civil infrastructure work;**
- **reconstruction of transmission infrastructure;**
- **sedimentation removal;**
- **modernisation involving an increase in capacity.**

The scope of identified high need stations is almost always exclusively focused on the modernisation of the electrical and electromechanical equipment of the plant. These typically include drivetrain components (i.e., generator, turbines, stators and rotors), control structures (i.e., gates, valves and cranes), transformers, high voltage switchgear, auxiliary electrical services, and electrical control systems. In a few cases, interventions on the civil structure are required. Still, these always aim to maintain the current infrastructure (housing, water intake and outlet, and dam) in a safe and reliable operating status rather than expanding the dam size.

In those cases which are predominantly focused on the rehabilitation or modernisation of the electromechanical equipment, the original E&S footprint of the plant generally remains unaltered as no significant alterations are made to the core civil infrastructures (as, for instance, the dam or the water intake and tailrace structures). Provided that all required assessment and mitigation measures are considered during the planning and implementation phases, these projects' cumulative environmental and social impacts on the operation of the plant should be relatively inconsequential.

They may even be positive in some instances.

Indeed, the scope of a modernisation project is often to rehabilitate the power plant to its original nameplate condition, which usually implies a better utilisation of water resources due to higher efficiency and enhanced unit regulating capacity, as well as more efficient and safer operations. Rehabilitated plants require less extraordinary maintenance and are often a safer working environment. Additionally, the introduction of modern and more efficient electromechanical equipment can, in specific cases, enable the plant to extend its operating range and may result in a reduction in start & stop operations, allowing better regulation of the water discharged from the plant and the maintenance of a minimum water level in the downstream river during the period of low water availability. Rehabilitation and modernisation projects can also be associated with implementing other measures aimed at mitigating the original project's possible negative impacts. These measures include improved fish passage by introducing fish ladders or improved turbine seals, which eliminate lubricant leakage. In general, one of the main aspects to be considered is the alteration or the diversion of the water flow passing through the power plants during the period of the works. This aspect has biological implications, due to the possible change in water supply in the downstream river, as well as social impacts, due to the possible utilisation of the water released by the plant for other activities.[87] It is generally recommended to rehabilitate hydropower power plants equipped with multiple units adopting a multi-stage approach with work being carried out sequentially on the various units. This approach will limit the overall impact of the results on the electricity production and water supply to the downstream river.

In those cases where modernisation of the generating units could be associated with a substantial increase in generating capacity. Typically, an ad-hoc analysis to identify and mitigate the possible consequences on the river's ecosystem and the activities carried out by the local communities in the downstream areas is recommended.

Although this is not the case for any of the plants reviewed in detail, it is essential to underline that if the work should also require an expansion of the dam, this will need a detailed assessment of the physical, biological and social implications associated with the additional upstream area impounded by the reservoir and the erection of the new civil structures. These cases are almost comparable to a greenfield project, as the major civil engineering interventions will substantially alter the E&S impact of the installation.

Finally, particular attention should be dedicated to projects for power plants located in World Heritage sites or with pre-existing conflicts with local communities. This may generate potential constraints on the extraction of additional water for electricity production as well as the accessibility of the site.[88]

The IHA has cooperated with various relevant stakeholders, including environmental & social NGOs, governments, operators, suppliers, and financial institutions, in preparing the Hydropower Sustainability Standard. This is a global certification scheme specifically designed for greenfields and brownfields hydropower projects.[88] The Standard is aligned with green finance initiatives such as the Climate Bonds Initiative's Hydropower Criteria, and is often required to access green finance.

Section 09
Conclusion and recommendations

09.1 | Mapping conclusions

Modernisation has a variety of drivers and potential improvements, which are determined by the conditions and options available for an individual site. Modernisation projects provide an opportunity to address legacy issues of older stations while offering a window to implement up-to-date energy technologies, capacity upgrades, and environmental measures at existing sites at relatively low cost. In countries with ambitious decarbonisation plans, modernising hydropower using technologies to enhance flexibility services will help support growth in variable renewables coming onto the system. Several case studies illustrated the approaches and benefits that can be achieved.

Moreover, the need for modernisation has never been more important. IEA's Special Hydropower Market Report 2021 forecasts that globally, around 45% (170 GW) of the projected increase in hydropower capacity by 2030 will derive from existing infrastructure; the forecast considers projected growth in the range of 4-5 GW from replacements and uprates of the existing fleet in Africa and the Middle East (primarily Sub-Saharan Africa). In all growth scenarios, adequate investment into today's hydropower capacity will be essential to sustain and enhance reliable electricity supplies for decades.

Out of the 24.2 GW of installed hydropower capacity covered in the study, 4.6 GW was assessed in high need of modernisation, making up over 10% of Africa's overall hydropower fleet and representing an estimated US$2.1 billion of required investment.[89] For the most part, the 21 high-need plants identified in the mapping were using old technology and experiencing frequent outages or mechanical issues limiting productivity, with generating units often working at limited power or completely out of service. This level of investment would not only restore roughly 800 MW of existing hydropower capacity currently out of out of service. Still, it could potentially increase up to 11% of these plants' overall installed nominal capacity.

A further 10.1 GW was assessed in medium need of modernisation, covering a further 25% of the Africa's total installed hydropower, and representing an additional US$4.7 billion of estimated investment required. The 36 plants categorised in medium need, while not experiencing such major problems as the high need cases, were nonetheless running old technologies and in many cases partially compromised and are likely to require investment in rehabilitation or upgrading of facilities in the coming years. Regionally, all plants identified in high need of modernisation were in Sub-Saharan Africa. In terms of installed capacity, just over 90% was located across West (2.1 GW), Central (1.6 GW) and East Africa (0.6 GW), with the remainder in Southern Africa (0.3 GW). All regions had additional capacity in medium need, particularly Southern Africa (5 GW) and North Africa (3 GW).

All these plants need extensive modernisation work to restore existing electromechanical infrastructure to full capability and improve annual production and performance by installing new, more efficient technologies. There are also opportunities to increase capacity through upgrades or expansions and/or by installing floating (or land-based) solar PV at or near the hydropower site. Each case would also support progress in decarbonisation and interconnection of grids by improving the availability and reliability of clean electricity supply. Additionally, the modernisations would provide a chance to adapt existing hydropower to be more resilient against climate change impacts, particularly in those countries experiencing hydrological variability. These projects are also likely to be cost-effective options compared to greenfield alternatives.

From an environmental & social perspective, rehabilitation works to increase efficiencies, replace equipment, and rectify ageing infrastructure issues could be considered usual asset management practice for operations and normally would not instigate a change in the project's impacts. These projects are often an excellent opportunity to implement measures that can improve the E&S footprint of the plant and its operations. Examples of these measures are the introduction of fish ladders or improved turbine seals, which eliminate lubricant leakage.

09.1 | Recommendations to the African Development Bank

The mapping has recommended a list of plants categorised in high or medium need, some of which would require further investigation to better understand the current status and specific investment needs. The study has also set out a shortlist of priority candidates for the AfDB to consider for modernisation and investment – with assessments and summaries compiled for these cases in collaboration with the plant owners.

Recommended next steps would be to investigate further the investment needs and scope of works and conduct feasibility for selected projects – also considering any potential additional barriers (e.g. financing or environmental & sustainability (E&S)) as well as other opportunities that could be included in a proposed modernisation (drawing on the drivers & opportunities outlined in Chapter 3, and any further E&S benefits identified). This would involve working closely with the owners, relevant specialists, and suppliers.

More specifically, for those stations identified as in high need of modernisation, it is recommended that a more detailed analysis be undertaken to optimise the investment needs for the facility. For those stations identified as medium needs, a comprehensive monitoring program is recommended to assess the condition and performance of the asset on a cyclical basis.

In many cases, in the overall assessment of modernisation needs for hydroelectric facilities in Africa, access to spare parts for even routine maintenance was identified as a barrier to the overall asset management strategy at the plant. This aspect should be addressed by plant owners working directly with equipment manufacturers who have experience with sourcing and supplying spare parts in Africa.

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