Hydropower site screening in Nigeria – adding value in the early phases of project planning

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1 Background

Nigeria has a critical shortage of electricity supply which is a major constraint to economic growth. The country currently has three large major hydropower plants: Kainji HPP (760 MW) and Jebba HPP (578 MW) on the Niger River and Shiroro HPP (600 MW) on the Kaduna River. A fourth large hydropower plant, Zungeru HPP (700 MW), is currently under construction on the Kaduna River downstream of Shiroro HPP.

Multipurpose projects (i.e. hydropower plus irrigation) are planned on the Niger River upstream of Nigeria. These include Kandadji MPP (Niger) which is nearing the construction phase and Taoussa MPP (Mali) and Fomi MPP (Guinea) which are currently in the planning phase. These developments are expected to reduce inflows to Nigeria and hence reduce the annual generation from the Kainji and Jebba HPPs.

There remains significant hydropower potential in Nigeria, particularly in the Benue River basin and along the Niger River between Jebba and Onitsha. The Benue River basin is the largest tributary of the Niger River in Nigeria and is largely unregulated. Natural flood events and uncontrolled releases from Lagdo MPP in Cameroon have resulted in a number of recent major flood events along the Benue and lower Niger rivers in Nigeria.

2 Introduction

The Transmission Company of Nigeria – Project Management Unit (TCN-PMU) contracted Tractebel Engineering S.A. (Tractebel) to undertake a hydropower site screening study in Nigeria. The study area included the Benue River basin within Nigeria and the main stem of the Niger River between Jebba and Onitsha, with the Benue River given priority for development in the short term.

The purpose of the study was to identify the best potential hydropower sites in the study area. The study assessed small (5-20 MW installed capacity), medium (20-100 MW) and large hydropower projects (> 100 MW), with consideration given to sites with potential multipurpose uses such as irrigation and flood mitigation. An inventory of potential sites was developed and multi-criteria analysis techniques were used to identify a shortlist of 12 sites and finally to recommend three sites for short-term development. Value was added by undertaking new data collection and analyses across the entire study area and to collaborate extensively with stakeholders throughout the study.

This study was part of the Niger Basin Water Resources Development and Sustainable Ecosystems Management Project (NBWRDSEMP) which is sponsored by the International Development Associated (IDA) of the World Bank. TCN-PMU is the national implementation agency and the Niger Basin Authority (NBA) is the regional implementation agency of this project. The study team also included counterpart staff from TCN-PMU (2), Federal Ministry of Water Resources (FMWR) (1), Federal Ministry of Power (FMP) (1) and Nigeria Hydrological Services Agency (NIHSA) (2). Other federal and state-level stakeholders also actively participated in the study.

3 Study area

The study area is defined as the Benue River basin within Nigeria and the Niger River main stem between Jebba and Onitsha. The Benue River basin falls within hydrological areas HA-III (Upper Benue) and HA-IV (Lower Benue) and was divided into 15 sub-basins for the purposes of this study. The Niger River main stem between Jebba and Onitsha falls with hydrological areas HA-II (Niger Central) and HA-V (Niger South). A map of the study area showing the hydrological areas is provided in Figure 1.

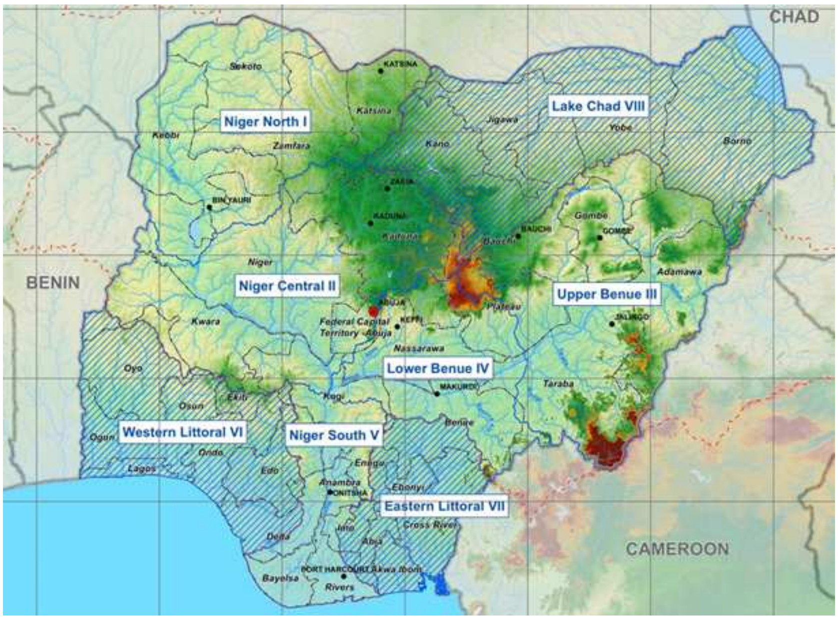

Figure 1: Hydrological areas of Nigeria showing study area

The Benue River basin (HA-III and HA-IV) has the following characteristics:

- The largest right bank tributary of the Benue River is the Gongola River (53 000 km^2) and the largest left bank tributaries are the Donga (20 000 km^2), Katsina-Ala (23 000 km^2) and Taraba (23 000 km^2) rivers.
- The basin is largely unregulated, with the only significant storages being Lagdo MPP (Cameroon), Dadin Kowa MPP (Gongola River, Nigeria) and Kiri MPP (Gongola River, Nigeria).
- The elevated topography is dominated by the North-Central Niger Plateau (Jos Plateau) at the headwaters of the Gongola River and the Eastern and North-Eastern Highlands (Adamawa Plateau) at the headwaters of the left bank tributaries. These areas are generally underlain by Basement Complex geology.
- The geology of the basin is dominated by the Benue Trough which forms a broad open valley through which flows the Benue River and the lower reaches of many tributaries. Here, Quaternary alluvium and Cretaceous sediments of substantial thickness overlie the Basement Complex.
- Mean annual precipitation varies from > 2000 mm in the Eastern and North-Eastern Highlands and reduces in a northwards direction across the basin to < 600 mm in the northern-most areas of the Gongola River catchment. The North-Central Niger Plateau has mean annual precipitation of 1200-1400 mm.
- The power system is inadequate in the study area with a lack of generation sources, no looped transmission network, high losses and instability issues.
- Land cover is characterised by deciduous forest in the Eastern and North-Eastern Highlands (underlain by Basement Complex geology) and mosaic croplands elsewhere.
- Identified areas of biodiversity value include the Gashaka-Gumti National Park in the Eastern and North-Eastern Highlands near the border with Cameroon and the Yankari National Park in the Pai River catchment on the right bank of the Benue River.

4 Study methodology

4.1 Site inventory

The hydropower site inventory developed for the study comprises a total of 54 sites which were divided into two categories:

- Potential sites (already identified) (23 sites): Potential hydropower sites (≥ 5 MW) within the study area, which have already been identified in previous studies. The inventory of potential sites (already identified) was based on the *National Water Resources Master Plan* by JICA (January 2014), Tractebel's knowledge of potential hydropower sites in Nigeria and other information sources.
- Potential sites (newly identified) (31 sites): Potential hydropower sites (≥ 5 MW) within the study area which were newly identified as part of this study. The inventory of potential sites (newly identified) was developed using two approaches:
    - Detailed visual analysis of valley topography was performed using Google earth and SRTM DEM to identify narrow valley sections (constrictions) favourable for dam construction (even if the natural river slope is small). The analysis covered the 15 identified sub-basins and the main stems of the Benue and Niger rivers.
    - Tractebel's in-house *Inventaire des Sites Hydroélectriques* (ISHY) tool was used to automatically identify potential hydropower sites where the river slope can create a significant hydraulic head between a dam site and a powerhouse at a reasonable distance downstream. The tool uses ArcGIS software and SRTM DEM.

4.2 Study data

A substantial amount of new data collection and analyses were undertaken across the entire study area, an overview of which is provided in Figure 2. The data was summarised in a number of study reports which provide a wealth of valuable information relevant to hydropower and water resources development, including: policy framework and energy needs report, hydrological and water resources report, reservoir operation and energy studies report and strategic environmental and social assessment report.

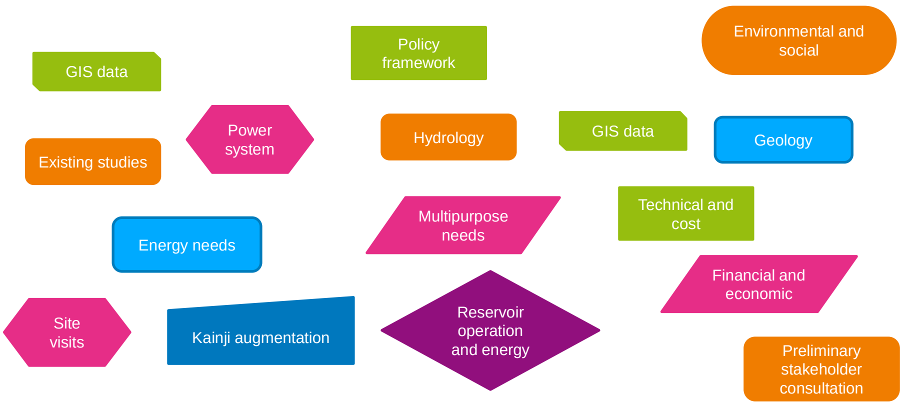

Figure 2: Overview of study data

The most important aspects of the study data were the site visits and the preliminary stakeholder consultation:

- The site visits included state and local level consultation and high level technical, environmental and social assessments. Visits to the sites were carried out by two teams of Tractebel's representatives and counterpart staff in January 2016. Team A visited seven sites (the site DON15 could not be visited) over 13 days. Team B also visited seven sites (the site BEN04 could not be visited) over 13 days. The site DON09 was visited in March 2016, giving a total of 15 sites visited for the study.
- The preliminary stakeholder consultation was planned to be carried out in six Nigerian cities (Bauchi, Jalingo, Lokoja, Makurdi, Onitsha and Yola) in late February and early March 2016. The consultation teams comprised the consultation leader (Tractebel's representative from Enviplan), socio-environmental experts, dams engineers, representatives from TCN-PMU as well as the counterpart staff. The consultations were successful, with a good attendance and participation, except in Lokoja where the meeting was not able to be held.

4.3 Site screening process

Multi-criteria analysis techniques were used to screen the inventory of 54 potential hydropower sites to the final three sites recommended for short-term development over four phases. Three screening methodologies were developed for application across the four screening phases, with each methodology having successively more detailed criteria and input data requirements. The site screening process is summarized in Table 1: the implementation column highlights the collaborative nature of the site screening process with stakeholders.

Phase	Description	Screening methodology	Sites assessed	Sites retained	Sites eliminated	Implementation
1	Site inventory	Inventory (basic)	54	26	28	Screening by Tractebel experts Gennevilliers, France – 09/2015
2	Site screening – preliminary shortlist	Integrated (basic)	26	17	9	Collaborative screening with stakeholders, Gennevilliers, France - 02-06/11/16
3	Site screening – validation of shortlist	Integrated (basic)	17	12	5	Collaborative screening with stakeholders, Abuja, Nigeria - 04-09/02/16
4	Recommendations for development	Integrated (detailed)	12	3	9	Collaborative screening with stakeholders, Abuja, Nigeria - 03-05/05/16

Table 1: Site screening process

The integrated (detailed) site screening methodology includes six screening criteria. Each criterion includes one or more contributing factors, which give detailed guidance on how to assign a score from 0 to 3, although it is highlighted that the contributing factors do not necessarily have an equal importance. In order to rank the results of the multi-criteria scoring, it is necessary to assign a relative weighting to each of the criteria. Table 2 details the integrated (detailed) screening methodology adopted for the phase for screening including the six criteria, the contributing factors and the relative weighting.

Criterion	Contributing factors	Weighting (%)
Technical constraints	Hydrological risks Geological and geotechnical risks Connection point to existing power system Contribution to regional power system stability and diversity Construction works constraints	15
Financial feasibility	Role of scheme within the power system of Nigeria Financial characteristics	30
Social impacts	Involuntary resettlement Local and regional social impacts	20
Environmental impacts	Natural habitats Local and regional environmental impacts	10
Governance constraints	Local, regional and national water and energy policies Trans-boundary water and energy policies	10
Multipurpose benefits	Potential for multipurpose developments	15
TOTAL		**100**

Table 2: Integrated (detailed) screening methodology – phase 4

The multi-criteria scores obtained in the phase 4 screening are detailed in Table 3.

ALL potential hydropower projects: Multi-criteria analysis for Benue basin and main stem of Niger River								
Project name	Name of the site	Technical constraints	Financial feasibility	Social impacts	Environmental impacts	Governance constraints	Multipurpose benefits	**Total weighted score**
BEN06	Makurdi	2,0	2,5	1,5	2,0	2,0	2,5	**2,13**
BEN01 (165)	Dasin Hausa	2,0	1,0	1,5	2,0	2,0	2,0	**1,60**
BEN01 (180)	Dasin Hausa	2,5	1,0	1,0	1,0	1,0	3,0	**1,53**
NIG02	Lokoja	1,5	1,5	0,0	1,5	1,5	2,0	**1,28**
NIG03	Onitsha	1,0	1,0	0,0	1,0	1,0	2,0	**0,95**
DON09	Manya	3,0	3,0	3,0	2,5	3,0	2,0	**2,80**
KAT02	Bawarku	3,0	3,0	2,5	3,0	3,0	2,0	**2,75**
TAR08	Jamtari	3,0	1,5	2,5	3,0	3,0	2,0	**2,30**
TAR12	Garin Dalli	2,5	1,5	2,0	2,0	3,0	3,0	**2,18**
KAT04	Achin-Kondoor	2,5	2,0	1,5	3,0	2,5	1,5	**2,05**
KAT07	Katsina-Ala	2,0	2,0	2,0	3,0	2,5	1,5	**2,08**
GON06	Kirfi	2,5	2,0	3,0	3,0	3,0	1,5	**2,40**
TAR05	Karamti	2,0	2,5	3,0	2,5	3,0	1,0	**2,35**

Large sites on the main stem of the Benue or Niger rivers
Medium and large sites on tributaries of the Benue River
Small sites on tributaries of the Benue River

Table 3: Multi-criteria scores obtained for the 12 shortlisted sites in the phase 4 screening

5 Shortlist of 12 hydropower sites

The locations of the 12 shortlisted hydropower sites are shown on the map in Figure 3. The site characteristics are detailed in Table 4.

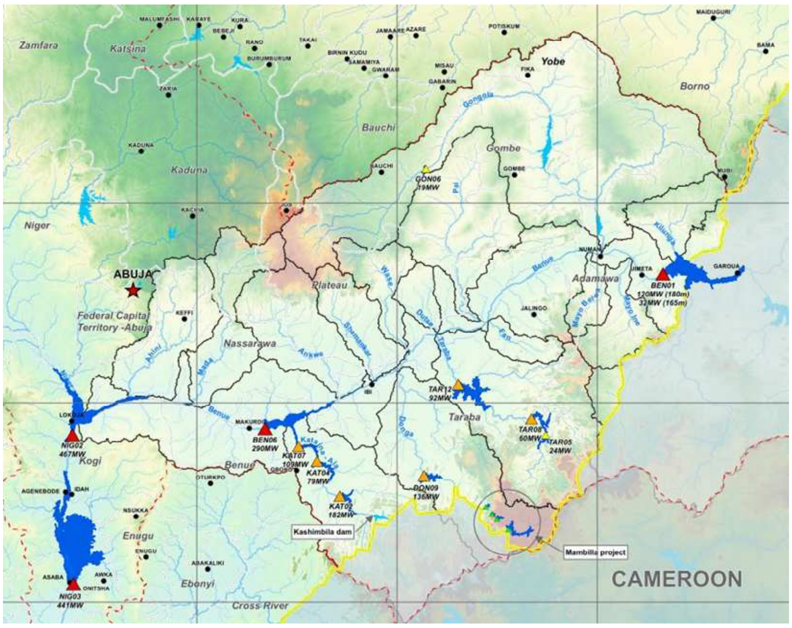

Figure 3: Map of the 12 shortlisted sites

Site ID	Site name	Sub-basin	Installed capacity (MW)	Annual total energy (GWh)
BEN01	Dasin Hausa	Benue main stem	120 (180 masl) 32 (165 masl)	526 (180 masl) 142 (165 masl)
BEN06	Makurdi	Benue main stem	290	1271
DON09	Manya	Donga	136	594
GON06	Kirfi	Gongola	19	84
KAT02	Bawarku	Katsina-Ala	182	798
KAT04	Achin-Kondoor	Katsina-Ala	79	344
KAT07	Katsina-Ala	Katsina-Ala	109	476
NIG02	Lokoja	Niger main stem	467	2443
NIG03	Onitsha	Niger main stem	441	2510
TAR05	Karamti	Taraba	24	103
TAR08	Jamtari	Taraba	60	265
TAR12	Garin Dalli	Taraba	92	403

Table 4: Characteristics of the 12 shortlisted sites

6 Final three hydropower sites

The phase 4 screening to identify the final three hydropower sites for short-term development was undertaken in Abuja over the period 03-05/05/16. The screening was undertaken collaboratively with stakeholders in a workshop environment. The workshop participants extensively debated the characteristics and multi-criteria scores of the 12 shortlisted hydropower sites and agreed to recommend the following three sites: DON09 (Manya), KAT02 (Bawarku) and TAR12 (Garin Dalli).

This recommendation was endorsed by the stakeholders present at the final validation workshop in Abuja on 15/06/16. The characteristics of the three sites are summarised in Table 5. DON09 and KAT02 are newly identified sites, while the TAR12 site was already identified in previous studies.

Site ID	Site name	Reservoir level (masl)	Installed capacity (MW)	Total annual energy (GWh)	Reservoir storage volume (Mm^3)	Reservoir surface area (km^2)
DON09	Manya	FSL 190 MWL 194	136	594	583	61
KAT02	Bawarku	FSL 156 MWL 160	182	798	361	57
TAR12	Garin Dalli	FSL 160 MWL 163	92	403	3 297	368
		TOTAL	**410**	**1795**		

Table 5: Characteristics of the final three sites recommended for short-term development

The final three sites are located on the Donga, Katsina-Ala and Taraba Rivers. These three sub-basins are on the left bank of the Benue River and have some of the largest catchment areas, highest relief, highest rainfall and highest runoff of all the sub-basins within the study area (with the exception of the Gongola River which has the largest catchment area).

7 Future development actions

Once the final three sites were endorsed by the stakeholders, the final task was to recommend future actions for FGN to facilitate project development in the short-term. These include the following:

- Impact mitigation planning and baseline data collection activities:
    - Plan to mitigate, reduce or eliminate negative impacts and enhance positive impacts of the projects. The suggested actions include planning, communication and design and construction measures.
    - Seek relevant environmental permits in coordination with the National Environmental Standards and Regulations Enforcement Agency.
    - Undertake environmental and social baseline data collection to provide information for the full environmental and social impact assessments and environmental management plans. These studies should be carried out during the detailed design phase and should include public consultation.
    - Acquire additional hydrological and meteorological data at each of the sites to provide information for the detailed design. This includes rehabilitation and re-calibration of existing nearby river gauging stations and installation of new river gauging and meteorological stations at the sites.
- Future feasibility studies:
    - Key issues and concerns were highlighted which influence the feasibility of the final three sites.
    - A draft scope of works was developed for future pre-feasibility and feasibility studies of the final three sites. The scope of works includes the following key components: topographic survey, hydrological studies, geological and geotechnical investigations, environmental and social studies, transmission network connection, technical studies and financial and economic analyses.

8 Key learnings from study

8.1 Study methodology

Key learnings relating to the study methodology include the following:

- Data collection was very challenging in Nigeria and this remains a barrier to project planning. Formal requests should be sent well in advance and adequate time should be allowed to collect the relevant data.
- While many studies have been undertaken on Nigeria's hydropower potential over the years, most of these refer to the same sites and quote similar hydropower site characteristics. Furthermore, the assumptions underlying the characteristics usually vary between sites and do not necessary reflect current approaches. By undertaking new data collection and analyses, the study added significant value by providing consistent characteristics across the entire study area.
- The decision to include the identification of new sites in the study scope was fortuitous. Many of the existing sites were found to be no longer feasible due to land development and many new sites were identified which are very promising. Two of the final three sites are new sites.

- Multi-criteria analysis (MCA) was found to be a very effective approach to ensure that the retained sites align well with federal and state level master planning in areas such as generation capacity, transmission network, irrigation development, flood mitigation, river navigation and water supply.
- MCA was found to be very useful to screen the initial inventory of 54 sites to the 12 shortlisted sites, but less useful at screening the 12 sites to the final three sites. When an inventory contains a manageable number of feasible sites, the screening process becomes more subjective and MCA less relevant.
- The study team chose six criteria for the MCA: each criterion included one or more contributing factors. This approach was found to work well when the data quality is limited and/or highly variable across sites, as it allows qualitative, subjective assessment. When the data quality is good and consistent, a larger number of quantitative criteria would result in a more streamlined process with less subjectivity.
- Workshops were held regularly throughout the study which facilitated collaboration amongst all stakeholders, understanding of the study scope and objectives and ownership of the study outputs.

8.2 Technical aspects of hydropower

Key learnings relating to the technical aspects of hydropower in the study area include the following:

- The accuracy of topographic data is very important during all phases of project development. Attempts were made to use high-quality satellite digital terrain models (DTM) which are commercially available but these were found to be inadequate in the study area.
- Large hydropower projects on the main stem of the Niger River are no longer considered feasible. The most suitable sites are located at narrower river sections where significant population centres have developed due to their close proximity to the river. Immense spillways are required to pass the enormous flood discharges of the lower Niger River which are technically and operationally complex and prohibitively expensive.
- The main stem of the Benue River and the largest left bank tributaries (the Donga, Katsina-Ala and Taraba rivers) provide the greatest hydropower potential in the study area. The abundant rainfall on the highlands produces good average annual inflows.
- There are only a limited number of feasible large hydropower sites (> 100 MW) in the study area but a significant number of medium (20-100 MW) and small (< 100 MW) sites.
- The large hydropower sites are generally located in the middle and lower reaches of the catchments where the rainfall and available head are lower but the average annual inflows and storage volumes are higher. The small and medium hydropower sites are generally located in the upper reaches of the catchments where the rainfall and available head are higher but the annual average inflows and storage volumes are lower.
- Many of the sites are located on large rivers in wide valleys of low grade. During the wet season when inflows are highest, tailwater levels also increase significantly. This can have a significant effect on hydropower output and hence adequate topographic data downstream of the dam and hydraulic modelling of tailwater levels is required as part of future feasibility studies.
- The Benue Trough is the dominant geological feature of the study area. Along the main stem of the Benue River and the lower reaches of the tributaries, very thick and permeable alluvial sediments overly the Basement Complex. These sediments pose increased geological risks for hydropower projects.
- Geological investigations were unable to be performed as part of this study due to administrative and schedule constraints. Such investigations will be the key focus of future pre-feasibility studies.
- The study area is located in a tropical climate with large variability between wet season and dry season inflows. Dry season power output is typically 15-20% of wet season output. Only very large storages such as BEN01 (Dasin Hausa) and TAR12 (Garin Dalli) significantly increase dry season flows downstream.
- The high variability between wet season and dry season inflows strongly influences the selection of the plant factor and installed capacity. This choice is generally made on financial and economic criteria, but a better knowledge of the electricity demand and potential development of the region will help in the optimization process.
- The tropical climate produces annual floods of very long durations and very large volumes across the study area. Even the very large storages (BEN01 and TAR12) provide limited flood mitigation benefits.
- Future climate change risks were assessed within the study area but were found to be difficult to quantify with any confidence at this early phase of project planning. Much of the Benue River basin has a wet risk

and the left bank tributaries of the Benue River have a stable to dry risk. The influence of climate change on project design should be assessed in more detail as part of future feasibility studies.

- The transmission network is inadequate in the study area and hydropower development will provide additional generation capacity, reduce losses and improve power system stability. Where new transmission lines are required this will improve the capacity and redundancy of the network.

8.3 Hydropower development aspects in Nigeria

Key learnings relating to hydropower development in Nigeria include the following:

- Trans-border issues are very important for Nigeria. Development of MPPs on the Niger River upstream of Nigeria are expected to reduce inflows to Nigeria and hence reduce the annual generation from the Kainji and Jebba HPPs. Uncontrolled releases from Lagdo MPP in Cameroon contribute to flooding in Nigeria and the promising BEN01 (Dasin Hausa) site creates a reservoir which inundates areas adjacent to the Benue River in Cameroon between Garoua and the Nigerian border. The NBA's role is to facilitate cooperation between Niger Basin countries in accordance with the *Niger Basin Water Charter*.
- Hydropower development in Nigeria is necessarily complicated by multiple levels of governance and competing interests for the water resource. Key stakeholders include the NBA, FGN ministries, state government ministries, local governments and local land owners and users. Multipurpose developments may need to consider a combination of hydropower generation, environmental flows, irrigation demands, flood mitigation, water supply, fisheries and recreational uses.
- Hydropower tariffs in Nigeria are adequate for small hydro up to 30 MW. Indications are that tariffs are satisfactory for medium and large hydro but more detailed discussions with wholesale power purchasers are necessary as part of future feasibility studies.
- Of the 12 shortlisted sites, the sites on the main stems of the Niger and Benue Rivers have the highest social and environmental impacts. These sites were retained in the screening because they are of large installed capacity and are of particular interest to FGN. The MCA effectively identified many sites on the tributaries of the Benue River in Nigeria with much lower and manageable social and environmental impacts.
- There are a number of areas of current social unrest in the study area. While this represents a development risk, stakeholders also highlighted that the positive impacts of project development has the potential to settle such unrest.
- Stakeholders at all levels were very happy to be consulted as part of this study. The key issues raised during the consultations were: (1) the need to consult with state ministries on technical aspects, (2) socio-environmental concerns and the need for thorough ESIA, (3) the risk of poor reservoir operation increasing flood risks downstream and (4) the potential for unintended social and environmental impacts such as the migration of people and animals.

9 Benefits of study to Nigeria

This study has delivered significant benefits to Nigeria in terms of hydropower and water resources master planning in the study area:

- Three sites have been recommended for short-term development with recommendations made for mitigation planning, baseline data collection activities and future feasibility studies.
- The study completion report summarises the characteristics and multi-criteria scores for the 54 potential hydropower sites analysed over the course of this study. The report can be used by FGN as input to a hydropower development master plan for the Benue River basin, as well as to identify small hydropower sites which may be of interest to private developers.
- Other study reports provide a wealth of valuable information relevant to hydropower and water resources development across the entire study area.

This study had a comprehensive methodology which added significant value to the early phases of project planning. The involvement of counterpart staff and extensive consultation ensured that the study recommendations are widely understood and accepted by the relevant stakeholders. FGN in collaboration with NBA can now proceed to the next project planning phase with confidence knowing that the best three sites have been recommended for development in the short-term, and that an inventory of potential projects is available for development in the medium and long-term.

10 Acknowledgements

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Patrick PICHAVANT graduated in Civil Engineering from Ecole Centrale de Lyon (France) and in Economics Sciences from University of Lyon in 1970, then obtained a Master's degree in Soils Mechanics at the University of California in Berkeley (USA). After teaching FEM applied to Soil Mechanics during four years at the Federal University of Rio de Janeiro, Brazil, he joined Coyne et Bellier in 1975 (now TF) where he got 41 years of experience in the dams engineering services. This experience has been developed mostly in France, Africa, Northern Africa, Middle East and Asia. He has a large experience of Nigeria where he worked on many projects including Kainji, Jebba, Shiroro, Zungeru, Gurara I, Gurara II, Lower Usuma.