8 *ANALYSIS OF ALTERNATIVES*

Queries expressed by some stakeholders (refer to the Comments and Response Report in *Annex B*) include the following:

- *Why hydropower?*
- *Are there any alternatives to hydropower, such as other forms of renewable energy, specifically wind and solar power?*
- *Why is the site selected for the Batoka not further downstream?*

This *Chapter* attempts to answer some of these queries. In addition, this *Chapter* presents the most recent alternatives that were considered for the proposed Batoka HES, and provides a motivation for choosing the preferred dam, power houses, waterways, access roads and townships; as well as transmission system scheme.

The following alternatives are as presented in the Studio Pietrangeli (SP) Batoka HES Phase II – Layout: Option Assessment Report E (March 2015).

8.1 *WHY HYDROPOWER?*

As discussed in *Chapter 2*, as of December 2012, total energy demand in Zambia exceeded internal generation capacity (1). This was as a result of the expansions in the mining and manufacturing sectors as well as overall expansions in the economy and population. The current power deficit has resulted in prolonged load shedding and power cuts, which have occasionally affected trade and production. At peak times supply is 1,700-1,800 MW and demand is 1,800-1,900 MW.

According to the Zimbabwean Ministry of Energy and Power Development's National Energy Policy of 2012, there is a net deficit in the supply of electrical power in Zimbabwe. The country requires nearly 2,200 MW in winter at peak, but generation locally can't meet the demand as only 1,300 MW are being produced; energy imports and load shedding cover for the deficit.

According to SP (2015), the maximum power peak demand for the SAPP will increase from 45,124 MW in 2012 to 121,421 MW in 2045, corresponding to an annual increase of 3 %. Under the same scenario, the maximum power peak demand in Zambia will increase from 1,681 MW in 2012 to 10,015 MW in 2045 (corresponding to an annual growth rate of 5.6 %), while in Zimbabwe, the maximum power peak demand will increase from 2,029 MW in 2012 to 6,071 MW in 2045 (corresponding to an annual growth rate of 3.4 %).

(1) Policy Monitoring and Research Centre (PMRC), 2013. *The State of the Energy Sector in Zambia: Implications for Industrial Development, Jobs and Poverty Reduction Background Note*

The Zambezi Basin has considerable potential for hydropower development. Presently, a total capacity of 4,684 MW (about 10 % of the total potential) has been developed in the Zambezi River Basin. According to estimates, the unused hydropower potential in the Zambezi Basin is 13,000 MW.

The Southern African Power Pool (SAPP) presents a Regional Generation and Transmission Expansion Study for the entire SAPP region (Nexant 2007), where a Base Case and an Alternative Case is proposed.

Both cases provide a reasonable set of generating unit additions balanced among peaking, mid-range, and base load units. For the entire SADC Region, the Base Case adds about 39,300 MW with greater emphasis on conventional coal fuelled steam plants. The Alternative Case instead adds about 36,600 MW with greater emphasis on hydro projects and the transmissions needed to move the power to areas of demand.

This Alternative Case over the period up to 2025 envisages development of almost all power plants in the Kariba Sub-basin, those in the Shire River/Lake Malawi/Nyasa/Niassa Sub-basin, Kafue Sub-basin and the two major power sites (Cahora Bassa II and Mepanda Uncua) in the Tete Sub-basin. By adopting this development package as the total expansion of the hydropower system, the total power development is estimated at approximately 53 % (6,616 MW) of the total hydropower potential of the Zambezi Basin.

As far as hydropower development in the Zambezi Basin is concerned, the difference between the SAPP Base Case and the Alternative Case is mainly in the timing of the construction of the Batoka HES. The total additional installed capacity at Batoka HES would be between 1,600 - 3000 MW in both cases.

Investment in energy is a prerequisite to achieving commercial and industrial development in Zambia and Zimbabwe. The use of solar power is favourable in providing rural and urban areas with access to power; however, if both countries are to achieve those targets and goals detailed in their Vision 2030 and Vision 2040, and other complimentary plans, these countries will require private sector investment in energy technology that is efficient, sustainable and reliable. The generation of energy through hydropower is a proven technology that is sustainable and which is actively being promoted at a national level in both Zambia and Zimbabwe. With a vast hydropower energy potential, hydropower is considered the most feasible and reasonable electrification option for both countries.

8.2 ALTERNATIVES TO HYDROPOWER

Apart from thermal coal, other generation alternatives include the use of wind and solar power.

Although Zimbabwe has enormous solar energy potential, and the ZERA and ZETDC have registered an increasing interest from IPPs to invest in solar power, according to the ZEPTC (2015), when comparing like for like capacity with all the competing technologies, solar has consistently shown to be undesirable; this mainly due to a high capital cost per kW to plant factor ratio.

In the ZETDC's (2015) System Development Plan, solar PV has been placed consistently at the bottom of the ranking order for new power generation projects, showing how undesirable the technology is from an investment efficiency perspective when compared to other technologies. Development of solar PV can therefore for now only be supported by strong renewable energy polices rather than technology competitiveness. This is consistent with the penetration of solar technology in other electricity markets (ZETDC, 2015). Where solar PV has penetrated the market significantly, high electricity tariffs reflect the cost of energy.

ZETDC (2015) present a summary of the associated supply side challenges of solar PV:

- It will not alleviate load shedding as intended in the ZIM-ASSET policy;
- The technology is expensive relative to investment utilisation level.
  - Thermal $/kw 2500 – 3000: Plant Factor above 75%
  - Hydro $/kw 2700: Plant Factor above 85%
  - Solar $/kw 2500 – 4000: Plant Factor 20 – 30%
- Changes output with weather elements;
- Not stable during disturbances;
- Cannot change output on demand and with demand; and
- Requires large amounts of land.

There is however a high demand for solar energy systems in Zimbabwe, especially in remote rural areas where there is no power grid; however the cost is prohibitive. Solar energy can, however be harnessed for pumping drinking water for rural communities, powering lights and appliances at rural institutions (schools and clinics), and water heating in urban areas. For these applications, local production of systems is being encouraged by the government to reduce the cost of solar equipment (ZETDC, 2015).

The situation with solar power is similar in Zambia, where solar penetration has remained relatively low due to high initial cost. As such the solar PV market in Zambia is dominated by donor funded projects, Government, NGOs and mission institutions for schools, clinics, related staff housing and water supply [(1)].

With regards to wind power, Zimbabwean meteorological records (with wind data available for periods of up to 30 years at some stations) do show that that wind power in some areas (Harare, Chivhu, Gweru, Bulawayo, and Chipinge) would be feasible for isolated local uses, and more can be developed with

(1) Zambia Development Agency (2014); Energy Sector Profile

proper financing, but in general, winds are irregular, both by season and by area, and vary widely diurnally.

In Zambia, wind energy is relatively low. Wind data collected at 10 meters per second (m/s) above the ground indicate speeds of between 0.1 to 3.5 meters per second with an annual average of 2.5 m/s. These wind speeds are not particularly suitable for electricity generation, but are well suited for water pumping for household use and irrigation purposes. There are specific areas where wind regimes are said to be as high as 6 m/s in the Western Province of Zambia, and as such, the Department of Energy has plans to develop a wind atlas to identify areas where electricity can be generated from wind [(1)].

The increased use of solar power specifically in both Zimbabwe and Zambia, and to a lesser extent wind, should therefore be explored *in addition* to hydropower.

8.3 DAM ALTERNATIVES

8.3.1 Dam Location

The proposed location of the Batoka HES was first selected in 1971 and thereafter moved approximately 12 km up river in 1981 at a section located at chainage +47 km from Victoria Falls. This location was thereafter studied through numerous geological investigations and compared with two other potential locations [(2)]. The BJVC (1993) Team established that this was the best site/preferred alternative, as there was no other site that would have such strong advantages in terms of geological, topographical, dam volumes and hydrological conditions (theoretical maximum production at the river section) as the identified site.

Further to that, the SP Team in 2014 also analysed the optimum location for the development of hydropower potential of the Zambezi River between Victoria Falls and Lake Kariba, that included the proposed Batoka HES (the same preferred site), as well as Devil's Gorge HPP, located at chainage + 65 km. Again, the preferred alternative was found to be the site located + 47 km from the Falls for the following reasons:

- Moving the dam downstream would reduce the capacity of any future development at Devil's Gorge;
- All the sites downstream, especially after chainage +55 km, are characterised by a widening of the valley. The concrete volumes calculated at the seven potential dam sites (from chainage +59 km to +89km) would require approximately 60 % to 200 % more concrete; moreover six of the seven downstream sites would require a saddle dam (another albeit smaller dam wall in another location); and

(1) Zambia Development Agency (2014); Energy Sector Profile
(2) In total seventeen project alternatives were assessed, including alternatives relating to dam type and full supply water level among others.

- Moving the dam upstream would result in a loss of total head, unless any future development at Devil's Gorge had its full supply level (FSL) raised.

Other promising sites do exist nearby to the proposed Batoka HES site (~4 km up and downstream), and whilst it was found that these sites are all comparable in terms of cost of construction, the energy production associated with these alternatives was significantly less (~15 %).

In addition to the Batoka HES site showing advantages in terms of energy production, this site also benefits from:

- A favourable river shape, having a "Z" turn upstream, which makes it favourable for the waterways intake and tunnel river diversion;
- Previous detailed geological studies have already been carried out for this location; and
- The location guarantees an overall good quality of rock foundations for the envisaged rigid concrete dam.

SP (2014) confirmed therefore that no other alternative location is as promising as the preferred Batoka HES site.

8.3.2 Dam Height

A full supply level (FSL) of the reservoir of 762 m was fixed by the average river level at the Victoria Falls power station (BJVC, 1993 and SP 2014). The Victoria Falls power station tailraces are controlled by weirs at their downstream ends which are set at 767.69 m amsl and 770.07 m amsl. While it would be possible to raise the FSL of the Batoka Dam by at least 5 m without significant impacts on the existing power station, a FSL for Batoka HES of 762 m amsl has been provisionally selected to ensure these outlets are not flooded.

A sensitivity analysis of the costs and benefits will be undertaken by SP, however, varying the dam height within a reasonable range, determined to be between the Base Case of 762 m FSL and 740 m FSL (minimum).

The motivation for the 740 m FSL is based on an assessment of impacts on water levels and flow velocities for the 762 m FSL undertaken in the 1993 Feasibility Study, where approximate water level increases post-dam, under a low flow scenario were estimated at approximately 18 m at the bottom of the 5th gorge. Dropping the FSL by 20 m (FSL of 740 m) would therefore limit the flooded extent due to the dam to around the bottom of the 5th gorge (based on low flow conditions in the river), which has environmental and social advantages (such as conserving rapids 1 to 11, which would mean a half-day rafting trip is still a possibility, and less habitat loss in the gorge).

8.3.3 Dam Type

The SP (2014) report states that previous feasibility studies compared the two following dam alternatives:

- A roller compacted concrete (RCC) gravity dam; and
- An RCC arch-gravity dam [(1)].

Although the analysis is still ongoing, based on the findings of the studies, further reviewed by SP, and according to preliminary conclusions the best option appears to be a roller compacted concrete (RCC) arch-gravity dam, based on the following technical and economic analysis:

Cost Analysis

The SP (2014) report states that the unit costs of the RCC for a gravity and arch-gravity dam at Batoka are quite similar. While many of the main cost items (equipment, aggregates, transport, placement, etc.) are practically identical, the major differences are the quantity of cement materials and joint preparation with bedding mix. Previous studies indicate the following typical unit prices:

- 65 US$/$m^3$ Batoka RCC gravity dam; and
- 75 US$/$m^3$ Batoka RCC arch-gravity dam.

Previous studies indicate that typical medium to large RCC dams cost approximately US$55 - US$90/m^3 (SP, 2014). Therefore, while there is a 10 US$/$m^3$ difference between the two prices, SP through other previous projects, has established that both prices are within a reasonable range for recent large RCC dams.

Selection of the Dam Type

The SP Report asserts that both the arch-gravity dam and gravity dam are technically feasible alternatives, considering the quality of the rock foundations. This means that the construction program would not greatly vary. Therefore, SP have focused this comparison on the economic aspects, as follows:

- The total cost of the two alternatives, gravity and arch-gravity, is controlled by several major components such as concrete volumes, excavation volumes, appurtenance structures, foundation treatment, RCC equipment, river diversion, etc;
- The total cost of several major works (such as RCC equipment, appurtenance structures, river diversion, etc.) is quite constant or varies slightly between the two dam types;

(1) It should be noted that earlier assessments also compared two other alternatives to dam type, namely double curvature arch dam and concrete faced rockfill dam, only the most promising alternatives were assessed in the SP report, 2014.

- The total volume, and consequently the total cost, of the RCC is substantially different between the two alternatives. Some other costs components would also vary (excavation, foundation treatments, etc.) but substantially less than the RCC; and
- The variation of the total cost of the concrete can be more accurately estimated than the one of the excavation and foundation treatments

The preliminary estimate of the RCC volumes gave the results indicated in the following table:

Table 8.1 Gravity vs Arch-gravity Dam: Total Cost of RCC

Dam Type	RCC Volumes	RCC Unit Cost	Total RCC Cost
	Mm^3	US$/$m^3$	M US$
Gravity	4.3	65	280
Arch-Gravity	3.2	75	240

The difference in the cost of the RCC is significant, approximately 40 M US$. The variation of the total cost of the excavation and/or foundation treatments between the two alternatives, considering the overall high quality of the foundations, would be quite small.

Conclusion

Therefore, as indicated previously, SP's analysis indicated that based on preliminary conclusions the arch-gravity dam type has been selected as the preferred alternative, as adopted in previous feasibility studies.

8.4 SPILLWAY

Four layout alternatives were looked at by SP (2014). In terms of the preliminary conclusions, the alternative identified as the preferred alternative by SP (2014), a separate spillway would be designed, ie, moving the spillway to a saddle on the right abutment, about 2 km from the dam site, as opposed to overflow over the top of the dam.

This not only shortens the waterways (ie replacing the long power tunnels with short penstocks in the dam body) but also ensures the controlled release of flows from the dam downstream so that the water does not overtop and damage or even destroy the dam.

The spillway section is lower than the other sections of the dam allowing water to flow over its top and down its front face.

As mentioned previously, excavated rock from this spillway, may be used as quarry materials in the construction of the dam wall, reducing the need for borrow pits and quarries outside of the inundation area.

In the other layout alternatives the spillway would not be separate to the dam wall and would overflow over the dam wall.

8.5 *POWER HOUSES AND WATERWAYS*

The following sections illustrate four alternative layouts for the powerhouses, namely:

8.5.1 *Underground Powerhouses and Waterways (1,600 MW)*

This layout include two underground powerhouses, one for each bank, located about 600 m from the intake on the left bank, and 400 m on the right bank. The two powerhouses host 4 turbines that are 200 MW each with a total installed capacity of 1,600 MW. The powerhouses include the main cavern, which totals 130 x 30 x 50 m, and a separate cavern for the transformers. In this layout, there are four identical waterways, two on each side of the river. The average length of the two waterways on the right side of the river is 963 m while for the left side is 712 m. Therefore, the total length of the power waterways is 3,350 m. The power waterway includes an intake, a shaft hosting the gates, a headrace tunnel, a penstock dividing in two manifolds and a tailrace outlet.

8.5.2 *Alternative A- Outdoor Powerhouses and Waterways (1,600 MW)*

Two outdoor powerhouses, specifically on the riverbanks and downstream of the plunge pool, are proposed in this layout. The number of turbines (8) and their size (200 MW each) remain the same as the option above, and the plant size remains the same.

Here the two waterways comprise one line for each river bank. The total length of the two waterways is about 1,930 m, divided in 930 m for the right and about 1,000 m for the left.

8.5.3 *Alternative B – Outdoor Powerhouses and Waterways (2,400 MW)*

Here, the layout is similar to Alternative A; however capacity is increased from 1,600 MW to 2,400 MW, which corresponds to the minimum proposed range for the installed power (2,400 -3,000 MW). The size of the turbines is also maintained, while each powerhouse has been enlarged hosting two more turbines (ie from 4 - 6).

Here there are four waterways, two for each bank. The waterways are identical in the components, but they differ for the length. The average length of the two waterways for the right side is 900 m, while for the left side waterway lengths are about 750 m, resulting in a total length of waterways of approximately 3,300 m.

8.5.4 *Alternative C - Powerhouses at the Dam Toe and Waterways (3,000 MW)*

This final alternative substantially differs from the previous ones. The two powerhouses are located at the downstream toe of the dam, perpendicular to the axis of the Zambezi River. This scheme has a "compact" layout with the dam, waterways and powerhouses close to each other. However the powerhouses are well separated from the dam, facilitating construction. The two structures are completely independent and the gap between the two will be filled at the end of the construction period. The total capacity of the plant is increased to 3,000 MW, having increased the turbine size up to 375 MW.

In this alternative, there are eight penstocks located in the dam body. Each penstock has a length of 203 m, resulting in a total length of 1,624 m for the entire waterway.

8.5.5 *Advantages of Outdoor Power Houses and Waterways*

SP therefore selected the most promising alternatives to ensure:

- The *shortest possible construction period*, which substantially improves the financial conditions of the project; and satisfies in the shortest possible time, the energy needs of the two countries; and
- A *significant reduction of uncertainties and risks of delays* during construction.

The time required to build an open-air powerhouse is not comparable to the time needed for an underground powerhouse, mainly because the construction of a large underground powerhouse:

- Can be started only once the access tunnels have been completed;
- Requires a longer construction time as the restricted space available does not allow the use of large cranes and simultaneous activities of several subcontractors;
- Interferes with other underground works such as manifolds and tailrace tunnel lengthens the construction time;
- Includes transformers caverns (and cable shaft, access tunnel, etc.) that are no longer necessary when the transformers are installed in the open-air;
- Has lower production rate of the civil works, that also causes an increase in the unit costs, which are generally 20 % higher than that of a corresponding open air power house;
- Presents a geological risk (special excavation support, etc.) which might cause delays; and
- Presents uncertainties which might offer contractors' potential grounds for claims and/or delays.

8.5.6 *Conclusion*

Although further studies are still on-going, based on preliminary conclusions, the preferred alternative is the outdoor power houses and waterways.

8.6 ACCESS ROADS AND TOWNSHIPS

8.6.1 *Access Roads*

The upgrading of existing roads and construction of new roads to access each bank from the main roads linking Livingstone to Lusaka (Zambia) and Victoria Falls to Bulawayo (Zimbabwe) will be required.

In the 1993 Feasibility Study, this included the rehabilitation of 9 km of road and the construction of 22 km of new road in Zambia, and the rehabilitation and upgrading of 40 km of road and the construction of 14 km of new road in Zimbabwe.

While there was consideration for the design of new direct tracks from Livingstone, Victoria Falls and/or Batoka, this was decided against by SP for the following reasons:

- The construction would be costly and time-consuming, given the stripping of vegetation required and the geometry of the track;
- The direct tracks would not pass through the existing villages, which would benefit from the new roads (incoming jobs, tourism, trade etc.); and
- The new routes would not differ much from the existing ones, gaining just a few kilometres in length.

Therefore, there are insufficient reasons for the construction of alternative roads and the exact routing of the roads will be elaborated as an output of the ESIA study.

8.6.2 *Permanent Villages*

Permanent villages will be located, on the North bank of the dam (in Zambia) and one on the South bank (in Zimbabwe). In the 1993 Study, the Zambian village was positioned approximately 6 km away from the dam and almost totally below the new access road. The total area covered 210 ha and was set between 860 and 930 m amsl.

As a further option to the two locations already mentioned, four alternative areas were preliminarily identified as potential alternative locations for the permanent village, as presented in *Chapter 3*. Each of these alternatives will be explored during the ESIA phase.

8.7 TRANSMISSION SCHEMES

The lines directed to Zimbabwe will lead to Hwange station, while in Zambia, two overhead lines from the Batoka HES (or even three, according to the selected power transmission scheme), will be routed respectively to the new Livingstone Station and to the existing Muzuma Station.

In Zambia, the first alternative foresees the route of one single circuit line to the new Livingstone station, and one single circuit line to Muzuma station; the latter route is composed of an initial 15 km long stretch in a north-west direction to reach the nearest point of the existing 220 kV corridor, then it runs parallel with the existing line up to the Muzuma station.

The second alternative is conceived to route both the outgoing lines from the Batoka station to the future new Livingstone station. The two 330 kV overhead lines will run in parallel, sharing a common right of way, for about 21 km up to the location of the new Livingstone station. From there, by means of a "line-in line-out" scheme, the line to Muzuma will follow the same route as the existing 220 kV line, ending at the Muzuma station; a total length of 160 km (ie 180 km from Batoka site).

The first alternative has the least power losses provided that the majority of the power flow is led to Zambian central and northern areas, without passing through the New Livingstone station. However, this line is reportedly already under study by third party project.

The second and alternative is proposed for several reasons, namely:

- It is the least-cost option and shortest line (2x20 km),
- It provides greater operational flexibility as it offers the advantage of switching station at New Livingstone for power routing towards Namibia, Zimbabwe (through the planned Victoria Falls Town 330 kV station) and Muzuma itself (through the new planned 330 kV line towards Kafue),
- It has transmission operation flexibility, since full power will be available at the new Livingstone station busbars for any switching operation; and
- Two outgoing lines will share the same right of way along the whole route.

In Zimbabwe, it is proposed that the transmission lines comprise 2 x 70 km 330 kV lines, running in parallel, and sharing a common right-of-way, to the existing Hwange 330 kV substation. An alternative has been identified, to take advantage of the existing A8 national road for the future construction and maintenance of the line infrastructure. In view of this, the alternative deviates approximately 30 km from the starting point towards the A8 motorway, and increases the route length by approximately 20 km.

At this stage of the project, transmission line corridors of 3 km in width will be investigated to allow for the investigation of possible environmental and social constraints, such as villages and homesteads, agricultural fields, industrial sites, pipelines etc.

Transmission line routes, and thereafter further refinement of transmission line positioning within the proposed corridors, will be investigated as part of the overall engineering feasibility and ESIA studies.