Ubangi – Lake Chad Water Transfer Using Solar Option

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Abstract

In 2011, CIMA International (Canada), under contract to the Lake Chad Basin Commission, completed a *Feasibility Study of the Water Transfer Project from the Ubangi to Lake Chad*. This study proposed a 360 MW hydroelectric dam on the Ubangi River at Palambo to provide 250 MW of power to pump water a distance of 128 km to the Lake Chad Basin. Not only was the proposed dam costly at $2.7 billion (2011 US dollars), it would flood 200 km upstream, inundating many villages in both the Central African Republic (CAR) and the Democratic Republic of Congo (DRC). Moreover, during periods of low water at the Palambo dam site, the project would not generate enough power to pump the planned flow of 100 m^3/s to Lake Chad.

However, recent reductions in the cost of solar power open a new opportunity for cost-effective, environmentally sustainable Inter-Basin Water Transfer (IBWT) to Lake Chad. This paper presents the Solar Option, as an alternative to a hydroelectric dam on the Ubangi River. One version of the Solar Option is summarized by the Sample Project Specifications, which show that the projected cost of solar energy may be less than 10% of the cost of the hydroelectric dam.

Key Words

- CIMA — CIMA+ Civil Engineering, Laval, Quebec; previous IBWT feasibility study
- Grid-scale battery — large energy storage used to extend hours of operation
- IBWT — Inter-basin Water Transfer (from the Ubangi River to Lake Chad)
- PV— Photovoltaic solar panels that generate electricity from sunlight
- Terms of Reference — Specification of engineering work to be done to plan a project
- Solar Option — The plan to use solar power as an alternative to a hydroelectric dam

Introduction

The CIMA Feasibility Study (1) specified a hydroelectric dam on the Ubangi River. The Solar Option is an alternative to this dam. The Sample Project Specifications below summarize details of one model of solar power development to pump water for IBWT from the Ubangi River to restore Lake Chad. Other versions of the specifications are possible.

Appendix 1 provides a detailed Terms of Reference for a new engineering feasibility study of IBWT to Lake Chad, employing the Solar Option.

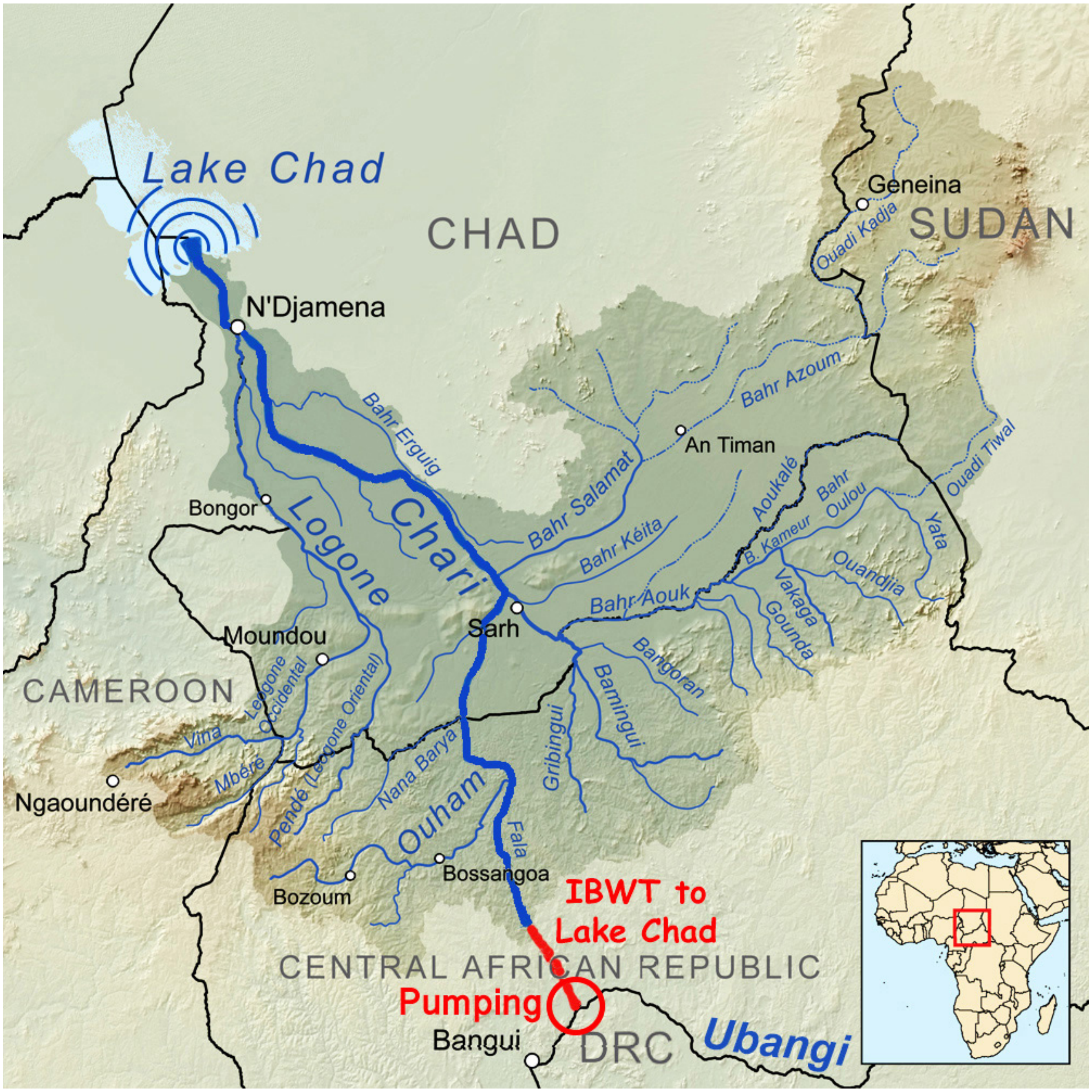

Figure 1: Map of Chari River in the Lake Chad Basin, showing the IBWT route for pumped water.
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A. Sample Project Specifications for the Solar Option
[N.B. cost estimates are in $US dollars.]

1. **Intakes and Pumps:** Four submerged intakes on the Ubangi River will supply the pumps and pipeline. The intakes will not require a dam and will screen for fish. Four independent pumping stations located on the north shore of the Ubangi in the CAR (above high river flow) will supply water to each of the four pipelines.

2. **Pipelines:** Four parallel conduits, 5 meters in diameter each, will convey water uphill from the Congo River Basin to the Lake Chad Basin. The IBWT pipelines will be 128 km in length and raise water 180 meters to the inter-basin crest.

3. **Canals:** Once the water is elevated to the inter-basin crest of the Lake Chad Basin, it will flow approximately 1000 km by gravity in natural waterways and improved canals to the Chari River, and thence to Lake Chad.

4. **Solar Power:** Recent cost reductions for silicon PV panels to less than $0.30/W (2) make solar power a viable replacement for hydroelectric power. Large arrays of solar panels (near the pumping site on the Ubangi River) will supply the power needed to pump a volume of 100 m^3/s during 8 daylight hours (the daily period of intense sunshine).

5. **Battery Pumping:** Projected cost reductions for grid-scale lithium-ion batteries (3) to $100/kWh allow for nighttime pumping for 16 hours per day. Initially, only 1 of 4 of conduits will be pumped by battery power after sunset, giving 24 hours per day flow at 25 m^3/s. Continuous pumping will keep water flowing at all times in canals and rivers to Lake Chad, assuring a minimum steady supply.

6. **Cost of Solar Option:** Installation of 375MW of solar panels will cost $135M. Installation of lithium-ion 1000MWh grid-scale battery will cost $130M. Total cost of Solar Option solar panels and a single grid-scale battery will be $267M (less than 10% of the cost of the hydroelectric dam).

7. **Impact on Rivers:** A volume of 100 m^3/s of water pumped to Lake Chad will use 0.7% to 5% of the Ubangi River flow (4). Water pumped to Lake Chad is about 0.25% of average Congo River discharge to ocean (5). These rates of water transfer to Lake Chad are unlikely to affect the ecology or navigability of the Ubangi River. IBWT will not impact the planned Grand Inga hydroelectric development on the Congo River in the DRC. The pumped output of the Solar Option could double the Chari River flow to Lake Chad in April and May (6), during low water years.

8. **Staged Construction:** Unlike the hydroelectric dam, the Solar Option allows for staged construction and earlier pumping than from a dam. Shown below are the incremental approximate costs for each stage.

   - **Stage 1.** One 5 m pipe; (8hr); requires 63MW solar; cost: **$23M**
   - **Stage 2.** One 5 m pipe; (24hr); add 125MW solar + 1000MWh battery; cost: **$175M**
   - **Stage 3.** Two 5 m pipes; (8hr & 24hr); add 63MW solar; cost: **$23M**
   - **Stage 4.** Three 5 m pipes; (8hr, 8hr & 24hr); add 63MW solar; cost: **$23M**
   - **Stage 5**. Four 5 m pipes; **(**8hr, 8hr, 8hr & 24hr); add 63MW solar; cost **$23M**

   The total cumulative cost is **$267M** for the Solar Option. [NB: This cost estimate for the Solar Option does not include water intakes, pumps, pipelines, canals or new roads.]

9. **Time to Fill Lake Chad:** The completed Solar Option will pump 1.58 billion m^3/year to Lake Chad (50% of the rate of the hydroelectric dam). Based on the CIMA Feasibility Study, solar pumping will raise Lake Chad by 50 cm and increase area by 3000 km^2 in 1 year. It may take 2 to 5 years to restore the Lake Chad fishery, depending on competing domestic and irrigation water consumption, as well as water loss from evaporation.

B. Calculations and Assumptions used for Solar Option Estimates

1. **Pipeline Options:** The 2011 CIMA Feasibility Study (1) specified three parallel conduits of 6 meters diameter to transfer 100 m^3/s, using 251 MW of power. For these estimates, the pipeline consists of 4 parallel conduits of 5 meters in diameter each. Another option is 7 parallel conduits at 4 meters diameter each. Selection of pipe size should be consistent with lowest cost and optimum staged construction. The 128 km pipelines must raise water 180 meters to the inter-basin crest, which implies a static pressure at the bottom of 1766 kPa (256 psi). Each conduit weighs 20 tonnes/meter and will need adequate supports. The pipelines must be buried beneath road crossings and not obstruct wildlife and grazing animals. [N.B. The costs of pipelines (purchase and installation) are not included in these estimates, since they are unchanged by the Solar Option. The CIMA Feasibility Study provide an estimated cost of $7.3 billion for pumping from the Palambo dam. This high cost needs review.]

2. **Solar Power:** The CIMA Study specifies that 250MW is required to pump 100 m^3/s to Lake Chad. The cost of PV solar panels has decreased from $76/W in 1977 to $0.30/W in US dollars in 2015 (2). Although future solar power costs will continue to decrease, a value of $0.30/W was used, with an additional factor of 1.2 to cover installation costs. For example, to pump water to fill a single 5 meter diameter conduit during 8 daylight hours, 63MW of power is needed; 63 X .30 X 1.2 = $23M cost (approximate).

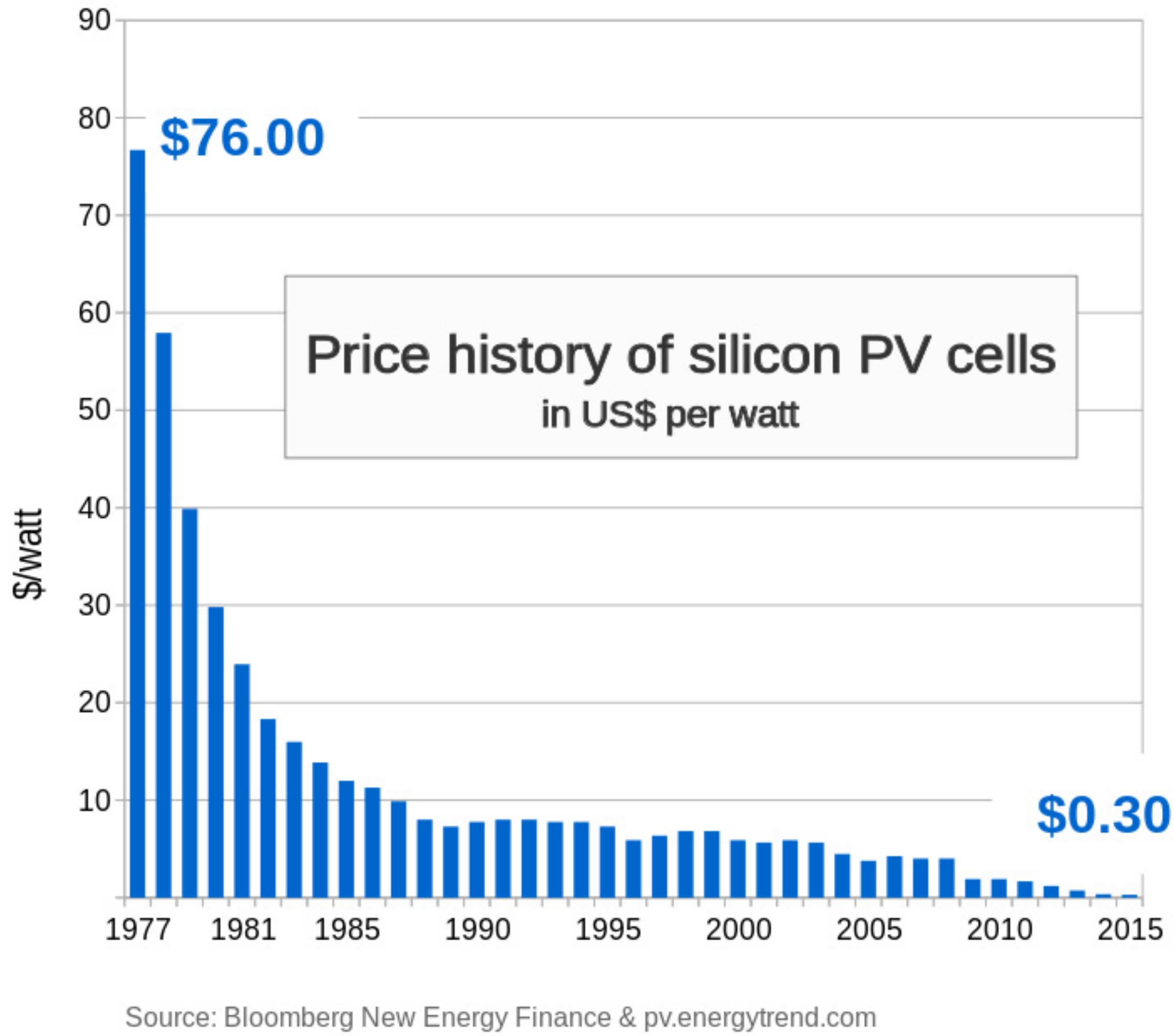

Figure 2: Price History of Silicon PV Cells
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3. **Transmission Line:** Initially, a solar powered grid can deliver electricity only during 8 daylight hours of intense sunshine. There are at least two possible locations for a solar power array: a) adjacent to the pumps on the Ubangi River bank; b) in the Sahel as part of the solar power installation at Djermaya, Chad (7), (near the airport servicing N'Djamena). The Sahel in Chad has 1.5 times more direct sunlight than in the CAR on the Ubangi River (where frequent rains limit average solar power). However, a solar power array in the Sahel will require an 1100 km transmission line (which may be desirable as part of a plan for rural electrification of Chad and the CAR).

4. **Cost of Grid-Scale Batteries:** The recent development of grid-scale lithium-ion batteries allows for nighttime pumping for 16 hours per day, increasing total pumping time to 24

hours per day. The cost of grid-scale batteries is the obstacle. Although lithium-ion batteries in 2007 cost more than $1000/kWh, current projections indicate that lithium-ion batteries will fall to $100/kWh by 2028 (3). For analysis of battery options, a figure of $100/kWh was used as a maximum viable price. If the actual cost remains high, then another battery technology may needed. [NB: Grid-scale battery technology is rapidly evolving. New battery solutions are likely in the future, which may allow 24 hour pumping all four conduits at full capacity of 100 m3/s.]

5. **Deployment of Grid-Scale Batteries:** The energy storage capacity of a grid-scale battery determines its cost. For a goal of continuous 24h/d pumping of a single 5 m diameter pipe, 63MW of continuous power is required (250MW/4). For 16 hours of nighttime pumping using battery power, a 1000MWh battery is required. At $100/kWh ($100,000/MWh), the battery will cost $130M (including estimated $30M for installation and switch gear). In addition, the 1000MWh gird-scale battery requires 125MW of additional solar panels (at a cost of $45M) to charge it during the 8-hour daytime, while the other solar panels directly pump water. Thus the incremental cost of installing 1000MWh grid scale battery is $175M.

6. **Staged Construction:** A major advantage of the Solar Option is that it can be built and operated in stages, providing water to Lake Chad sooner than a hydroelectric dam. The Sample Project Specifications specify five construction stages.

   - Stage 1. A single conduit of 5 meters diameter and 128 km in length will be installed from the Ubangi River pumping station to the inter-basin crest between the Congo Basin and the Lake Chad Basin. The goal is to pump 25 m^3/s for 8 hours each day during daylight hours. This will require 63MW solar at cost of $23M (for solar only, not the cost of the pipeline). While this is not enough water to restore Lake Chad, it will test the pumping system and the 1000 km of gravity-fed canals and natural waterways that lead to Lake Chad. The total water pumped (in one 5 m diameter pipe) to Lake Chad will be **0.72 million m^3/day.**

   - Stage 2. With recent cost reductions of solar energy, the most expensive system components will be the pumps and 128 km of pipelines. The goal of Stage 2 is extend the pumping time of a single 5-meter diameter pipeline to 24 hours per day. A grid-scale battery of 1000MWh, costing $130M, will supply 16 hours of nighttime power to the pump. To charge this large battery, an additional 125MW of solar panels are needed, at a cost of $45M. While the incremental cost of grid-scale battery pumping of just one conduit is high at $175M, this may be small compared to the cost of the pipeline, which is a compelling reason to keep the pipelines full of water and not let them sit idle during the night. Battery pumping demonstrates feasibility and will increase water flow (in one 5 m diameter pipe) to Lake Chad by 1.44 million m^3/day, for a tripled total flow in a single pipe of **2.16 million m^3/day** (788 million m^3/year)**.**

   - Stages 3, 4, and 5. For the Sample Project Specifications, a total of four 5 meter diameter parallel pipes (128 km each) are planned. Stages 1 and 2 will pump water in a single 5 m diameter pipe. Stages 3, 4, and 5 add three more 5 m diameter pipes in succession. For 8 hours daytime pumping in each new pipe, 63MW of solar power must be added at a cost of $23M per pipe. For three additional conduits, a total of 187.5MW solar panels must be added for 8 hours daytime operation. The Sample Project Specifications do not include additional grid-scale batteries for Stages 3, 4, and 5, since less expensive battery technology may be available in the future. However, the long-term goal must be to achieve 24 hours per day pumping on all conduits. With all four 5 m diameter parallel pipes being used (1 pipe 24 h/day and 3 pipes at 8 h/day), the total flow to Lake Chad will be **4.32 million m^3/day** (1.58 billion m^3/year)**.** Total cost of solar panels and one grid-scale battery will be $267 million, which is less than 10% of the CIMA estimate of $2.7 billion for the cost of the hydroelectric dam on the Ubangi River.

7. **Time to Fill Lake Chad:** Estimating the time needed to fill Lake Chad is complicated. Firstly, there are competing water uses: domestic and irrigation water consumption, as well as water loss from evaporation. Secondly, the flow rates of rivers feeding Lake Chad vary from year to year. Thirdly, the contour of the shallow lake bottom varies, so that area covered is not proportional to added volume. The CIMA Feasibility Study specified that full time pumping at a rate of 100 m^3/s would add 3.15 billion m^3/year to the Lake Chad (potentially doubling the Chari River flow in April-May, during low flow); in 6 months the lake level would rise 50 cm, adding 3,000 km^2 to the surface area. Although this is small compared to the 26,000 km^2 area of Lake Chad in the 1960s, it may be enough to partially restore the fishery. The Sample Project Specifications for the Solar Option indicate a pumping rate of 1.58 billion m^3/year (half of the CIMA rate from the hydroelectric dam), which means that it may take 1 year to raise the level of Lake Chad by 50 cm (increasing area by 3,000 km^2). In conclusion, the Solar Option will satisfy the fundamental goal of reversing the desiccation and reduction of Lake Chad, adding billions of cubic meters of water each year.

8. **Construction and Cross-Border Issues:** The Palambo site in the CAR on the Ubangi River can be developed for solar power, adjacent to water intakes and pumps. This site can be reached by developed road along the river or by barge during high water in summer months from Bangui in the CAR. Since no dam on the Ubangi is required, all project infrastructures will be in the CAR. There will be no developments in the territory of the DRC (8). Pumped water will flow by gravity in natural rivers and developed canals along the Fala and Ouham Rivers into Chad, where the water enters the Chari River, which flows into Lake Chad.

C. Conclusions

The Solar Option is a viable power source for IBWT to Lake Chad. The Solar Option offers the following benefits:

- Dramatic cost reduction: approximately 10% of the cost of a dam on the Ubangi River;
- No dam flooding of 200 km of the Ubangi River: no displacing villages, no impeding navigation, and no compromised fisheries;
- No impact on the territory of the DRC; all infrastructure in the CAR and Chad;
- Potential to expand electric grid to Bangui and other sites in the CAR.

- Low environmental impacts on the Ubangi and Congo Rivers;
- Restoration of 3000 km^2 of Lake Chad in 1 year.

D. References

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