The Future of SAPP, WAPP, CAPP, and EAPP - With Inga

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Abstract: New high voltage (HV) transmission lines are at the top of the agenda for many energy planners in the various regions of Africa. These lines are identified within the power pools of Southern Africa and West Africa. The new Central Africa Power Pool is in the process of identifying its new HV lines and the East Africa region is about to start. This paper looks at the centrality of the huge hydropower potential of the Grand Inga Project and the sensitivity of pricing electricity exports as they relate to transmitting power across Africa's proposed new HV lines.

Key Words: Economic gains, new HV transmission, African power pool policy, Grand Inga, electricity export pricing.

Introduction

Capacity planning in Africa's power pools will be significantly affected by the proposed new HV lines. This paper considers the costs of interconnection across Africa and draws upon comparisons with HV line networks in other locations. The Southern African Power Pool (SAPP), West African Power Pool (WAPP), Egypt, and the East African Power Pool (EAPP) have each expressed their interest in continental interconnection. The hydropower potential from the River Congo is a big attraction to regional planners and the key development project of Grand Inga (39GW potential, located 150km from Kinshasa) necessitates the planning of very long HV lines. The Central African Power Pool (CAPP) and the Democratic Republic of Congo (DRC) have much to gain from exporting the potential hydropower at the right price.

Section 1 of this paper provides an introduction to Africa's power pools showing how each has an interest in the hydropower potential of Grand Inga. Section 2 outlines the North America experience with long-distance trading, and Section 3 discusses the creation of the CAPP. Section 4 considers investment and pricing of electricity exports, and Section 5 draws conclusions and recommendations for future electricity modeling in Africa.

1. African Power Pools and the Centrality of Inga

Over the past decade there have been major initiatives taken by African governments to improve reliability and reduce costs by promoting the development of regional power pools.

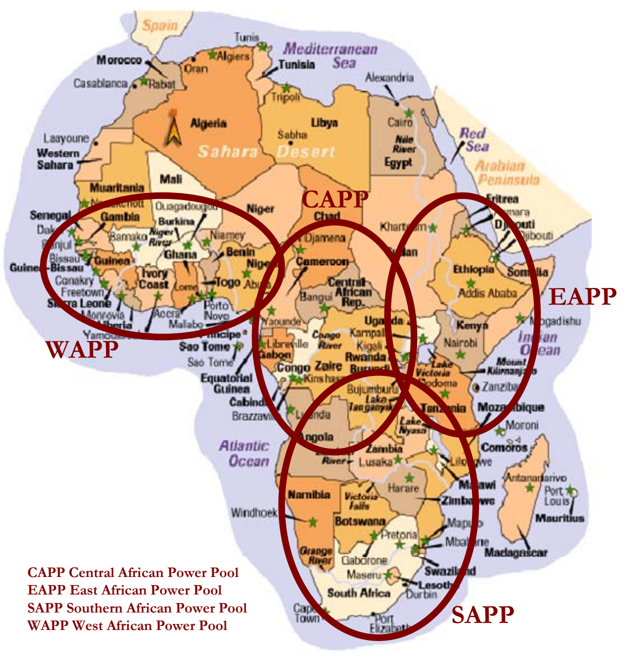


Figure 1. Africa Regional Power Pools, CAPP, EAPP, SAPP, and WAPP

The Southern African Development Community (SADC) created the SAPP in 1995 and the Economic Community of West African States (ECOWAS) created the WAPP in 2001. Each of these power pools cover a very extensive area including 12 countries in the first instance and 14 in the latter (Figure 1).

Power Pool	Total Existing Generation (MW)	Sub-Sahara Generation (Percentage)
CAPP	4,561	8%
EAPP	3,092	5%
SAPP	42,324	72%
WAPP	8,579	15%
Total	58,556	100%

Table 1. Sub-Sahara Regional MW Totals
Reference: [1]

Most recently the CAPP was created in early 2005 and there is currently discussion for developing an EAPP. These regional initiatives for improving trade among states all depend on new international HV transmission lines being built.

Africa's largest regional power pool is the SAPP with over 42GW of generation capacity (Table 1). Total electricity generating capacity of Sub-Sahara Africa is about 59GW (7% of U.S. total of 983GW). With Africa's much larger area and smaller generating capacity there is a question if such a large spread-out continental grid, involving expensive long transmission lines with large line losses can be economically justified. There is an ever growing interest, in spite of the economic challenges, to transmit the enormous hydropower potential of the River Congo to the north, south, east and west of the continent. The Purdue modeling team has built models for SAPP and WAPP. A preliminary CAPP model has now been built and a proposal prepared for modeling the East Africa region. These modeling initiatives will provide top level planners with quantitative economic assessments of the new regional interconnections, demonstrating the magnitude of the gains from joint construction and trade.

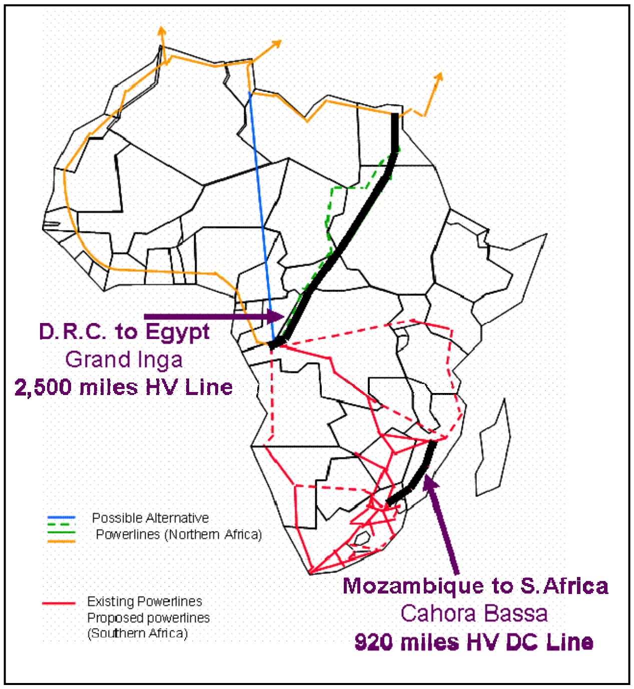


Figure 2. Long-Term Transmission Planning in Africa

What are the most critical new lines required in each of these four regions of Africa and how can the experiences of the United States and other large interconnected networks assist in the planning of a network across Africa?

The great hydropower potential of the River Congo, especially at Inga, can certainly play an important role in providing power regionally. Located at the heart of Africa (150km from Kinshasa) it is at the center of a future continent-wide power network (Figure 2). DRC-Inga currently exports and wheels power to SAPP countries including Zambia, Zimbabwe, Botswana and South Africa. Power from Inga is transmitted to the Zambian grid along a 500-KV direct current (DC) line from Inga to Kolwezi in southern DRC, and a 220-KV line from Kolwezi to Kitwe in northern Zambia [2]. Viability of a second southern interconnection, from DRC to SAPP via Angola and Namibia, rests solely on expanding the generating capability of the Inga facility. Expansion of Inga 3 (3,500MW) coupled with the rehabilitation of Inga 1 and 2 can provide enough excess generating capacity that will justify the creation of an expanded regional electricity export scheme. The Western Energy Highway, will connect DRC-Inga to Nigeria and WAPP, providing 1,000 MW of electricity. The fully implemented Grand Inga scheme will be the largest generating facility in Africa with 39,000 MW and feasibility studies indicate that it's interconnector to Egypt would be viable with the construction of the Northern Energy Highway, passing through Congo, the Central African Republic, and Sudan to Egypt, a distance of about 2,500 miles.

Region/Country	Surface Area (1000 km^2)	HV Transmission Line Length Above 110kV (km)
Sub-Sahara Africa	24,267	n/a
SADC	9,275	5,710
Rep. South Africa	1,221	25,181
Nigeria	924	11,000
U.S.A.	9,629	248,648
Canada	9,971	n/a
Mexico	1,958	23,500

Table 2. HV Transmission Lines in Africa and America
Reference: [2,3]

There are striking differences in the amounts of HV transmission lines in Africa and North America. Sub Sahara Africa is about 2.5 times the size of the U.S. The SADC has an almost equal area to that of the U.S. Its 5,710km of international HV lines together with South Africa's 25,180km of HV lines amounts to 12% of the HV lines in the U.S. (Table 2). The high demand centers in Africa are mostly concentrated in the capital urban areas and are very widely dispersed making a marked difference with the much higher number of high demand centers in the U.S.

2. Electricity Trading Between the North American Interconnects

Long distance electricity shipments in the U.S. were originally reserved for unexpected outages in generation. An interesting exception to this comes from the Canada's net flows of hydropower exports to New England and the west coast states. Net power flows between the three U.S. interconnections tends to be very limited. Canada's exports account for 5% to 10% of it's total generation. In the case of CAPP these numbers will become reversed, with domestic consumption taking the 5% to 10% of Inga's total production, assuming new continent wide interconnections will be constructed.

In the 1990s the wholesale trade of electricity in the U.S. was promoted and the FERC (Federal Energy Regulatory Commission) established procedures to ensure the availability of non-discriminatory transmission access. It had been the formation of the North American Electric Reliability Council (NERC) in 1965 which ensured compliance with guidelines for providing overall reliability and system security. In Africa there is going to be need for a similar organization as several countries will be involved with the proposed long HV lines.

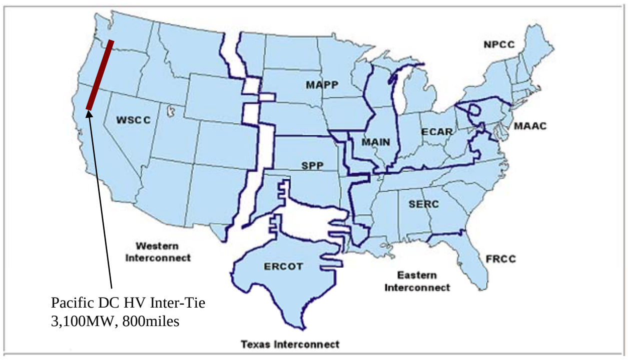


Figure 3. The Main Interconnections of the U.S. Electric Power Grid and the 10 North American Electric Reliability Council Regions

North America's three interconnected networks (Figure 3) are the Eastern Interconnect (the largest), Western Interconnect (second largest, west of the Rocky Mountain ranges) and the Texas Interconnect. There is very little load carrying capability between these three regions. Is it a technical problem or economics or simply no demand exists at present? Each regional grid operates as a single large utility with a common set of operating rules. The Texas System is not interconnected with the other two networks (except by certain direct current lines). The other two networks have limited interconnections to each other. Both the Western and the Texas Interconnect are linked with different parts of Mexico. The Eastern and Western Interconnects are completely integrated with most of Canada or have links to the Quebec Province power grid. Virtually all U.S. utilities are interconnected with at least one other utility by these three major grids. Mexico has a national interconnected grid with four regional divisions and about 23,500 miles of HV lines. It connects with the U.S. at several points over the border and in 2003 imported about 72GWh and exported 953GWh.

Voltage	1990	1999	Change
230kV	70,511	76,762	6,251
345kV	47,948	49,250	1,302
500kV	23,958	26,038	2,080
765kV	2,428	2,453	25
Total	144,845	154,5033	9,658

Table 3. U.S. High Voltage AC Transmission Mileage - Selected Years

Reference: [4]

In the planning of Africa's new HV lines the control of the lines is to be an important issue. The FERC expects new regional transmission organizations (RTO) to improve power grid reliability while reducing discriminatory transmission practices, and increasing investments in the transmission infrastructure. The issue of exactly who will control the transmission of electricity under a nationwide system of RTOs needs resolving [5]. During this debate, in the 1990s, over 9,500 miles of new HV transmission lines were built in the U.S. giving approximately a 7% increase (Table 3).

Interface	Peak Demand (MW)
NEPOOL to NYPP	27
NYPP to NEPOOL	888
Net, NYPP to NEPOOL	861
NYPP to MAAC	1,261
MAAC to NYPP	1,684
Net, MAAC to NYPP	422
MAAC to ECAR	969
ECAR to MAAC	3,908
Net, ECAR to MAAC	2,939
Total Gross Transactions, Four NERC Regions	**8,737**

Table 4. U.S. Electric Transmission Network - A Multi-Region Analysis Interregional Gross and Net Tie Line Transactions

Reference: [6]

The early 21st century has seen less new HV lines being constructed and this is becoming of great national concern especially for the summer peaking seasons. At what level of administration is Africa to debate the construction and transmission controls of the inter-power pool interconnections? To date the HV lines have been limited to within the regional power pools.

Most electricity trade in the U.S. takes place not between the three interconnect systems but among the power pools in each interconnect. The main exception to this, as already noted, is in the case of Canada's exporting it's hydropower. Major transfers of more than 3,900MW of peak demand moves between the two NERC regions ECAR and MAAC for example. Typical tie line transactions between U.S. power pools can vary between about 30 MW and over 3,000 MW (Table 4) but the lines are shorter than those being proposed for Africa.

Voltage (kV)	Length (miles)	Maximum Capacity (GW)
765	100	3.8
	400	2.0
500	100	1.3
	400	0.6
230	100	0.2
	400	0.1

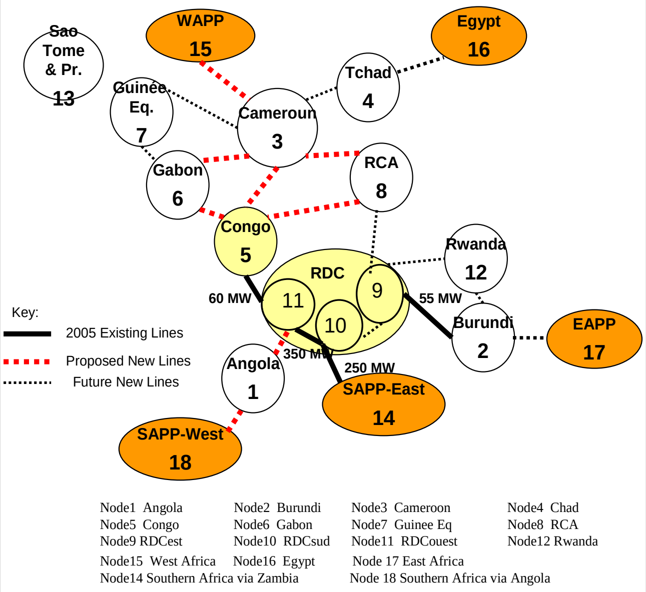
Table 5. Capacity Limits for Electrical Transmission Lines *Reference:* [7]

In the U.S. a 765kV line might carry 3.8 GW but it will only be 100 miles long (Table 5). Extra long lines as being considered in Africa will need further technical study and will be much more expensive. In the U.S. the transfer of 3,000MW over several hundred mile and more will normally involve several lines. Transmission lines which are 1,000 miles long or more, similar to the Mozambique to South Africa DC line, are special designs for which the capital costing and operating costs requires extra evaluation.

Exporting electricity from Mozambique's Hydro Cahora Bassa (HCB) to South Africa, and Canada's hydropower generation to the U.S. provides significant revenues to the exporting countries. In the case of DRC the export revenues could become substantial from building Grand Inga (Stages 1 and 2) with initial exports of 8,000MW (56,000 GWH/year). This could raise annual export revenues of $1.5 Billion or more once the full demand is being supplied.

In the case of Canada it is one of the world's largest producers of hydroelectricity, generating over 315,500 GWh (2002). Very similar to DRC it is estimated that Canada has 180 GW of hydroelectricity potential remaining, although only 34 GW is currently deemed economically feasible. The economic analogy of building more hydropower in Canada with the DRC's Inga might help planners in Africa. Export potential for sending power to the U.S. from Canada has the attraction of further massive energy revenues but the capital intensive nature of new hydro capacity could overwhelm benefits from trading. This is an issue that confronts the Inga project. Correctly pricing Inga's electricity exports is going to be essential for the successful launching of the project as it looks towards providing mutual benefits to consumers in Africa's power pools as well as to DRC.

3. The Preliminary CAPP Model



Note: RDC is French for DRC, similarly Tchad for Chad

Figure 4. The Preliminary CAPP Model - With 18 Nodes Including 5 Export Nodes

Recently, Purdue's Power Pool Development Group's (PPDG) long-term planning software has been utilized to explore the economic gains that could be expected from the future development of the CAPP with its' 10 connected countries as indicated in Figure 4 [8].

As Figures 1 and 2 indicate, the central location of CAPP allows it to consider exports to each of the two major Power Pools already in existence, SAPP and WAPP, as well as possible sales to Egypt and EAPP. These export opportunities, along with the well documented advantages of common operation and expansion of the grid within the 10 country region, should make the establishment of CAPP a top priority for any Pan-African electricity generation planning project.

The model simultaneously cost minimizes expansions in both the generation and transmission sectors [9,10]. The water cost was set at $0.5/MWh which was the value stipulated by the SAPP some years earlier [11]. For demonstration purposes initial export demands were set at 1,000 MW each for SAPPwest, WAPP, and EAPP, 250 MW for SAPPeast, and 4,000 MW for Egypt. A general growth rate was assumed of 5% for CAPP as well as at the export nodes of SAPP, WAPP, Egypt and EAPP.

The 18 node model provides an optimal planning strategy for new lines emanating from Inga (node 11, DRCwest, Figure 4). It is a 20 year long-term capacity expansion and electricity trade model as developed over the past several years for the SAPP and WAPP [12]. Unserved energy costs are set at $140/MWh and unmet MW at $3M/MW. The unserved energy and unmet MW costs could be argued for being raised but these values have been used in SAPP and WAPP and were therefore employed in the preliminary CAPP model.

While the CAPP modeling report [8] is still in draft form and cannot yet be released, it should come as no surprise that the model predicts the need for major transmission construction projects to serve the need for power flows within CAPP, and even larger investments in HV lines to allow power flows from the Inga sites to the five export markets shown in Figure 4. As the demand from Egypt, SAPP, WAPP, and EAPP increase, as well as demand within CAPP, then a portion of the larger expansion capacity envisioned at Grand Inga appears to be justified. However, the CAPP data still needs careful compilation and validation, a task planned for the next phase of the project.

4. Investment and Electricity Pricing Issues

The determination of the electricity demand growth rates, demand forecast figures, and electricity prices are critically important in the planning process for new capacity. Improved forecast training in many countries of Africa, with more detailed data collection, will improve the determination of such critical numbers. The less industrialized nations frequently have problems with inadequate power supplies. These are reflected in the growth rates data as “hoped for rates” and do not provide satisfactory input data for planners.

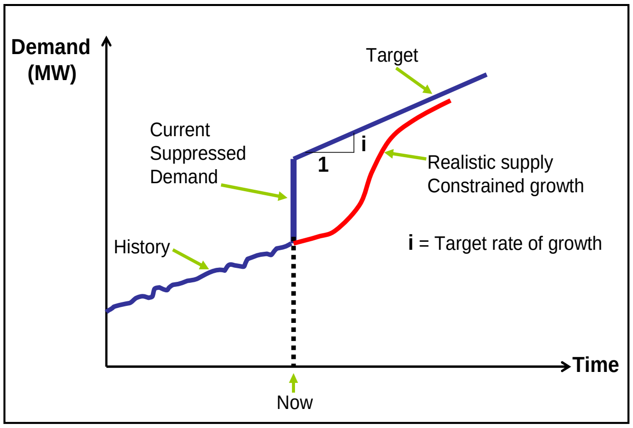


Figure 5. Electricity Growth Rate and Suppressed Demand

The problem with all the plans to utilize the enormous hydro power potential of the Conga lies in the fact that, unlike distributed generation projects having short construction times and small construction costs, centralized hydro projects require very large initial investments in dams and the transmission lines long before any project revenues are generated. The demand growth numbers for projects like Inga have significant affects.

A realistic model of constrained growth will improve the forecasting technique (Figure 5). The demand numbers significantly affect the attraction of suitable investments for the two Inga projects (Inga 3 and Grand Inga Stage 1) being modeled. The growth rates of 5% and more are often considered as reasonable but looking at the historic numbers for the instances of Egypt, Nigeria and South Africa this is higher than what has been happening.

Billion kWh	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**
Egypt	40.45	44.41	46.56	48.44	48.13	51.65	55.6
Nigeria	13.15	12.84	13.74	12.92	13.36	13.67	13.5
S.Africa	144.6	149.37	156.2	160.89	168.3	175.5	175

Growth Rates		**1993**	**1994**	**1995**	**1996**	**1997**	**1998**
Egypt		9.8%	4.8%	4.0%	-0.6%	7.3%	7.7%
Nigeria		-2.4%	7.0%	-6.0%	3.4%	2.3%	-1.1%
S.Africa		3.3%	4.6%	3.0%	4.6%	4.3%	0.1%

Billion kWh	**1999**	**2000**	**2001**	**2002**
Egypt	60.59	66.86	72.93	75.58
Nigeria	13.83	13.11	16.13	18.43
S.Africa	178.14	183.76	185.90	189.36

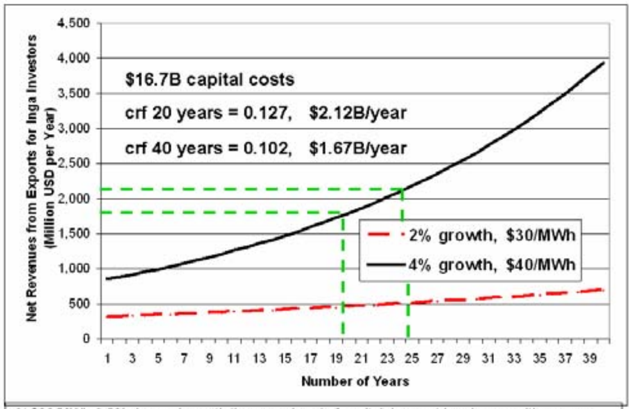
Growth Rates	**1999**	**2000**	**2001**	**2002**	Total	**Average**
Egypt	8.9%	10.3%	9.1%	3.6%	25.9%	**2.6**
Nigeria	2.4%	-5.2%	23.0%	14.3%	18.4%	**1.8**
S.Africa	1.3%	3.2%	1.2%	1.9%	14.4%	**1.4**

Table 8. World Total Net Electricity Consumption and Demand Growth Rates for 1993-2002

Reference: [13]

The average historic electricity demand growth rates for the largest national utilities in Africa over the past 10 years or more has been in the order of about 2%. This rate has been considered as a “low case” expansion scenario in the SAPP and WAPP. The numbers in Table 8 show the historic and average growth rates for these three countries.

Consider an illustration of the magnitude of the problem with having low demand growths. The two Inga hydro projects; the 3500MW Inga 3, and the 4000MW Grand Inga Phase 1 project – which are the driving forces behind much of the power pool activity in Africa - have estimated capital costs of roughly $4 Billion each. To this must be added the estimated transmission costs of $8.7 Billion to hook up the Inga sites to the export markets within SAPP ($1 Billion estimation at $1M/MW), WAPP ($1 Billion estimation), EAPP ($1 billion), and Egypt ($5.7 Billion). Thus the total upfront investment costs of the two Inga projects are in excess of $16.7 Billion.



At $30/MWh & 2% demand growth the annual cost of capital does not break even with revenue from exports within a 20 year or 40 year planning horizon. At $40/MWh and 4% demand growth the annual cost of capital breaks even at 19 years (20 year horizon) and 25years (40 year horizon)

Figure 6. Net Revenues from Exports for Inga Investors With 2% and 4% Demand Growth (USD)

Assuming a capital cost 10% and a project life time of 40 years, a range of $2.12 to $1.67 Billion dollars a year in returns to the investors must be assured for the projects to be financially viable. Further, all these export markets, each a functioning or planned power pool in itself, have local base load combined cycle generation construction options whose capital and operating costs are in the range of $30 to $40 per MWh (gas price range of $2.00 to $3.00 per MBtu), depending on the price of natural gas in these regions. These gas prices are reasonable estimates of current gas prices in Africa. If opportunities for LNG exports develop then these prices could increase. These domestic regional options will determine the maximum price these markets would be willing to pay for hydro electricity imported from the Inga projects. A further complication is that many of these regions already have capacity expansion projects on-going to satisfy near term needs for new capacity.

If we make the optimistic (for Inga) assumption that all projected growth in demand beyond 2005 in the four regions would be met by Inga power, as long as the price does not exceed the $/MWh range indicated above, we have the basic structure of a procedure to determine if the Inga projects make economic sense.

Figure 6 shows the yearly net revenue stream available to the investors in the Inga projects assuming a range of demand growth rates from 2% to 4% in the four markets, using the base electricity consumption in 2005. The revenue stream, obtained by extrapolating the kWh figures in Table 8, is what remains as a return for investors, after having subtracted from the revenue estimates hydro operating costs of $2/MWh, and assuming no line loss. Also shown in Figure 6 are the annual required returns to the investors, assuming two alternative lifetimes for the Inga projects of 20 years, and 40 years, and capital cost of 10%.

Figure 6 also shows the most optimistic assumption with a 4% growth rate in demand being well in excess of historical rates as shown in Table 8. This results in the project yearly cash flows not covering the yearly required returns until year 19, while the pessimistic assumption with a 4% growth rate results in the annual revenue stream equaling the required annual return only after 25 years have passed. Note that if the growth rate is 2%, the revenue stream never generates the required annual revenue stream during the lifetime of the Inga projects. Does this mean that the Inga projects should be abandoned? Not at all but it simply means that much more analysis must be done before any investor group will look seriously at Inga as a viable investment option with these export assumptions.

Comparative assessment to similar sized projects can always help if it were possible to obtain the growth and cost data involved. Certainly Mozambique’s exports to South Africa are more appropriate for the Inga project than say Canadian hydropower to the U.S. The level of risk in North America is less and the cost of borrowing capital therefore reduced. High electricity growth rates elsewhere in the world make a major difference and China comes to mind. The huge Three Gorges project can be justified with the 8% to 10% historic growth rate but can the much smaller African growth rates justify the construction of such large projects?

Perhaps it is Egypt and the Mediterranean region with its large and growing demand for electricity that is the only obvious additional market for an enlarged Inga. If this is the case then the expansion costs of the DRC to Egypt line together with Inga, and the electricity export prices appear to be the first two most important issues for consideration. Secondly firm power contracts as well as wheeling rates will need to be agreed upon among all the players and stakeholders to secure adequate investments.

Without the Egyptian export gateway it is hard to justify the capacity expansions as growth rates as high as 4% or higher for many African countries are not taking place. The suppressed demand has to be remembered but still massive rural and urban electrification programs are required to take place to see the needed growth levels. These are some of the opportunities and challenges facing those energy planners promoting the substantial expansions for Inga and the inter-regional power grid of Africa.

One very important last point: Over 40 years ago, Alan Manne, pointed out [14] that with economies of scale in construction and a given growth rate in demand, the higher the cost of capital, then "the smaller will become the optimal size of each installation" (p.637). Given the high cost of capital, due to the inherent risk of the hydro projects being considered because of their location, Manne's advice should be taken to heart by Inga promoters – they should look to smaller size projects.

5. Conclusions

The vision of a continent wide HV power grid across Africa with Inga at the heart of the network has inspired African electricity planners for many years. The concepts and documented benefits of integrated African power pools, as demonstrated by the studies done by Purdue's PPDG for the SAPP and WAPP, support the impetus towards implementing the Pan-African HV network plan. Central to a strong future continental network is the creation of an efficient CAPP because of its location and the potential of Inga.

While the results of current work by PPDG support the general economic feasibility of the vision, this paper questions the approach taken by some supporters in their promotion of several very large projects, rather than a series of smaller ones. Both economic theory and industrial practice tell electricity planners that in situations, as in Africa, where capital costs are high and demand growth rates are low, it is best to forgo the scale economies present in constructing a few large projects, and choose instead to expand capacity slowly to allow the expansion in capacity to better match demand growth.

There might be enormous revenues and benefits from building Grand Inga and major new HV lines across Africa but it is believed, by the authors, that the time has arrived for a combined in-depth analysis of the three broad development scenarios referred to, (a) building Grand Inga for power exports to the Mediterranean, (b) building Grand Inga as a power source for all Africa, and (c) planning for massive urban and rural electrification. Each scenario holds great potential but each one needs to be considered within the complementary inclusiveness of all three scenarios combined, if sustainable development is Africa's goal.

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