Project proposal for funding under the
USAID co-operative agreement on Equity And
Growth through Economic Research/Trade
Regimes and Growth (EAGER/TRADE)

MODELING ELECTRICITY TRADE

IN SOUTHERN AFRICA

Purdue University
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SUMMARY

Electricity trade is leading the process of regional integration in Southern Africa, driven by the Southern African Power Pool (SAPP) agreement signed in December 1995. This agreement aims to foster greater co-operation and trust amongst the 12 national utilities, and so promote increased trade and a mutually beneficial inter-dependence, in contrast with the national self-sufficiency goals which have dominated electricity policy in most countries since independence.

Since signing the SAPP agreement, representatives of each national utility have been meeting frequently to resolve technical issues and consider possible new trading arrangements and transmission infrastructure. Current trading arrangements involve bilateral contracts, but a variety of exchange or auction systems could be introduced to increase the flexibility with which trading occurs. The effects of any such new trading arrangement would be closely related to the quality and capacity of the region's transmission infrastructure. Several new interconnectors are already being built, and additional investments are being considered. There are enormous potential benefits from the combination of new trading arrangements and new transmission infrastructure, but obtaining these benefits would require substantial adjustments in both importing and exporting countries.

To help SAPP members predict the effects of new trade agreements and new transmission infrastructure, it is necessary to construct an engineering model of the region's electricity grid, linked to an economic model of costs and benefits. Such a model can then be used to simulate the effects of any change in the SAPP's trading or transmission systems, and evaluate its impact on each SAPP member. The model could be used simultaneously by engineers in each national utility, helping them negotiate with one another to reach agreement on the most mutually-beneficial combination and sequencing of changes.

The SAPP agreement and its implementation is among Africa's most significant recent initiatives in regional integration. Increased electricity trade can yield dramatic benefits, but involves very complex interactions between national systems. SAPP members are aware that Purdue University's State Utility Forecasting Group (SUFG) is a global leader in building engineering/economic models to inform inter-utility negotiations and electricity-trade regulations, and they have responded positively to the SUFG proposal to work with them in constructing an appropriate model for the SADC region. To initiate the project, a working group of SADC engineers would be convened in January 1997, as part of a regular SAPP meeting. Purdue staff would then collaborate with the group to develop the model. In mid-year, three members of the SAPP group would come to Purdue to evaluate its progress, and at the end of the year two Purdue staff members would travel to a SAPP meeting to present their work, disseminating both some initial simulations and a running model with which other options could be simulated. The result will be a much better-informed set of trade negotiations, and ultimately a more successful integration process.

1. Objective of the project

Newspapers across Southern Africa have paid close attention to the potential gains from more efficient electricity market in the region (references 1, 2, 3, 4, and 5). The August 1995 Inter-Governmental agreement (IGMOU) creating a Southern African Power Pool (SAPP) confirmed the region's commitment to expanding electricity trade, in pursuit of lower costs and greater supply stability for all of the region's 12 national utilities (Appendix I).

The proposed research involves collaboration between Purdue University and SAPP members on the development and use of electricity-trade models, to simulate possible new trading arrangements and infrastructural investments in the SAPP region. The model would build on the previous experience of Purdue University's State Utility Forecasting Group (SUFG) in assisting U.S. utilities and government regulators, using quantitative models to anticipate the direction and magnitude of changes associated with various policy options and economic conditions.

Further consultation with African collaborators will identify and set priorities among the various possible modeling options and policy scenarios to be considered. Then, through a process of collaborative model development, engineers within the national utilities will be able to use the model to simulate the implications of specific scenarios, permitting the national utilities and their governments to negotiate amongst themselves for the most appropriate combinations of new infrastructure and trade agreements.

The SAPP has already been a successful pioneer in Southern African economic integration. Even greater changes could soon occur, with the creation of a SADC Energy Commission to replace the Energy Technical and Administrative Unit (TAU), the development of a more fully interlinked regional grid, and the negotiation of new trading arrangements among SAPP members. Negotiators have repeatedly expressed the need for quantitative assessments of these changes, and for SAPP members to develop modeling tools that are comparable to those used by other utilities around the world. Such a model would permit new trading arrangements and infrastructure investments to be specified, and their effects simulated.

The proposed project offers an opportunity to contribute significantly to regional economic integration in a key area. The SAPP agreement, and electricity trading more generally, receives a high level of public attention. It has enormous symbolic value, and has wide-ranging effects on the costs and location of industry, as well as on residential consumers. By providing timely and accurate information to SAPP members, electricity-trade negotiations can be made more realistic and more successful, ultimately leading to more effective electricity service for each country in the region.

2. The significance of trading for Southern Africa

A recent study at Purdue (6) has shown that more efficient trading between utilities in Indiana could save 6% of total annual generation costs. Savings in Southern Africa are likely to be far greater, because there is greater variation in electricity prices across the national utilities. In 1995, these ranged from 0.5 to 10.3 U.S. cents per kWh (Table 1).

Table 1. Southern Africa - Average electricity prices

Country	1995 US cents/kWh	Country	1995 US cents/kWh
Angola	0.5	South Africa	3.0
Botswana	10.3	Swaziland	4.3
Lesotho	4.5	Tanzania	9.0
Malawi	3.0	Zambia	1.0
Mozambique	4.5	Zimbabwe	3.0
Namibia	3.7		

Source: Reference (12)

Whenever utilities produce at different costs, it may be economical for utilities to agree to trade. The types of models used to estimate the magnitude of gains, and the adjustments required to obtain them, are detailed in section 6.1 of this proposal. The potential benefits of trade are widely appreciated in Southern Africa: SADC's 1996 energy strategy document (7) sees the increase in electricity trade as:

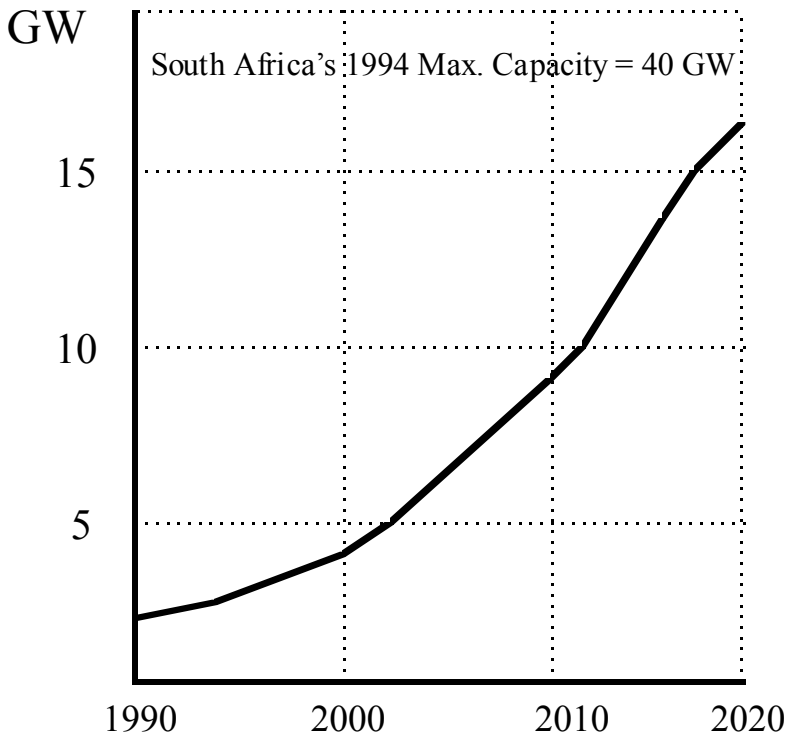
(a) providing optimization of energy use and least cost options;
(b) allowing postponed investments in generation plant; and
(c) providing exchange of technical information and know-how.

To move this agenda forward, there is now a great need to develop models which can be used directly by SAPP members. The experience of SUFG in assisting with the deregulation and restructuring of U.S. utilities suggests that such models can be of decisive importance in advancing inter-utility negotiations, as each analyst can perform their own simulations to assess their various options.

The magnitude of potential gains from increased trade is very large. A 1993 study by SADC and the World Bank (8) estimated that optimal use of regional resources and installations could provide savings of US$1.6 billion over 10 years, in comparison with a scenario under which each country pursues its individual power development plans. South Africa was not included in this study, and the potential benefits now available through its collaboration are much greater. In particular, South Africa offers vast potential demand for hydro power from the northern utilities.

This will provide large income for the exporting utilities as well as savings for Eskom not requiring capacity expansion investments. Dutkiewicz (9) predicts an Eskom import potential of nearly 20 GW by the end of the first quarter of the next century (see Figure 1 below).

Figure 1. Electricity import potential into the South Africa system



Source: Reference (9)

Current South African policy is considering 15% of its future maximum demand being from external sources. With present South African rates this would amount to imports of US$ 600 million each year from other SADC utilities (9).

An important attribute of trade is the improved reliability of supply, particularly when relying on hydro power that is vulnerable to drought. In the case of Zimbabwe, the 1992 drought caused electricity shortages in 1993 that cost the country US$ 435 million in lost export earnings (10), nearly 10% of its GDP.

Regional cooperation will be increasingly important over time, as demand grows. SAD-ELEC, an independent consultancy firm created by South Africa's Eskom (12a), estimates that with 4 to 4.5% annual growth in demand, peak levels of electricity use are expected to almost double by 2010. SAD-ELEC maintains that with power sharing there would be a need for nearly 11,000

MW in new generation capacity. With the establishment new trading arrangements and transmission infrastructure this capacity could be met from hydro sources rather than coal, and significant environmental benefits can be expected in terms of reduced generation emissions (13a).

The value of trade creates a demand for more interconnectors, whose construction costs are now about US$ 0.25 million per kilometer (5). Several interconnectors are now under construction and others are planned (Table 2), and these are discussed later in the proposal. They are essential prerequisites for improved trade and have been discussed extensively in the publications from Southern Africa and the World Bank (8,15,16,17). Present connections can overcome some energy shortages in the region. Lewis (14) presents the case for more appropriate connections if a viable power pool is to have sufficient capability for reliable long term volume exchange.

Table 2. Regional HV interconnectors (110kV and above) existing and planned

	In-service date (kV)	Voltage level	Length (km)	Transfer capacity (MW)	Comment
Existing					
Zaire-Zambia	1955	One 220	435	250	Unfirm
Moz-Zimbabwe	1955/1992	One 132	85	40	Standby
Zambia-Zimbabwe	1961	Two 330	3	1,200	Firm import
S.Africa-Swaziland	1970	Three 132	75	150	Firm import
S.Africa-Mozambique	1975	One 275	100	150	Unfirm
		One 110	120	50	Standby
S.Africa-Namibia	1975	Two 220	860	215	Firm import & export
S.Africa-Botswana	1980/1994	Three 132	145	200	Firm import
Zimbabwe-Botswana	1991	One 220	185	120	Export
S.Africa-Lesotho	1992	Two 132	n/a	60	Firm import
S.Africa-Zimbabwe	1994	One 132	22	40	Unfirm
	1995	One 400	420	500	Unfirm
Approved/under construction					
Moz.-S.Africa	1975/1997	533 DC	1,420	2000	Firm import
Moz.-Zimbabwe	1997	One 330	310	500	Firm import
S.Africa-Swaziland	1997	One 275 (eng 132)	155	220	Firm import
Proposed/under investigation					
Malawi-Mozambique	1998/1999	One 220	175	100	Under negotiation
Moz.-Swaziland		One 275	150	100	Under discussion
S.Africa-Namibia		One 400	890	600	Under negotiation
Zambia-Malawi		One 220	430	170	Under negotiation
Zambia-Tanzania		One 330	650	200	Under negotiation

Power is imported by the second country named from the first country named. Moz. = Mozambique

Source: Reference (12) & Eskom fax Nov.5,1996

3. Electricity trade and economic growth in Southern Africa

Economic growth throughout the world is strongly linked with increased use of electricity (18). As the level and location of electricity use changes, there is a need for continuous adjustment in electricity generation and transmission. Expanding trade through new interconnectors and inter-utility trade almost always helps to lower total costs, and the possibility of trade has major implications for the location and scale of new generating capacity (21-24).

As electricity use and exchange grows, an increasingly important question is what sort of trading arrangements should govern electricity trade. Unlike ordinary commodities, electricity cannot be "shipped"--it must be inserted into a grid, which may have multiple sources of generation and multiple locations of demand. As a result, the tools needed to determine the appropriate price of electricity and the value of transmission are different from those used with ordinary commodities. A wide variety of contracting mechanisms have been developed over time, involving both government-owned and private utilities, in a wide variety of regulatory environments. Quantitative models can simulate the effects of each alternative, but only with a substantial investment in collaborative research to capture the specific issues associated with a particular electricity supply and demand system.

The Southern African region is characterized by enormous hydro power potential in the north, and enormous electricity demand in the south. Trade between the two could grow very rapidly, supporting rapid economic growth throughout the region. Potential and actual hydro capacities are listed in Table 3. The vast potential of Zaire together with that of Mozambique, Angola, and Tanzania could provide low-cost power for decades, fueling economic growth within those countries and keeping power prices low in importing countries as well.

Table 3. Southern Africa's potential and actual hydro-power

	Hydro-potential capacity (MW)	*1995 actual hydro-power capacity (MW)*	*1995 Total gen. capacity (MW)*
Angola	16,000	301	567
Botswana	0	0	261
Lesotho *	350	2	5
Malawi	515	219	244
Mozambique	9,250	2,181	2,387
Namibia	900	240	429
S.Africa	3,500	1,940	39,000
Swaziland *	75	41	50
Tanzania	5,040	326	580
Zambia	3,970	1,753	1,800
Zaire +	100,000	1,775 y	2,551
Zimbabwe	2,515	666	1,961
TOTAL	142,115	9444	49835

Key: * imports nearly all from RSA
+ not SADC member
y 30% utilized

Source: References (7),(12) & (16)

Table 4. Access to domestic electricity in southern Africa

Country	Percentage of population with access to electricity	Population (millions)
Botswana	3.0	1.0
Lesotho	2.0	1.0
Malawi	2.5	8.0
Mozambique	2.7	14.0
South Africa	45.0	38.0
Swaziland	8.5	0.7
Tanzania	13.0	22.0
Zaire	2.0	28.0
Zambia	7.5	6.0
Zimbabwe	16.0	9.0

Source: Reference (13)

The annual growth in electricity use varies widely throughout the region (Table 5). A 4 to 4.5% growth rate is an average value for the region. This is considerably higher than the rate for the industrialized OECD countries over the same period (Tables 5 & 6).

Table 5. Electricity growth in annual sales in SADC utilities

	1990	1991	1992	1993	1994
BOTSWANA	6.5%	9.9%	10.8%	5.4%	2.7%
SOUTH AFRICA	1.4	1.8	-0.4	4.1	3.9
ZAMBIA	-5.7	6.9	1.8		
ZIMBABWE	1.7	4.3	2 .1	18.3	7.6

Source: Reference(31)

Table 6. OECD electricity average annual growth rates

	1960-1973	1974-1993
TOTAL	7.81%	3.01%
Industry	6.67	2.08
Residential	9.81	3.38

Source: Reference (32)

4. Electricity and development in regional co-operation

In August 1995, SADC governments signed the SAPP Memorandum of Understanding (MOU), committing themselves to greater regional integration among national utilities. Electricity trade in Southern Africa has been growing at an annual rate of around 15%, and is now estimated to be worth US $125 million a year (12a). Agreements to be negotiated through the SAPP could dramatically increase the level of trade, making electricity the leader in regional economic integration.

In its meetings to date, the SAPP has focused entirely on technical issues associated with current (bilateral) trading arrangements. Potential new contracting mechanisms or trading arrangements have not yet come under discussion, but are on the agenda for the future along with the infrastructure investments needed to support them. Because of the complexity of the system, it will be very difficult for SAPP negotiators to agree on appropriate changes without a common model of their current operations and principal options for new contracts and new infrastructure. For example, some SAPP participants have discussed the possibility of implementing centralized dispatch for the entire SAPP area, but are unsure of the nature and location of the controls that would be required, as well as the economic effects it would bring.

There is a growing consensus among both utility and government leaders on the need for greater regional cooperation (13b), but there remain differing perceptions of the effects of specific integration options such as broker matching rules (11a). To assess the effects of changing from current bilateral agreements to any kind of electricity-exchange "market", substantial research will be needed using quantitative models of the system under alternative trading rules. There has been simulation of load flows under current arrangements, and numerous feasibility studies on specific investments, but no modeling of possible changes in trading arrangements. Such models are analytically complex, and have high development costs. But Purdue University's SUFG has been constructing models of changes in inter-utility trading arrangements for the United States, under conditions which are quite similar to those of the SAPP. SUFG's analytical approach (although not the specific models) is therefore highly applicable to the SAPP, and a cooperative effort can be extremely cost-effective.

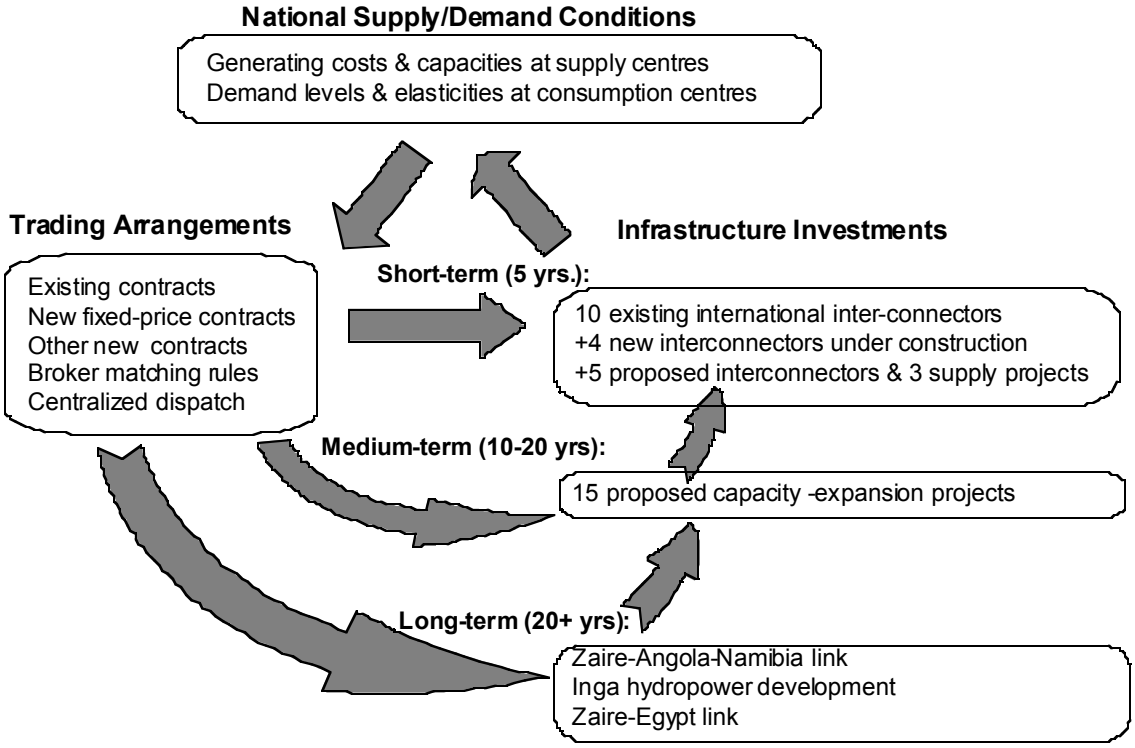
5. SAPP's electricity supply scenarios

A pre-proposal trip to Southern Africa found great interest in modeling three kinds of scenarios, addressing short-term, medium-term and long-term issues. Each kind of scenario would require substantially different model structures, and only the short-term choices can be addressed in a one-year project at relatively low cost. The medium- and long-term models would be substantially more complex, due to uncertainty over future drought conditions (especially for more hydro power on the Zambezi) and electricity demand for residential and industrial use. To put the proposed one-year research project in context, and to show how it can provide a basis for continued research in the future, proposed short-, medium- and long-term scenarios are sketched below and summarized in Figure 2.

5.1 Short-term scenarios

The purpose of the short-term modeling effort is to consider the effects of moving from current intra-SADC trading arrangements to alternative contracting methods, using only the existing infrastructure (which includes ten international inter-connectors) and a limited amount of new investment in control capacity. The key alternative trading arrangements include fixed-price and other types of contracts, brokerage systems, and centralized dispatch.

Figure 2. Short-, Medium- and Long-Term Scenarios



5.1.1 The four new regional interconnectors

Current infrastructure is limited to ten international interconnectors, but four new links will soon be in service and should be included in the model. These are:

Location and Completion Date	Capacity/Voltage & Estimated costs	Length
(a) Mozambique to South Africa Cahora Bassa to Appolo/Pretoria (1997)	1400MW-500DC	1480km
(b) Mozambique to Zimbabwe Songo to Bindura (1996)	500MW-420/330kV US$ 45 m.	310km
(c) South Africa to Swaziland (1997)	220MW-275kV US$ 22 m.	155km
(d) Mozambique to Zimbabwe Chibatu to Orange Grove	220kV US$ 15 m.	

5.1.2 The five proposed interconnectors and three capacity-expansion options

To capture electricity-trade options through the year 2000, it is essential to simulate the impact of new trading arrangements both with and without the five new links whose construction is currently under consideration:

Proposed interconnector	Capacity/Voltage	Length	Estimated cost (1996)
(a) Malawi to Mozambique (Blantyre to Matambo)	100MW-220kV	175km	US$ 25 m.
(b) Mozambique to Swaziland (Matola to Zombobze)	50/100MW-275kV	150km	US$ 22 m.
(c) South Africa to Namibia	600MW-400kV	890km	
(d) Zambia to Malawi	One 190MW-220kV	430km	US$ 53 m
(e) Zambia to Tanzania (ZESCO to TANESCO/Mbeya)	200MW-330kV	650km	US$ 130-150 m.

In addition to the five interconnectors listed above, three capacity-expansion projects are also being considered in the short term:

(a) Malawi - Kapichira hydropower project
4 x 32MW - in two phases.
Estimated Cost of phase 1 US$ 158 m. (1999)

(b) Botswana - Phokoje substation
400/220kV substation near Selebi-Phikwe, to tap into the 400 kV Matimba-Insukameni line.
Estimated Cost US$ 18M (1998)

(c) Lesotho - Muela hydro-power plant
72MW

Statistics in section 5.1 are obtained from reference (12) and a fax from Eskom; Nov.5,1996.

5.2 Medium-term scenario

There are fifteen major possible projects that could develop within the region in the medium term of 10 to 20 years. These are mainly capacity expansion projects. They are listed and briefly described below with increased uncertainty for longer term scenarios. Some probability weighting will be applied to the supply and demand equations. Upper and lower limits would be predicted. These decisions will have enormous importance for the development of the region, but since they are not as urgent as the choices to be simulated in the short-term scenarios, and construction of a model to simulate these changes can be postponed to 1998.

PROJECTS	ESTIMATED COST
(a) Botswana - Moropule power	
two new units each 120MW starting possibly in 2007	US$ 333 m. (1994)
(b) Botswana -	
Construction of 1 large coal fired power station	US$2.2 b. (1995)
2400MW for export power - possibly starting in 2010	
(c) Mozambique -	
Mepanda Uncua hydro-power project - 1700MW	
(d) Mozambique -	
Cahora Bassa II (North Bank) -1240MW	
and Alto Malema - 60 to 80MW hydro-power station	
(e) Namibia -	
Epupa hydroelectric power scheme - 415 MW	US$408 m. (1996)
Starting possibly in 2005	
An alternative scheme to this might be the Kudu gas field,	
with potential to sustain 4000MW for more than 50 years.	
(f) Tanzania -	
Power VI Project - including the Lower Kihansi	US$440 m. (1993)
hydroelectric scheme & improvement in distribution	
First stage = 180MW - Possibly starting in 2000	
(g) Zaire - General rehabilitation to the year 2000	US$200 m. (1996)
(h) Zaire - Transmission & distribution to the year 2000	US$700 m. (1996)
(i) Zambia - Kafue Gorge Lower	
Adding 600MW to Kafue Gorge Upper Hydro station	US$430 m. (1995)
(j) Zambia - Itezhi-Tezhi hydro-power station - 80MW	US$74 m. (1995)
(k) Zambia - Kariba North Bank Extension	
(l) Zambia - Batoka Gorge hydro-power Station - 1600MW	
to share with Zimbabwe	
(m) Zimbabwe - Kariba South Extension, Hwange (coal)	
Extension & Batoka & Sengwe projects	
Total investment	US$ 2.63 b. (1995)
(n) Zimbabwe - Generation refurbishment, distribution expansion,	
transmission developments, new main substations	
For the period 1997-2013	US$ 1.41b. (1995)

Several of these medium-term projects are dependent on flow rates from the River Zambezi. Over recent years, the drought has curtailed generation at Kariba. Average inflows to Kariba from 1961 to 1991 were 41.2 km^3 compared to 43.9 for 1961 to 1984 (8). The uncertainty of flow over the next several years can be a crucial factor in policy formulation. Modeling alternative flow rates can be considered.

5.3 Long-term scenario

Although long-term projections have a wide range of uncertainty, the large magnitude and long gestation period of major hydropower projects call for studies over a time horizon of twenty years or more. In the Southern Africa case, such a long-term study would consider at least three key projects currently being discussed in the region, each of which would have major effects on electricity trade across much of the continent. The long-term study could be conducted in 1998 or 1999, building on the short-term study proposed for 1997, and the medium-term model which

could be undertaken in 1998. The three major long-term projects to be considered in this analysis are listed in the order of probability::

(a) Interconnectors from Zaire to Angola and from Angola to Namibia
(b) Zaire - Inga III hydro-power project (3,500MW)
& Grand Inga (39,000MW)-- having 13 generating units each of 3000MW.
Each unit would consist of 4 machine of 750MW US$ 13b. (1994)
(c) Zaire power line to North Africa US$ 15b. (1994)

The modeling priorities for the medium and long-term scenarios will be finalized at the first working group meeting in early 1997. The transmission lines and regional interconnectors for the short-term model are already in place or to be most likely put in place in the next couple of years.

The short-term scenario will mainly analyze the regional value of trade with nearly all of the interconnectors in place. The medium and long term scenarios will be mostly concerned with new hydro-power capacity.

6. Proposed research themes

For each of the scenarios described in the previous section, the modeling will capture the economic costs and benefits of alternative new SAPP trading arrangements and new infrastructure. The model will consist of supply from a number of locations being transmitted to a number of demand centers. The transmission over the specified interconnectors will be an aspect of the modeling which will require considerable attention.

Time periods of one month will be used for the short-term scenario. Yearly periods will be employed for the medium and long term scenarios. Multilateral trade and centralized dispatch will be modeled and compared to bilateral agreements. The approach to electricity forecasting models at the SUFG of Purdue University (sample publications in Refs. 24 to 29) is described below. The approach to transmission modeling is also outlined. First of all, let us consider trade models in general for electricity.

6.1 Electricity trade models

A simple three panel trade diagram will illustrate how trade between low cost and high cost SAPP regions can be modeled. The three panel trade diagram, illustrated below in Figure 3, shows supply and demand schedules for a low-cost utility on the left-hand panel, and shows supply and demand schedules for a higher-cost utility on the right-hand panel. Note supply and demand schedules are shown as straight lines on the diagrams, but would be nonlinear in the empirical model. The third panel, in the middle, shows the schedules of excess demand of the importer and excess supply for the exporter which can be derived from the other two panels.

Each panel reveals the prices and quantities which would arise under alternative trading arrangements. P_x would be the price in the exporting region without trade: at that price, the supply and demand schedules meet and demanders want to purchase exactly the amount producers want to sell (Q_x). If higher prices were to prevail, then suppliers would offer additional production, demanders would offer to purchase less, and there would be excess supply, in the amount of the horizontal difference between the demand curve and the supply curve at that price. In the importing region, there would be excess demand if prices were lower than P_m .

The curves in the middle panel are constructed by tracing out the excess supply schedule from the exporter and excess demand schedule from the importer.. With no transaction costs (losses or other costs of transmission), the equilibrium price with trade would be equal to P_t, and quantity Q_t would be traded (ie., produced by the exporter and sold to consumers in the importing region).

The model can take account of transmission costs as a wedge between the price received by the importer and the price paid by the importer. Thus, in Figure 4, if the transmission charge/kWh were C, importers would pay $P_t^{im} = P_t^{ex} + C$, and trade would be reduced to Q_t* rather than Q_t.

Fig. 3 The three panel trade diagram

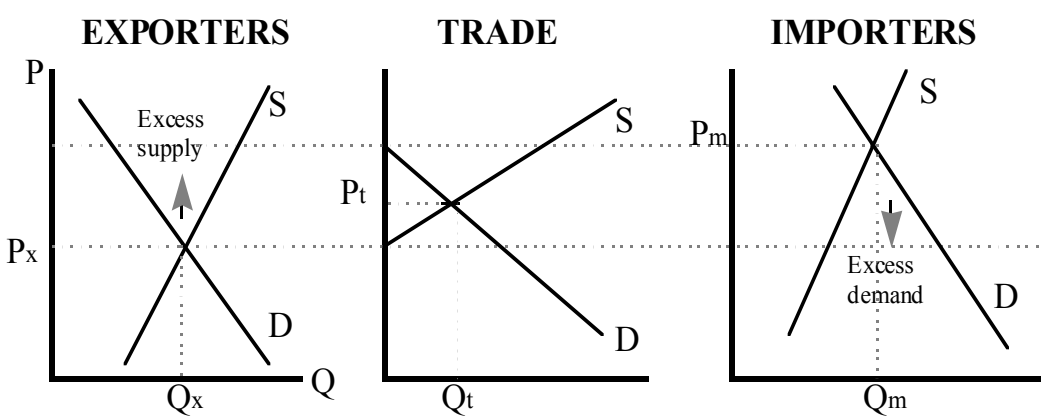
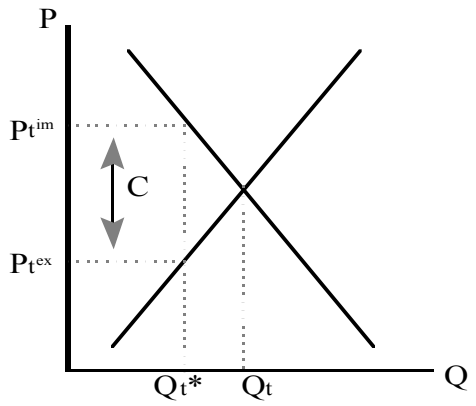


Figure 4. The effect of transmission cost on trade



6.2 SUFG's approach to electricity modeling

SUFG's integrated electricity modeling system projects electricity demand, supply, and price for each electric utility in the state of Indiana, USA. The modeling system captures the dynamic interactions between customer demand, the utility's operating and investment decisions, and customer rates by cycling through the various bus-models until an equilibrium is attained. The SUFG modeling system is unique among utility forecasting and planning models because of its comprehensive and integrated characteristics.

Publications and information from SUFG can be obtained from sandersp@ecn.purdue.edu (Email) or 317- 494 - 2351 (Fax). Some titles are listed in the bibliography (24-29).

6.2.1 Energy submodel

SUFG has developed and acquired both econometric and end-use models to project energy use for each major customer group. These models use fuel prices and economic drivers to simulate growth in energy use. The end-use models provide detailed projections of end-use saturations, building shell choices, and equipment choices (fuel type, efficiency, and rate of utilization). The econometric models capture the same effects but in a more aggregate way. These models use statistical relationships estimated from historical data on fuel prices and economic activity variables. The energy impacts and hourly load profiles of existing and planned DSM programs are estimated from information provided by Indiana's electric utilities.

6.2.2 System overview

Developed by Electric Power Software, the Load Management Strategy Testing Model (LMSTM) is an electric utility system simulation model that integrates four submodels: demand, supply, finance, and rates. Combined in this way, LMSTM simulates the interaction of customer demand, system generation, total revenue requirements, and customer rates. LMSTM also preserves chronological load shape information throughout the simulation to capture time dependencies between customer demand (including DSM), system operations, and customer rates.

LMSTM is used to model the five investor-owned utilities (IOUs), which include: Indiana Michigan Power Company (I & M), a subsidiary of American Electric Power (AEP); Indianapolis Power & Light Company (IPL); Northern Indiana Public Service Company (NIPSCO); PSI Energy, Inc. (PSI Energy), a subsidiary of CINergy; and Southern Indiana Gas & Electric Company (SIGECO). In addition, LMSTM is used for the three not-for-profit (NFP) utilities: Hoosier Energy Rural Electric Cooperative, Inc. (HEREC); Indiana Municipal Power Agency (IMPA) and Wabash Valley Power Association (WVPA). Forecasts for unaffiliated rural electric membership cooperatives (UREMCs) and unaffiliated municipalities (UMUNYs) are derived from the forecasts for the five IOUs. The techniques employed with these utilities can be applied to the 12 SAPP utilities.

6.2.3. Demand submodel

The demand submodel projects the hourly demand for each customer class for each year of the forecast period. The system demand, including peak load, is obtained by simply aggregating hourly demands across all customer sectors. The hourly load impacts of individual DSM programs are aggregated with the corresponding sector's hourly demand profile. System load impacts of DSM programs are obtained by aggregating the "adjusted" hourly demand profiles of each customer class.

Major inputs to the demand submodel include annual energy projections by customer class (developed by the energy submodel), load profiles for each customer class, and hourly DSM program impacts.

6.2.4. Supply submodel

The supply submodel simulates the operation of the generation system: it commits and dispatches existing generating resources hour-by-hour in a way that minimizes the daily operating costs of meeting the projected system demand. By preserving the chronological order of system demand throughout the simulation, this submodel captures the time dependencies between customer demand, system operations, and customer rates, i.e., hourly marginal cost detail.

Major inputs to the supply submodel include the system demand profile (developed by the demand submodel), generating unit characteristics, investment in new plants, and operation and maintenance (O & M) costs.

Generating additions are determined from a statewide as well as individual utility perspective. The modeling system matches supply to demand (peak load plus reserves) on a statewide level by adding capacity whenever demand exceeds supply. These capacity additions are then allocated to individual utilities based on their individual need for generating capacity. Although this approach provides a reasonable basis for estimating future electricity prices for planning purposes, it does not ensure that the resource plans are least cost.

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6.2.5. Finance Submodel

The finance submodel simulates a utility's annual revenue requirements and assigns all costs and revenues to functional categories. DSM program costs are input to the financial submodel as a separate functional category and can be either capitalized in rate base or treated as an operating expense. Major inputs to the financial submodel include the existing asset base, annual projections of utility investments in new generation, transmission and distribution plants as well as annual O & M expenses. The financial submodel calculates the rate base, the return on rate base, and the recovery of capital investment and taxes.

6.2.6 Rates submodel and price iteration

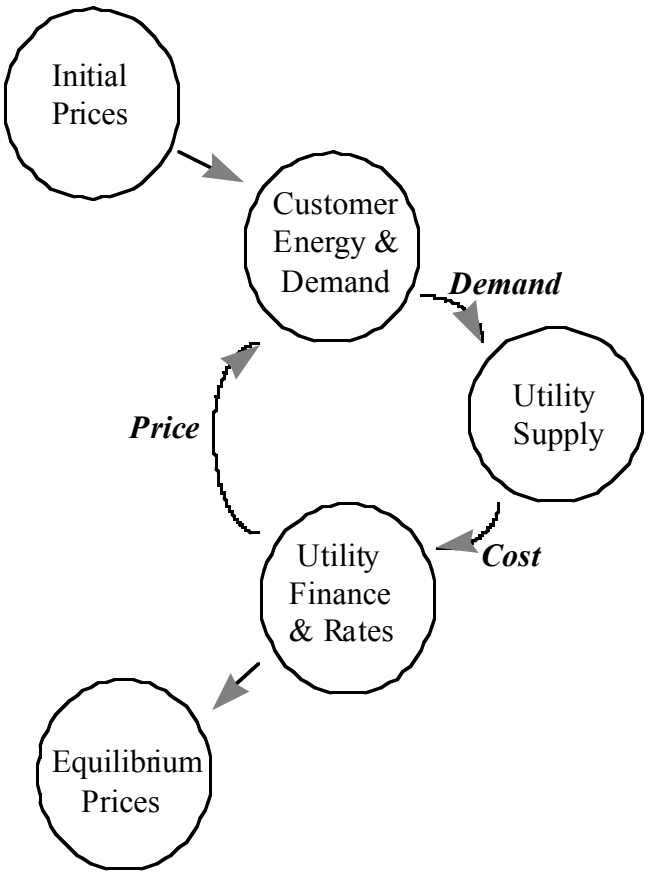
The rates submodel simulates the average cost-of-service for each customer sector. Cost allocation factors, based on hourly customer demands which include the projected load impacts of DSM programs (from the demand submodel), are used to apportion revenue requirements in each functional category, including DSM program costs, to each customer class.

The energy modeling system cycles through the five integrated submodels just described: energy, demand, supply, finance, and rates. During each cycle, price changes in the model cause customers to adjust their consumption of electricity, which in turn affects system demand, which in turn affects the utility's operating and investment decisions. These changes in demand and supply bring forth yet another change in price and the cycle is complete. After each cycle, the modeling system compares the "after" electricity prices from the rates submodel to the "before" prices input to the energy consumption models. If these prices match, they are termed equilibrium prices in the sense that they balance demand and supply, and the iteration ends. Otherwise, the modeling system continues to cycle through the submodels until an equilibrium is attained.

The iterative process just described, known as the cost-price-demand feedback loop, is often referred to as "closing the loop" and is illustrated in Figure 5. Many analysts believe the major reason the utility industry grossly overforecast electricity demand during the decade following

the first Arab oil embargo was because it ignored the price consequences of its investment decisions on customer demand, i.e., it failed to close the loop.

Figure 5. Cost-price-demand feedback loop



6.2.7 Uncertainty

As indicated above, SUFG's electricity projections are conditional on assumptions, or exogenous variables, such as economic growth, construction costs, and fossil fuel prices. These assumptions are a principal source of uncertainty in any energy forecast. Another major source of load uncertainty is the statistical error inherent in the structure of any forecasting model. To provide an indication of the importance of these sources of uncertainty, scenario-based projections were developed by operating the modeling system under varying sets of assumptions. These low probability, low and high scenarios capture much of the uncertainty associated with economic growth, fossil fuel prices, and statistical error in the model structure.

SADC regional uncertainties include drought related figures, growth rates of national economies, investment activities, population growth, global competitiveness of manufacturing industries, and government policy.

6.3 The approach to transmission modeling

The simplest approach and a good starting point to modeling the transmission sub-model would be to consider each country or each utility as being a center of trade. This would mean that only 12 nodes would be considered in the model. For accuracy in the model however it will be necessary to consider the actual generation sites and load centers.

The number of existing generation sites will influence the complexity of the model. As can be seen from Table 7 below, if larger capacity sites only are considered, such as greater than 100 MW, then a total of 40 would be involved. If all current stations in the region are included in the model, then over 130 will be involved. The multi-area unit commitment problem is currently of significant research interest to utilities all over the world where the regulatory environment is undergoing change (30).

Significant investments are being made in SAPP's transmission network. The modeling of transmission has a crucial part to play in developing the grid. There is a strategic need for this type of study in the region. Collaborators at Purdue would help to meet this need.

Table 7. SADC Generation sites

	HYDRO	COAL	OTHER	TOTAL
All generation sites	56	20	58	134
Generation sites > 5MW	39	20	31	90
Generation sites > 100MW	13	18	9	40

Source: Reference (33)

In order for SUFG to do detailed multi-area production simulation to simulate the electricity trade among the 12 countries, it will be necessary to obtain detailed topology of the transmission system of the region. This topology can be illustrated via a connection matrix as illustrated in Table.8.

The transmission capacity between major generation and consumption centers can be updated for each year there is any connection change. A second matrix will also be required for illustrating transmission impedance. This matrix will also be updated if any change happens to the

ransmission network. These two matrix will be employed to optimize the total production cost and associated energy exchanges.

Table 8. Connection matrix

Sites	1	2	3	4	5 . . . . . n
1					
2					
3					
4					
. . n					

Constraints will be added to the multi-area production cost objective function for SAPP, such that given the transmission capacity limits, the minimum operation cost can be calculated without violating the transmission limits. The marginal cost can also be found if some transmission line reaches its limit. This marginal cost can be used to measure the economic benefit of expanding this line.This transmission submodel with unique regional characteristics will be a very important part of the overall SAPP electricity trade model.

7. Collaborative research approach for 1997

A pre-proposal trip to Southern Africa provided excellent opportunities to discuss the research proposal individually with policy makers and utility planners in Southern Africa. That trip has been supplemented by frequent exchanges via e-mail and fax.

The proposed research project will begin by convening those collaborators and others from the region to meet with each other in January 1997, for the purpose of reviewing the modeling options and priorities. The project is proposed to end with a second meeting of the same group, at which the model and its results will be disseminated, for use in each of the SAPP member utilities. Both of these working group meetings would occur in the context of regularly-scheduled SAPP planning meetings.

At Purdue, four staff members will work on the model. Their positions and contact numbers are listed below, and their CV's are attached in Appendix III.

- Professor F.T. Sparrow is the Director of the State Utility Forecasting Group, Professor of Industrial Engineering, Professor of Economics, and Director of the Institute of

Interdisciplinary Engineering Studies (IIES). He is the major designer behind the SUFG Modeling System.

- Professor William A. Masters is Associate Professor of Agricultural Economics with extensive experience in trade and policy reform in southern Africa, having worked in Zimbabwe for several years.

- Dr. Zuwei Yu is a senior analyst with the SUFG. He has long experience in modeling electricity policy reform, with regard to deregulation and non-discriminatory access to transmission systems.

- Mr. Brian Bowen is a research assistant with the SUFG. He has wide experience in industrial organization in Africa and a background in operations research.

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Brian Bowen	*317-494-1873* .	*317-494-2351*	*bhbowen@ecn.purdue.edu*

The final arrangements for the two meetings in Africa are expected to be planned in co-operation with the SAPP management committee. Eskom holds the chair for the first year of operation of SAPP. Two Purdue staff will travel to Southern Africa for the two meetings. Between these two meetings, three key planners from the region will come to Purdue to work on the model . These three collaborators will each spend two to three weeks at Purdue, not necessarily at the same time. The proposal budget includes the travel and accommodation costs for these three visits.

Provision must be made for any non-utility collaborator to attend the two regional meetings in southern Africa. For all the collaborators representing their national utilities at the regular SAPP meeting, no expenses are required from the proposal. Their travel and accommodation will have been covered by their respective utilities as part of their participation in SAPP.

9. Summary of work objectives for 1997

The work proposed in this project can be summarized into three phases:

- **Setting research priorities** through a SAPP working group meeting in Africa.
- Completing **research through collaboration** between Purdue and SAPP members.
- **Disseminating research results** through a second SAPP working group meeting.

9.1 Setting research priorities

The members of SAPP have all shown intense interest in the proposed research, to help inform their moves toward greater regional integration. To ensure that the research responds to the

specific and evolving concerns of each member, it is appropriate to begin the research by convening a "working group" of analysts from each SAPP utility, in the context of a regularly scheduled SAPP meeting. This working group will review the broad outlines of the proposed analyses, and suggest specific questions to be considered. Such a dialogue among SAPP members and with Purdue staff will help ensure that EAGER research is fully integrated into the SAPP decision-making process, and strikes a balance between the diverse interests of each SAPP utility.

Preliminary discussions have shown that South Africa's ESKOM is most interested in analyzing new infrastructure under current trading arrangements, while the other utilities are more interested in analyzing new trading arrangements under current infrastructure. Purdue's experience with electricity trade modeling reveals that the two questions are closely inter-related, as new infrastructure is often needed to take advantage of new trading arrangements, and vice-versa. But an open dialogue among the electricity analysts negotiating in the SAPP will be needed for the specific research priorities to be identified and agreed upon.

The proposed working group meeting will be convened by the SAPP chairman, in conjunction with the routine SAPP meeting that is likely to occur in January 1997. Invitees will be those analysts from each member country who are currently negotiating SAPP's technical-cooperation agreements, plus the project's Zimbabwean consultant (Dr. Peter Robinson) and Purdue staff (Dr. Tom Sparrow and Mr. Brian Bowen). The agenda will include a brief presentation of relevant results from previous research including worldwide experience with alternative trading arrangements, and a "menu" of specific research options with their associated data requirements and likely outcomes. Each SAPP member will be expected to contribute to the group's assessment of the relative priority to be placed on each research issue, given its importance and the availability or quality of the necessary data. Some of the key specifications to which SAPP members may wish to contribute include:

(a) the level of geographic aggregation;
(b) the specification of existing generating systems and transmission infrastructure;
(c) the treatment of risk in power generation, transmission and demand;
(d) the treatment of trends in generating costs and electricity demand;
(e) the specification of infrastructure development options;
(f) the specification of alternative trading arrangements.

Much of the debate within SAPP concerns the feasibility and effects of alternative trading arrangements. The basic options for inter-utility contracts include:

(1) self-sufficiency (no contracts);
(2) bilateral agreements, which might specify:
  (2.1) fixed prices and/or quantities,
  (2.2) schedules of price-quantity relationships, or
  (2.3) bilateral auctions; and
(3) multilateral agreements, including specification of:
  (3.1) fixed prices and/or quantities,

(3.2) schedules of price-quantity relationships, or
(3.3) multilateral auctions.

The SAPP is now governed by a variety of bilateral agreements, mostly with fixed-price/fixed-quantity contracts (option 2.1 above). It is likely that moving towards more flexible bilateral trading schedules, permitting more variation in the level of purchases and sales, would substantially increase the realized gains from trade. But moving towards even greater flexibility through auctions, particularly under multilateral agreements, is likely to result in far greater economic benefits, including more stability as well as lower costs. A variety of auction arrangements are possible. Which are feasible, and which produces the most desirable outcomes, depends on the infrastructure available to transmit and measure electrical flows. By specifying the U.S. experience with alternative arrangements, and the possibilities for quantitative modeling of the options for Southern Africa, SAPP members will be able to identify which of the many possible trading arrangements and infrastructure investments should be investigated further.

If required, then SUFG staff will be available for booking meetings for SAPP personnel to discuss these issues at other institutions in the USA.

9.2 Research through collaboration

After the priority-setting meeting, the 1997 calendar year will be devoted to building a detailed quantitative electricity trade model to measure the effects of alternative policy options. In implementing this research, effective collaboration between the SAPP utilities and Purdue will be essential to ensuring that the results are reliable and significant for policy-making in the region.

Modeling electricity trade involves significant technical problems beyond those that are involved in other kinds of international trade, due to the importance of the transmission path and congestion effects. A key difference between electricity and other commodities is that electricity will choose its own path, like water flowing down a slope, unless costly flow-control equipment is built into the system. As a result, transmission pathways cannot usually be pre-specified, and transmission costs and losses depend on the state of the entire grid. To predict the consequences of any one change in the system, complex new transmission-modeling techniques developed at Purdue and other centers of electrical-engineering research will be needed.

The first few months of modeling will require development of a regional transmission sub-model and integration into the larger trade model. The modeling of existing and proposed new hydro-power stations will be the second major modeling issue (for medium-term scenario only). Uncertainties of water inflow rates into existing and proposed reservoirs creates a major modeling problem. Substantial sets of data will be required for modeling the region's thermal power stations.

Throughout the modeling period extensive interaction (especially via fax and email) between collaborators in Africa and America is expected to take place. Then during the Fall of 1997, three collaborators from Southern Africa will join the staff at Purdue for the final stages of developing the model. Working with Purdue staff, the three collaborators from Africa will assess the details in the modeling assumptions, inputs and outputs from the model, and make adjustments where considered necessary. These three collaborators will also prepare their presentations for the December working group meeting.

Besides the three collaborators supported by the project, others from Southern Africa will be welcomed at Purdue to work on the model if their utilities or governments can send them.

9.3 Disseminating research results

At the end of 1997, the research findings will be presented at a second SAPP working group meeting in Southern Africa. Again, two Purdue researchers will attend, along with the three SAPP collaborators who worked on the model at Purdue. Each will present some aspect of the research approach and model structure, the scenarios and policy options considered, and their implications for national utilities and electricity users.

Although it is not possible to predict the content of the research results, it is likely that the findings will support some sort of change in current SAPP arrangements, and indicate what sort of contracting and payment system can ensure that all members gain from increased trading. Most members of SAPP expect that increased trade, and increased flexibility in trading, will lower the costs and improve the stability of their national systems. But demonstrating these effects, and showing which trading arrangements and transmission investments will be most successful in attaining SAPP goals, is likely to make a major contribution towards a more informed and successful process of regional integration.

Once the electricity analysts in the SAPP working group have debated the research results and identified one or more preferred policy options, it will be up to them to use these findings in national and international policy debates. Each country differs in how that debate can proceed, but in many cases it will be very helpful to be able to use the EAGER research to document likely consequences of various alternatives. Because very little similar research has yet been done, it is likely that the EAGER findings will be of great importance in the evolution of the SAPP, and the first-year's experience may lead to a demand for additional research.

Appendix I

The twelve national power utilities

BPC Botswana Power Corporation

EDM Electricidade de Mocambique

ENE Empresa Nacional de Electricidade (Angola)

Escom Electricity Supply Commission of Malawi

Eskom South Africa parastatal power utility (not an acronym)

LEC Lesotho Electricity Corporation

NamPower…Namibia parastatal power utility

SEB Swaziland Electricity Board

SNEL Societe Nationale d'Electricite (Zaire)

Tanesco Tanzania Electric Supply Company

Zesa Zimbabwe Electricity Supply Authority

Zesco Zambia Electricity Supply Corporation

Appendix II

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Appendix III

Purdue staff CVs

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Education & Qualifications:

1994-Present	PhD studies in School of Industrial Engineering, PURDUE UNIVERSITY, Indiana
1987	Post-grad Masters courses in CAD/CAM, LIVERPOOL POLYTECHNIC, England
1985	Master of Science in Energy Studies, UNIVERSITY COLLEGE, Cardiff, UK
1978	C.Eng., MI Mech E, Professional Chartered Engineer Status
1974	Post-grad Teacher's Certificate of Education, OXFORD UNIVERSITY, England
1971	Bachelor of Science (with honors) in Mechanical Engineering, LANCHESTER POLYTECHNIC, Coventry, England

Work Experience:

1994-Present	Graduate Teaching Staff in School of Technology, PURDUE UNIVERSITY
1993-1994	Three part-time lecturing posts at MANCHESTER UNIVERSITY, MANCHESTER METROPOLITAN UNIVERSITY & WIRRAL METROPOLITAN COLLEGE, England. Subjects taught: Design and engineering management
1990-1993	Lecturer in Drawing & Design, UNIVERSITY OF ZIMBABWE, Harare, Zimbabwe, Africa. Courses taught: Design for manufacture, CNC controls, engineering management. Research: CNC implementation and energy utilization
1987-1990	Senior Teaching Associate, LIVERPOOL POLYTECHNIC/OTIS ELEVATORS Teaching Company Program, England. Subjects taught: Manufacturing & CAM
1974-1986	Lecturer in Mechanical Engineering, UNIVERSITY OF SIERRA LEONE, Freetown, Sierra Leone, Africa. Subjects taught: Mechanical design & applied mechanics. Research: Solar collector design and testing
1971-1973	IVS Lecturer in Mechanical Engineering, UNIVERSITY OF MAURITIUS, Indian Ocean. Subjects taught: Drawing and applied mechanics

1964-1971 Technical Trainee & Student Engineer with the international electric cable manufacturers BICC-British Insulated Callender's Cables Ltd. (Trained in design office, foundry, maintenance and production divisions to meet professional training requirements of the Institution of Mechanical Engineers, I. Mech. E.)

Publications:

1. "Loading characteristics of 4 pocket hydrodynamic journal bearings," Dissertation for BSc Hons, 1971, Lanchester Polytechnic, Coventry, England.

2. "The role of technical education in Mauritius," PGCert.Ed. Dissertation, 1974, Oxford University, England.

3. "A screw press for low cost palm oil extraction," Department of Engineering, Fourah Bay College, University of Sierra Leone, Engineering Research Paper No. TE12, May 1976.

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Stanford University, Food Research Institute
M.A. (1986), Ph.D. (1991) in Agricultural Economics
Thesis title: "Comparative Advantage and Government Policy in Zimbabwean Agriculture."
Yale University
BA (1984) in Economics and Political Science
Deep Springs College
(1979-1982)

Fields of Expertise:
Trade and development policy analysis, indicator methods, impact of agricultural research. Regional experience in Zimbabwe, Mali, Colombia, Haiti.

Languages: Fluent French, some Spanish.

Employment:

Purdue University
Associate Professor (1996-present), Assistant Professor (1991-1996)
Major research projects have included:
- Assessment of alternative policy analysis and comparative advantage indicators, e.g. effective protection, domestic resource costs (DRC) and other measures;
- Impact of agricultural research in West Africa, using farm-household models and market-level economic surplus measures;
- Impact of grain market reform in Zimbabwe, including a variety of consulting activities for USAID and the World Bank;
- Impact of grain market reform in Zambia, based on new types of spatial-equilibrium modeling.

Principal teaching activities include:
- "Economics of World Agricultural Development", an upper-level undergraduate course taught annually since 1992.
- "Agriculture and Trade Policy in Developing Countries", and "Agricultural Development in Africa", graduate seminars taught in 1993-1995.
- "Agricultural Policy", a graduate course beginning Fall 1996.
- "Impact of Agricultural Research", a short course taught at the Institut du Sahel (Bamako, Mali) annually since 1994.

Major professor for three MS theses and six PhD dissertations.

Stanford University (1987 - 1991)
Teaching Assistant for courses in trade policy, microeconomic theory, and the world food economy;
Research Assistant for Prof. Bruce Johnston to help write teaching materials for use in World Bank/EDI courses, and Research Assistant for Prof. Scott Pearson to help write a book on Indonesian food policy.

University of Zimbabwe, Harare, Zimbabwe (1988-1990)
Research Associate and part-time lecturer. Stationed primarily at the Ministry of Lands, Agriculture, and Rural Resettlement, to collaborate on the first nation-wide small holder farm survey and other assist with other policy analysis activities.
Funded by a Fulbright Dissertation Research Grant (1988-89) and a Rockefeller Foundation research grant (1990).

International Food Policy Research Institute, Washington (1987)
Research Assistant for Dr. John W. Mellor

Mavhudzi Government Secondary School, Nyazura, Zimbabwe (1985)
Teacher -- Form IV English Language

COLANTA Dairy Cooperative, Medellin, Colombia (1983)
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Intern in Head Office Staff

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- US Dept. of Education - Building Agribusiness Capacity (1996-98)
- USAID - Equity and Growth through Economic Research (EAGER/Trade) (1995-99)
- USAID - Economic Impact of Agricultural Technology in West and Central Africa (Joint with Prof. John H. Sanders) (1993-97)
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"Panterritorial versus Regional Pricing for Maize in Zimbabwe" (1993), with Ernst-August Nuppenau, World Development 21(10): 1647-1658.

"Trade Policy and Agriculture: Measuring the Real Exchange Rate in Zimbabwe" (1991), Quarterly Journal of International Agriculture 30(1): 21-36.

"The Changing Roles of Multilateral and Bilateral Foreign Assistance" (1991), with John W. Mellor, in Transitions in Development: The Role of Aid and Commercial Flows, edited by Uma Lele and Ijaz Nabi. San Francisco: ICS Press.

Book reviews

Review of Agricultural Policies in Developing Countries by Frank Ellis" (1993). American Journal of Agricultural Economics, 75(2): 502-503, 1993.

Review of Transforming Agrarian Economies by Thomas P. Tomich, Peter Kilby and Bruce F. Johnston (1996). European Review of Agricultural Economics, forthcoming.

Other publications

"The Economic Impact of Agricultural Research: A Practical Guide" (1996), also available in French. Bamako, Mali: Institut du Sahel.

"Guidelines on National Comparative Advantage and Agricultural Trade" (1995), APAP Methods and Guidelines Series 40001. Bethesda, MD: Abt Associates (74 pages).

Professional Associations and Activities:

- Member of the American Agricultural Economics Association, the American Economics Association, the International Association of Agricultural Economists, the International Agricultural Trade Research Consortium, and the African Studies Association.
- Reviewer for articles submitted to Agricultural Economics, American Journal of Agricultural Economics, Economic Development and Cultural Change, Food Policy, World Development, and other professional journals.
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Education:

B.S., Geology, University of Michigan, 1953
M.B.A., Managerial Economics, with distinction, Cornell University, 1956
Ph.D., Economics and Operations Research, University of Michigan, 1962

Work Experience:

1979-Present:
Purdue University -
Professor of Industrial Engineering, School of Industrial Engineering
Professor of Economics, Department of Economics
Director, Institute for Interdisciplinary Engineering Studies
Director, State Utility Forecasting Group
Director, Coating Applications Research Laboratory

1976-1978:
University of Houston -
Professor, Department of Economics, and Chairman, Department of Industrial Engineering

1973-1976:
National Science Foundation -
Deputy Assistant Director for Analysis and Planning, Research Applications Directorate

1962-1973:
The Johns Hopkins University -
Assistant and Associate Professor of Economics and Operations Research

1956-1958:
U.S. Atomic Energy Commission -
Operations Analyst, Office of Operations Analysis, Washington, D.C. (GS-9)

Current Research Interests:

Energy, with emphasis on Electricity
Energy Conservation
Industrial Use of Electricity
Natural Resource Economics

Memberships:

Association of Demand-Side Management Professionals
American Institute of Industrial Engineers
American Society for Engineering Education
Demand-Side Management Society of AEE
The Association of Energy Engineers

Consulting & Appointments:

Argonne National Laboratory
Battelle National Laboratory
Bonneville Power Administration
Electric Power Research Institute
Hydro Quebec
Niagara Mohawk Power Company
Ontario Hydro
Barakat and Chamberlin, Inc.
BENTEK Energy Research Inc.
Brookhaven National Laboratories
Gas Research Institute
Illinois Power
Southern California Edison

Industrial/Technical/Professional Committees:

1988-1994, Advisory Panel Member, National Science Foundation
1990, Member, Environmental Advisory Panel, PSI Energy
1990, Member, Indiana Coal Forum
1991-Present, Member, Indiana Energy and Recycling Development Board
1992-1994, Member, National Research Council Committee on Integrated Resource Planning
1994-1995, American Council for an Energy-Efficient Economy, Industrial Energy Conservation Workshop Committee and Summer Study Program Committee

Selected Recent Publications:

"Average Cost Pricing, Equity, Efficiency, and DSM" (with R. Cearley, L. McKinzie, F. Holland), *Proceedings, 5th National Demand-Side Management Conference,* Boston, MA, July 30-August 1, 1991.

"Equity, Efficiency, and Effectiveness in DSM Rate Design" (with Reed Cearley, Forrest Holland, and Lance McKinzie), *The Electricity Journal,* May 1992, pp. 25-33.

"Demand-Side Management Implications of Electrically-Based Manufacturing Technologies" (with P.S. Schmidt, University of Texas at Austin), *Proceedings, 27th Intersociety Energy Conversion Engineering Conference,* San Diego, CA, August 3-7, 1992.

"The Design of DSM Incentives for the Industrial Sector" (with L. McKinzie, J. Lee, R. Cearley, F. Holland), *Proceedings, 1991 International Energy Efficiency and DSM Conference,* Toronto, Canada, October 20-22, 1992.

"Demand-Side Management Implications of Electrically-Based Manufacturing Technologies" (with P.S. Schmidt, University of Texas at Austin), *Energy,* Vol. 18, No. 10, pp. 1067-1076, 1993.

"The Likely Market Potential for Electricity Saving ASD Devices" (with L. McKinzie), in *Innovative Energy and Environmental Applications,* The Fairmont Press, Inc., Lilburn, GA, 1993, Chapter 23, pp. 119-126.

Neoelectrification of Industry in the Information Age, (with P.S. Schmidt, J.H. Vanston, J.W. Zarnikau), Technology Futures, Inc., Austin, TX, 1994.

Promotion of Energy Efficiency Through Environmental Compliance (with A. Faruqui and P. Kyricopoulos), Barakat & Chamberlin, Oakland, California, 1995.

"Rural Electrification and Economic Growth in the New South Africa" (with Brian H. Bowen), *Southern Africa Journal,* submitted, August 1995.

Selected Recent Presentations:

"Predicting Electricity Use by the Iron and Steel Industry Using Mathematical Programming" (with L. McKinzie), presented at the Joint International Meeting, TIMS XXX - SOBRAPO XXIII, Rio de Janeiro, Brazil, July 15-17, 1991.

"Experiments with a Model of the Indiana Iron and Steel Industry" (with L. McKinzie, A. McKinzie, R. Cearley, F. Holland, P. Degner), presented at the Joint International Meeting, TIMS XXX - SOBRAPO XXIII, Rio de Janeiro, Brazil, July 15-17, 1991.

"Average Cost Pricing, Equity, Efficiency, and DSM" (with R. Cearley, L. McKinzie, F. Holland), presented at the 5th National Demand-Side Management Conference, Boston, MA, July-Aug. 1991.

"Engineering Economics," short course, Management Training and Economics Education in Central and Eastern Europe, Project Managed by School of Business, Indiana University, held in Warsaw, Poland, Budapest, Hungary, and Prague, Czechoslovakia, March 8-18, 1992; and held in Budapest, Hungary, and Prague, Czechoslovakia, May 8-14, 1993.

"Marginal Cost Pricing as a Solution to Equity Problems," presented at Washington Gas Company's Least Cost Planning Workshop, Washington, D.C., April 7-8, 1992.

"Energy, Electricity, and Demand-Side Management," presented at the VI Latin-Ibera-American Meeting on Operations Systems and Systems Engineering, Mexico City, Mexico, October 8, 1992.

"Electrification and Economic Growth -- A Two-Way Street," Mexico City, Mexico, September 8, 1994.

Selected Recent Technical/Staff Reports:

"Indiana Electricity Demand, The 1990 Forecast," Staff Report, State Utility Forecasting Group, Institute for Interdisciplinary Engineering Studies, Purdue University, February 1991.

"Demand Side Management (DSM) Rate Design Issues When Utility Prices Exceed Marginal Costs" (with R. Cearley, F. Holland, L. McKinzie), Technical Report, State Utility Forecasting Group, October 1991.

"The Proper Design of DSM Incentives," Staff Report, State Utility Forecasting Group, Institute for Interdisciplinary Engineering Studies, Purdue University, presented at the Least Cost Planning Conference, Washington, D.C., April 7-8, 1992.

"Indiana Electricity Demand: The 1993 Forecast," Staff Report, State Utility Forecasting Group, prepared for Indiana Utility Regulatory Commission, June 1993.

"Water Resources Issues for the Indiana Electric Power Industry" (with Edward Haslam and Harry Smolen), Indiana Water Resources Research Center (Purdue University) and State Utility Forecasting Group, July 1993.

"The 1994 Indiana Electricity Projections," Staff Report, State Utility Forecasting Group, prepared for the Indiana Utility Regulatory Commission, May 1995.

"1996 Indiana Electricity Projections," Staff Report, State Utility Forecasting Group, prepared for the Indiana Utility Regulatory Commission, September 1996.

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Ph.D. of EE (Fall, 1995), with a *minor in industrial engineering/operation research*, School of Electrical Engineering, University of Oklahoma, Norman, OK 73019, USA.
MS and BS of EE, Dept. of EE, Beijing University of Aero & Astro, Beijing, China.
Trainee (1985), economics, cost & pricing, econometrics, and contract management, GD, USA.

Expertise:

- Extensive and in depth knowledge in power system engineering, especially in the following areas:

power system economics	load forecasting & DSM	multi-area production simulation	least-cost planning
competitive pricing/risk	power economics & regulation	wheeling & transaction	power system reliability
optimal power flow, etc.			

- Very knowledgeable in:

econometrics	probability, stochastic processes, and applications	
linear programming	nonlinear programming	dynamic programming
network flow models	interior point method	engineering management, etc.

- Very strong analytical and quantitative skills.
- Strong organizational and communication skills.
- Self-motivated and very responsible for what is done.

Experience (Partial):

5/96 - present: Senior Analyst, State Utility Forecast Group, Purdue University.
- Unit commitment/generation scheduling, multi-area production simulation and power flow analysis.

2/92 - 4/96: IEEE technical paper reviewer, IEEE Transmission Open Access Subcommittee.
- Evaluated IEEE PES technical papers on transmission open access, deregulation, and electrical power industry restructuring issues.

6/90 - 8/95: Research assistant, Power Lab., School of EE, Univ. of Oklahoma.

- Power system economic, competitive pricing, risk evaluation, optimal pricing, rate making issues.
- Engaged in load forecasting projects for utilities in Oklahoma using Multi-regression, Neural Networks, State Space, Categorical Regression models, etc.
- Developed a Compensated Box-Jenkins Transfer Function Model and a Temperature Match Based Optimization Model for load prediction.
- Developed security constrained Economic Dispatch algorithm for energy exchange/wheeling pricing.
- Screened DSM methodologies and applications.
- Completed an integrated resource planning project jointly sponsored by EPRI & OG&E.
- Introduced a Level-crossing Based Analytical Method in the DSM control of electrical appliances.
- Engaged in production costing considering capacity reserve & risk, and least cost planning.
- Developed a Unit Commitment Model by using a modified DPSTC method.
- Introduced a Line Flow Magnitude Method and a Multi-level Optimization Method in electrical power wheeling study.

1/83 - 8/89: Engineer, deputy director and executive director, Electrical & Power Systems Dept., Technology and Economics Consulting Center (TECC), CARITE, Beijing, China.

- Long term and short term forecasting, econometrics models, and engineering economics.
- Analysis of electrical and power systems, including software development and simulation.
- Integrated analysis of engineering problems, including risk and uncertainty analysis, by using technology, engineering economics and operations research models.
- Planned the research activities of that department.
- Job allocation, research supervision, and engineering management, etc.

Publications (partial):

1. Z. Yu, F.T. Sparrow, et al, "A Linear Mixed Integer Programming Formulation of Unit Commitment Problem with Unconditional Minimum-up & Down Time Constraints", submitted to IEEE PES 1997 Winter Meeting, PWRS.

2&3. Z. Yu, et al, "Competitive Pricing in the Deregulated and Open Access Electric Energy Market. Part I, A Theoretical Background", "Part II, Pricing Risk Evaluation", under review for presentation at the IEEE PES 1997 Winter Meeting, IEEE-PWRS.

4. Z. Yu, A.M. Breipohl, F.N. Lee and R Adapa, "The Extension of an Analytical Method for Comparing Natural Diversity to DSM Controlled Diversity", presented at *IEEE 96 Winter Meeting, PWRS* and scheduled for publishing in the *IEEE Trans. on PWRS*, 1996.

5. Z. Yu, "A Temperature Match Based Optimization Method for Daily Load Forecasting Considering DLC Effect", *IEEE 95 Summer Meeting, paper PWRS SM 503-3* and published in the *IEEE Trans. on PWRS*, May, 1996.

6. Z. Yu, A.M. Breipohl, F.N. Lee and R. Adapa, "An Analytical Method for Comparing Natural Diversity to DSM Controlled Diversity", *IEEE 95 Summer Meeting, paper PWRS 95SM 504-1* and published in the *IEEE Trans. on Power Systems*, August 1996.

7. Z. Yu, A.M. Breipohl and F.N. Lee, "Line Flow Magnitude Method - A Proposed Method for Evaluating the Capital Cost of Transmission Due to Wheeling", *Proceedings of the American Power Conference*, Vol. 56 - I, 1994.

8. T. Trafalis and Z. Yu, "A New Optimization Model for Minimizing the Cost of Electrical Power Wheeling in Multiple Control Areas", *Proceedings of the American Power Conference*, Vol. 56-I.

9. Z. Yu, "A New Method For Power System Control and Economic Operation", IEEE *Proceedings of the first IEEE Conference on Control Applications*, 1992.

10. Z. Yu, A.M. Breipohl, and F.N. Lee, "A Compensated Box-Jenkins Transfer Function Method for Short Term Load Forecasting", *Proceedings of the American Power Conference*, Vol. 54-II, 1992.

11. More than 12 other papers and a book, on forecasting, econometrics models, electrical & power systems, and engineering economics & engineering optimization applications, etc., were published in China from 1983 to 1989.