ENTRO

EASTERN NILE POWER TRADE PROGRAM STUDY

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COORDINATED INVESTMENT PLANNING

VOL 1: EXECUTIVE SUMARY

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with participation of:

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- Tropics (Ethiopia)
- YAM (Sudan)

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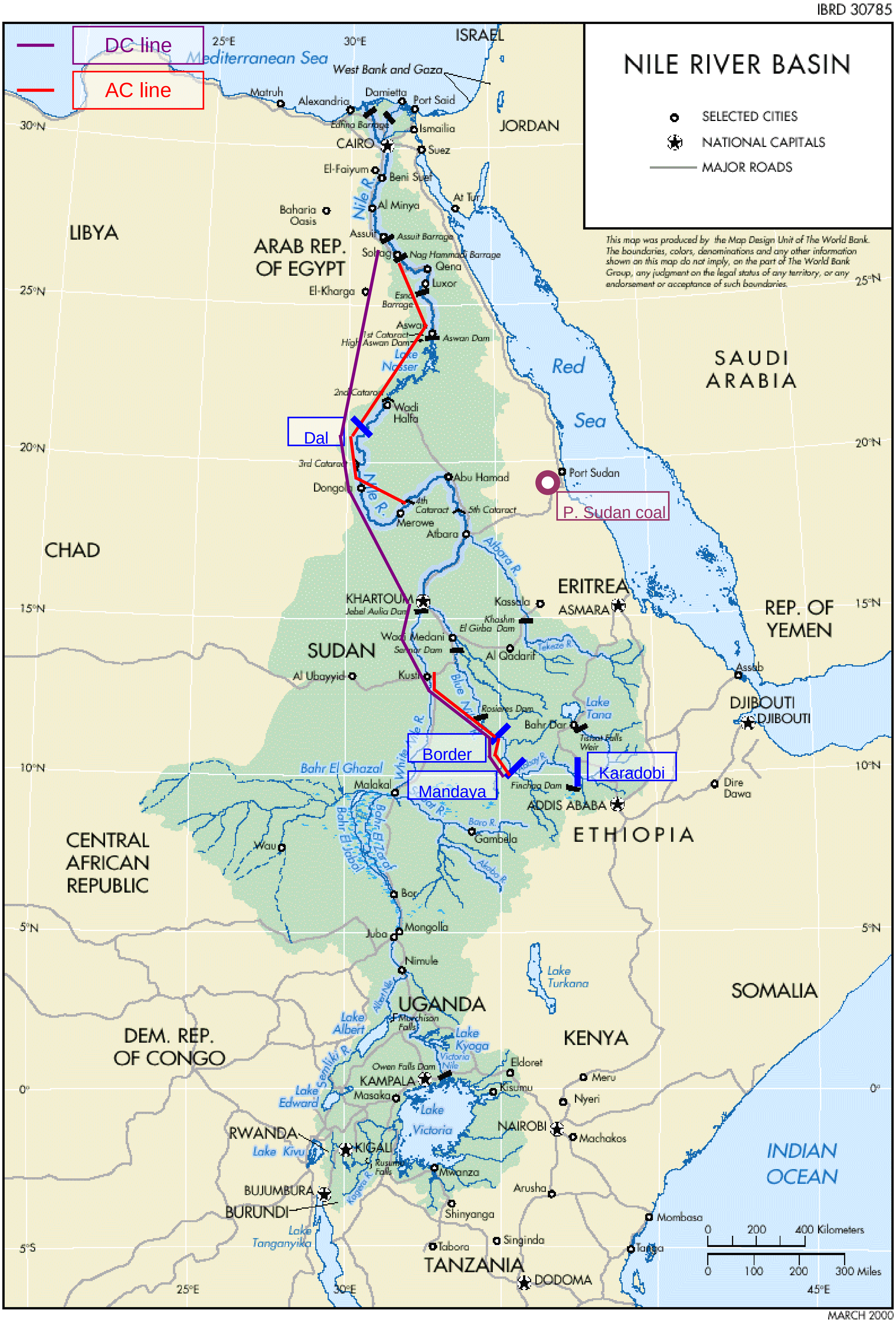
IBRD 30785
DC line
AC line
NILE RIVER BASIN
SELECTED CITIES
NATIONAL CAPITALS
MAJOR ROADS
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Border
Mandaya
Karadobi
Port Sudan
Lake Nasser
Lake Tana
Lake Victoria
Lake Turkana
Lake Albert
Lake Kyoga
Lake Edward
Lake Kivu
Lake Tanganyika
Nile R.
Blue Nile
White Nile R.
Atbara R.
Bahr El Ghazal
0 200 400 Kilometers
0 100 200 300 Miles
MARCH 2000

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PHYSICAL UNITS AND CONVERSION FACTORS

bbl	barrel	(1t = 7.3 bbl)
cal	calorie	(1 cal = 4.1868 J)
Gcal	Giga calorie	
GWh	Gigawatt-hour	
h	hour	
km	kilometer	
km^2	square kilometer	
kW	kilo Watt	
kWh	kilo Watt hour	(1 kWh = 3.6 MJ)
MBtu	Million British Thermal Units	(= 1 055 MJ = 252 kCal)
	one cubic foot of natural gas produces approximately 1,000 BTU	
MJ	Million Joule	(= 0,948.10^{-3} MBtu = 238.8 kcal)
MW	Mega Watt	
m	meter	
m^3/d	cubic meter per day	
mm	millimeter	
mm^3	million cubic meter	
Nm^3	Normal cubic meter, i.e. measured under normal conditions, i.e. 0°C and 1013 mbar (1 Nm^3 = 1.057 m^3 measured under standard conditions, i.e. 15°C and 1013 mbar)	
t	ton	
toe	tons of oil equivalent	
tcf	ton cubic feet	
°C	Degrees Celsius	

General Conversion Factors for Energy

To:	TJ	Gcal	Mtoe	MBtu	GWh
From:	multiply by:				
TJ	1	238.8	2.388×10^{-5}	947.8	0.2778
Gcal	4.1868×10^{-3}	1	10^{-7}	3.968	1.163×10^{-3}
Mtoe	4.1868×10^{4}	10^{7}	1	3.968×10^{7}	11630
MBtu	1.0551×10^{-3}	0.252	2.52×10^{-8}	1	2.931×10^{-4}
GWh	3.6	860	8.6×10^{-5}	3412	1

ABBREVIATIONS AND ACRONYMS

ADB	African Development Bank
ADF	African Development Fund
CC	Combined Cycle
CCGT	Combined Cycle Gas Turbine
CIDA	Canadian International Development Agency
CT	Combustion Turbine
DANIDA	Danish Development Assistance
DFID	Department for International Development (UK)
DIDC	Department for International Development Cooperation (GoF)
DSA	Daily Subsistence Allowance
EEHC	Egyptian Electricity Holding Company
EEPCO	Ethiopian Electric Power Corporation
EHV	Extra High Voltage
EHVAC	Extra High Voltage Alternating Current
EIA	Environmental Impact Assessment
EIRR	Economic Internal Rate of Return
EN	Eastern Nile
ENCOM	Eastern Nile Council of Ministers
ENSAP	Eastern Nile Subsidiary Action Program
ENSAPT	Eastern Nile Subsidiary Action Program Team
ENTRO	Eastern Nile Technical Regional Office
ENTRO PCU	Eastern Nile Technical Regional Office Power Coordination Unit
FIRR	Financial Internal Rate of Return
GEP	Generation Expansion Plan
GTZ	German Technical Co-operation
HPP	Hydro Power Plant
HFO	Heavy fuel oil
HV	High Voltage
HVDC	High Voltage Direct Current
ICCON	International Consortium for Cooperation on the Nile
ICS	Interconnected System
IDEN	Integrated Development of the Eastern Nile
IDO	Industrial Diesel Oil
IMF	International Monetary Fund
JICA	Japanese International Co-operation Agency
JMP	Joint Multipurpose Project
LNG	Liquefied Natural Gas
LOLP	Loss of Load Probability
LPG	Liquefied Petroleum Gas
LRFO	Light Residuel Fuel Oil
MENA	Middle East, North Africa Countries
MIWR	Ministry of Irrigation & Water Resources (Sudan)
MWR	Ministry of Water Resources (Ethiopia)
MWRI	Ministry of Water Resources and Irrigation (Egypt)
MSD	Medium Speed Diesel (TPP)
NBI	Nile Basin Initiative
NEC	National Electricity Corporation (Sudan)
NECC	National Electricity Control Centre (Egypt)
NELCOM	Nile Equatorial Lake Council of Ministers
NELSAP	Nile Equatorial Lake Subsidiary Action Program
NG	Natural Gas
NGO	Non Governmental Organization

NORAD	Norwegian Aid Development
NPV	Net Present Value
O&M	Operations and Maintenance
OCGT	Open Cycle Gas Turbine
OPEC	Organization of the Petroleum Exporting Countries
PBP	Pay Back Period
PHRD	Policy & Human Resource Development Fund
PIU	Project Implementation Unit
PRSP	Poverty Reduction Strategy Paper
RCC	Regional Electricity Control Centre (Egypt)
RE	Rural Electrification
SAPP	Southern Africa Power Pool
SIDA	Swedish International Development Agency
SSD	Slow speed diesel (TPP)
STPP	Steam Turbine Power Plant
STS	Senior Technical Specialist
TAF	Technical Assistant Fund
TPP	Thermal Power Plant
UA	Unit of Account
UNDP	United Nations Development Program
WB	World Bank

1. ORGANISATION OF THE EASTERN NILE POWER TRADE PROGRAM STUDY

The Eastern Nile Power Trade Program Study is fully funded by the African Development Bank and has the general objective:

To promote regional power trade between Egypt, Ethiopia and Sudan through creation of an enabling environment, coordinated regional investment planning of power generation and transmission interconnection projects.

The kick-off meeting led by ENTRO took place on 20 October 2006. The project duration is 21 months up to the end of September 2008.

The Project is carried out in **close contact and co-operation** with the three countries Utilities: EEHC, EEPCO, NEC. In addition, other relevant institutions, in particular the Nile Basin Initiative, the Ministry of Water Resources and Irrigation of Egypt, the Ministry of Water Resources of Ethiopia, the Ministry of Irrigation & Water Resources of Sudan are intensively involved in the project, with strong support of the local team experts in the three countries.

The Eastern Nile Power Trade Program Study is divided in 2 phases:

Phase 1: Cooperative Regional Assessment of Power Trade Opportunities between Ethiopia, Egypt and Sudan.

Phase 2: Feasibility Study of the Power Interconnection between Ethiopia, Egypt and Sudan.

The decision to proceed to Phase 2 will be taken by ENTRO on the basis of the findings of Phase1.

Phase 1 consists of 9 Modules:

- M1: Inception Mission & initial data collection
- M2: Market and Power Trade assessment
- M3: Energy sector profiles & projections
- M4: Planning & Evaluation criteria
- M5: HPP Pre-feasibility study (Dal –I, Mandaya, Border)
- M6: Coordinated Investment planning (least cost interconnection option, coordinated regional generation expansion plans)
- M7: Development of a Strategy for Power
- M8: Public consultations
- M9: Training program

Phase 2 consists of 8 Modules:

- M 1: Detailed power system studies
- M 2: Topography and survey for line routing
- M 3: Environmental & Social Impact Assessment
- M 4: Preparation of Technical specifications
- M 5: Operation & Maintenance requirements
- M 6: Implementation Arrangements
- M 7: Institutional analysis
- M 8: Financial & Economic analysis

2. EXECUTIVE SUMMARY

2.1 OBJECTIVE OF MODULE 6

The overall objective of Module 6 is to evaluate the potential benefits for the region (Egypt, Ethiopia and Sudan) provided by an interconnection of the three power systems according to various level of integration (or coordination) of these systems.

Accordingly Module 6 will cover:

- the determination of least-cost generation expansion plan for the three isolated systems,
- the determination of least-cost generation expansion plan for the coordinated system,
- the determination of the least cost interconnection option in term of technology,
- the transmission system analysis,
- the recommendation of a Regional Investment Program.

The present Volume 1 provides an executive summary of the Module 6 findings.

2.2 GENERATION EXPANSION PLAN

2.2.1 METHODOLOGY

2.2.1.1 Minimizing regional costs

The potential benefits for the region resulting from the interconnection will be evaluated by the comparison of two situations:

S1: independent development of the three power systems assuming the presence of no interconnection, this situation would lead to the determination by the Consultant of one investment program for each power system: P_{Egypt}, $P_{Ethiopia}$, P_{Sudan}.

S2: combined development of the three power systems assuming the presence of an interconnection and various level of coordination between the power systems. This would lead to the determination by the Consultant of a coordinated investment program P_{Intercon}.

The potential benefits provided by the interconnection will be given by the difference of costs between these two situations:

Benefits from the interconnection = Cost [P_{Egypt}, P_{Ethiopia}, P_{Sudan}] – Cost [P_{Intercon}]

2.2.1.2 Power pool models

Economic power exchanges take advantage of generation cost differences between the interconnected power systems in order to minimize the global regional generation cost: at any time, the demand is supplied from the lowest cost generation units available in the region (global merit order), within the limits of the interconnection capacity and possible operation constraints. The resulting power exchanges may vary in amount and direction according to the evolution of each power system (demand variation, hydrology variation, generation investments, etc).

In the present economic Study the amount of power trades between Egypt, Ethiopia and Sudan, and the resulting benefits for the region, will be assessed along two approaches (as per TOR) in order to cover a large range of possible situations: loose pool and tight pool models. These two models, described hereafter, can be understood as two different stages of power market development, or in other words, as two different levels of coordination between the power systems.

2.2.1.2.1 Loose Pool model: coordination of operation

The loose pool model refers to a scheme where the operation of the generation is coordinated regionally (either by direct coordination or through a power pool) while each country keeps its independence for the decision of generation investment. In other words, each country keeps its own generation expansion plan unchanged, and its ability to be self-sufficient and cover its own peak demand.

The loose pool model represents the first stage of development of a regional power market providing the relevant price signals for operation (spot market and market for forwards within the current year).

The generation investment cost of the region remains unchanged, while the operation cost (fuel savings) is reduced through regional coordination and the use of Ethiopian hydro surplus.

This approach is similar to the one carried out for the Ethiopia-Sudan interconnection Study (2005).

2.2.1.2.2 Tight pool model: coordination of generation investment and operation

The tight pool model could be understood as a fully integrated regional power system.

In this theoretical model, further to the operation which is regionally coordinated (as in the loose pool model), the generation investment decisions are also coordinated and optimised at a regional level allowing to take advantage of the countries complementary resources (low cost hydro generation in a country, low cost thermal generation in an other, etc).

Of course, even in this theoretical case, some part of the generation would be still dispatched on a non economic basis (e.g. irrigation), and the transmission and distribution network would set limits to amount of power exchanges possible between the different areas.

The tight model represents a highly developed power market providing the relevant price signal for:

- operation decisions: through a spot market and a forward market the actors could decide whether to buy/sell energy on the market or operate their own existing generation units,
- investment decisions: through a forward market with a medium term horizon (> 4 - 5 years), the actors could decide whether to contract now for energy to be delivered in n years, or to invest in new generation units of their own.

This regional operation and investment coordination would result in:

- operation cost savings: expensive fuel in one country would be substituted by lower cost generation fuel available in another country,
- investment savings: the commissioning of "expensive" plants in one country might be postponed if a corresponding less expensive capacity is available in another country.

2.2.1.2.3 Summary table

Model	Level of coordination	Generation Expansion Plans	Type of savings
Isolated systems	No coordination	GEP Egypt, GEP Ethiopia, GEP Sudan	Reference situation
Loose pool model	Operation	Same as above	Fuel costs
Tight pool model	Operation and investment	Updated GEP	Fuel costs and investment costs

Table 2.2-1 - Tight and loose pool models - Main characteristics

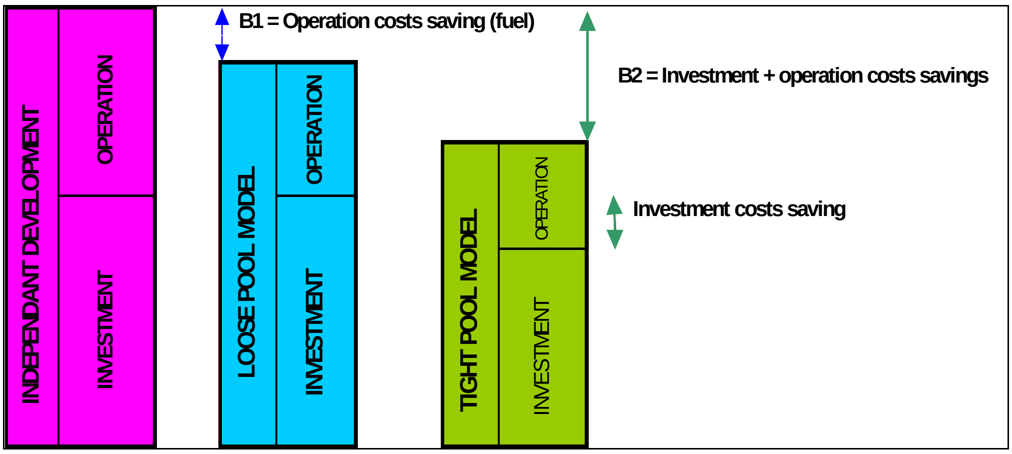

Figure 2.2-1 - Savings from tight and loose pool models

2.2.1.3 Point of view of the economic analysis

2.2.1.3.1 A cost approach

In the course of the Eastern Nile Power Trade Program Study, the point of view of the analysis starts from a regional view (Phase I) to progressively focus on the Interconnection project (Phase II). In the present Module 6, the point of view of the economic analysis is regional, meaning the objective is to measure the potential global benefit (in fact cost savings) for the region, and not the specific benefit for each country.

As per TOR, and according to good methodology, a cost approach[1] is carried out in the present economic Study, with the objective to determinate the least cost regional plan. The costs involved here are generation and interconnection investment costs, and the operation costs depending on the presence or not of the interconnection[2].

This means, for example, that the share of cost of projects (interconnection or HPP) between the different countries is not considered or relevant at this stage, because it does not change the global cost for the region. Subsidies to fuel, duties or taxes are not considered either because they don't change the cost paid by the countries to develop their generation mixes.

In the same way, the allocation of the benefits to the different stakeholders is not relevant at this stage. In other words, the possible selling price of power and wheeling tariff are not relevant in the present economic analysis[3].

In this way, the global benefits (i.e. the global cost reduction) for the region could be evaluated.

By contrast, the economic and financial analysis from the point of view of the interconnection project (Business Plan of the project) will be evaluated in Phase II of Eastern Nile Power Trade Program Study, while the economic and financial analysis from the point of view of the HPP projects are evaluated in the relevant pre-feasibility or feasibility studies.

In this way, the global benefits (i.e. the global cost reduction) for the region could be evaluated.

2.2.1.3.2 Selling price and sharing savings

In order to give more understanding on the cost approach, the relation between the selling price of energy, the generation cost of energy and the sharing of global savings can be illustrated by the following simple example:

<u>Hypothesis</u>:

Country A exports to country B one MWh generated at 40 $/MWh, which comes in substitution of 100 $/MWh generation in country B.

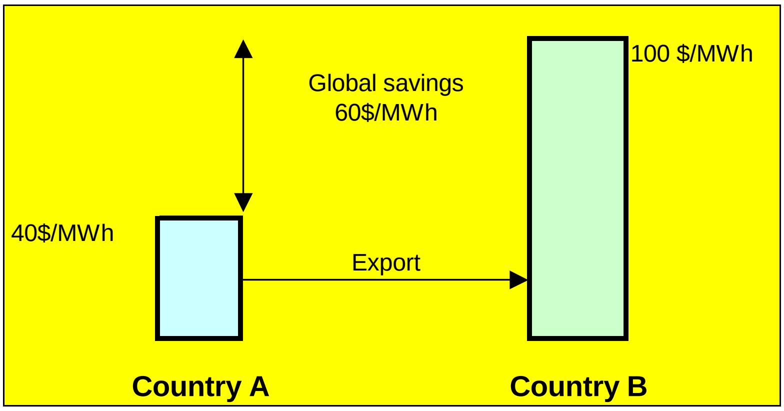

Figure 2.2-2 - Relation between savings and selling price (1)

[1] costs include externalities : non energetic benefits and mitigation costs
[2] the costs independent of the presence or not of the interconnection are not relevant for the Study
[3] The selling price of energy would be relevant for the economic Study if the point of view of the analysis was from the Utilities.

Economic approach of the global savings:

In country A: the generation cost increases by 1 x 40 $.

In country B: the generation cost decreases by 1 x 100 $.

Global cost savings for A + B: 1 x 60 $.

What are the savings for each country ?

The savings for each country depend on how the global saving is shared between A and B, which is a result from the negotiation of selling price.

If the negotiated selling price is 70 $/MWh (savings shared 50% for each country):

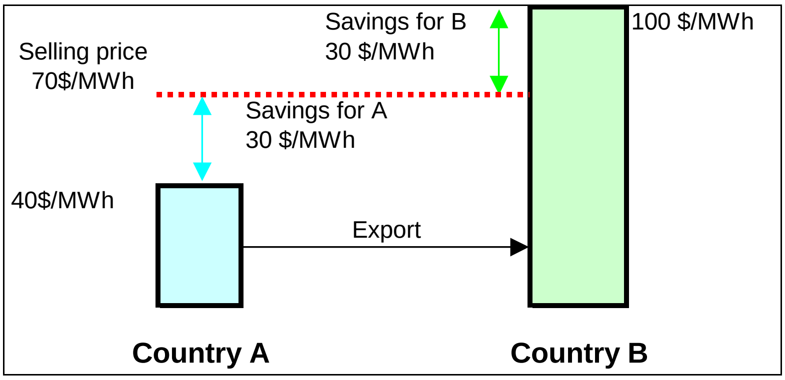

Figure 2.2-3 - Relation between savings and selling price (2)

- For country A: 100 $ generation is saved, 70 $ import is paid for import -> net savings = 30 $.

- For country B: 40 $ additional generation is paid, 70 $ is received from export ->net savings= 30$

The global saving is 60 $, which is of course the same value found by the cost approach.

Conclusion:

- the selling price is a way of sharing the global cost savings between the actors.
- the net savings for each country depends on the negotiated selling prices:

  Net savings for the importing country = Fuel savings – Selling price per MWh x Imported energy

  Net savings for the exporting country = Selling price per MWh x Exported energy – Generation cost of the exported energy

2.2.2 COMPARISON OF GENERATION COSTS IN THE THREE POWER SYSTEMS

A first picture of the possible economic power exchanges in the region can be given though the comparison of the generation cost in the different power systems:

The comparison of economic costs of generation (also called levelized cost[4]) is pertinent when power trade are the result of new generation investments purposely decided in the exporting country to come in substitution of otherwise necessary (and more expensive) generation investments in the importing country.

The comparison variable cost of generation[5] is pertinent when the investment decisions are not related to the power trade, but only to the demand development of each country, and available power is exported from one country to the other in substitution to more expensive generation.

The generation costs are evaluated on the basis of the market fuel price projection[6] (because the purpose of the Study is the evaluation of power exchanges – see Module 3 Vol 4,) which might be very different than the present fuel costs paid by the Utilities.

2.2.2.1 Comparison of economic costs of generation

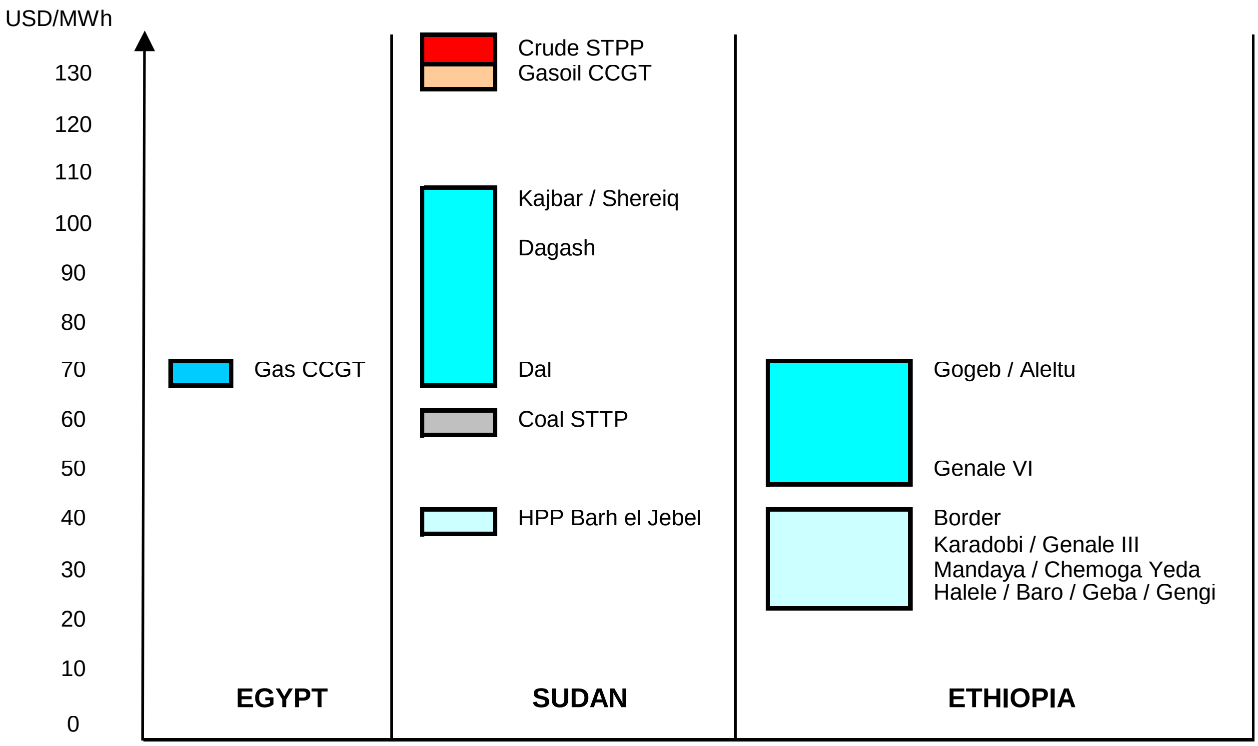

Figure 2.2-4 - Comparison of economic generation costs in the different generation mixes (6 000 hours/ year) - Year 2030 - Medium fuel price scenario (60 USD/bbl) - 10% discount rate

From the most cost effective projects to the more expensive we found:

- the lower cost generation projects is composed by a group of Ethiopian HPP projects (Mandaya, Karadobi, Border, Halele, Geba, etc) with economic cost from 25 to 40 USD/MWh;
- close to 40 USD/MWh, we found the Bahr el Jebel HPP projects in South Sudan;

[4] includes fixed (=investment + fixed O&M cost) and variable cost of generation
[5] includes solely the part of cost dependant on the amount of generation = fuel cost + variable O&M cost
[6] Annual Energy Outlook 2006 from US Department of Energy

- close to 60-70 USD/MWh, we found gas-fired CCGT in Egypt, coal-fired STPP in Sudan (but the number of coal-fired STTP is Sudan is limited by transmission capacity), and a group of hydro projects in Ethiopia;
- from 70 to 110 USD/MWh, we find the HPP projects in the Main Nile river in Sudan;
- finally, the most expensive units are gas oil-fired CCGT and crude oil-fired STPP in Sudan.

Accordingly, considering the cost and availability of power surplus, the bulk of power export in the region will come from cost effective HPP projects in Ethiopia (all Sudanese cost effective hydro power being absorbed by Sudan own internal demand).

Power export to Sudan would lead to the greater economic savings, because of greater cost differential between saved and imported energy, as well as lower transmission cost (shorter transmission line).

2.2.2.2 Comparison of variable costs of generation

While the economic cost of generation (related to what is often called Long Term Marginal Cost of generation) includes investment and operation costs, the variable cost (related to what is called Short Term Marginal cost) only includes fuel and variable O&M cost.

The following table compares, for year 2030, and for the medium fuel price projection the economic cost and the variable cost of generation for the main TPP candidates (crude oil = 60 USD/bbl, to be compared to market prices over 90 USD/bbl in November 2007):

	Economic cost (6 000 hours/year)	Variable cost	Ratio var. cost / economic cost
(Egypt) gas-fired 750 MW CCGT	71 USD/MWh	55 USD/MWh	77%
(Sudan) 500 MW gas oil-fired CCGT	130 USD/MWh	112 USD/MWh	86%
(Sudan) 500 MW crude oil-fired STPP	133 USD/MWh	105 USD/MWh	79%
(Sudan) coal-fired STPP	57 USD/MWh	29 USD/MWh	51%

Table 2.2-2 - Comparison of economic and variable costs of generation – Year 2030 – Medium fuel price projection – 10% discount rate

The variable cost represents most of the generation cost of CCGT and STPP (between 77 to 85%). This proportion increases in time along the general increase of fuel prices. This means that most of the future savings resulting from power trade will come from fuel savings (and not investment savings).

2.2.3 INDEPENDENT DEVELOPMENT OF THE THREE POWER SYSTEMS

This paragraph presents the main characteristics of the least cost generation expansion plans determined by the Consultant for the three isolated systems in absence interconnection between them. The reference hypothesis considered are described in detail in Modules 2 and 3 of the present Study.

2.2.3.1 Egypt

Main hypothesis:

- Medium demand projection (5.6% average annual growth rate).
- Medium fuel price projection (crude oil: 60 USD/bbl, NG = 8.6 USD/MBTU in 2030).
- Power export to Jordan (200 MW) and Libya (200 MW).
- No exchange with Sudan or Ethiopia.

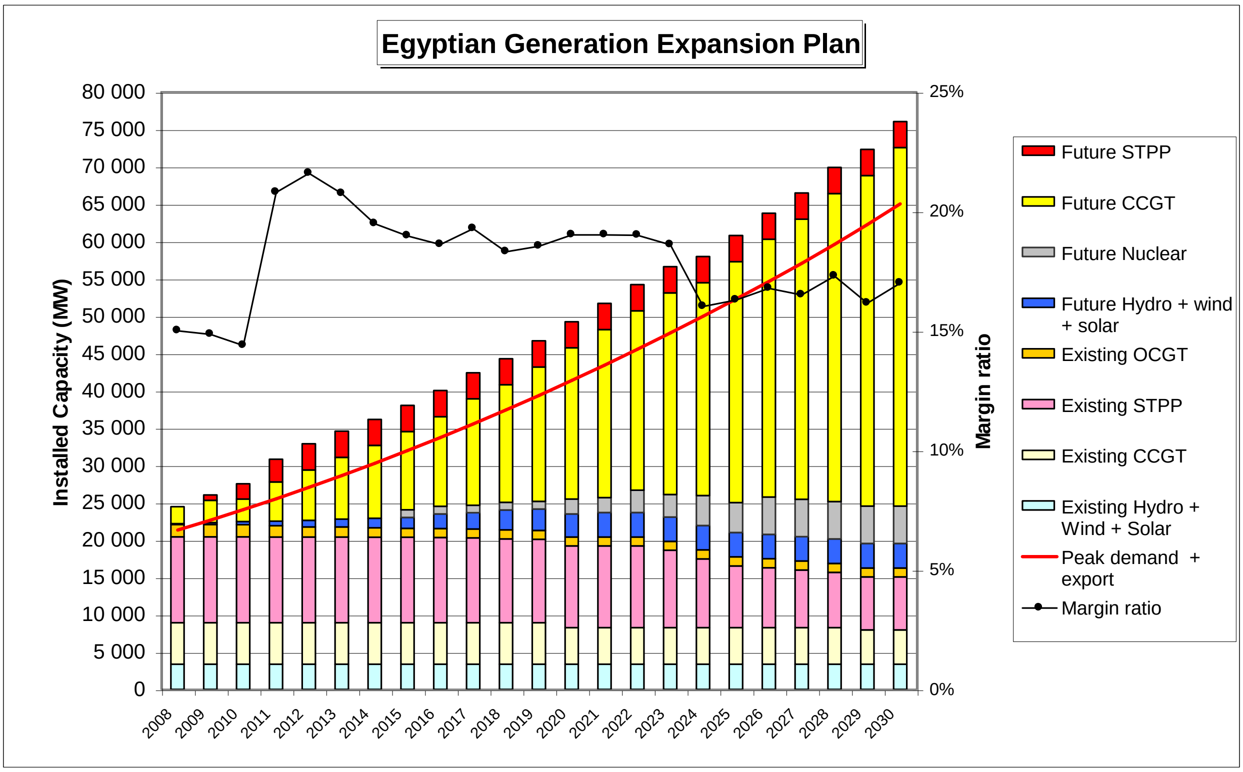

Figure 2.2-5 - Generation Expansion Plan – Egypt – Medium demand projection - No interconnection with Sudan / Ethiopia

Because of the large availability of natural gas in Egypt, the main part of the future development of generation capacity will be made on gas-fired CCGT. From 2020 on, the Egyptian power system needs, on average, three new 750 MW CCGT every year.

2.2.3.2 Ethiopia

Generation expansion plan for the Medium demand projection - Main hypothesis:

- Medium demand projection (average annual growth rate: 10.9%).
- Medium fuel price projection (crude oil: 60 USD/bbl in 2030).
- No exchange with Egypt or Sudan.
- Power export to Kenya (200 MW in 2011, 600 MW in 2020 and 1 200 MW in 2030).
- Power export to Djibouti (<53 MW).

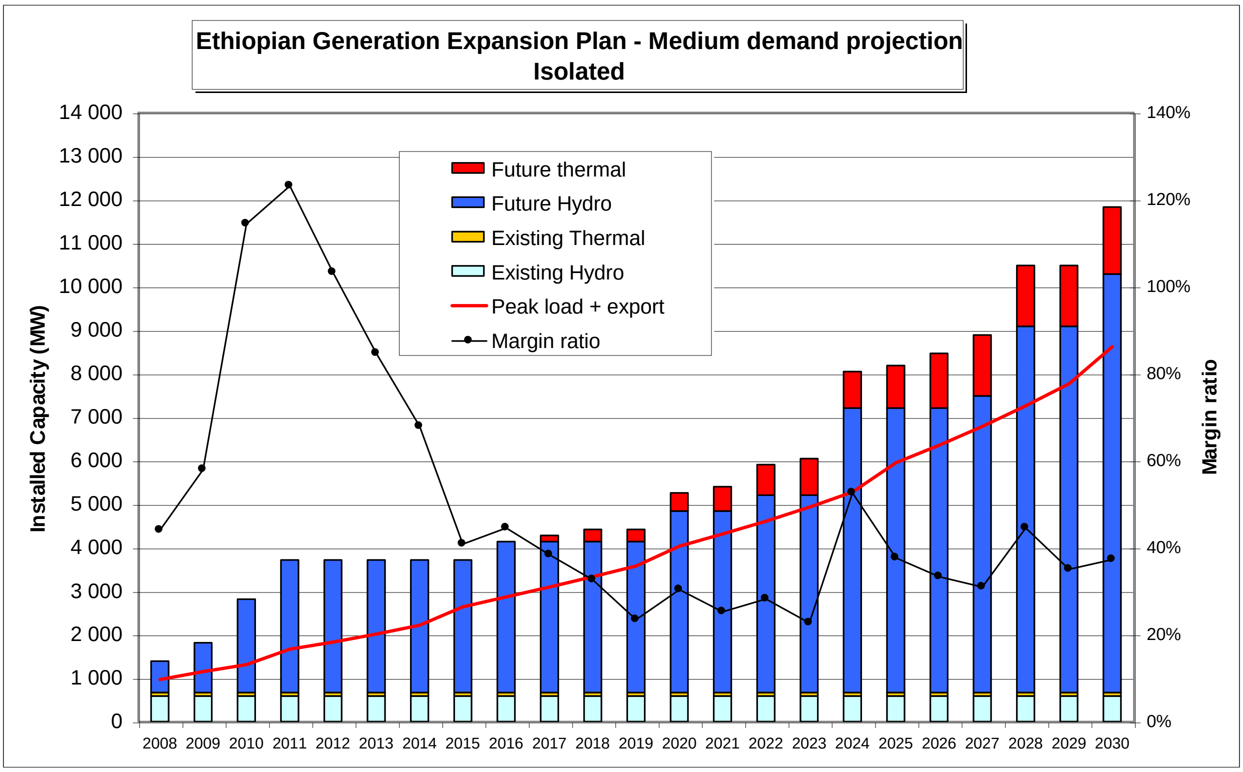

Figure 2.2-6 - Generation Expansion Plan - Ethiopia – Medium demand projection - No interconnection with Sudan / Egypt

The associated schedule of HPP commissioning is the following:

Commisioning Date	Hydro Project	Capacity MW	Average Generation GWh	TPP	Capacity MW
2008	Gibe II	420	1 600		
	Tekeze	300	1 200		
2009	Beles	420	2 000		
2010	Neshe	97	225		
2011	Gibe III (I)				
2012	Gibe III (II)	1 870	6 240		
2014					
2015					
2016	Halele Worabesa	420	2 245		
2017				OCGT	140
2018				OCGT	140
2019					
2020	Baro I + I + Gengi	700	4 409	OCGT	140
2021				OCGT	140
2022	Geba I + II	368	1 788	OCGT	140
2023				OCGT	140
2024	Mandaya	2 000	12 100		
2025				OCGT	140
2026				OCGT	280
2027	Chemoga Yeda	280	1 415	OCGT	140
2028	Karadobi	1 600	6 000		
2029					
2030	Border	1 200		OCGT	140
Total		9 675			1 540

Table 2.2-3 - Generation expansion plan - Ethiopia - HPP schedule – Medium demand projection

From 2010 to 2014, and with the commissioning of Gibe III (1870 MW), Ethiopia can take advantage of a significant surplus of hydro generation which can be exported to Sudan through the future 200 MW Ethiopia – Sudan interconnection.

To provide a satisfactory balance between supply and demand, the commissioning of the three large HPP on Blue Nile River (Mandaya, Karadobi, Border) is required from 2024 to 2030.

Generation expansion plan for the Target demand projection - Main hypothesis:

- High demand projection (also called "target scenario"): average annual growth rate =14.3%
- Medium fuel price projection.
- No exchange with Egypt or Sudan.
- Power export to Kenya (from 200 MW in 2011 to 1 200 MW in 2030) and Djibouti (<53 MW).

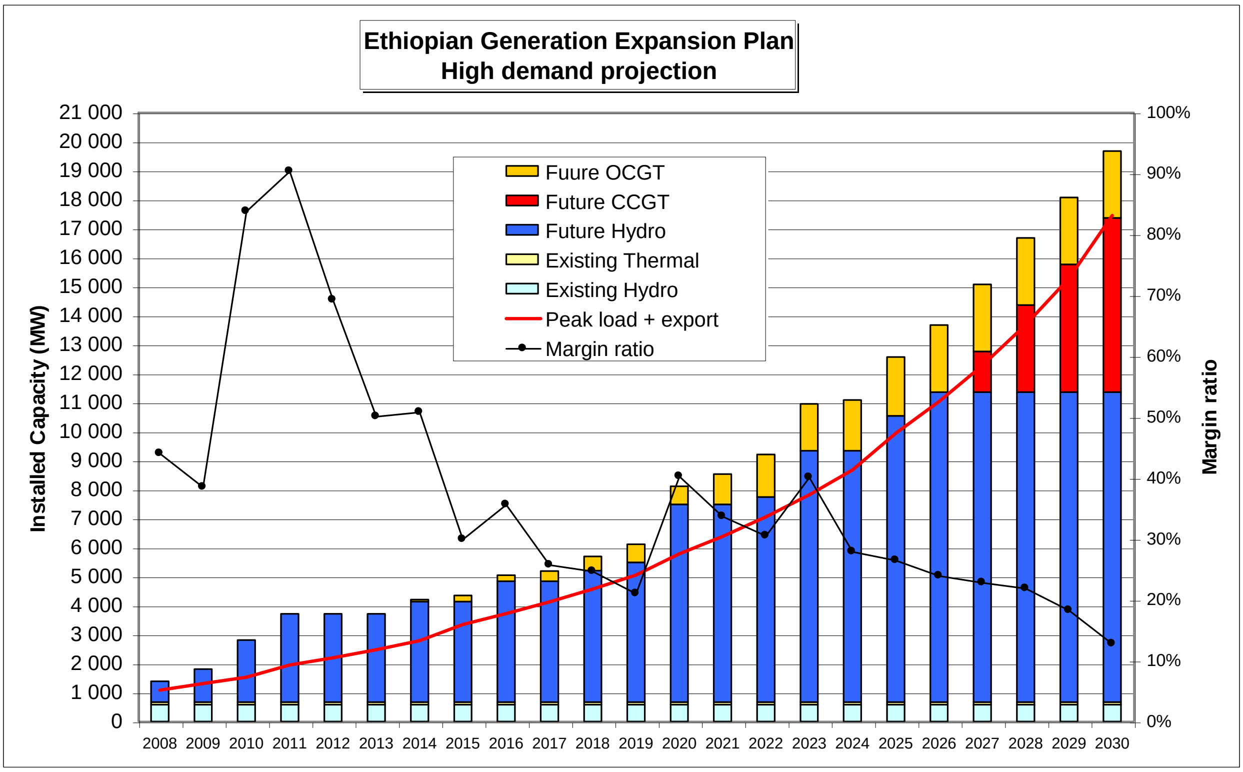

Figure 2.2-7 - Generation expansion plan - Ethiopia - High demand projection

In the target demand projection, the peak demand in 2030 is more than twice the peak demand in the medium projection: 14 330 MW instead of 6 814 MW. The largest HPP projects, Mandaya, Karadobi and Border are required in 2020, 2023 and 2025 (instead of 2024, 2028 and 2030 in the medium demand projection). All the hydropower projects identified in Module 3 Vol 3 (including Gojeb) are required in the Ethiopian power system by 2027.

The following table gives the schedule of commissioning:

Commisioning Date	Hydro Project	Capacity MW	Average Generation GWh	CCGT MW	OCGT MW
2008	Gibe II	420	1 600		
	Tekeze	300	1 200		
2009	Beles	420	2 000		
2010	Neshe	97	225		
2011	Gibe III (I)				
2012	Gibe III (II)	1 870	6 240		
2014	Halele Worabesa	420	2 245		70
2015					140
2016	Baro I + I + Gengi	700	4 409		
2018	Geba I + II	368	1 788		140
2019	Chemoga Yeda	280	1 415		140
2020	Mandaya	2 000	12 100		140
2021					-
2022	Genale III	254			420
2023	Karadobi	1 600	8 600		420
2024					140
2025	Border	1 200	6 000		140
2026	GenaleVI - Aleltu E&W	569	2 850		280
2027	Gogeb	153	520	1400	280
2028				1600	
2029				1400	
2030				1600	
Total		10 651		6000	2310

Table 2.2-4 - Generation expansion plan - Ethiopia - High demand projection

2.2.3.3 Sudan

Main hypothesis:

- Medium demand projection (average annual growth rate: 9.8%).
- Medium fuel price projection (crude oil: 60 USD/bbl in 2030).
- No exchange with Egypt or Sudan.

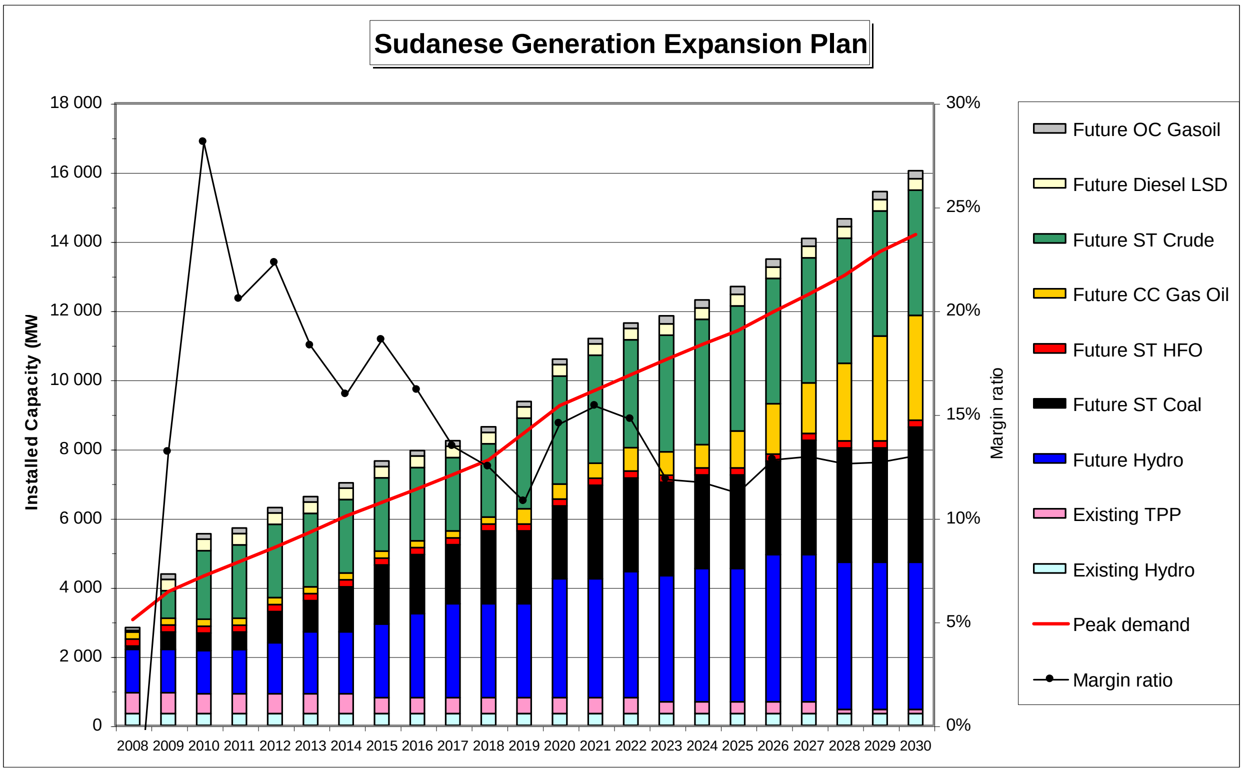

Figure 2.2-8 - Generation Expansion Plan – Sudan – Medium demand scenario

In the next 25 years, the Sudanese power system will evolve from a 50/50 thermal/hydro generation mix to a thermal dominated (75/25) generation mix. The new thermal generation capacity will be a combination of imported coal fired STPP, gas-oil fired CCGT and crude oil-fired STPP.

The resulting increase in fuel consumption, the proximity with Ethiopia, and the complementarity with the Ethiopian hydro based system, makes Sudan a natural market for the Ethiopian hydro export.

2.2.4 COMBINED DEVELOPMENT OF THE THREE POWER SYSTEMS

This paragraph examines the combined development of the three power systems upon the two levels of coordination described previously (loose and tight pool models). The amount of economic power exchanges is determined for various levels of interconnection capacity through simulation of the power systems. The economic profitability of the interconnection is evaluated under the key economic parameters.

2.2.4.1 Commissioning date and phasing of the interconnection

Based on the duration of technical studies, tender process and construction, the earliest commissioning date of the interconnection is close to 2015.

Regarding hydro generation, the earliest commissioning date of the large Ethiopian HPP projects on the Blue Nile (Mandaya, Karadobi, Border) is around 2020.

Accordingly, the present Study will consider 2020 as the commissioning date of the new interconnection project. However, the design of the interconnection (AC link between Ethiopia and

Sudan, AC or DC link up to Egypt) offers some flexibility and a commissioning in two phases of the (2015 to Sudan and 2020 to Egypt) is also examined in the Study.

2.2.4.2 Loose pool model

The operation optimization software SDDP was used to simulate the optimal operation (i.e. least cost dispatch) of the integrated system according to the capacity of the interconnection.

2.2.4.2.1 Characteristics of the hydro surplus in the loose pool model

Origin of the hydro surplus :

Basically, the Ethiopian hydro surplus in the loose pool approach are inherent to the development of a purely hydro system based on large size HPP:

a. Due to the large size of Ethiopian HPP projects compared to the Ethiopian internal demand (e.g. Mandaya represents more than 1/3 of the Ethiopian demand in 2024), hydro power surpluses are available for export during the first years following commissioning until the Ethiopian demand growth completely absorbs them. The surpluses are maximal on the commissioning of large HPP, and minimal just before new commissioning.

   NB: Smaller HPP projects would be included at a faster rate into the Ethiopian Generation Expansion Plan (i.e absorbed more rapidly by the demand growth) and would result in much less hydro surplus, but the resulting Ethiopian generation plan would be more expensive due to the reduced competitiveness of smaller HPP projects.

b. In a hydro dominated power system, a large amount of installed overcapacity is required in order to keep a proper supply / demand balance all year long, and even on the driest years.

The resulting hydro surplus, can be provided for export, on favourable hydrological conditions, at no additional cost for the Ethiopian power system.

Characteristics and costs of the hydro surplus

In the loose pool model, the generation expansion plan of Ethiopia is left unchanged compared to the "independent" development, with the exception of Mandaya which is anticipated from 2024 to 2020 in line with the commissioning of the connection to Egypt.

This model is typical of the actual power exchanges between European countries (spot market, month to month exchanges) which take benefits of temporary (short to medium term) power surplus appearing in one country or another. The additional HPP investments for Ethiopia are minimized, resulting in possible lower selling costs, but with the drawback of having more variability of the amount of power export from one year to another.

In actual operation, the main part of the power exchanges could probably be arranged on an annual basis, at the end of each wet season, when the amount of available energy in the reservoirs for the remaining part of the hydrological cycle is known.

2.2.4.2.2 Power exchanges

The power exchanges and the resulting generation savings have been evaluated for a variety of interconnection capacities (up to 1 200 MW to Sudan and up to 2 000 MW to Egypt). The following figure presents the evolution of the economic power exchanges for a scheme with 1 200 MW capacity between Ethiopia and Sudan and 700 W capacity between Ethiopia and Egypt:

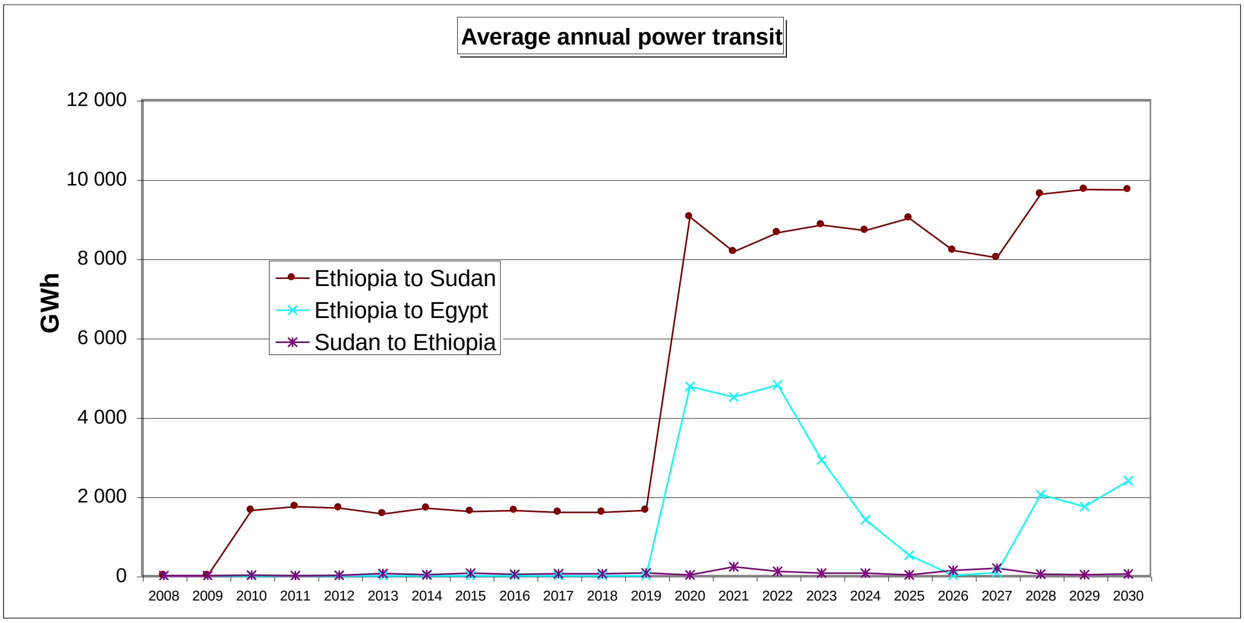

Figure 2.2-9 - Average annual power transit – ET-SU=1 200 MW – ET-EG= 700 MW – Loose pool

In order to minimize the regional operation costs, the economic exchanges develop preferably toward Sudan where the fuel savings are higher (because of higher local generation cost). The average annual power export from Ethiopia to Sudan, arises to 8 900 GWh/year over the 2020-2030 period, and nearly saturates the 1 200 MW capacity continuously.

The average annual power export from Ethiopia to Egypt, arises to 2 300 GWh/year over the 2020-2030 period, peaking during the first years following the commissioning of Mandaya (2020), Karadobi (2028) and Border (2030).

2.2.4.2.3 Sensitivity analysis

The basic principle in the sensitivity analysis is to change one single key economic parameter of the Study at a time in order to check its impact on the results.

In addition to the sensitivity to the capacity of the interconnection, the sensitivity was check along:

- high / medium / low fuel price projections (impact on fuel cost savings),
- high / medium / low Ethiopia demand projections (impact on the amount of hydro surplus),
- high / medium / low discount rate,
- phasing of the commissioning (one or two stages).

An overview of the economic results is presented in §0.

2.2.4.2.4 CO2 savings

The following table presents the annual quantity of CO_2 savings in tons and the corresponding present worth value of the CO_2 savings in 2008, based on a 5 or 10 USD/t CO_2 value:

Case		Additional export TWh/year	CO2 reduction M ton	8% discount rate 5 USD/tCO$_2$ MUSD	8% discount rate 10 USD/tCO$_2$ MUSD	10% discount rate 5 USD/tCO$_2$ MUSD	10% discount rate 10 USD/tCO$_2$ MUSD	12% discount rate 5 USD/tCO$_2$ MUSD	12% discount rate 10 USD/tCO$_2$ MUSD
Ethiopia-Sudan :	700 MW	4.1	3.09	83	166	54	108	37	74
Egypt-Ethiopia :	700 MW	3.9	1.68	45	90	29	59	20	40
Total		8.0	**4.77**	128	256	84	167	57	114
Ethiopia-Sudan :	1200 MW	7.1	5.34	143	286	94	187	64	128
Egypt-Ethiopia :	700 MW	2.3	0.99	27	53	17	35	12	24
Total		9.4	**6.33**	170	339	111	222	76	152
Ethiopia-Sudan :	1200 MW	7.1	5.34	143	286	94	187	64	128
Egypt-Ethiopia :	2000 MW	2.9	1.25	33	67	22	44	15	30
Total		10.0	**6.59**	177	353	115	231	79	158

Table 2.2-5 - Present worth value of CO_2 emission savings – Loose pool

These savings will have to be included in the economic analysis if the interconnection project is eligible to Clean development Mechanism (CDM).

2.2.4.2.5 Economic analysis

The economic analysis consists in comparing the net balance between:

- the cost of the interconnection (given in §2.2.4.2.5.1),
- the "benefits" provided by the interconnection consisting in generation cost savings (given in §2.2.4.2.5.2) and CO_2 emission savings (given in §2.2.4.3.3) (if the interconnection project is CDM eligible).

The classic economic criteria "Net Present value" and "Benefit to Cost ratio" are used hereafter to quantify the profitability of the interconnection project. It is reminded that the point of view of the analysis is regional.

2.2.4.2.5.1 Cost of the interconnection

The following table summarizes the investment cost (including IDC) of interconnection project for the three main options (more details are provided in Module 6 Vol 3):

Option			Investment cost ($MUSD_{2006}$)		
Capacity to Egypt	**Capacity to Sudan**	**Interconnection points**	**a = 10%**	**a = 12%**	**a = 8%**
700 MW	700 MW	Mandaya - Rabak / Merowe -Nag Hammadi 500 kV AC			
		Total :	**1 033**	**1 071**	**995**
700 MW	1200 MW	Mandaya - Rabak 500 kV AC	554	575	534
		Merowe -Nag Hammadi 500 kV AC	666	691	642
		Total :	**1 220**	**1 265**	**1 176**
2000 MW	1200 MW	Mandaya - Rabak 500 kV AC	363	376	350
		800 kV DC link + 500 KV AC Assiut-Samalut	2 520	2 645	2 414
		Total :	**2 883**	**3 021**	**2 764**

Table 2.2-6 - Investment cost of the interconnection options

The following table gives the present worth of the interconnection cost in 2008, for a commissioning of the interconnection in 2020, calculated on the base of the expenditure schedule of the interconnection during construction, the annual O&M cost and the discount rate:

Option			PW cost ($MUSD_{2006}$)		
Capacity to Egypt	**Capacity to Sudan**	**Interconnection points**	**a = 10%**	**a = 12%**	**a = 8%**
700 MW	700 MW	Mandaya - Rabak / Merowe -Nag Hammadi 500 kV AC	374	305	464
700 MW	1200 MW	Mandaya - Rabak 500 kV AC Merowe -Nag Hammadi 500 kV AC	433	355	534
2000 MW	1200 MW	Mandaya - Rabak 500 kV AC 800 kV DC link + 500 KV AC Assiut-Samalut	1 014	841	1 244

Table 2.2-7 - Present Worth Cost in 2008 of the interconnection options

2.2.4.2.5.2 Present worth of generation savings

In order to determine the additional generation savings provided solely by the new interconnection project, without inclusion of those provided by the future 200 MW Ethiopian-Sudanese interconnection, the savings are measured by comparison to the following reference situation:

- commissioning of the 200 MW Ethiopia-Sudan interconnection in 2010,
- generation expansion plans of Egypt, Ethiopia and Sudan resulting from the independent development of the three power systems.

The following table summarizes the present worth of generation savings for the main capacity options and key economic parameters of the study (10% discount rate):

Present worth of generation savings (MUSD2006) :

Ethiopian demand	Fuel projection	SU : 700 MW, EG : 0 MW	SU : 700 MW, EG : 700 MW	SU : 700 MW, EG : 2000 MW	SU : 1200 MW, EG : 700 MW	SU : 1200 MW, EG : 2000 MW
Median	High		2 610		3 360	3 610
Median	Median	1 150	1 710	1 870	2 090	2 210
Median	Low	840	1 120	1 340	1 520	1 520
Low	Median	1 170	1 920	2 260	2 540	2 590
High	Median	820	1 170		1 590	1 640

Table 2.2-8 - Present worth value of generation savings – Loose Pool

These generation savings result are fuel cost reduction from substitution of hydro power to thermal power. The values given are net of the interconnection transmission losses and from additional HPP investment cost in some scenarios (eg Mandaya anticipated in 2020 instead of 2024 in the medium demand projection).

NB: Other "non power" downstream benefits resulting from Ethiopian large new hydro projects (such as sediment capture, flood alleviation, etc) remain the same whether the interconnection is committed or not, because there is no change in the schedule on HPP commissioning in the loose pool approach.

2.2.4.2.5.3 Net savings

The following table presents the net savings (= generation savings minus interconnection cost) according to the various capacity options and key economic parameters of the study:

Net Present Value (MUSD2006):

Ethiopian demand	Fuel projection	SU : 700 MW, EG : 700 MW	SU : 1200 MW, EG : 700 MW	SU : 1200 MW, EG : 2000 MW
Median	High	2 240	2 930	2 600
Median	Median	1 340	1 660	1 200
Median	Low	750	1 090	500
Low	Median	1 540	2 110	1 580
High	Median	800	1 160	630

Ethiopian demand	Fuel projection	Discount rate	SU : 1200 MW, EG : 700 MW	SU : 1200 MW, EG : 2000 MW
Median	Median	8%	2 570	1 950
Median	Median	12%	940	490

Table 2.2-9 - Net Present Value of the interconnection – Loose pool model

The interconnection project is profitable under a wide range of hypothesis: its Net Present Value is positive for every capacity options considered and a wide range of key economic parameters. The following comments can be added:

FAVORABLE EVOLUTION OF ECONOMIC PARAMETERS :	
High fuel price	100 USD/bbl crude oil price projected in 2030 (instead of 60 USD/bbl in medium projection). For comparison the current market price, probably deeply distorted by speculations, is in the range of 90 to 100 USD/bbl (November 2007)
Low discount rate	8%, instead of 10% in base case : favors long term investment (i.e HPP against TPP)
UNFAVORABLE EVOLUTIONS OF ECONOMIC PARAMETERS:	
Low fuel price	35 USD/bbl crude oil price projected in 2030. Though this level cannot be completely rejected, it might not be the most probable one considering the past two years evolutions.
Ethiopian High demand	A 14.3% annual growth rate of the Ethiopian demand (instead of 10.9%) would leave reduced hydro surplus available for export (except if additional cost efficient HPP projects are studied).
High discount rate	12%, instead of 10% in base case : favors short term investment (i.e TPP against HPP)
INDIFFERENT ECONOMIC PARAMETERS :	
Egyptian and Sudanese Demand	The level of Egyptian and Sudanese demands has no impact on the profitability of the interconnection because the same type and amount of generation will be "saved" : gas-fired CCGT in Egypt, combination of gasoil-CCGT and crude oil STPP in Sudan.

2.2.4.2.5.4 Comparing options

The different option capacities can be compared through the NPV, and also through the Benefit to Cost Ratio (also called BCR), which is given in the table below:

Benefit / Cost ratio (present worth of benefits / present worth of cost) :

Ethiopian demand	Fuel projection	SU : 700 MW, EG : 700 MW	SU : 1200 MW, EG : 700 MW	SU : 1200 MW, EG : 2000 MW
Median	High	7.1	7.8	3.6
Median	Median	4.6	4.8	2.2
Median	Low	3.0	3.5	1.5
Low	Median	5.2	5.9	2.6
High	Median	3.2	3.7	1.6

Ethiopian demand	Fuel projection	Discount rate	SU : 1200 MW, EG : 700 MW	SU : 1200 MW, EG : 2000 MW
Median	Median	8%	5.8	2.6
Median	Median	12%	3.6	1.6

Table 2.2-10 - Benefit to Cost Ratio – Loose pool model

The benefit to Cost ratio is another way to express the profitability. It is equal to the Net Present value of the benefits (called here "generation savings") divided by the Net Present value of the cost. A value greater than one means the benefits outbalance the cost of the project.

The NPV is maximized for a 1 200 MW (Sudan) 700 MW (Egypt) scheme. While still positive, the NPV decreases going up to a 2 000 MW (for Egypt) and 1 200 MW (for Sudan) scheme. This is due to the significantly higher cost of the 2 000 MW link to Egypt (because of longer distance) while the additional fuel savings are low, the main part of the Ethiopia hydro surplus having already been provided for export.

The analysis of the BCR shows an equivalence – for this criteria - between the 700 MW (Sudan) 700 MW (Egypt) scheme and the 1 200 MW (Sudan) 700 MW (Egypt) scheme. This is explained by the lower investment cost of 700 MW / 700 MW option.

The BCR then decreases going up to a 2 000 MW (for Egypt) for the same reason as the NPV, but remains largely greater than 1.

2.2.4.2.5.5 Savings per country and Pay back period

The pay-back period is the period of time necessary for the savings (i.e. mainly fuel savings) to balance the expenses (interconnection cost and anticipation cost of Mandaya HPP[7]). At the end of the payback period the present value of the savings is equal to the present value of the expenses.

For a scheme with 1 200 MW capacity to Sudan and 700 MW capacity to Egypt, the interconnection investment is paid after 4 full years of operation (medium demand projection for all countries, medium fuel price projection, 10% discount rate). This very short pay back period is consistent with the high benefit to cost ratio of the interconnection project.

The average export to Egypt amounts to 2.3 TWh/year, with 120 $MUSD_{2006}$/year average fuel savings (natural gas), while the average export to Sudan amounts to 8.9 TWh/year, with an average fuel savings of 760 $MUSD_{2006}$/year (450 $MUSD_{2006}$/year from crude oil and 210 $MUSD_{2006}$/year from gas oil).

2.2.4.2.5.6 Phasing of the interconnection

[7] For the Ethiopian medium demand projection, the commissioning of Mandaya in the loose pool model is anticipated from 2024 (independent development approach) to 2020. For the low demand projection, Mandaya is anticipated from 2025 to 2020. For the target projection, there is no anticipation because the "natural" commissioning date of Mandaya is 2020.

An underlying finding from the previous results is the significant benefit to increase significantly the An underlying finding from the previous results is the large benefit that would result from a significant increase of the committed Ethiopia-Sudan interconnection beyond its original 200 MW.

In the previous analysis, the selected commissioning date of the new interconnection project is 2020, because from that date large amount of hydro surplus could be provided from large Ethiopian HPP projects on Blue Nile (Mandaya, Karadobi, Border).

The previous economic analysis shows that the most promising interconnection options are 1 200 MW export capacity to Sudan and 700 or 2 000 MW export capacity to Egypt. It is interesting to note that these options gives some flexibility in the phasing of the interconnection, which in turn provides some additional economic return.

For example, in the 2 000 MW (Egypt) – 1 200 MW (Sudan) scheme, the interconnection between Ethiopia and Sudan is through a double circuit 500 kV AC line between Mandaya to Rabak. If commissioned before 2020 (i.e. before the connection of Mandaya on the grid) the maximum transmission capacity of this line would be around 500 MW[8]. On the Sudanese side, the 500 kV Rabak-Merigan and Rabak-Jebel Aulia would have to be anticipated accordingly from its initial commissioning date (2020 in Sudanese Transmission Master Plan) in order to receive this additional power.

Considering the time necessary for detailed study, tender, construction, the earliest date of commissioning for this part of the interconnection between Ethiopia and Sudan is around 2015. This means an additional equivalent 500 MW transit capacity could be connected from 2015.

The simulations show that the resulting additional power exchanges during the 2015 to 2020 period would bring an additional fuel saving of 440 MUSD (Present Worth Value in 2008), while the additional investment cost for the interconnection is in the range of 120 to 160 MUSD (Present Worth Value in 2008) depending on the actual interconnection option[9].

Accordingly, the Consultant would suggest to consider in the Phase II of the present Study a commissioning in two phases of the interconnection, the first phase in 2015, increasing the capacity between Ethiopia and Sudan, the second phase in 2020 with the completion of the interconnection to Egypt.

2.2.4.3 Tight pool model

2.2.4.3.1 Introduction

The tight pool approach is probably more relevant to the final objective of the interconnection and the emergence of a large power market. In this approach, the countries coordinate their decisions of generation investments in order to minimize the global regional generation cost (investment and operation). More precisely, this means that hydro generation investments in Ethiopia are purposely anticipated (compared to the pool approach) in order to provide additional and more regular export power to Egypt and Sudan.

Theoretically, some generation investments could be delayed in Egypt and Sudan due to the increased power import. However, due to the continuous increase of the fuel prices all over the period of the Study, the investment cost represents only 15 to 25% of the total generation cost of new thermal plants by 2020-2030. Accordingly, the Consultant would not recommend any

[8] Before the commission of Mandaya, the maximum transmission capacity is be limited by the fact that there would be no injection of MVAR at Mandaya substation to maintain the voltage.
[9] This cost is split in: 80 to 120 MW (depending on the option) for the anticipation of Mandaya-Rabak, and 35 MUSD for the anticipation of 500 kV Rabak-Meringan and 500 kV Rabak-Jebel Aulia

modification of the Generation Expansion Plans of Egypt and Sudan, which means these countries would keep their ability to balance their power demand with their own supply whenever power import are not available.

The tight pool approach has been carried out for the medium and the low Ethiopian demand projections. Indeed, the tight schedule of Ethiopian HPP for the high demand projection (independent development case) offers virtually no room for anticipation of any HPP projects.

2.2.4.3.2 Economic power exchanges

2.2.4.3.2.1 Medium demand projection for Ethiopia

The following figure presents the evolution of the economic power exchanges for a scheme with 1 200 MW capacity between Ethiopia and Sudan and 2 000 MW capacity between Ethiopia and Egypt, and the medium demand projection for Ethiopia:

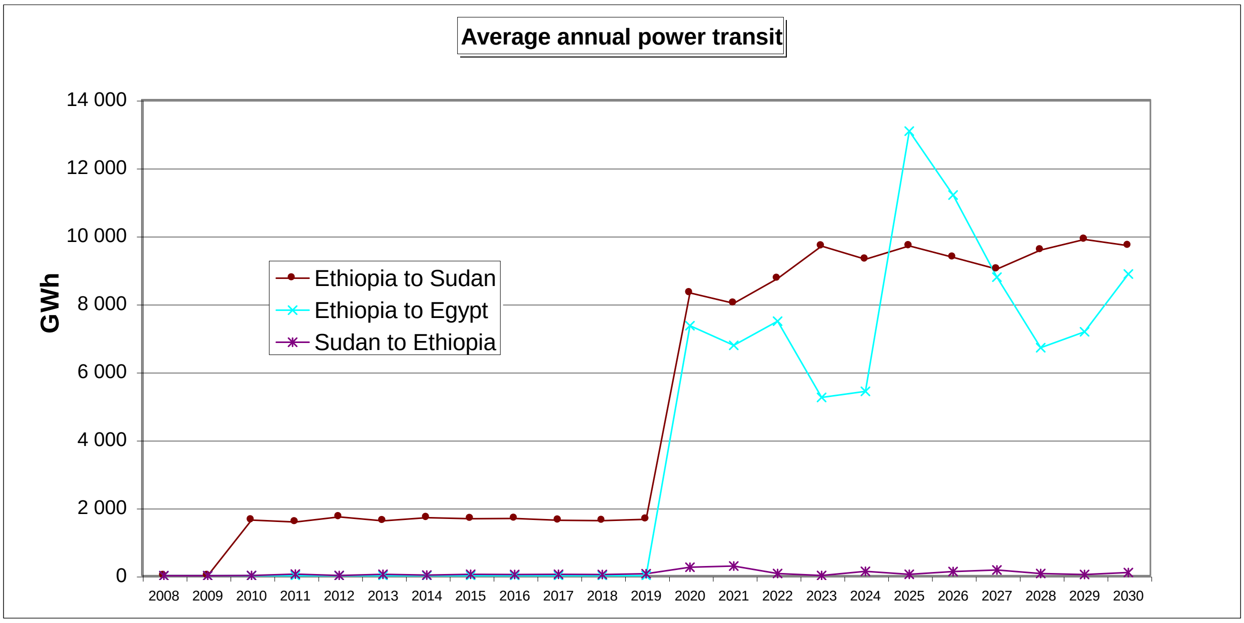

Figure 2.2-10 - Average annual power transit - ET-SU=1 200 MW, ET-EG=2 000 MW- Tight pool – Medium demand projection for Ethiopia

The increase of power exchange is readily appearing with comparison to the loose pool situation:

- The average annual power export from Ethiopia to Sudan arises to 9 200 GWh/year over the 2020-2030 period, and saturates the 1 200 MW capacity continuously (equivalent to 7 700 h / year at 1 200 MW).
- The average annual power export from Ethiopia to Egypt arises to 7 700 GWh/year over the 2020-2030 period (equivalent to 4 380 h / year at 2 000 MW).

The underlying generation expansion plan for Ethiopia includes the following modifications compared to the "independent development" situation:

- anticipation of Mandaya from 2024 to 2020,
- anticipation of Geba I+II: from 2022 to 2021,

- anticipation of Chemoga Yeda from 2027 to 2022,
- anticipation of Karadobi from 2028 to 2025,
- Genale III enters the GEP in 2022,
- Genale IV enters the GEP in 2023,
- Aleltu East and West enters the GEP in 2029.

Border commissioning date is left unchanged at 2030 in order to keep a 5-year interval between the commissioning dates of Mandaya, Karadobi and Border, compatible with the reduction of the negative downstream effects during the successive filling of these large reservoirs.

2.2.4.3.2.2 Low demand projection for Ethiopia

Apart from the Ethiopian hydro projects identified for the present Study in Module 3, other medium scale hydro projects might exist which could cover part of the internal Ethiopian power demand evolution. Accordingly, the low demand projection might give some additional appreciation of the potential amount of power that could be exported from Ethiopia.

For a scheme with 1 200 MW capacity to Sudan and 2 000 MW capacity to Egypt, the amount of power exchanges to Egypt increases to 12 700 GWh/year over the 2020-2030 period (equivalent to 6 300 h / year at 2 000 MW):

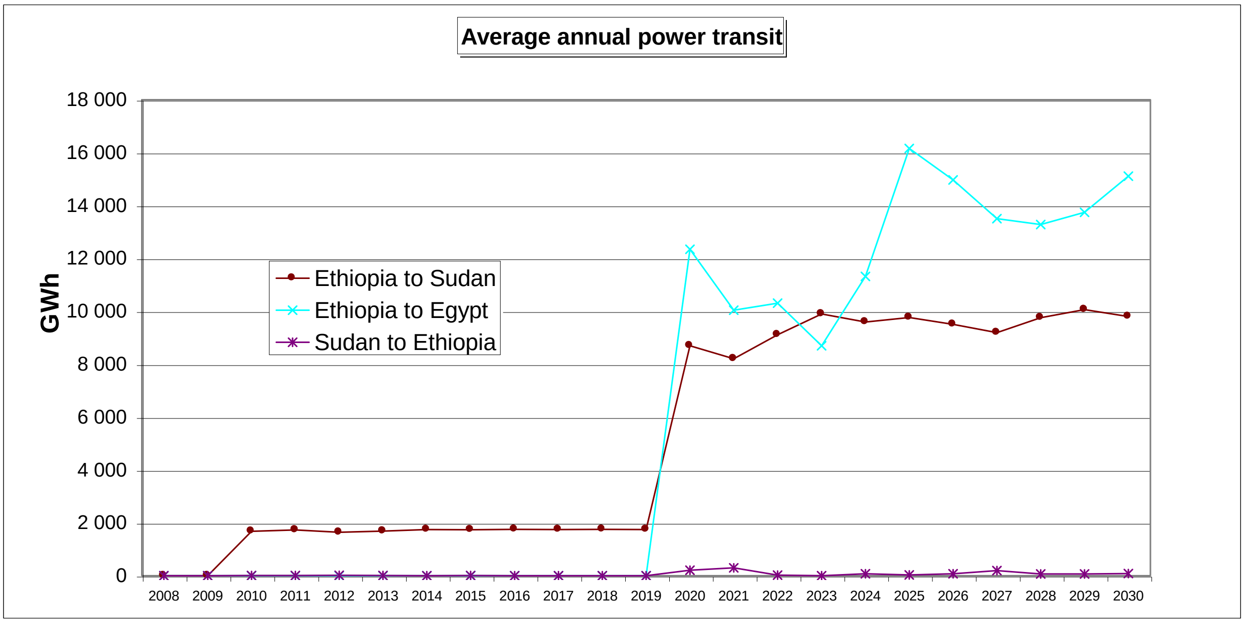

Figure 2.2-11 - Average annual power transit - ET-SU=1 200 MW, ET-EG=2 000 MW- Tight pool – Low demand projection for Ethiopia

2.2.4.3.3 CO2 savings

The following table presents the annual quantity of CO_2 savings in tons and the corresponding present worth value of the CO_2 savings in 2008, based on a 5 or 10 USD/t CO_2 value:

Case		Additional export TWh/year	CO2 reduction M ton	Present worth value: 8% discount rate, 5 USD/tCO$_2$ MUSD	8% discount rate, 10 USD/tCO$_2$ MUSD	10% discount rate, 5 USD/tCO$_2$ MUSD	10% discount rate, 10 USD/tCO$_2$ MUSD	12% discount rate, 5 USD/tCO$_2$ MUSD	12% discount rate, 10 USD/tCO$_2$ MUSD
Ethiopia-Sudan :	1200 MW	8.1	6.1	163	327	107	214	73	146
Egypt-Ethiopia :	700 MW	5.2	2.2	60	120	39	78	27	54
Total		13.3	**8.3**	223	446	146	292	100	199
Ethiopia-Sudan :	1200 MW	7.5	5.6	151	302	99	198	68	135
Egypt-Ethiopia :	2000 MW	7.7	3.3	89	178	58	116	40	79
Total		15.2	**9.0**	240	480	157	314	107	214

Table 2.2-11 - Present worth value of CO_2 emission savings – Tight pool model

These savings will have to be included in the economic analysis if the interconnection project is eligible to Clean development Mechanism (CDM).

2.2.4.3.4 Economic analysis

2.2.4.3.4.1 Present worth of generation benefits

The following table gives the present worth of generation savings for the most relevant options (10% discount rate):

Present worth of generation savings ($MUSD_{2006}$)

Ethiopian demand	Fuel projection	SU : 1200 MW, EG : 700 MW	SU : 1200 MW, EG : 2000 MW
Medium	High	3 800	4 150
Medium	Medium	2 360	2 600
Medium	Low	1 360	1 490
Low	High	3 140	4 020
Low	Medium	2 420	3 020

Table 2.2-12 - Present worth value of generation savings – Tight Pool model

NB: These generation savings are net of interconnection transmission looses, and of the additional investment costs resulting from the anticipation of several HPP in Ethiopia (compared to the independent development of Ethiopia).

2.2.4.3.4.2 Net savings

The following table presents the net savings (generation savings minus interconnection cost) according of the various capacity options and key parameters of the study:

NPV ($MUSD_{2006}$):

Ethiopian demand	Fuel projection	SU : 1200 MW, EG : 700 MW	SU : 1200 MW, EG : 2000 MW
Medium	High	3 310	3 110
Medium	Medium	1 870	1 560
Medium	Low	870	450
Low	High	2 650	2 980
Low	Medium	1 930	1 980

Ethiopian demand	Fuel projection	Discount rate	SU : 1200 MW, EG : 700 MW	SU : 1200 MW, EG : 2000 MW
Medium	Medium	8%	3 320	2 760
Medium	Medium	12%	1 180	910

Table 2.2-13 - Net Present Value of the interconnection – Tight pool model

The anticipation of large Ethiopian HPP, along with an increase of power exports, provides an increase of the profitability of the interconnection project for the region.

2.2.4.3.4.3 Comparing options

The next table provides the Benefit to Cost Ratio:

Benefit / Cost ratio :

Ethiopian demand	Fuel projection	SU : 1200 MW, EG : 700 MW	SU : 1200 MW, EG : 2000 MW
Medium	High	7.8	4.0
Medium	Medium	4.8	2.5
Medium	Low	2.8	1.4
Low	High	6.4	3.9
Low	Medium	4.9	2.9

Table 2.2-14 - Benefit to Cost Ratio – Tight pool model

While the benefit to cost ratio would favors the ET-SU: 1 200 MW – ET-EG: 700 MW scheme, the Net Present Value is close to the ET-SU: 1 200 MW – ET-EG: 2000 MW scheme. Accordingly, this larger design is probably preferable for the region, giving more flexibility for the future expansion of the power market in the region .

2.2.4.3.4.4 Savings per country and Pay back period

For a scheme with 1 200 MW capacity to Sudan and 2 000 MW capacity to Egypt, the interconnection investment is paid after 7 full years of operation (medium demand projection for all countries, medium fuel price projection, 10% discount rate). The average export to Egypt would be 7.7 TWh/year, with 420 $MUSD_{2006}$/year average fuel savings, while the average export to Sudan would be 9.2 TWh/year, with an average fuel savings of 810 $MUSD_{2006}$/year.

Whenever the Ethiopia demand follows the low demand projection, the pay back period would be 8 years. The average export to Egypt would increase to 12.7 TWh/year, with 680 $MUSD_{2006}$/year average fuel savings, while the average export to Sudan would be 9.4 TWh/year, with an average fuel savings of 820 $MUSD_{2006}$/year.

2.2.5 SUMMARY OF ADVANTAGES / DISADVANTAGES RESULTING FROM THE INTERCONNECTION PROJECT

A large part of the benefits from the interconnection (power trades, downstream power effects) can be evaluated in terms of monetary values, however these benefits do not represents all the possible positive outcome from the project.

In order to widen the view, the following simplified tables summarizes for the region and for each country, the main advantages and disadvantages from the interconnection project (these tables are adapted from the detailed information provided Module 5 EIA). In order to be more specific, the tables indicate the origin of the advantages or disadvantages:

- Power market: when the advantage/disadvantage exists if and only if the interconnection exists.
- HPP projects in Blue Nile River: when the advantage/disadvantage exists even in the absence of the interconnection.

Regarding the HPP positive or negative impacts and associated mitigation measures, only a brief overview is provided here, the reader is invited to find more information in the relevant pre-feasibility HPP Studies (Mandaya, Border, etc).

<u>Note on relation between the interconnection project and HPP downstream benefits</u>:

In the following table, for the sake of simplification, the downstream benefits are attributed to the HPP and not to the interconnection project.

Indeed, one of the results of the Study is to show that, even without interconnection, Ethiopia needs to develop the large hydro projects (identified in Module 3 Vol 4) in order to cover its own power demand over the next 25 years. The main part of the downstream benefits (regulation of flow, flood mitigation, uplift effect, etc) will be provided by the first large HPP project commissioned on the Blue Nile river (Mandaya or Karadobi). Subsequent projects would bring much lower additional downstream benefits.

For the target demand projection in Ethiopia, and without interconnection, the Study shows that Mandaya is required in 2020 and Karadobi in 2023. Accordingly, in this situation the downstream benefits are not attributable to the presence of the interconnection (commissioned in 2020)

In the Ethiopian medium demand projection, Mandaya is required in 2024 in the independent development situation, or in 2020 in the interconnected situation. Accordingly, the interconnection will induce a 4 years anticipation of Mandaya, and of the associated downstream benefits compared to the independent development scheme.

However, the possibility of selling part of the power from the large Blue Nile HPP projects for export would make these projects more bankable, favouring the possibility of rising funds for actually building them. Accordingly, there is an indirect link between the interconnection project, favouring the financial feasibility of the large Blue Nile HPP projects, and the resulting HPP downstream benefits.

2.2.5.1 Region

Origin	Advantages
Power market	Creation of a power pool: - global generation cost savings, - reduction of the cost of electricity for final user would favor overall development, - economies of scale in new generation capacity: development of larger low-cost hydropower plants made possible through the creation of larger power market, - hydro-thermal complementarity between Egypt, Ethiopia and Sudan, - mutual assistance in case of disturbances, - first step to the connection of the North Africa power systems to the South East African power pool. Regional cooperation and trust building.
Hydro projects	Coordination of the operation of HPP on the Nile river for overall regional benefit. Regulation of inflows and continuous availability of water. Reduction in CO_2 emissions

Origin	Disadvantages
Power market	None

Table 2.2-15 - Advantages / disadvantages for the region

2.2.5.2 Egypt

Origin	Advantages
Power market	Fuel savings (mainly Natural gas). Reduction in CO_2 emission. Securisation of the long term cost of generation (hydro power base imports have a generation cost independent of the variation of fossil fuels). Possibility for Egyptian generator companies to invest in low-cost hydro generation in Ethiopia.
Hydro projects	Regulation of inflows: - improved guarantee for irrigation, - opportunity to operate Aswan at lower level for a reduction of evaporation and a conversion to usable supply yield which may more than offset the reduction in power generation, - opportunity to avoid / reduce spilled energy (eg 1998/199). Reduced sediment: extension in life of High Aswan dam.

Origin	Disadvantages
Power market	None
Hydro projects	Head loss on Aswan during filling large reservoirs on Blue Nile river: - impact along time to be studied under a variety of conditions (hydrology, sequence of HPP, reservoir sizes, etc) in term of irrigation, capacity (MW), energy (GWh).

Table 2.2-16 - Advantages / disadvantages for Egypt

2.2.5.3 Ethiopia

Origin	Advantages
Power market	Valorisation of the hydro power surplus inherent to the Ethiopian power system. Valorisation of the hydro potential of Ethiopia for the benefit of Ethiopia and the interconnected countries. Boost for the development of the Ethiopian power mix, and consequently to the electrification rate in Ethiopia. Securisation of power supply in Ethiopia in case of drought conditions (possibility of thermal power import from Egypt and Sudan). Important role for the connection to Kenya and at a latter stage to the SAPP. Increase foreign exchange earnings. Construction employment, new skills for the future.
Hydro projects	Major energy benefits Low-cost renewable energy. Regional development (new roads, bridge, development of rural electrification, etc). Poverty reduction. Construction employment, new skills for the future. Development of irrigation.

Origin	Disadvantages
Hydro projects	Capital intensive projects may take time to be finance. Negative ES impacts (but can be mitigated through identified measures)

Table 2.2-17 - Advantages / disadvantages for Ethiopia

2.2.5.4 Sudan

Origin	Advantages
Power market	Fuel savings (crude oil and derivatives). Saved fossil fuel could be exported at a higher price rather than burned in thermal plants. Access to the Mediterranean power market, and in the long term to the SAPP. Re-enforcement of the complementarily between the Ethiopian hydro system and the Sudanese hydro/thermal system.

Hydro projects	Regulation of inflows (additional irrigation, navigation, uplift effect at Roseires, Sennar and Merowe: 2 200 GWh/year, equivalent to DAL generation). Reduced sediment: reduction in dredging costs at Roseires, reduction in drainage canal desilting maintenance cost, reduction in pump replacement cost. Increased irrigation supply reliability / Development of Irrigation agriculture: two crops per year. Flood reduction.

Origin	Disadvantages
Hydro projects	Reduction in flooding and sediment will lead to the conversion of recession agriculture to irrigation agriculture (but can be mitigated through identified measures).

Table 2.2-18 - Advantages / disadvantages for Sudan

2.2.6 CONCLUSION

The present Power Trade Study is the first quantitative Study bringing lights to the future evolution of the Egyptian, Ethiopian and Sudanese power systems up to 2030, and evaluating the benefits that would result from the establishment a regional power market between Egypt, Ethiopia and Sudan.

Previously, the generation expansion plan of Sudan (LTPPS 2006) was studied up to 2030, the Egyptian generation expansion plan covered the period up to 2028, the Ethiopian expansion plan (EPSEMPU June 2006) the period up to 2015, while power exchanges potential was assessed at scooping level.

The present Study demonstrates there are significant benefits for the Egypt, Ethiopia, and Sudan to develop an interconnection project in order provide Egypt and Sudan with the hydro surplus available from the large Ethiopian HPP projects, and consequently save fossil fuels and reduce CO_2 emissions in Egypt and Sudan.

2.2.6.1 Ethiopian hydro surplus

Ethiopia is well endowed with hydro resources. The hydro potential is estimated at about 30 000 MW, with only a fraction of which has been exploited so far. Accordingly, the Ethiopian power system will be the main source of power export in the Egyptian, Ethiopian, Sudanese regional market.

Part of the Ethiopian hydro surplus available for export are inherent to the internal development of the Ethiopian hydro mix:

a - Due to the large size of Ethiopian HPP projects compared to the Ethiopian internal demand (e.g. Mandaya represents more than 1/3 of the Ethiopian demand in 2024), hydro power surpluses are available for export during the first years following the commissioning of these large HPP projects, until the Ethiopian demand growth gradually absorbs them.

b - In order to maintain a proper supply / demand balance all year long, and even on the driest years, the Ethiopian hydro power system requires a large amount of installed overcapacity. The resulting hydro surplus can be provided for export on favorable hydrological conditions.

Further to these surplus "inherent" to any hydro power system, additional hydro power could be made available if the commissioning of large Ethiopian hydro plants is purposely anticipated (with respect to their "natural" schedule when Ethiopia develops "independently") or if hydro power projects are specifically developed for export.

The final amount economic hydro power available for export will also depend on the growth rate of the Ethiopian demand, the amount of power exported to other countries (e.g. Kenya) and the cost effectiveness of possible other Ethiopian hydro projects.

2.2.6.2 Phasing of the interconnection

The design of the interconnection (AC link between Ethiopia and Sudan, AC or DC link up to Egypt) gives some flexibility in the phasing of the interconnection. A commissioning in two phases would add to the profitability of the project: connection to Sudan in 2015 (earliest possible date considering duration of technical studies, tender process, construction) followed by a connection to Egypt in 2020 (earliest possible date when large amount of hydro power would be available from Ethiopian Blue Nile HPP projects).

2.2.6.3 Economy of the interconnection

The present Study shows that the interconnection project is characterized economically by a very good profitability, a short payback period and a high benefit to cost ratio.

The economy and optimal capacity of the interconnection were analyzed for two levels of coordination (or two types of power markets) between the three power systems: the loose pool and the tight pool models which are reminded briefly hereafter.

2.2.6.3.1 Loose pool model

The loose pool model consists basically in exporting the hydro surplus inherent to "independent" development the Ethiopian power system. The main characteristic of this model are:

- generation expansion plan of Ethiopia left unchanged compared to the "independent" development, with the exception of Mandaya which is anticipated from 2024[10] to 2020 in line with the commissioning of the connection to Egypt.
- the generation expansion plans of Egypt and Sudan left unchanged,
- lower amount of power export (compared to the tight pool approach).

This model is typical of the actual power exchanges between European countries (spot market, month to month exchanges) which take benefits of temporary (short to medium term) power surplus appearing in one country or another. The additional HPP investments in Ethiopia are minimized, resulting in possible lower selling costs, but with the drawback of having more variability of the amount of power export from one year to another.

In actual operation, the main part of the power exchanges could probably be arranged on an annual basis, at the end of each wet season, when the amount of available energy in the reservoirs for the remaining part of the hydrological cycle is known.

Accordingly very good BCR and short payback periods are achieved, the variability of the hydro surplus being balanced by the low global additional generation investment cost. The best scheme, from a strictly economic point of view, would be ET-SUD: 1 200 MW and ET-EG: 700 MW, with a

[10] For the Ethiopian low demand projection, Mandaya is anticipated from 2025 to 2020, while for the high demand projection no anticipation is required because the "natural" date of commissioning of Mandaya is 2020.

benefit to cost ratio of 4.8 and a very short 5 year-payback period for the reference hypothesis (medium demand projection, medium price projection).

However, going up to 2 000 MW capacity to Egypt would still be very profitable for the region (benefit to cost ratio =2.2), and would give more freedom and flexibility for a future evolution to a tight pool model and an expansion of the power market to the South (Kenya and SAPP) and to the North.

2.2.6.3.2 Tight pool model

In the tight pool model, the commissioning of several large hydro Ethiopian plants (Mandaya, Karadobi, Border, etc) is purposely anticipated, compared to the "independent" development of Ethiopia, in order to provide an additional and more regular amount of power export. Thus, the power exports arise for one part, from the "natural" hydro surplus inherent to the Ethiopian hydro generation mix, and for the other part from the anticipation of major Ethiopian HPP.

It is suggested to keep unchanged the generation expansion plans of Egypt and Sudan because, due to the projected fuel price increase along the period of the Study, the investment represents only 15 to 25% of the total generation of new thermal plants (or even 10 to 20% if crude oil reaches 100 USD/bbl). These countries would still keep their ability to balance their power demand with their own supply whenever power import are available or not.

The tight pool model is characterized by:

- increased amount of exports (compared to loose pool),
- lower variability of the power export to Egypt along the period of study (compared to loose pool),
- higher generation investment cost in Ethiopia (because of HPP anticipation).

The profitability of the project is still very good. The Net Present Value and the Benefit to Cost Ratio (BCR) are relatively similar than those in the loose pool model, the larger HPP investment costs being compensated by the larger fuel savings associated with larger export. The payback period is longer but still shorter than 10 years for the medium demand projections.

The BCR criteria would give some economic advantage to the scheme with ET-EG: 700 MW, but as in the loose pool approach, going to 2 000 MW for the connection to Egypt is certainly preferable, with still a short pay back period of 7 to 8 years, and a Benefit to Cost ratio of 2.7 to 4, according to hypothesis considered.

In actual operation, because of the increased HPP investment in Ethiopia, the power exchanges would probably be arranged largely on PPA basis, while additional exchanges on a spot to year basis are still possible according to the actual condition of the power systems.

The selling price of energy would be higher than in the loose pool model in order to recover the anticipated HPP investment.

2.2.6.3.3 Preservation of the benefits on adverse evolution of key hypothesis

The key parameters affecting the profitability of the interconnection project are the evolution of the fuel cost (a lower fuel cost evolution would reduce fuel savings), and to a lower extend the evolution of the Ethiopian demand (a higher Ethiopian demand would reduce the amount of hydro surplus).

However the interconnection project retains a good profitability (overall benefits for the region greater than costs) in all scenarios considered in the Study.

While it would difficult to derive any definite conclusion, it can be observed that the average crude oil market price during the last 12 months amounted to about 70 USD/bbl (with a maximum of 95 USD/bbl reached in November 2007). This is nearly half way between the high and medium fuel price projections considered in the present Study (55 USD/bbl and 91 USD/bbl respectively on average over 2015 to 2030).

2.2.6.4 Potential and actual savings

The generation savings evaluated in this Module 6 are potential (i.e. theoretical) savings resulting either from the optimal coordination of the three generation mixes, or from a "perfect" power market (either loose or tight pool). The actual savings will depend on the nature and importance of the future power pool, the type of possible power exchanges (spot, forwards, PPA, etc,), the actual level of coordination between the different Utilities, the policy to share costs and benefits of the interconnection and the HPP, the agreed selling price of energy, the wheeling tariff, etc.

2.2.6.5 Looking into the future

The interconnection project presents a short pay back period (<10 years) for the most relevant projections (high or medium fuel price projections, medium or low demand projections for Ethiopia).

At the end of the payback period (i.e before 2030), the investment cost of the interconnection will be recovered. The remaining cost associated with the transmission of power will be the transmission losses, and to a lesser extend the O&M costs. This reduction of transmission cost will boost the relative economic advantage of hydro power export from Ethiopia, giving opportunity to even more hydro investments, for the benefit of the interconnected power systems (lower cost of electricity and reduction of emissions). In the same way, the hydro economic advantage over thermal generation will probably keep on increasing with the probable continuing increase of crude oil price after 2030.

Finally, when the perspective is widen to the development of the African power markets, the commissioning of the interconnection between Egypt, Ethiopia and Sudan will be a determining step forward to the completion of the connection between the North Africa power markets and the South African power markets (SAPP).

2.3 TRANSMISSION STUDIES

2.3.1 ASSESSMENT OF THE TRANSMISSION SYSTEMS

2.3.1.1 Presentation

The transmission system of the three countries, Egypt, Ethiopia and Sudan was examined for the year 2015/2016.

This analysis was based on the master plan proposed by the companies.

For EEPCO, the master plan is described in the report “Ethiopian Power System Expansion Master Plan Updated – June 2006”.

For NEC, the master plan is described on the “Long Term Power System Planning Study”.

For EEHC, the analysis was based on computer files containing the 2006/2007 network and excel files listing the elements of the transmission system for the years 2002, 2005, 2010 and 2015, and other files with the network modifications.

The Ethiopian and Sudan power systems were examined for the year 2015/2016 with the 220 kV interconnection between Ethiopia and Sudan (planned for the year 2009) in operation. Ethiopia exported 100 MW to Sudan.

The behaviour of the power systems was analysed in steady state. This analysis enabled to point out the possible weak points of the future transmission system. Several load flow calculations were performed in normal and in contingency situations for the annual peak.

The results of this analysis are presented hereafter.

2.3.1.2 Egypt

The behaviour of the transmission system planned for the year 2015/2016, based on the 2015 planning data, was analysed.

Load Flow calculations were performed in normal, N-1 and in N-2 situations for the peak demand.

To face the N situation, the proposed reinforcements are listed hereafter:

- a second circuit between North Delta and Abu Zaabal
- a second circuit between Nobaria and Cairo 500
- a new circuit between Suez 500 and Heliopolis
- a new circuit between Sidi-Krir and a new 500 kV substation in Abu Kir
- a new circuit between Abu-Kir and Nobaria
- a fourth and a fifth 500 MVA 500/220 kV transformer in Cairo 500
- a third and a fourth 500 MVA 500/220 kV transformer in Abu Zaabal
- a second, a third and a fourth 500 MVA 500/220 kV transformer in Heliopolis
- a second 500 MVA 500/220 kV transformer in Bassous
- a second 500 MVA 500/220 kV transformer in Tebbin
- a second 500 MVA 500/220 kV transformer in High Dam
- a second 500 MVA 500/220 kV transformer in Kurimat
- two 500 MVA 500/220 kV transformers in Abu Kir

In Normal situation, taking into account the previous reinforcements, the behaviour of the system was satisfactory. The flows over the lines and through the transformers were below the rating of the equipment. The voltage profile was within the limits.

Due to the number of reinforcement proposed around Cairo, the N-1 situations were analysed on the backbone between High Dam and Cairo, where the interconnection is most likely to be connected.

- the 500 kV line N-1 criteria was satisfied on the network except for the line Samalut - Kurimat, an additional circuit would be needed,

- the 500/220 kV transformer N-1 criteria was not satisfied in High Dam and Nag Hammadi, and additional 500/220 kV transformer is necessary in both substation,
- the 500/132 kV transformer N-1 criteria was not satisfied in Nag Hammadi and Samalut, and additional 500/132 kV transformer is necessary in both substation,
- the 220 kV line N-2 criteria was satisfied between Kurimat and High Dam, except for the lines Nag Hammadi - Qena West, Kurimat - B.Suif East, Kurimat - Fayoum, and Sohag - Sohag East, additional circuit would be needed.

The proposed reinforcements described above will be included in the Egyptian transmission system for the study of the interconnection between Ethiopia, Sudan and Egypt.

2.3.1.3 Ethiopia

The VHV/132 kV transformation was examined. Some reinforcements of this transformation were necessary to satisfy the N-1 criterion. The proposed reinforcements are listed hereafter:

- Gefersa: Replacement of the four existing 24 MVA transformers by one new 100 MVA transformer (total installed capacity: 4 x 100 MVA);
- Kaliti I: Replacement of the three existing 45 MVA transformers by two new 100 MVA transformers (total installed capacity: 6 x 100 MVA);
- Two of these 45 MVA transformers could be installed at Melka Wakana and one at Gilgel Gibe;
- Woleita Sodo: Addition of a third 100 MVA 400/132 kV transformer (total installed capacity: 3 x 100 MVA);
- Melka Wakana: Replacement of the existing 22 MVA transformer by two new 45 MVA transformers (total installed capacity: 2 x 45 MVA);
- Addis North: Addition of one new 63 MVA transformer (total installed capacity: 3 x 63 MVA);
- Cotebe: Addition of one 63 MVA transformer (total installed capacity: 2 x 63 MVA);
- Kombolcha: Addition of one 63 MVA transformer (total installed capacity: 2 x 63 MVA);
- Gilgel Gibe I: Addition of one 45 MVA transformer (total installed capacity: 2 x 45 MVA);
- Sebeta: Addition of one 100 MVA transformer (total installed capacity: 3 x 63 MVA and 2 x 100 MVA).

In Normal situation, taking into account the previous reinforcement of the VHV/132 kV transformation, the behaviour of the system was satisfactory. The flows over the lines and through the transformers were below the rating of the equipment. The voltage profile was within the limits.

In N-1 situations:

- The 400/230 kV transformer at Bahir Dar was overloaded following the tripping of the 400 kV Debre Markos – Bahir Dar line.

To overcome this problem, it is proposed to install a second 400/230 kV transformer at Bahir Dar.

Whatever the other N-1 situations, there are no constraint on the system.

The proposed reinforcements described above will be included in the Ethiopian transmission system for the study of the interconnection between Ethiopia, Egypt and Sudan.

2.3.1.4 Sudan

In Normal situation, the behaviour of the transmission system was not totally satisfactory. Indeed, the three 300 MVA 500/220 kV transformers of Hasaheisa were slightly overloaded by 3%. Therefore, a fourth 300 MVA 500/220 kV transformer was assumed to be installed at Hasaheisa to recover a satisfactory behaviour and to comply with planning criteria adopted by NEC.

In N-1 situations, several constraints appeared on the system:

- Overload of the 500/220 kV transformations of Hasaheisa, Merowe and Nyala.
- Collapse of the western part of the system (Darfur area) following the tripping of the 500 kV line Fula - Nyala.
- Overload of the two 220 kV circuits between Bager and Giad, following the tripping of the third circuit.

To overcome these constraints and recover a system that satisfies the N-1 criterion, the following reinforcements are proposed:

- A fifth 300 MVA 500/220 kV transformer at Hasaheisa (or commissioning of a new 500/220 kV substation at Meringan).
- A third 150 MVA 500/220 kV transformer at Merowe.
- Operation of Bager 220 kV substation with two separate bus bars in N-1 situation.
- A fourth 150 MVA 500/220 kV transformer at Nyala and a second 500 kV line Fula - Nyala with the convenient shunt reactors.

The proposed reinforcements described above will be included in the Sudanese transmission system - proposed by NEC Master Plan - for the study of the interconnection between Ethiopia, Egypt and Sudan.

2.3.2 STUDY OF THE INTERCONNECTION ALTERNATIVES

2.3.2.1 Presentation of the study

Hydropower studies investigated the hydro generation resources along the Blue Nile River. They selected three sites, Mandaya, Border and Karadobi to built huge hydropower stations able to provide large amount of energy which the generation cost would be much lower than thermal generation cost.

Economic studies demonstrated that exporting hydropower generation from Ethiopia to Egypt and Sudan in substitution to thermal generation was profitable for the three countries. Simulations of the generation equipment operation in the interconnected system were performed.

A large range of power export from Ethiopia was investigated in the economic studies.

Three options of power exchange were proposed:

- Option 1: Ethiopia exports 690 MW to Egypt and 700 MW to Sudan.

- Option 2: Ethiopia export 690 MW to Egypt and 1 200 MW to Sudan.

- Option 3: Ethiopia exports 2 000 MW to Egypt and 1 200 MW to Sudan.

2.3.2.2 General design of interconnection alternatives

Based on these data, network studies were launched to investigate different solutions to interconnect the three countries and propose the least cost interconnection alternative that would be able to transmit the expected power exchanges and satisfy the technical requirements and the planning criteria.

It is recalled that Ethiopia and Sudan are expected to be interconnected by the year 2010 with one 220 kV double circuit line between Gonder and Gedaref.

The amount of transmitted power and the distance between the countries are the main parameters to design an interconnection link. With a range of power within 1 400 MW to 3 200 MW exported from Ethiopia over a distance of 700 km to Sudan and 2 100 km to Egypt, DC technology appeared as the best suitable solution. But with the presence of the Sudanese system, that allows controlling the voltage along the interconnection path, AC alternatives or mix AC+DC alternatives are technically possible and could also be competitive solutions to interconnect the three systems and transmit consequent power.

DC alternatives consist in a DC double pole line connecting Ethiopia to Egypt with a tapping station located in Sudan. Three voltage levels, 500 kV, 600 kV and 800 kV were used to design the interconnection link.

AC alternatives consist in two 500 kV AC lines, the first line between Ethiopia and the South of Sudan close to the border. A 500/400 kV transformation was installed at Mandaya HPP substation. The power exchange to Egypt flows over the Sudanese transmission system. The second line connects the North of Sudan to the South part of the Egyptian transmission system. The 500 kV voltage level, the highest voltage in operation in the interconnected system, was selected because it allows a maximum power transfer over long distance.

AC+DC mix alternatives consist in two 500 kV AC line between Ethiopia and Sudan and one DC 800 kV single pole link between Ethiopia and Sudan for the Option 2. For the Option 3, the DC link includes a 800 kV double pole+ one 800 kV single pole link.

Several interconnection points were selected in order to minimize the length of the interconnection line and to avoid as much as possible constraints on the transmission system of the three countries. Reducing the length of the line allows reducing the investment cost of the interconnection and the amount of losses and leads obtaining the least cost alternative.

In Ethiopia, Mandaya HPP 400 kV substation was the interconnection point for AC and DC alternatives.

In Sudan, for AC alternatives, Hasaheisa, Meringan and Rabak 500 kV substations, the main load centres close to the border with Ethiopia, were selected as interconnection points to receive power from Ethiopia. Merowe HPP and Port Sudan TPP 500 kV power stations, in the North of the country, were interconnections points to send power to Egypt.

For DC alternatives, Hasaheisa, the huge load centre close to the border, was the interconnection point selected to receive the tapping DC/AC converter. Due to the high population density between

Hasaheisa and Khartoum area, some difficulty could occur to build a new line in this area between the two towns. The DC/AC substation could be installed in Rabak instead of Hasaheisa.

In Egypt, for AC alternatives, Nag Hammadi, Sohag and Assiut 500 kV were the interconnection points. Beyond Assiut in the North, AC alternatives would not be technically feasible.

For DC alternatives, Nag Hammadi, Sohag, Assiut, Cairo 500 and Suez 500 kV substations were interconnection points. High Dam HPP 500 kV substation, close to the border with Sudan, cannot be extended and cannot receive the interconnection link.

Load flow calculations were performed to simulate the operation of the interconnected system and analyse its behaviour in normal operation and in emergency situation, one network equipment being out of operation. The system must satisfy the N-1 criterion. In emergency situation, the main electrical parameters, current, voltage, generated power, frequency, must be kept within the limits defined by the planning criteria without any adverse effect on the interconnection and on the three systems.

The study examined the connection of Mandaya HPP to the Ethiopian system, the interconnection with Egypt and Sudan being in operation. The different AC and DC interconnection alternatives were examined and the impact of the power exchange on the three systems was investigated. For AC alternatives, the power exchange devoted to Egypt flowed through the Sudanese system. Consequently, the impact of this exchange on Sudan was deeply investigated. Transmission losses over the interconnection were determined. The investment cost and the transmission cost of each alternative were calculated. The transmission cost, expressed in $/MWh, included the investment cost, the cost of losses and the operation and maintenance cost.

The main results for the three power exchange options are presented hereafter.

2.3.2.3 Study of Option 1: results

Option 1: Ethiopia exports 690 MW to Egypt and 700 MW to Sudan

2.3.2.3.1 Connection of Mandaya HPP to the Ethiopian transmission system.

It is proposed to connect Mandaya HPP to Debre Markos 400 kV substation with a 400 kV double circuit line equipped with 2x450 mm² bundle conductors. To discharge the power flow arriving at Debre Markos, the 400 kV system has to be reinforced with a single circuit line Debre Markos-Sululta and a third 400/220 kV 250 MVA transformer must be installed at Sululta.

2.3.2.3.2 Description of AC alternatives.

The interconnection between Ethiopia, Sudan and Egypt includes:

- 500/400 kV substation located on Mandaya HPP site, equipped with two 500/400kV 660 MVA transformers. This transformation is composed by six 220 MVA single-phase units + one 220 MVA single-phase unit as a spare part.

- 500 kV AC double circuit line between Mandaya HPP and Meringan 500 kV substation, (or Hasaheisa, or Rabak). The length of the line is 620 km (respectively 670 km, 570 km). The two circuits of the line are equipped at each end by one 255 MVAr reactor to energize the line in good condition and to control the voltage profile in operation.

- 500 kV AC double circuit line between Merowe HPP (or Port Sudan) and Nag Hammadi 500 kV substation. The total length of the line is 1 120 km (1 030 km). To control the voltage profile along the line and to facilitate the energizing of the line, an intermediate switching substation is installed in the middle of the line, close to the border between Sudan and Egypt. The two sections of the line are equipped at each end by one 230 MVAr reactor. Moreover, one 100 MVAr reactor is connected on the 500 kV bus bar of the intermediate switching substation, to facilitate the energizing of the line.

In Egypt the other interconnection points are Sohag (length of the line = 1 210 km) and Assiut (length of the line = 1 325 km).

2.3.2.3.3 Description of DC alternatives

Each DC link, built with a double pole line, includes two sections:

- First section between Mandaya AC/DC converter station and Hasaheisa tapping DC/AC converter station.
- Second section between Hasaheisa and DC/AC converter station in Egypt.

The cross section of the conductors and the number of conductors of the DC line are determined to respect a maximum value of the field strength and to respect a value of voltage drop or an amount of Joule losses along the line. The lines were designed to respect a 5% voltage drop that is equivalent to an amount of losses equal to 5% of the transmitted power.

Higher is the DC voltage larger is the total cross section of the conductors to respect the field strength and lower is the voltage drop.

Longer is the DC line, higher is the voltage drop and larger is the total cross section of the conductors.

The size of the AC/DC converters is:

- Mandaya = about 1 300 MW
- Hasaheisa = 500 MW
- Egyptian converter = 700 MW

It has been assumed that 200 MW of the 700 MW Sudanese import flowed over the 220 kV AC interconnection Gonder-Gedaref.

+/- 500 kV alternatives:

One double pole line equipped with 6 bundle Linnet conductors between Mandaya and Hasaheisa.

Section between Hasaheisa and Egyptian converter, double pole line equipped with:

- 6 bundle Ibis conductors for Nag Hammadi (length = 1 530 km)

- 6 bundle Hawk conductors for Sohag (length = 1 620 km)
- 6 bundle Hawk conductors for Assiut (length = 1 735 km)
- 6 bundle Dove conductors for Cairo 500 (length = 2 095 km)
- 8 bundle Hawk conductors for Suez (length = 2 165 km)

+/- 600 kV alternatives:

One double pole line equipped with 6 bundle Oriole conductors between Mandaya and Hasaheisa.

One double pole line equipped with 6 bundle Ibis conductors between Hasaheisa and Egyptian converter.

+/- 800 kV alternatives

The field strength was the most severe constraint, 8 Hawk bundle conductors were used for the double pole DC line from Mandaya to the Egyptian converter.

2.3.2.3.4 Impact of the power exchange on the transmission systems.

2.3.2.3.4.1 Sudan

Without new interconnection, the area of Hasaheisa, Meringan and Rabak was mainly supplied by the power stations located in the North of the country and close to Khartoum such as Merowe HPP, Port Sudan TPP. Power flowed over the 500 kV lines and the under laying 220 kV network from the North to the South.

The power exchange coming from Ethiopia has a benefit effect on the transmission system. It discharged the transmission system, reduced the power flows over the lines and decreased the amount of losses. The lines close to the interconnection points were loaded below 50% of their rating. Whatever the tripped element, no constraint appeared on the system.

2.3.2.3.4.2 Egypt

The Upper Egypt transmission system was supplied from High Dam HPP. Power flowed over the two 500 kV circuits from High Dam to Nag Hammadi and Sohag.

The power imported by the interconnection has a positive effect on the behaviour of the Egyptian system, since it reduced the power flow from Cairo area to the south. The N-1 criteria is satisfied on the 500 kV backbone between Cairo and High Dam, including the 500/220 kV and 500/132 kV transformation, and the N-2 criteria is similar to the N-2 without interconnection.

2.3.2.3.5 Behaviour of the interconnection in N-1 situation

2.3.2.3.5.1 AC Alternatives

The interconnected system satisfied the N-1 criterion. Whatever the tripped line, 500 kV or 220 kV, the behaviour of the interconnected system was satisfactory.

Nevertheless, following the tripping of one of the two 500/400 kV transformers at Mandaya, the remaining transformer would be overloaded by 51% of its emergency rating (1197 MVA). To overcome this constraint, two or three 250 MW units of Mandaya HPP should be automatically tripped. The loss of generation in the interconnected system would be compensated by the delivery of the primary reserve without any adverse effect of the systems. The power exchange would be reduced to about 700 MW until the replacement of the faulted single-phase element by the spare element.

Another solution would be to install three 510 MVA transformers at Mandaya (9 + 1 x170 MVA single phase elements).

2.3.2.3.5.2 DC Alternatives

The tripping of one pole or the blocking of one converter induced the lost of half of the power exchange. The three systems remained interconnected with a single pole that can operate with a return path by earth. Moreover, the AC 220 kV double circuit line Gonder-Gedaref interconnected Ethiopia and Sudan.

In Egypt, the loss of 50% of the power exchange (345 MW) induced a frequency drop. The speed governor of the machines operated to increase the generation and recover the missing generation without any adverse effect on the system.

The excess of power in the interconnected system Ethiopia + Sudan amounted to about 400 MW (half of the power exchange to Egypt and generation produced to compensate the losses) would induced a frequency surge.

To reduce the excess of generation in Ethiopia and the constraint on the system, it is necessary to reduce Mandaya generation. Two or three 250 MW units should be automatically tripped.

2.3.2.3.6 Costs

The investment cost of each interconnection alternative was calculated.

The costs of AC alternatives were similar, with the interconnection point at Nag Hammadi in Egypt,

The average value amounted to about (discount rate i = 10%):

1,070,000 k$

For DC alternatives, with the interconnection point at Nag Hammadi in Egypt,

The average value amounted to about:

1,200,000 k$

To compare the alternatives, transmission costs were calculated. The results are displayed below.

AC Alternatives:

Mandaya to	Hasaheisa			Meringan			Rabak		
Total Transmission Cost ($/MWh)	i=10%	i=12%	i=8%	i=10%	i=12%	i=8%	i=10%	i=12%	i=8%
Connection point Nag Hamadi	23.7	27.8	19.9	23.3	27.4	19.5	22.8	26.8	19.2
Connection point Sohag	24.5	28.7	20.5	24.1	28.3	20.2	23.6	27.7	19.8
Connection point Assiut	25.4	29.8	21.4	25.1	29.4	21.0	24.6	28.8	20.7

Table 2-19 Transmission cost of AC alternatives between Ethiopia and Egypt by Merowe

Mandaya to	Hasaheisa			Meringan			Rabak		
Total Transmission Cost ($/MWh)	i=10%	i=12%	i=8%	i=10%	i=12%	i=8%	i=10%	i=12%	i=8%
Connection point Nag Hamadi	22.9	26.9	19.2	22.5	26.5	18.9	22.0	25.9	18.5

Table 2-20 Transmission cost of AC alternatives between Ethiopia and Egypt by Port Sudan

Mandaya to	Meringan			Hasaheisa			Rabak		
	i=10%	i=12%	i=8%	i=10%	i=12%	i=8%	i=10%	i=12%	i=8%
Total Transmission Cost ($/MWh)	7.5	8.4	6.6	7.9	8.9	7.3	7	7.9	6.2

Table 2-21 Transmission cost of AC Alternatives between Ethiopia and Sudan

DC Alternatives:

Transmission cost ($/MWh) Sudan	+/- 500 kV			+/- 600 kV			+/- 800 kV		
	i=10%	i=12%	i=8%	i=10%	i=12%	i=8%	i=10%	i=12%	i=8%
Section Mandaya - Hasaheisa	14.3	16.2	12.7	14.7	16.7	12.9	15.6	17.9	13.6

Table 2-22 Transmission costs between Ethiopia and Sudan for 500, 600 and 800 kV DC

Total Transmission Cost ($/MWh)	500 kV			600 kV			800 kV		
	i=10%	i=12%	i=8%	i=10%	i=12%	i=8%	i=10%	i=12%	i=8%
Section Hasaheisa - Nag Hamadi	24.4	28.6	20.6	24.1	28.5	20.3	27.4	32.6	22.9
Section Hasaheisa - Sohag	25.7	30.3	21.7	24.9	29.4	20.9	28.3	33.7	23.6
Section Hasaheisa - Assiut	26.8	31.6	22.5	25.9	30.6	21.8	29.5	35.1	24.6
Section Hasaheisa - Cairo	30.6	36.3	25.6	29.0	34.3	24.3	33.2	39.6	27.7
Section Hasaheisa - Suez	31.6	37.6	26.4	29.6	35.0	24.8	34.0	40.4	28.3

Table 2-23 - Total transmission Cost between Ethiopia and Egypt

Based on the calculated values of the transmission cost, it is possible to conclude the following for Option 1:

Ethiopia exports 700 MW to Sudan: AC alternatives were the less expensive solutions. The transmission cost reached within 7 and 8 $/MWh (i=10%), then it reached 14 $/MWh for DC alternatives.

Ethiopia exports 690 MW to Egypt: the transmission cost was similar for AC and DC alternatives. It reached about 23 $/MWh for the less expensive alternative, Nag Hammadi interconnection point.

2.3.2.4 Study of Option 2: results

2.3.2.4.1 Presentation

In this Option 2, the power exchanges between Ethiopia, Sudan and Egypt were:

- Ethiopia exports 690 MW to Egypt (as in Option 1).
- Ethiopia exports 1200 MW to Sudan.

The duration of the power exchanges between Ethiopia and Sudan and between Ethiopia and Egypt are respectively 8 600 hours and 7 800 hours per year.

2.3.2.4.2 Description of the AC alternatives

The interconnection between Ethiopia, Sudan and Egypt includes:

- A 500/400 kV substation located on Mandaya HPP site, equipped with three 500/400 kV 660 MVA transformers. This transformation is composed by nine 220 MVA single-phase units + one 220 MVA single-phase unit as a spare part.

- Three 500 kV AC circuits between Mandaya HPP and Rabak 500 kV substation. The length of the line is 570 km. The three circuits are equipped at each end by one 230 MVAr reactor to energize the line in good condition and to control the voltage profile in operation.
- A 500 kV AC double circuit line between Merowe HPP and Nag Hammadi 500 kV substation. The total length of the line is 1 120 km. To control the voltage profile along the line and to facilitate the energizing of the line, an intermediate switching substation is installed in the middle of the line, close to the border between Sudan and Egypt. The two sections of the line are equipped at each end by one 230 MVAr reactor. Moreover, one 230 MVAr reactor is connected on the 500 kV bus bar of the intermediate switching substation, to facilitate the energizing of the line.

2.3.2.4.3 Description of DC alternatives

The interconnection between Ethiopia, Sudan and Egypt includes:

- A 500/400 kV substation located on Mandaya HPP site, equipped with three 500/400 kV 510 MVA transformers. This transformation is composed by nine 170 MVA single-phase units + one 170 MVA single-phase unit as a spare part.
- A 500 kV AC double circuit line between Mandaya HPP and Rabak 500 kV substation. The length of the line is 570 km. The two circuits are equipped at each end by one 230 MVAr reactor to energize the line in good condition and to control the voltage profile in operation.
- One 750 MW AC/DC converter station at Mandaya.
- One 700 MW DC/AC converter station at Nag Hamadi.
- One single pole DC line between Mandaya and Nag Hamadi.

There is no DC/AC taping station in Sudan.

The length of the line is equal to 2 200 km. Two voltage levels were examined: 600 kV and 800 kV.

For the 600 kV, the DC line is equipped with bundle Canary conductors (total cross section: 6 x 456 mm²).

For the 800 kV, the DC line is equipped with 8 bundle Hawk conductors (total cross section: 8 x 241 mm²).

2.3.2.4.4 Cost of the alternatives

The investment cost of each interconnection alternative was calculated.

The costs of AC alternative, with interconnection points at Rabak in Sudan and at Nag Hamadi in Egypt, amounted to: (discount rate i=10%).

1,220,350 k$

For AC+DC mix alternative, with the same interconnection points Rabak and Nag Hamadi, the average value amounted to about:

1,315,090 k$

To compare the alternatives, transmission costs were calculated. The results are displayed below.

AC Alternative: Between Mandaya and Rabak and between Merowe and Nag Hamadi

Transmission Cost ($/MWh)		
i=10%	i=12%	i=8%
22.2	26.0	18.6

Table 2-24 - Transmission cost of AC alternatives between Ethiopia and Egypt by Rabak and Merowe

Transmission Cost ($/MWh)		
i=10%	i=12%	i=8%
7.3	8.2	6.5

Table 2-25 - Transmission cost of AC Alternatives between Ethiopia and Sudan

AC+DC mix Alternative:

Transmission Cost ($/MWh)		
i=10%	i=12%	i=8%
23.4	27.8	19.6

Table 2-26 **-** Transmission costs between Ethiopia and Egypt for 800 kV DC

Transmission Cost ($/MWh)		
i=10%	i=12%	i=8%
5.9	6.8	5.1

Table 2-27 - Transmission Cost between Ethiopia and Sudan

Based on the calculated values of the transmission cost, it is possible to conclude the following for Option 2:

Ethiopia exports 1 200 MW to Sudan: AC+DC mix alternative is the less expensive solution. The transmission cost reaches about 6 $/MWh, then it reaches 7.3 $/MWh for the AC alternative.

Ethiopia exports 690 MW to Egypt: the transmission cost is similar for AC and AC+DC mix alternative. It reaches about 22 $/MWh for the less expensive alternative.

2.3.2.5 Study of Option 3: results

2.3.2.5.1 Presentation

In this Option 3, the power exchanges between Ethiopia, Sudan and Egypt were:

- Ethiopia exports 2 000 MW to Egypt.

- Ethiopia exports 1 200 MW to Sudan as in option 2.

The duration of the power exchanges between Ethiopia and Sudan and between Ethiopia and Egypt are respectively 7 800 hours and 6 300 hours per year.

With such an amount exchange imported by Egypt, the interconnection has to be connected downstream the Nile River, in Assiut, to limit the constraint on the 500 kV Egyptian system.

2.3.2.5.2 Description of the AC+DC mix alternative

The interconnection between Ethiopia, Sudan and Egypt includes:

- A 500/400 kV substation located on Mandaya HPP site, equipped with three 500/400 kV 510 MVA transformers. This transformation is composed by nine 170 MVA single-phase units + one 170 MVA single-phase unit as a spare part.

- A 500 kV AC double circuit line between Mandaya HPP and Rabak 500 kV substation. The length of the line is 570 km. The two circuits are equipped at each end by one 230 MVAr reactor to energize the line in good condition and to control the voltage profile in operation.
- One 728 MW AC/DC single pole converter station and one 1455 MW AC/DC double pole converter station at Mandaya.

- One 679 MW DC/AC single pole converter station and one 1357 MW DC/AC double pole converter station at Assiut.

- One 800 kV DC double pole line and one 800 kV DC single pole line between Mandaya and Assiut.

The capacity of each DC pole is equal to 670 MW (2000/3).

There is no DC/AC taping station in Sudan.

The length of the line is equal to 2385 km.

The 800 kV DC lines are equipped with 8 bundle Hawk conductors (total cross section: 8 x 241 mm²).

A new 500 kV line between Assiut and Samalut is necessary to transmit the 2 000 MW imported from Ethiopia, without any constraint in N-1 situation.

2.3.2.5.3 Cost of the alternative AC+DC

The investment cost of the interconnection alternative was calculated.

The costs of the alternative, with interconnection points at Rabak in Sudan and at Assiut in Egypt, amounted to: (discount rate i=10%)

2,894,000 k$

The transmission costs are displayed below.

Transmission Cost ($/MWh)		
i=10%	i=12%	i=8%
25.9	30.8	21.6

Table 2-28 - Transmission cost of AC alternatives between Ethiopia and Egypt by Rabak and Merowe

Transmission Cost ($/MWh)		
i=10%	i=12%	i=8%
6.3	7.3	5.5

Table 2-29 - Transmission cost of AC Alternatives between Ethiopia and Sudan

Based on the calculated values of the transmission cost, it is possible to conclude the following for Option 3:

Ethiopia exports 1 200 MW to Sudan: the transmission cost reaches 6.3 $/MWh. This cost is higher than in option 2, because the duration of the exchange between Ethiopia and Sudan is shorter, 7 800 hours in place of 8 600 hours.

Ethiopia exports 2 000 MW to Egypt: the transmission cost reaches 26 $/MWh. This is higher than in option 3, because the duration of the exchange between Ethiopia and Egypt is shorter, 6 300 hours in place of 7 800 hours.

Remark: Whatever the alternative, the transmission cost increases by 80% when the duration of the power exchange is divided by 2.

2.4 RECOMMENDATIONS FOR A REGIONAL INVESTMENT PLAN

2.4.1 GENERATION

2.4.1.1 Hydro power project studies in Ethiopia

All three largest hydro power plant projects identified in Module 3 for Ethiopia are required in the Ethiopian generation expansion plan determined by the Consultant (even in absence of the interconnection). On the basis of present available studies (pre-feasibility level) for Mandaya, Karadobi and Border, Mandaya is potentially the project with the lowest economic cost, but this is to be confirmed to feasibility level. Considering the time necessary to carry out feasibility study, detailed study, call for tender, construction, the earliest date of commissioning for these projects is in the range of 2020-2022, which is about the time when the first large hydro project is required in the Ethiopian generation expansion plan (depending on the Ethiopian demand growth and on level of export from Ethiopia to Kenya). The feasibility study of Karadobi was to start in the second semester of 2007.

Accordingly, the Consultant recommends to carry out the feasibility study of Mandaya at the earliest, in order to confirm whether Karadobi or Mandaya presents the most overall benefits, and which one is to be commissioned first. This feasibility Study would also provide a significant input to the Joint Multi-Purpose Project analysis.

The Consultant also recommends to carry out the feasibility study of Border, which although being ranked after Karadobi and Mandaya, might be one of the most interesting large hydro projects in the Ethiopia.

Other promising large hydro sites exist in Ethiopia with limited (if any) negative downstream impact on Nile hydropower schemes. the Consultant recommends to give attention to these promising sites which would provide energy for export with limited downstream impact in neighbouring countries (eg. 2 000 MW Gibe IV).

2.4.1.2 Blue Nile river optimisation study

The Blue Nile river scheme, mainly composed of Karadobi, Mandaya, Border has the potential to become one of the main source of power export in the region in the next 15 years.

These projects have been studied to pre-feasibility level, each study being obviously focused on each project, while including some analysis of downstream impacts and more rarely relative impacts of one project to the other. Furthermore, these studies were carried out independently of the Ethiopian power demand evolution, assuming that all the generation will be absorbed by the power system.

The Consultant recommends to carried out an Study of the overall Blue Nile river scheme whose objective would be to optimise the overall design of the Blue Nile hydro scheme:

- size of reservoirs, installed capacities, maximum discharges,
- combined operation strategy,
- schedule of commissioning and filling strategy,
- overall downstream impact analysis, down to Egypt, during filling and operation. In particular, there is a need for specific and detailed studies of Aswan operation (opportunity to operate at a lower level reducing evaporation losses, reduction of sediment inflow increasing life expectancy, etc), in relation to the sequence of construction and filling of all the potential reservoirs on the Blue Nile (Karadobi, Beko Abo, Mandaya and Border).

This global study should consider (but not limit to):

- the downstream water requirements (eg. irrigation in Egypt and Sudan),
- the overall supply / demand balance of Ethiopia (which actually constraints the operation policy of these non marginal hydro power plants).

2.4.1.3 Generation investments in Egypt and Sudan

Strictly speaking, some generation investments could be delayed in Egypt and Sudan due to the increased power import. However, due to the raising of the projected fuel prices all along the next

25 years, the investment represents only 15 to 25% of the total generation cost of new thermal plants. Accordingly, the Consultant would not recommend any modification of the Generation Expansion Plans of Egypt and Sudan, which means these countries would still keep their ability to balance their power demand with their own supply whenever power import are not available.

2.4.1.4 Future operation strategy in the integrated system

The nature and the size of the Ethiopian and Sudanese power system will evolved considerably over the next 20 years. New operation tools and software will probably be need in the future in order to optimise the operation of these larger power systems.

Furthermore, the Consultant recommends to implement close cooperation for operation between the three countries. Possible directions are:

- Improvement of national hydrometeorological networks in Ethiopia and Sudan.
- Exchanges of information related to the hydro system: target outflows in Ethiopia and Sudan. Irrigation needs in Sudan. Probably on a monthly basis.
- Exchanges of information related to the demand and supply (present and forecasted).

This cooperation could lead to the establishment of short term bilateral contracts (power exchanges on a monthly time step) taking advantage of complementarities between the hydro and thermal power resource, on the base of the actual and evolving situation of the generation mixes (level of reservoirs, availability of thermal plants, etc). With the development of the power market, these bilateral contracts would progressively take place through the power market.

2.4.2 TRANSMISSION

Low cost hydro generation would be available in Ethiopia to export power to Egypt and Sudan. Network studies were performed to investigate the interconnection between the three countries and determine the least cost alternative.

A large range of power export from Ethiopia was investigated in the economic studies.

Three options of power exchange were proposed:

- Option 1: Ethiopia exports 1 390 MW: 690 MW to Egypt and 700 MW to Sudan
- Option 2: Ethiopia export 1 890 MW: 690 MW to Egypt and 1 200 MW to Sudan
- Option 3: Ethiopia exports 3 200 MW: 2 000 MW to Egypt and 1 200 MW to Sudan

Several alternatives, to export these amounts of power exchanges to Egypt and Sudan, were examined. These alternatives combined:

- Two technologies, AC and DC link.
- Several voltage levels, AC 500 kV and 750 kV, DC 500 kV, 600 kV and 800 kV.
- Different interconnection points with different lines routes in Egypt and Sudan.

Based on this analysis, the transmission cost, in $/MWh, was calculated.

For the power exchange between Ethiopia and Sudan, the values are within:

- for AC technology
  - 8 $/MWh for 700 MW of power exchange
  - 6 $/MWh for 1 200 MW of power exchange
- for DC technology
  - 14 $/MWh for 700 MW of power exchange

For the power exchange between Ethiopia and Egypt, the value is close to 24 $/MWh whatever the technology, AC or DC and whatever the power exchange, 700 MW to 2 000 MW.

Therefore, it is recommended to adopt a mix alternative: AC alternative between Ethiopia and Sudan and DC alternative between Ethiopia and Egypt.

The lowest cost AC alternative includes a 500 kV double circuit line between Mandaya HPP and Rabak.

The lowest cost DC alternative, between Ethiopia and Egypt, includes a 600 kV or a 800 kV link, single pole 700 MW, and a double pole + a single pole for 2 000 MW.

The existing 220 kV interconnection link Gonder – Gedaref between Ethiopia and Sudan could operate in parallel with the 500 kV link.

If the three countries intended to commission the interconnection in the coming 10 or 15 years, it would be necessary to prepare the operating rules of the interconnected system some years before the commissioning date. It is recommended to set a working group, including a technical team and a commercial team, in charge of the harmonization of the grid code for the three countries.

This task will be fed by the experience of Egypt in the operation of the interconnections with Jordan and Libya. This task will also be based on the previous adaptation of the grid codes of Ethiopia and Sudan performed for the commissioning of the 220 kV interconnection link between Gonder and Gedaref.

The commissioning and the operation of an international interconnection concern two parts of a grid code, a technical part and a commercial part.

Concerning the technical part, the following points must be assessed and reviewed by the technical team.

Operation of the interconnection link:

- Selection of compatible Electronic Technology (ET) for measurement and data exchange.
- Agreement concerning the language for communication between the Control Centres.
- Agreement concerning the time reference.
- Agreement concerning the voltage control on the border substations and the reactive flows on the interconnection link.

Preparation of the operation of the interconnection link:

- Mutual training of the control centre staff in particular of the shift operators.

- Coordination of the maintenance planning of the interconnection link and of the vicinity network equipment close to the border substations.
- Coordination of Network expansion in the vicinity of the border substations.
- Coordination about network studies and exchange of data.
- Agreement concerning the post mortem analysis, period, type and volume of data...

Operation of the interconnected system:

- Agreement concerning the primary reserve, amount and sharing between the three countries.
- Elaboration of a common defence plan, including a common load shedding scheme.
- Agreement concerning the time adjustment.
- Implementation of Automatic Generation Control (AGC) in the three countries with common rules for the calculation of the secondary reserve.

Concerning the commercial part, the following points must be assessed and reviewed by the commercial team taking into account the different contracts between the three parties (long term contract, short term contract, economy energy contract).

- Agreement concerning the metering equipment.
- Agreement concerning the billing and settlement.
- Agreement concerning the transit fees and the inadvertent energy compensation.
- Agreement about the procedure to announce the type of the contract.

2.4.3 REGIONAL GENERATION AND INTERCONNECTION INVESTMENTS

2.4.3.1 Ethiopia- Sudan 200 MW interconnection

A by-product of the present Study is to identify the large benefit that would result from a significantly increase of the Ethiopia-Sudan interconnection between beyond its original capacity (200 MW in 2010). Indeed, since the completion of the Ethiopian-Sudan interconnection Study (2005), new elements have appeared:

- Gibe III will bring nearly 1 900 MW to the Ethiopian power system in 2011-2012 (not considered in Ethiopian-Sudan interconnection Study - 2005),
- the crude oil is sustaining a substantial price increase since 2005 (84.6 USD/bbl reached on October,18 2007).

Accordingly, the Consultant recommends to evaluate the possibility of increasing the capacity of the committed interconnection between Ethiopia and Sudan beyond the original 200 MW design.

2.4.3.2 Egypt-Ethiopia- Sudan interconnection

The interconnection project is characterized economically by a good profitability, a short payback period and a high benefit to cost ratio under a large range of hypothesis.

Several capacities, designs and line routes have been analyzed.

From the economic point of view, an export capacity of 1 200 MW to Sudan, and 700 MW or 2 000 MW to Egypt, are the most promising options. The 700 MW export capacity to Egypt may be more cost effective (BRC ratio). However, going up to 2 000 MW capacity to Egypt would still be very profitable for the region (benefit to cost ratio = 2.7 with the medium fuel price projection, up to 4.0 for the high price projection, payback period < 10 years), and would give more freedom and flexibility for future expansion of the power market to the South (Kenya and SAPP) and to the North.

The recommended lowest cost design for a 1 200 MW export capacity to Sudan and 2 000 MW export capacity to Egypt is as follow:

- between Ethiopia and Sudan: a 500 kV double circuit line between Mandaya HPP and Rabak,

- between Ethiopia and Egypt: a 600 kV or a 800 kV DC link, single pole 700 MW, and a double pole + a single pole for 2 000 MW.

The design of the interconnection (AC link between Ethiopia and Sudan, AC or DC link up to Egypt) gives some flexibility in the phasing of the interconnection. A commissioning in two phases would add to the profitability of the project:

- connection to Sudan in 2015 (earliest possible date considering duration of technical studies, tender process, construction),
- followed by a connection to Egypt in 2020 (earliest possible date when large amount of hydro power would be available from Ethiopian Blue Nile HPP projects).

2.4.4 ETHIOPIAN HPP INVESTMENTS

The HPP investment decisions in Ethiopia will depend on the type and amount of power exchanges agreed between the countries.

Loose pool model:

In the loose pool model, the generation expansion plan of Ethiopia is left unchanged compared to the "independent" development, with the exception of Mandaya which is anticipated from 2024 to 2020 in line with the commissioning of the connection to Egypt.

Tight pool model:

In the tight pool model, the commissioning of several large hydro Ethiopian plants (Mandaya, Karadobi, Border, etc) is purposely anticipated, compared to the "independent" development of Ethiopia, in order to provide an additional and more regular amount of power export.

In this model, because of the increased HPP investments in Ethiopia, the largest part of the power exchanges would probably be arranged on PPA basis. The selling price of energy would be higher that in the loose pool model in order to recover the increased HPP investment costs.

Additional power exchanges could also be arranged on an annual basis depending on the actual hydrological situation and on demand / supply balance of the Ethiopian generation mix.

Finally, the amplitude of HPP investment anticipations in Ethiopia would depend on the amount of agreed power sales and type of contacts and water Security to EN countries.

2.4.5 SUMMARY OF RECOMMENDATIONS

Subsector / Proposed Action	Proposed institution in charge
(1) Studies:	
Feasibility Study of Mandaya	ENTRO
Feasibility Study of Border	ENTRO
Blue Nile River Optimisation Study	ENTRO
(2) Coordination of operation of the power systems:	
Development of cooperation between the Utilities in the perspective of the future power market	EEHC/EEPCO/NEC
(3) Regional investments:	
Evaluate possibilities to increase the capacity of the committed interconnection between Ethiopia and Sudan beyond its original 200 MW design	EEPCO/NEC
Start Feasibility Study of the Interconnection between Egypt, Ethiopia and Sudan (Phase II of Power Trade Study)	ENTRO

Table 2.4-1 - Summary of recommendations

3. ORGANISATION AND CONTENTS OF THE PREVIOUS REPORTS

According the Study organisation described in the previous paragraph, the different reports are organized along the following scheme:

3.1 MODULE 1: INCEPTION REPORT

The Inception Report covers the period of Project Month 1, i.e. from October 20th to November 13th 2006, which is also defined as the Inception Mission of Phase 1 of the Project.

3.2 MODULE 2: ASSESSMENT OF EXISTING MARKET AND POWER TRADE

Module 2 deals with the assessment of the existing market and power trade situation in the Egypt, Ethiopia and Sudan.

This Module is organized in four Volumes:

- Volume 1: Overview of Module M2
- Volume 2: Market of Power Trade assessment for Egypt
- Volume 3: Market of Power Trade assessment for Ethiopia
- Volume 4: Market of Power Trade assessment for Sudan

Each volume from Vol 2 to Vol 4 analyses the existing situation in each country along the following items:

- Review of the electricity sector.
- Assessment of existing generation mix (TPP, HPP, geothermal, etc).
- Assessment of existing power trade.
- Assessment of existing transmission system.

3.3 MODULE 3: ENERGY SECTOR PROFILE & PROJECTIONS

Module 3 deals with the future evolution of the demand and identification of supply and interconnection options. The findings of this Module will constitute the base on which the regional investment plan will be determinate.

This Module 3 report is organized in five Volume:

- Volume 1: Executive summary of Module M3
- Volume 2: Energy Sector Profile & Projections for Egypt
    - Review and update of previous demand forecast.

  - Potential trade opportunities.
  - Review of the existing Generation Expansion Plan.
  - Identification of generation supply options.
  - Review of existing transmission master plan.
- Volume 3: Energy Sector Profile & Projections for Ethiopia
  - Review and update of previous demand forecast.
  - Potential trade opportunities.
  - Review of the existing Generation Expansion Plan.
  - Identification of generation supply options.
  - Review of existing transmission master plan.
- Volume 4: Energy Sector Profile & Projections for Sudan
  - Review and update of previous demand forecast.
  - Potential trade opportunities.
  - Review of the existing Generation Expansion Plan.
  - Identification of generation supply options.
  - Review of existing transmission master plan.
- Volume 5: Pre-feasability studies
  - Fuel prices Projections.
  - Interconnection options.
  - First evaluation of economic profitability of exports from Sudan-Ethiopia.
  - Interconnection options (Line routes / technologies / costs).
  - Transmission study (necessary reinforcements resulting from the interconnection, load low, short circuit analysis, etc).

3.4 MODULE 4: PLANNING AND EVALUATION CRITERIA

The first purpose of Module 4 is to establish the multi-criteria ranking methodology which will be used to rank the 24 potential hydro power candidates identified in Module 3. The result of this ranking, applied to these potential hydro power candidates, will be one of the most essential input to Module 6 (Coordinated regional Investment Planning), and as such will be validated by the Steering Committee.

The second purpose of Module 4 is to review the criteria, currently used in Egypt, Ethiopia and Sudan, for generation and transmission investment criteria, and to propose common criteria to be used in the determination of the coordinated regional investment plan (Module 6).

Accordingly, Module 4 is organized in three parts:

- Elaboration of a multi-criteria ranking methodology for ranking hydropower candidates.

- Draft application of this multi-criteria ranking methodology on the hydropower candidates identified in Module 3.
- Review of the current criteria used in the different Utilities for generation (LOLP, cost of unserved energy, etc) and transmission planning (N-1, voltage, etc), and proposition of common criteria for the present study.

4. OBJECTIVE OF MODULE 6

The overall objective of Module 6 is to evaluate the benefits for the region (Egypt, Ethiopia and Sudan) provided by an interconnection of the three power systems according to various level of integration (or coordination) of these systems.

The questions related to this issue are:

- What are the options for the interconnection: line route, technology, capacity, commissioning date, etc ?
- Is there any need / benefit to reinforce the planned interconnection between Ethiopia and Sudan (planned capacity: 200 MW commissioning date: 2010) ?
- Is there any need, because of the interconnection, to reinforce the planned development of the transmission system in each power system ?
- What is the amount of economic power exchanges between the countries ?
- What are the resulting benefits for the region according to what options ?

Accordingly Module 6 will cover:

- the determination of least-cost generation expansion plan for the coordinated system,
- the determination of the least cost interconnection option in term of technology,
- the transmission system analysis,
- the recommendation of a Regional Investment Program.

5. ORGANISATION OF MODULE 6 REPORT

This Module is organized in four Volumes:

- Volume 1: Executive summary of Module 6
- Volume 2: Generation Investment Planning and Economic Study
  - Least cost Generation Expansion Plan for the three isolated power systems.
  - Least cost Generation Expansion Plan for the interconnected system according to tight pool or loose pool power market.

  - Evaluation of the potential benefits for the region provided by the interconnection according to various level of integration (or coordination).
- Volume 3: Transmission Study
  - Volume 3-1: Analysis of the Network Expansion Plan - Egypt
  - Volume 3-2: Analysis of the Network Expansion Plan - Ethiopia
  - Volume 3-3: Analysis of the Network Expansion Plan - Sudan
  - Volume 3-4:
    - Volume 3-4.1: Analysis in permanent state of the interconnected system - Option 1: Ethiopia to Egypt 690 MW - Ethiopia to Sudan 700 MW
    - Volume 3-4.2: Analysis in permanent state of the interconnected system - Option 1: Ethiopia to Egypt 690 MW - Ethiopia to Sudan 1 200 MW
    - Volume 3-4.3: Analysis in permanent state of the interconnected system - Option 1: Ethiopia to Egypt 2 000 MW - Ethiopia to Sudan 1 200 MW
- Volume 4: Recommendation for a coordinated regional investment plan.