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EASTERN NILE POWER TRADE PROGRAM STUDY

AfDB

MODULE 4: PLANNING & EVALUATION CRITERIA

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with participation of:

- EPS (Egypt)
- Tropics (Ethiopia)
- YAM (Sudan)

DRAFT REPORT

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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			
km²	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
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
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
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)
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
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. BRIEF ABOUT THE PREVIOUS MODULES

1.1 OVERVIEW M2

1.1.1 EGYPT

Egypt occupies the north-eastern corner of the continent of Africa, including the Sinai Peninsula, with a population of about 69.997 millions (2005), 43% in urban areas and 57% in rural areas. The growth rate of population is currently 1.96% (2006).

The economy of the country has developed in the last years with an annual GDP rate of 5%, pushed up by a significant production of petroleum products, electricity developments, and industrialization.

Egypt has a per capita electric energy consumption of 1 350 kWh (2001/2002). Access to electricity is high, around 98%, with negligible isolated systems.

Environmental improvements can be notice by the rate of CO_2 production in Egypt. It has been reduced from about 2.8 tons of CO_2 per Toe in 1981/1982 to about 2.5 in the year 2001/2002. This is because of the increase of the use of natural gas in the electric energy production.

1.1.1.1 Egypt Utility

Egyptian electric company is currently comprised of nine regional electricity distribution companies, five regional electricity generation companies, one electricity transmission companies. All these companies are blended in a Holding company, the Egyptian Electricity Holding Company (EEHC). Different authorities, such as New & Renewable Energy and Hydro Power, are directly linked to the Ministry of Electricity & Energy.

1.1.1.2 Current demand and generation supply

In Egypt, peak demand increased from 5 400 MW (1985/1986) to 17 300 MW (2005/2006). In the same period, energy generated increased from 32 TWh to 108 TWh, with a growth rate of 7% in the last ten years.

The total installed capacity in 2006 is 20 508 MW, with 17 543 MW of thermal plants, 225 MW of wind farms, and 2 740 MW of hydropower (4 plants).

Installed Capacity (MW)	ST	CCGT	OCGT	WIND	HYDRO	Total
Cairo	2270	1485	600			4355
West Delta	3330	1224	837			5391
East Delta	3991	1409	453	225		6078
Upper Egypt	1944					1944
Hydro					2740	2740
Total	11535	4118	1890	225	2740	20508
Installed Capacity (%)	56%	20%	9%	1%	13%	

Table 1.1-1- Total installed capacity in Egypt in 2006

One hydro, two thermal plants, and two wind farms are committed:

- ✓ The New Naga-Hammadi 64 MW and 460 GWh/year is planned to operate in 2008/2009
- ✓ Talkha 750 MW CC (NG/HFO) in East Delta is planned to operate in 2007/2008
- ✓ Kurimat (2) 750 MW CC (NG/HFO) in Upper Egypt is planned to operate in 2007/2008
- ✓ Zafarana / Gabal El-Zait 55 MW is planned to operate in 2006/2007
- ✓ Zafarana / Gabal El-Zait 150 MW is planned to operate in 2007/2008

In the Egyptian hydro system, irrigation is the priority, the power production is only a by-product. The Water Resources and Irrigation Ministry defines the daily discharges in power plants and send this information to NECC every week.

1.1.1.3 Existing transmission system and power trade

Egypt is interconnected with Libya and Jordan. These interconnections are used in emergency situations and in some extent to trade exchanges between Egypt and Jordan. Exports and imports measured from 2003 to 2005 are quite weak, less than 1% of total Egyptian electrical generation. An export balance of 20 GWh to Lybia and of 680 GWh to Jordan were measured in 2004/2005.

The existing transmission system is equipped with a double circuit 500 kV backbone along the Nile river, from High Dam (2 100 MW) to Cairo (main load centre), and a single circuit (500 KV) from Cairo to the interconnection with Jordan. A 132 kV and 220 kV circuit follows the 500 kV backbone along the Nile river. The delta zone is supplied with a meshed 220 kV network, and extends towards west to Libya with a double circuit interconnection. An extension of the 500 kV network is currently under construction from Cairo 500 to Sidi Krir in West Delta. It is also the first milestone to reinforcement of the interconnection with Libya in 500/400 kV.

1.1.2 ETHIOPIA

Ethiopia located in the Eastern Africa, has a population of about 75 million inhabitants. 16% of the people are urban. The growth rate of population is currently 2.8%.

The economy of the country, one of the poorest in the world, is not in line with its endowed natural resources. These resources include natural gas, coal, geothermal, considerable hydroelectric power potential, very large livestock population and extensive irrigation potential.

Ethiopia has one of the lowest levels of energy consumption per capita in the world at 28 kWh. Access to electricity is considered to be 17% of population at present.

1.1.2.1 Ethiopian utility

Ethiopian Electric Power Corporation (EEPCO) is responsible for generation, transmission and distribution of the interconnected system (ISC) as well as some isolated or self contained system (SCS). The current trend for development of generation using IPP (Independent Power Producers) which entitles EEPCO to buy generated power at negotiated rates is also encouraged.

1.1.2.2 Current generation supply

The Interconnected System (ICS) has a total installed capacity of 766,9 MW (end of 2006) including 96,3 MW of Diesel plants at Dire Dawa, Awash, and Kaliti, and a Geothermal plant at Aluto-Langano. The existing thermal plants in the ICS (end of 2006) are as follows:

Power Plants	Plant Type	Installed capacity (MW)
Dire Dawa Diesel	Diesel	38
Awash 7 Kilo Diesel	Diesel	27
Kaliti Diesel	Diesel	12
Others	Diesel	12
Aluto Geothermal*	Geothermal	7,3
Total Thermal Power Plant (ICS)		**96,3 MW**
Gigel Gibe I (in 2004)	Hydro	192 (with 3 units)
Maleka Wakana (in 1988)	Hydro	153
Finchaa (1973-2003)	Hydro	134 (with 4 units)
Tis Abay I (in 1964)	Hydro	11,4
Tis Abay II (in 2001)	Hydro	73
Koka (in 1960)	Hydro	43,2
Awash II (in 1966)	Hydro	32
Awash III (in 1971)	Hydro	32
Total Hydro Power Plant (ICS)		**670,6 MW**

Table 1.1-2- Existing Ethiopian power plants

1.1.2.3 Committed projects

Five hydropower projects are committed by EEPCO in 2006 and under construction: Gilgel Gibe II and Gibe III, Tekeze, Upper Beles and Neshe which main characteristic and commissioning dates are shown in the following table:

Hydro Power Plant (Commissioning date)	Installed capacity (MW)	Average energy capacity (GWh)
Gigel Gibe II - 2008	420	1 600
Gibe III - 2012	1870	6 240
Tekeze - 2008	300	960
Beles - 2009 (w/o Tis Abay I & II)	460 (376)	2 000 (1 630)
Neshe HPP - 2010	97	225
Total new capacity (w/o Tis Abay I & II)	3 147 MW **(3 063 MW)**	11 025 GWh **(10 655 GWh)**

Table 1.1-3- Ethiopian Committed Projects

1.1.2.4 Existing transmission system and power trade

The Ethiopian system consists mainly of 230 and 132 kV lines. The 230 kV network extends from Addis Ababa about 400 km eastward to Dire Dawa, about 300 km southward to Shashemene and about 1000 km northward to Tekeze and Gonder.

Three 230 kV substations supply Addis Ababa, that represents 60% of the total demand.

A 400 kV network will be soon erected to evacuate the generation of Gilgel Gibe II HPP until Addis Ababa.

Ethiopia will be interconnected with Sudan with a 230 kV double circuit line between Gonder and Gedaref in Sudan. The commissioning is expected in year 2008.

1.1.3 SUDAN

Sudan is an afro-Arab country occupying a remarkable strategic position in the centre of the Africa continent, has a population of 35 millions inhabitants. The growth rate of population is 2,6%. It shares its extensive borders with nine countries of northern, eastern, central and western Africa. Such juxtaposition engenders a mix of trade, culture, social, ethnic and other human ties built throughout history.

Agriculture remains the backbone of Sudanese economy and oil exportation is very recent.

The electrification ratio of the Sudan (percentage of households with electricity supply) is one of the lowest in the world, estimated at about 19 per cent (made up from about 16.3% metered NEC connections, 2.3% connections to private supply companies and 0.2% unmetered connections).

1.1.3.1 Sudan utility

The National Electricity Corporation (NEC) is the governmental entity responsible for generation, transmission and distribution of electric power in the Sudan. NEC's power system comprises mainly the national grid (NG) and a number of isolated diesel power stations.

The electricity system within Sudan is comprised of the main National Grid, a number of isolated off-grid systems and some existing private generation companies. NEC's main grid system is divided into the Khartoum, Central, Eastern and Northern areas.

The towns of Atbara and Shendi in River Nile state, which were previously supplied by local off-grid generation, were connected to the National Grid as part of the Merowe transmission reinforcement scheme in the second half of 2005.

1.1.3.2 Current generation supply

In 2003 Gerri I and Gerri II combined cycle power generating facilities were commissioned. Adding to the grid about 386 MW generating capacity the supply exceeds the demand and the power cuts are mainly limited to failures in transmission and distribution.

At the time being the total capacity available for dispatch on the National Grid is about 826 MW, of which some 59% is conventional thermal plant and the remaining 41% is hydroelectric plant.

In the table here below, is set out the generation mix on the National Grid as at July 2006 and provide a summary of installed and available capacities from the existing on-grid power plants.

Power Plant	Plant Type	Fuel Type	Net Capacity (MW)
Khartoum North ST's	Thermal	HFO	157.0
Khartoum North GT's	Thermal	Gas Oil	50.4
Garri 1 CCGT's	Thermal	Gas Oil	164.0
Garri 2 OCGT's	Thermal	Gas Oil	84.0
El Fau Diesel	Thermal	Gas Oil	10.0
Kassala Diesel's	Thermal	Gas Oil	7.9
Girba Diesel's	Thermal	Diesel	4.0
Kuku GT's	Thermal	Gas Oil	19.0
Total Thermal Plant			**496.3**
Roseires	Hydro		280.0
Sennar	Hydro		15.0
Kashm El Girba	Hydro		18.1
Jebel Aulia	Hydro		28.1
Total Hydro Plant			**341.2**
Net Installed Capacity			**837.5**
Thermal Capacity Part			59%
Hydro Capacity Part			41%

Table 1.1-4- Existing Sudanese power plants

1.1.3.3 Committed projects

According to NEC master plan, the following power plants have been identified as committed contributors to the Sudan generation expansion plan.

- Khartoum North Units 5 and 6 (100 MW each – 2008)
- Conversion of Garri 2 power station to combined cycle operation (200 MW – 2008)
- Kilo X GT (80 MW - 2007)
- Garri (3) steam plant (540 MW - 2010)
- Garri (4) steam plant (100MW – 2007)
- Port Sudan steam plant (405 MW – 2009)
- Kosti steam plant (500 MW – 2010)
- El Bagair steam plant (540 MW – 2010)
- Kassala diesel plant (50 MW – 2007)

- Al Fula steam plant (540 MW – 2010)
- Merowe hydroelectric plant (1 250 MW – 2008)
- Sennar extension hydroelectric plant (1 250 MW – 2008)
- The heightening of the Rosieres hydroelectric plant, with Dinder (135 MW – 2012)

1.1.3.4 Existing transmission system and power trade

At present there is no international power trade between Sudan and the neighbouring countries. This is partly because until today there was no transmission facilities to enable such trade.

The Sudanese system consists mainly of 110 and 220 kV lines. The system includes a 800 km 220 kV double circuit line from Roseires HPP, located in the south close to Ethiopia border, to Khartoum along to the Blue Nile River. A 110 kV double circuit ring supplies Khartoum, that represents 50% of the total load. This 110 kV ring is connected to the 220 kV system with two 220/110 kV substations at Eid Babiker and Kilo X.

In the coming year 2007, the network will be reinforced with a 500 kV double circuit line from Merowe HPP (installed capacity 1 250 MW) to Khartoum and a 500 kV single circuit line between Merowe and Atbara located on the Nile, 300 km north east of Khartoum.

In the next years, NEC intends to extend its 220 kV system by about 2 000 km of new lines.

1.2 OVERVIEW M3

1.2.1 EGYPT

1.2.1.1 Historical evolution of power Demand

In Egypt, peak demand increased from 5.4 GW in 1986 to 17.3 GW in 2006. In the same period, energy generated increased from 32 TWh to 108 TWh, with an average annual growth rate of 7% in the last ten years.

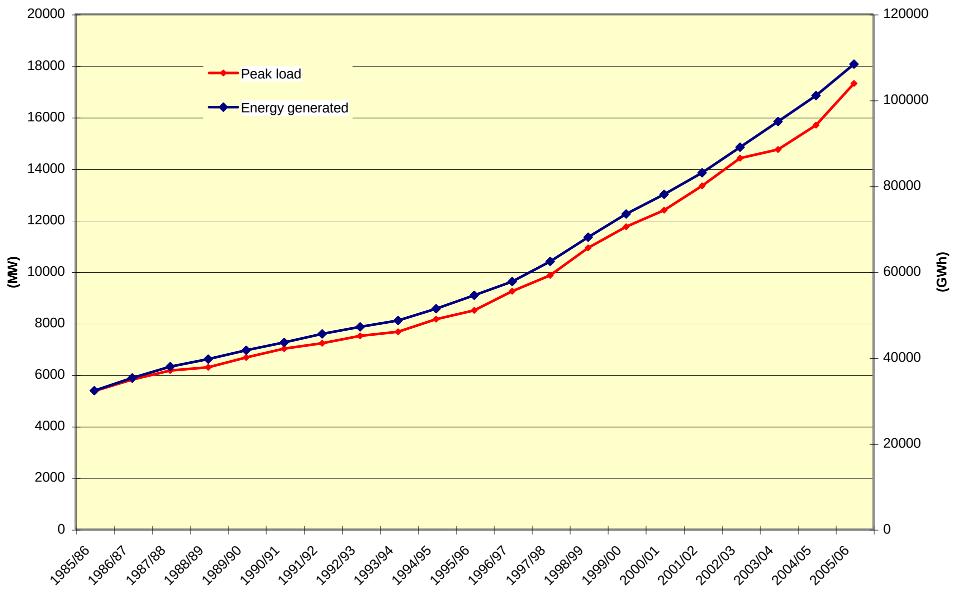

Figure 1.2.1-1- Annual growth

The share of consumption by consumer sector has changed in the last 20 years, with the industry sector decreasing from 55% to 35% and residential sector rising from 23% to 37%.

The load factor during this period remained constant, with an average value around 72%.

Losses have been decreased in the recent years to achieve a value of 14.7% in the year 2005/2006.

The peak load is observed during the summer, at 21h00 in working day. Last data concerning peak load are:

	2003	2004	2005	2006
Peak load (MW)	14 723	15 491	16 650	18 160

Table 1.2-1- Peak load

1.2.1.2 Demand Forecast

In 2006, EEHC prepared demand projections for the period from 2006/2007 to 2029/2030 for three scenarios (high, medium, and low).

Demand Forecast		07/2008	10/2011	15/2016	20/2021	25/2026	29/2030
TOTAL GENERATED ENERGY (GWh)	High	125653	155512	213438	279753	358909	437696
	Medium	123065	148538	198960	259708	334639	407272
	Low	120470	141901	186111	242846	317964	392195
PEAK LOAD (MW)	High	20059	24769	33860	44125	55610	66443
	Medium	19646	23658	31564	40963	51850	61825
	Low	19232	22601	29525	38304	49266	59536

Table 1.2-2-Demand forecast 2008-2030

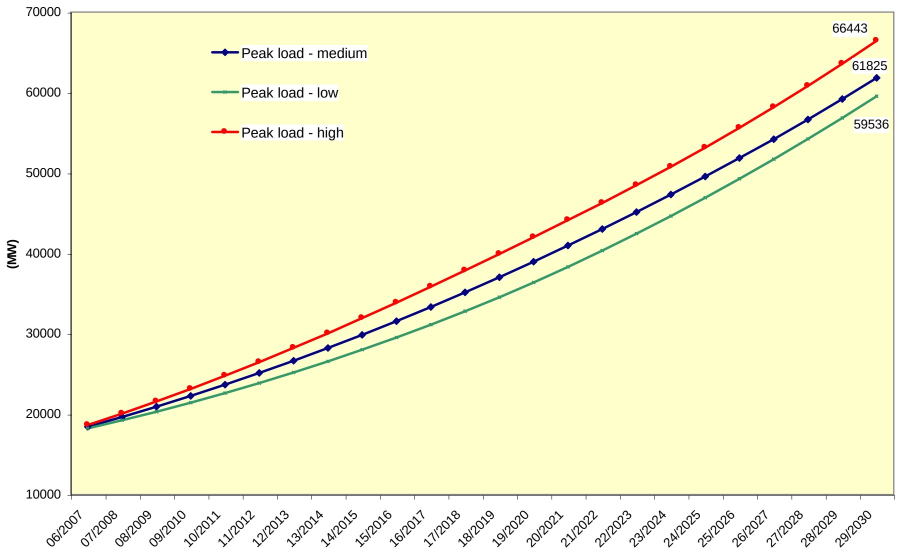

Figure 1.2.1-2- Peak load forecast from 2006/2007 to 2029/2030 for three scenarios

The respective annual growth rates for the high, medium and low scenarios for generation during the period from 2006/2007 to 2029/2030 are 5.9%, 5.6% and 5.5%. Annual growth rates for peak load are respectively 5.7%, 5.4% and 5.3%.

1.2.1.3 Potential power trades

In spite of available information and the Local Consultants expertise, the establishment of trade opportunities figures remains an speculative exercise. It is widely known that opportunities of trade depend on future plans of neighbouring countries as well as the other interconnections in the considered country (e.g. Sudan and Ethiopia and its transmission to Egypt and its neighbours).

Nevertheless, a tentative long term exchange hypothesis can be based on the following assumptions:

- ✓ Egypt will continue to present an export balance ;
- ✓ Exports will be quite similar in both directions ;
- ✓ Energy exported will be stable over the time according to the future long term contracts.

A conservative export hypothesis is considered in the present Study:

Annual energy balance (GWh)	2007	2008	2009	2010	2015	2020	2030
Egypt - Libya	800	800	800	800	800	800	800
Egypt - Jordan	800	800	800	800	800	800	800

Table 1.2-3- Conservative export hypothesis

1.2.1.4 Generation supply options

Considering the large availability of natural gas in Egypt, the thermal candidates identified are:

- 750 MW dual-fired (NG / HFO) CCGT for base load,
- 250 MW dual-fired (NG / HFO) OCGT for peak-load,
- 350 MW /450 MW / 650 MW dual-fired (NG / HFO) steam turbine.

Few significant hydro plants projects are considered in the Egyptian Nile basin. Only run of the river HPP are projected, with a clear priority of the water resources given to irrigation. Three plants are planned until 2012/2013: Damietta (13 MW), Zefta Barrage (5.5 MW), Assiut (40 MW).

The development of wind energy will be significant reaching a total installed capacity of 3 000 MW by 2030.

EEHC generation expansion plan includes the commissioning of five units of 1000 MW for Dabaa nuclear plant from 2016 until 2027.

The target considered for the development of Solar energy is 750 MW by the year 2020.

1.2.1.5 Review of the generation expansion plan

EEHC develops five-year plans for the generation expansion and network expansion including substations and transmission. A least cost generation plan was prepared up to the year 2011/2012. For further horizons, no economical analysis has been done yet. The following table presents the most recent generation expansion data prepared by EEHC.

Name of the plant	Plant site location	Type of generation unit	Fuel(s) types	Installed capacity (MW)	Net available capacity (MW)	08/09	09/10	10/11	11/12	12/13	13/14	14/15	15/16	16/17	17/18	18/19	19/20	20/21	21/22	22/23	23/24	24/25	25/26	26/27
Sidi Krir	East Delta	CCGT	NG/HFO	750	691.1	500	250																	
Kurimat (3)	Upper Egypt	CCGT	NG/HFO	750	691.1	500	250																	
Nobaria (3)	West Delta	CCGT	NG/HFO	750	691.1	500	250																	
Atfe	West Delta	CCGT	NG/HFO	750	691.1	500	250																	
Sharm El-Sheik	West Delta	CCGT	NG/HFO	750	691.1				750															
Alexandria East	West Delta	CCGT	NG/HFO	750	691.1						500	500	500											
Combined Cycle 750MW		CCGT	NG/HFO	750	691.1						500	500		500	500	500	1000	500	500	500	500	500		
Open Cycle GT 250 MW		OCGT	NG/HFO	250	232.8																			
Abu Qir	West Delta	ST	NG/HFO	650	624.0			650	650															
Suez	East Delta	ST	NG/HFO	450	432.0					450														
Steam Units 450MW		ST	NG/HFO	450	432.0						1350	450	450		450	450				450	900	900	1350	450
Cairo West Ext.	Cairo	ST	NG/HFO	350	336.0			700																
Tebbin	Cairo	ST	NG/HFO	350	336.0		700																	
Ayoun Musa Ext.	Upper Egypt	ST	NG/HFO	350	336.0				350															
Steam Units 650MW		ST	NG/HFO	350	336.0					1300		650		1300	1300	1300	1300	650	1950	650	1300		1300	1300
Borg El-Arab		Solar/Thermal		300										300		300								
Kurimat	Upper Egypt	Solar/Thermal	NG/HFO	150		150																		
Dabaa Nuclear		Nuclear		1000									1000					1000		1000		1000		1000
New Naga Hammadi		Hydro		64		64																		
Assiut		Hydro		40						40														
Damietta		Hydro		13				13																
Zefta		Hydro		5.5					5.5															
Zafarana	East Delta	Wind		125		125																		
Zafarana / Gabal El-Zait	East Delta	Wind					130	160	200	200	200	200	200	200	200	200	200	200	200					

Table 1.2-4- EEHC Generation Expansion Plan from 2008 until 2027.

1.2.1.6 Environmental concerns

The Egyptian electrical system planning takes into account in its major steps the improvements concerning environmental protection. It can be notice on the reduction of demand (demand side management, reduction of losses, etc.) and the environmental friendly supply options. An important program is carried out to implemented new & renewable sources of energy as well as thermal generation emitting lower quantities of GHG.

1.2.1.7 Review of the transmission master plan

The proposed transmission expansion scheme provides a list of new equipments expected by 2010 and 2015. The 500 kV network is expended to the west side, from Cairo to Saloum, via Sidi-Krir and Dabba. Two new 500/220 kV substations are created in Heliopolis and in Sohag. The 220 kV is reinforced in the Delta zone and around Cairo. The ELTAM project proposes a reinforcement of the existing interconnection with Libya by a 500/400 kV circuit.

1.2.2 ETHIOPIA

1.2.2.1 Demand forecast

The review of the demand forecast made by EEPCO in the Ethiopian Power System Expansion Master Plan Update (EPSEMPU 2006) proved that the methodology and forecast models used by EEPCO are robust.

Considering the relatively high growth rates adopted in two EPSEMPU scenarios (target and moderate), the Consultant considered necessary to introduce a low scenario.

The following table presents the main characteristics of these scenarios:

Scenario	Definition	2015	2030	Energy growth rate 2005-2030
High	EEPCO target scenario	12 704 GWh 2 544 MW	71 570 GWh 14 330 MW	14.3%
Reference	EEPCO moderate scenario	9 823 GWh 1 967 MW	34 030 GWh 6 814 MW	10.9%
Low	scenario introduced by the Consultant	7 439 GWh 1 489 MW	27 701 GWh 5 506 MW	10.0%

Table 1.2-5- Main characteristics of the demand forecast scenario in Ethiopia

1.2.2.2 Power trade

The interconnection line with Djibouti has been financed, the tender for construction is planned for January 2007.

The feasibility study of the interconnection line with Sudan is completed.

The Ethiopian and Kenyan governments have signed a memorandum of understanding for the interconnection of the respective power systems. Currently the two countries have secured the finance to undertake the feasibility study. The most probable date for the realization of the interconnection is 2011 which coincides with the completion of the first phase of Gibe III. This power plant will have a capacity of 1 870 MW. The volume of exchange could range from 200 MW to 1 200 MW, which actually be determined from the result of the feasibility study. In addition in the long run the production from Genale Dawa project will supplement the export volume size.

The export scenario considered in the Study is the following:

to	2008	2009	2010	2011	2015	2020	2030
Djibouti	0	150 GWh	318 GWh	318 GWh	369 GWh	380 GWh	380 GWh
Kenya (for 5000 h)	0	0	0	200 MW	400 MW	600 MW	1 200 MW
Sudan	0	0	200 MW max	200 MW max	Result of M6	Result of M6	Result of M6

Table 1.2-6- Power trade in Ethiopia

1.2.2.3 Review of the existing generation plan and Identification of the generation options

Wind and geothermal power is considered in the EEPCO investment program (EPSEMPU June 2006) and the plants recommended between 2010 and 2015 are mainly the Tendaho geothermal plant (3/5 MW) after 2011 and the Wind Park (50 MW) after 2011.

For thermal and hydro power plants, the investment program is summarized as following:

Year	Plant	Plant type	Capacity (MW)
2008	GILGEL GIBE II	Hydro	4 x 105
2008	TEKEZE	Hydro	4 x 75
2009	BELES	Hydro	4 x 115
2010	YAYU COAL	Coal	2 X 50
2011	GIBE III (Phase 1)	Hydro	4 x 226
2012	GIBE III (Phase 2)	Hydro	4 x 226
2014	HALELE WORABESA	Hydro	2 x 48,5 + 4 x 81,5
2015	CHEMOGA YEDA	Hydro	2 x 81 + 2 x 59

Table 1.2-7- Medium term Investment program for thermal and hydro power plants in Ethiopia

The generation plan would also incorporate in long term other hydro power plants such as Geba, Genale, Baro, Gilgel Gibe IV, Awash IV, Karadobi, Gojeb, Aleltu, Mendaya and Border.

1.2.2.4 Review of the transmission master plan

The master plan provided a detailed planning of new equipments up to 2015. The planned elements over the next 9 years will double the total length of the HV network, due to the extension of the HV network to supply rural areas, and the connection of new hydro plants to face the demand increase. A new voltage level - 400 kV - is to be commissioned within the next couple of years, for the evacuation of the generation of new plants (Gilgel Gibe II - 420 MW in 2008, Beles - 460 MW in 2009, Gibe III – 1 800 MW in 2011 and 2012). Interconnection projects are also mentioned. The hydro candidates, Border and Mandaya, are not included in the master plan. The power injection of such plants will impact the network development.

1.2.3 SUDAN

1.2.3.1 Demand forecast

The demand forecast study has formed the basic input data to LTPSPS implementation by Sudan Long Term Power Plan Study.

For the present Power Trade Study, in order to remain consistent with the NEC 2006 Long Term Power System Planning Study, the Consultant will keep the same assumptions of demand forecast and the same scenarios : Base, High and Low .

The main assumption for the base case demand forecast are the following:

	2006	2010	2030
Population annual growth rate		2.5%	1.7%
GDP annual growth rate		8.6%	3.6%
Electrification ratio	18%	52%	83%
Power losses	25%		12.5%
Load factor	65%	70%	70%

Table 1.2-8- Main assumption for the base case demand forecast

The total customer sales forecast is the summation of the individual sector forecasts. Overall electricity sales are forecast to increase to about 75 TWh by 2030 at an average annual growth rate of 10.8%. The influence of the industrial sector in the medium-term sees its share increase to over 40% in 2010 (overtaking the domestic sector which drops to 37% in that year). In the long-term the commercial sector share of total sales increases to over 20% by 2026.

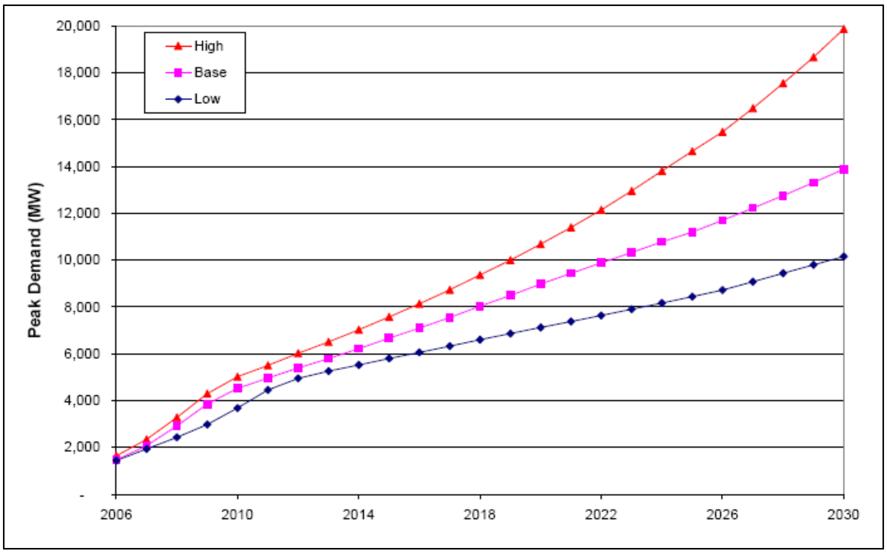

Figure 1.2.3-1- Total customer sales forecast

	Peak forecast (MW)					
	2006	2010	2015	2020	2025	2030
High case	1475	4731	7199	10191	14023	19184
Base case	1475	4550	6693	8995	11205	13883
Low case	1475	3987	5513	6800	8086	9808

Table 1.2-9- Main characteristics of the demand forecast

1.2.3.2 Power trade opportunities

The present Study assumes that the only power trade opportunities for the next 25 years will be with Egyptian and Ethiopian power systems.

Considering the Feasibility study results of the interconnection between Ethiopia and Sudan, the Consultant assumes a commissioning date of this interconnection in 2010 with a maximum transfer capacity of 200 MW.

The simulation and economic analysis carried out in Module 6 will evaluate the potential of economic power trade between Egypt, Ethiopia and Sudan, and the economic opportunity of reinforcement of the Ethiopia – Sudan power connection (>200MW).

1.2.3.3 Generation options

The generation candidates are one of the key elements of the "Power Trade Study", as for the implementation of the domestic electricity master plan accomplished by Sudan Long Term Power Plan Study.

For the present Power Trade Study, and to remain homogenous with the NEC master plan, we will keep the same assumptions of generation candidates.

1.2.3.3.1 Thermal candidates

In line with Sudan Long Term Power Plan Study 2006, the following thermal candidates will be considered in the economic Study (Module 6):

- coal-fired steam power plant for base-load generation:

    • 150 MW circulating fluidised bed combustion technology (CFB) STPP,

    • 400 and 600 MW Pulverised Fuel technology (PF) STPP.

- crude oil-fired steam turbine for base-load generation (150 MW, 250 MW, 500 MW),

- gas oil-fired CCGT for semi-base generation (200 MW, 350 MW and 450 MW),
- gas oil-fired OCGT for peak-load generation (41 MW to 268 MW),

- 40 MW Low Speed Diesel.

Environmental preservation:

Emissions control is an important aspect of all types of PF coal-fired steam plant. For the purposes of this Study, we assume that the design will incorporate the following features:

• Moderate sulphur coal (blending coals so that the sulphur content is less than 2% by mass) in order to take advantage of the seawater flue gas desulphurisation process, which avoids the additional cost of sorbent such as lime or limestone;

• Low NOx combustion system, with allowance in the boiler design for selective catalytic reduction (SCR) equipment to be fitted at a later date ;

• Use of bag filters to control the emission of particulates.

With these design features, a new PF plant, be it subcritical, supercritical or advanced supercritical, will meet the environmental emissions targets such as those set by the World bank or the even more stringent requirements of the Large Combustion Plant Directive (LCPD) in Europe.

Fluidised bed combustion technologies have some inherent environmental benefits over conventional PF type plants:

• Combustion temperatures are generally lower than those found in typical PF plant. In this regard, lower NOx emissions are achievable without the need for special combustion systems.

• The need for expensive flue gas desulphurisation equipment can be avoided by injecting sorbent (e.g. limestone) directly into the fluidised bed boiler. This has the added benefit of fuel flexibility to burn coals with a wide range of sulphur content.

In this Study we consider the circulating fluidised bed combustion (CFB) technology as being the most suitable plant type owing to its suitability for use with coal.

Coal CFB is a well-proven technology suitable for medium size (less than 300 MW) coal-fired plants located inland, i.e. it does not require the availability of seawater for flue gas desulphurisation. For the purposes of this Study, we assume that the design of a CFB steam plant will be optimised to incorporate the following features:

• Injection of sorbent into the boiler to control sulphur emissions, with sorbent recirculation from the bag filter to enhance utilisation;

• Use of bag filters to control the emission of particulates and enhance sulphur capture.

1.2.3.3.2 Hydraulic candidates

The list of hydro candidates to be considered in the economic evaluation (Module 6) are presented in the table below.

Project	River	Level of Study	Installed capacity MW	Total cost MUSD2006	Comments
Rumela	Atbara river	M&M/Gibb 1979	30	193	Irrigation pupose
Shereiq	Main Nile	F (1990)	315	1 190	Prioritary
Dagash	Main Nile	Acers 1993	285	1 048	
Kajbar	Main Nile	F (Hydroproject 1997)	300	1 125	
Dal Low	Main Nile	On going PF	340	1 247	cost to be updated in PF
Total :	Sub Total		1 240		
Fula Alt 1	Barh el jebel	Acers 1993	720	1 319	limited information
Shukoli	Barh el jebel	Acers 1993	210	420	available
Lakki	Barh el jebel	Acers 1993	210	429	comm. date > 2020
Bedden	Barh el jebel	Acers 1993	400	880	(Pre-Feasibility : starting in 2007)
Total :	Sub Total		1 540		

Table 1.2-10- List of hydro candidates to be considered in the economic evaluation

The figures relative to Dal project will be updated in the course of the Feasibility Study carried out in Module 5.

1.2.3.4 Review of the generation expansion plan

The last least cost generation plan was determined by Sudan Long Term Power Plan Study in November 2006.

For the base case, the main hypothesis are:

- planning period from 2006 to 2030,

- discount rate: 10-12%

- base case demand scenario,

- 3% LOLP decreasing to 1% from 2009 to 2026,

- chosen alternative of High Dal (instead of Low Dal + Kajbar).

The commissioning of short construction duration units (low speed Diesel and gas oil-fired gas turbine) in 2009 boats the installed capacity to a level compatible of a good reliability of the power supply. This is demonstrated by the margin ratio which jumps to 30% in 2009.

The development of cost effective coal-fired capacity at Port Sudan being limited by the Grid capability, gas oil-fired CCGT, while being more expensive, become significant contributors to the generation mix (first commissioning in 2014).

Finally, all identified HPP candidates are included in the generation expansion plan by 2026.

1.2.3.5 Review of the transmission master plan

The master plan provided a detailed planning of new equipments up to 2009. The planned elements over the next 3 years will triple the total length of the HV network, due to a major extension of the 220 kV network to Port-Sudan, along the White Nile, to the Kordofan area, to the Gedaref area, and downstream Merowe along the Nile. A new voltage level - 500 kV - is to be commissioned within the next couple of years, for the evacuation of the generation of Merowe hydro power plant. The interconnection project with Ethiopia is not mentioned. The 2015 load-flow display indicate mainly a 500 kV reinforcement from Port-Sudan to Khartoum, and a HV reinforcement in the Korfdofan and Darfur areas.

1.2.4 INTERCONNECTION OPTIONS AND PRELIMINARY ECONOMIC EVALUATION

1.2.4.1 Interconnection views for the interconnected system

Four views have been selected to interconnect the system, two AC views (PV) and two DC views. The interconnection points are the following:

- In Egypt: High Dam for the AC views and Assiut for the DC view.

- In Ethiopia: Border HPP and Mandaya HPP for the AC views and Mandaya HPP for the DC views.

- In Sudan: Merowe HPP and Hasaheisa 500 kV substation for AC views. The DC view passes through Sudan without taping station.

<u>View A1</u>:

Consists in a 500 kV AC single circuit line between High Dam and Merowe and between Hasaheisa and Border HPP. One 500/400 kV 660 MVA transformer is installed at Border HPP. The power exchange, equal to 600 MW, is not guaranteed in N-1 situation.

<u>View A2</u>:

Consists in a 500 kV AC double circuit line between High Dam and Merowe and between Hasaheisa and Mandaya HPP. Two 500/400 kV 555 MVA transformers are installed at Mandaya HPP. The 500kV Egyptian system is reinforced with a 500 kV single circuit line High Dam-Assiut. The power exchange, equal to 1000 MW, is guaranteed in N-1.

<u>View A3a</u>:

Consists in a ± 500 kV double pole line between Mandaya HPP and Assiut. One AC/DC 1200 MW converter is installed at Mandaya and one at Assiut. The power exchange is equal to 1200 MW, only 600 MW are guaranteed in N-1.

<u>View A3b</u>:

Consists in a ± 500 kV double pole line between Mandaya HPP and Assiut. One AC/DC 1200 MW converter is installed at Mandaya and one at Assiut. The power exchange is equal to 1200 MW, only 600 MW are guaranteed in N-1.

View A3c:

Same as A3b but with a DC/AC tapping station located at Khartoum.

The investment cost of the three views and the transmission cost per MWh have been calculated, based on the following hypothesis:

- Duration of the power exchange = 5000 hours/year.

- Cost of losses = 40 $/MWh.

- Discount rate = 10-12%.

The results are displayed in the following table:

	V A1	V A2	V A3	V A3
Voltage	500 kV AC	500 kV AC	± 500 kV DC	± 500 kV DC
Investment cost	465 MUSD	1 025 MUSD	760 MUSD (no substation in Sudan)	764 MUSD DC/AC substation in Sudan
Transmission cost	24.4 USD/MWh	30.6 USD/MWh	21.9 USD/MWh	28.2 USD/MWh
Transfer capacity in N situation	600 MW	1 000 MW	1 200 MW	1 200 MW
Transfer capacity in N-1 situation	0 MW	1 000 MW	600 MW	600 MW

Table 1.2-11- Investment cost of the three primary views

These results confirm that to transmit a huge power over a long distance, such as between Ethiopia and Egypt, DC solutions are the less expensive ones.

For the coming step of the Study, Module 6, other alternatives – connection points, line route and technical characteristics - will be investigated. They will be designed according to the results of the economic Study - power exchange, duration of exchange and the HPP location. In particular, a mix solution, combining AC and DC links, could be considered.

1.2.4.2 Fuel price projections

The Consultant find relevant to use the following international fuel price projections:

- Oil price projections from the Energy Information Administration (AEO 2006):

Unit : 2006 USD/bbl

Scenario	2006	2007	2008	2009	2010	2015	2020	2025	2030
High	62.0	62.2	62.8	64.1	65.7	80.0	89.2	94.7	100.4
Refrence	62.0	58.3	54.9	52.6	49.6	50.1	53.2	56.7	59.8
Low	62.0	56.5	51.3	47.1	42.3	35.4	35.7	36.1	35.4

Table 1.2-12- Oil price projections

- Natural gas projections from the European Commission for the European and African market:

Unit : USD_{2006}/MBTU

Scenario	2006	2010	2015	2020	2025	2030
High	6.5	6.4	7.4	7.9	9.0	10.5
Reference	6.5	6.4	6.4	7.0	8.1	8.4
Low	6.5	4.8	4.9	5.0	5.1	6.6

Table 1.2-13- Natural gas projections

- The coal price is considered constant all over the Study period: 63 €/t.

1.2.4.3 First indications of the profitability of the interconnection

The profitability of the power exports from the Ethiopia - Sudan area to Egypt is determined by the competition between gas-fired CCGT in Egypt and hydro power supplied to Egypt through the interconnection. The interconnection is economically founded if the average cost of the MWh supplied to Egypt through the interconnection is lower than the average cost of the MWh directly supplied by a gas-fired CCGT in Egypt.

From the previous first estimation of interconnection views and costs it is possible to compare:

- the economic cost of gas-fired Egyptian CCGT generation,
- the economic cost of hydro generation supplied to Egypt though the interconnection.

It is found that, if the power exports from Ethiopia – Sudan area are supplied from a 40 USD/MWh HPP (not including interconnection cost), then the exported hydro generation would become competitive when the natural gas price in Egypt is greater than 6.5 USD/MBTU. This value is reached in the 2016 in the reference projection of natural gas price, 5 years earlier in the high price projection, and after 2030 in the low price projections.

In other words, the interconnection would become profitable from the earliest possible commissioning date, giving the construction duration (2015), in the high and medium price natural gas projection (see figure hereafter).

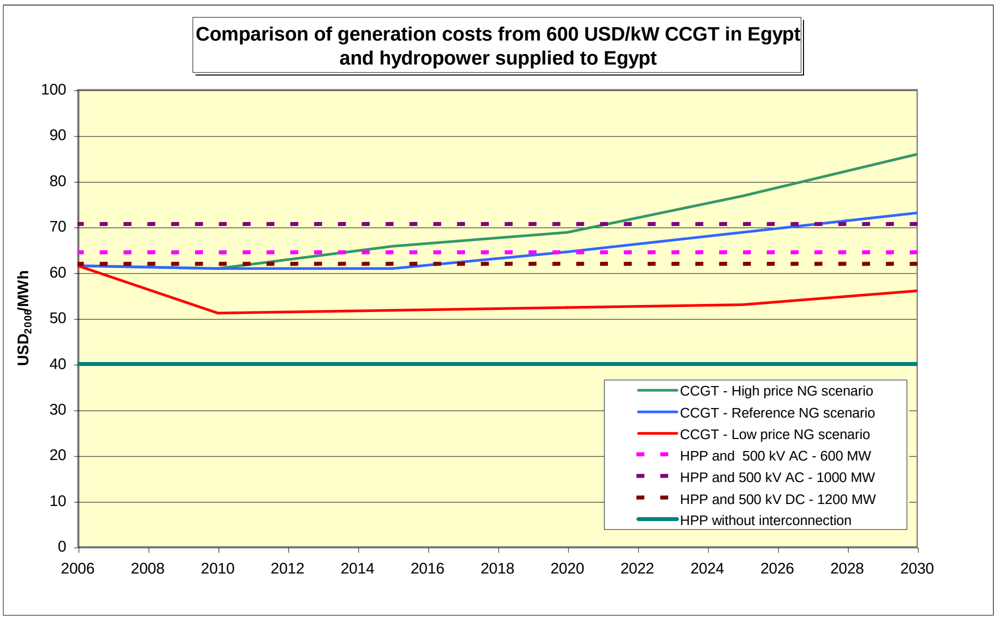

Figure 1.2.4-1- Comparison of generation costs

If the power exports from Ethiopia – Sudan area were supplied from a 35 USD/MWh HPP (not including interconnection cost), then the exported hydro generation would be competitive from now on (except for the low price natural gas projection).

At this stage of the Study, these figures are to be considered as purely indicative because they are based on a simplified economic approach, preliminary identification of interconnection alternatives. Nevertheless they strongly support the confidence in the profitability of the interconnection from 2015.

The purpose of Module 6, through the economic Study, generation expansion plan determination and interconnection optimisation (design and line route), will be to confirm this economic profitability and to precisely assess the associated benefits for the region.

2. OVERVIEW

The first purpose of Module M4 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 M4 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 M3.
- 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.

2.1 MULTI-CRITERIA RANKING METHODOLOGY

The objective of the ranking is not to rank HPPs between countries but to identify subsets of projects having similar evaluation marks. It will be done, within each country (Sudan and Ethiopia), on the basis of a simplified analytical tool using a summarized set of data for each HPP. This information will be used in the planning model (Module M6) to sequence the commissioning of HPPs projects by sets of projects of comparable evaluation mark (from higher to lower mark).

Six families of criteria were identified (the sub criteria are indicated in brackets):

- General,
- Environmental (Greenhouse gas reductions, Upstream impact, Downstream impact, Ratio Reservoir area / Energy output),

- Social (Resettlement, Multipurpose benefit),
- Political (Trans-boundary benefits, Poverty reduction, balancing benefits between rural and urban populations, level of services, mechanisms for benefits sharing),
- Economic / Financial (Capacity cost, Generation cost),
- Technical (Hydro-generation risk, Reservoir filling time, Construction risk, Accesses/Lines, Grid integration, Hydraulic link).

For each criteria the quotation is in the range **[1 (low) to 5 (high)]**.

This exercise shows a consistent result. The quotation was built on good bases: a high percentage of criteria was quoted (except for Social in South Sudan).

The weighting was made for different combinations to highlight and identify the "the higher quoted" set of projects regarding:

- pure economic criteria,
- pure socio-environmental criteria,
- pure technical criteria,
- balanced technico-economic criteria,
- linear combination with all criteria, keeping a high weight for economic criteria and giving preference to socio environmental criteria compared to technical criteria,
- linear combination with all criteria, keeping a high weight for economic criteria and giving preference to technical criteria compared to socio environmental criteria.

The results allow to identify the group of higher quoted set of hydropower projects which will have to be considered in priority for each country in the planning model (Module 6).

The analysis is robust: the short listed projects are almost the same even when the weighting combination is changed.

The final ranking results are summarized in the following tables:

Sequencing	**SUDAN**
1	Rumela
2	Shereiq
3	Low Dal
4	Kaibar
5	Dagash
6	Southern HPP Projects

Table 2.1-1- Final sequencing for Sudan

Sequencing	ETHIOPIA
1	Mandaya
2	Genale
3	Karadobi
4	Chemoga Yeda
5	Baro
6	Geba
7	Border
8	Halele Worabesa
9	Aleltu East
10	Aleltu West

Table 2.1-2- Final Sequencing for Ethiopia

2.2 CRITERIA FOR GENERATION INVESTMENT PLANNING

The criteria currently used in the different countries are:

	Egypt	Ethiopia	Sudan
Discount rate*	7%	12% (9% & 15%)	12% (10% & 15%)
LOLP	8 hour / year	10 days / year	3.65 day / year
Cost of unserved energy	900 USD /MWh	520 USD/MWh	not used explicitly
Margin ratio	15 to 23%	20%	not used
HPP firm energy	not relevant	97.3% reliability	95% reliability
Planning model	EGEAS	GENSIM + ARSP	ASPLAN + RAPSO

Table 2.2-1 - List of criteria currently used

Notes:

- The discount rate is an economic parameter rather than a criteria for planning investment studies.

However, because of its importance in the economic calculation, and the need for a common value to be used in the Study, the Consultant proposes to discuss it in the present Module. The values between bracket are for the sensitivity analysis.

- The LOLP (the Loss Of Load Probability) is the average number of hours of power shortage per year. This is the most widely used measure to express the level of supply reliability of a power generation mix.

- The Cost of Unserved Energy (CUE), is an evaluation of the costs to the economy of the country induced by power shortage. Giving a high CUE to a generation investment planning model means setting a high level a power supply reliability.

- The LOLP and the CUE are two related notions and represent two different ways to express the target level of power supply reliability.

*: the values between brackets refer to the values used for sensitivity analysis.

The criteria proposed by the Consultant for the present Study are described below.

Discount rate : base case 12%, sensitivity analysis 10%.

The connection of the three countries through a high voltage interconnection will raise the three power systems to the same level of reliability of power supply (this is one of the technical benefit of an interconnection). Accordingly, the Consultant proposes to set this value to a target value of 8 hours / year for the LOLP, which corresponds to a Cost of Unserved Energy to be considered by the planning model equal to 13 000 USD/MWh.

2.3 CRITERIA FOR TRANSMISSION PLANNING

The criteria currently used in the different countries are:

	Egypt	Ethiopia	Sudan
General criterion	220 kV: N-2 criterion 500 kV: N-1 criterion	N-1 criterion	N-1 criterion
Normal conditions	Voltage ~~within~~ limits : 95%-105% ~~limits~~ Generation within their reactive capabilities Respect of thermal rating	Voltage ~~within~~ limits : 95%-105% ~~limits~~ Generation within their reactive capabilities Respect of thermal rating	Voltage ~~within~~ limits : 95%-105% ~~limits~~ Generation within their reactive capabilities Respect of thermal rating
Emergency conditions	Voltage ~~within~~ limits : 90%-105% ~~limits~~ Respect of thermal rating	Voltage dips <10% Flow <120% of thermal rating	Voltage ~~within~~ limits : 90%-105% ~~limits~~ Respect of thermal rating
Transient situations	Stability maintained after 3-phase default and correct operation of protections. Power and voltage oscillations quickly damped.	Stability maintained after 3-phase default and correct operation of protections. Power and voltage oscillations quickly damped.	Stability maintained after 3-phase default and correct operation of protections. Power and voltage oscillations quickly damped
Frequency limits	Load shedding (first stage): < 49.~~5~~ 2 Hz Tripping of interconnection with Libya: 49.5 Hz Over frequency: > 51 Hz	Load shedding (first stage): < 48.6 Hz Over frequency: > 52 Hz	Load shedding (first stage): < 49.2 Hz Over frequency: > 52 Hz

Table 2.3-1 - Criteria for transmission planning

The interconnections between the three power systems must respect some rules to comply with technical and economic constraints:

- As the distances between the transmission systems are consequent and huge power exchange could be profitable, the AC interconnection links must be designed with the highest voltage used in the countries in order to maximise the power transfer capacity and minimise the transmission losses.

- The interconnection links must be connected close to a huge power station in the exporting country and close to a main load centre in the receiving country to minimise the impact of the power exchanges on the internal networks.

- AC links are technically and economically feasible whether the distance does not exceed 500 or 600 km. For longer distance beyond 800 km without tapping substations, DC solution has to be recommended.

- The interconnection must follow the shortest route to minimise the investment cost and the transmission losses. Moreover to facilitate the construction of the line and the maintenance during its operation, the line route must be kept close to roads or tracks.

The proposed criterion for the interconnection is that the interconnected system must satisfy the N-1 criterion, that is the planning criterion used in the three countries.

In normal and in emergency situations, the operation of the interconnection must not adversely affect the operation of the three interconnected systems. Whatever the situation, the electrical parameters of these systems (currents, voltages, frequency,...) must be kept within their operation limits recalled in the previous table.

Moreover, as each system complies with N-1 criterion, any single outage in one of the three systems must not adversely affect the operation of the interconnection and of the two other systems.

The two interconnection links between Ethiopia and Sudan, and then Sudan and Egypt, must be properly linked together with a robust interconnection, subjected to the same planning criteria.

<u>Emergency situation for the interconnection</u>:

It consists in the outage of one element of the interconnection link:

One circuit for an AC line,

One pole for a DC line,

Blocking of one pole of a converter.

Following the outage, the interconnected system shall operate without the faulted element.

<u>Technical constraint on the power exchange</u>:

The transfer capacity of the interconnection will be deduced from the results of Economic Study, the interconnection will be sized to transmit all the profitable power exchanges, taking into account the benefit due to fuel substitution and the transmission cost.

In N-1 situation, the power exchange could be affected by the outage of one element of the interconnection link according to the design of the interconnection: single circuit line, double circuit line or double pole DC link or several circuit link. The following cases could be examined:

- <u>Single circuit link</u> (AC single circuit line or DC single pole link)
The outage of the interconnection entails the loss of the whole power exchange. In this situation, there is a shortage of generation in the receiving country, and consequently a frequency drop. The under frequency load shedding scheme in the receiving country must not be activated. In the exporting country, the frequency surge due to the extra generation

must not activate the over frequency protection of the generating units. To respect these limits – under frequency and over frequency – the power exchange will have to be limited.

- Double circuit line

  - AC double circuit line: following the outage of one circuit, two situations can appear:

    - The power exchange is not affected ; the N-1 criterion is satisfied. The remaining circuit will be sized to transmit the whole power exchange.

    - The power exchange has to be reduced ; the N-1 criterion is not totally satisfied. The remaining circuit will be sized to be temporarily overloaded, until the decrease of the power exchange will be effective.

  - DC double pole link: Following the outage of one DC pole, half of the initial power exchange is lost. As in the situation "Single circuit link", the receiving system must avoid the activation of the under frequency load shedding scheme and the exporting system must avoid over frequency.

- Multi circuit link: the interconnection satisfies the N-1 criterion ; following the outage of one circuit, the power exchange is not affected.

3. ORGANISATION OF THE REPORT

The first purpose of Module M4 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.

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4. MULTI-CRITERIA RANKING METHODOLOGY

4.1 GENERAL

4.1.1 CONTEXT AND DECISION-MAKING

The word “context” has to be understood in a broad sense, as it may address:

- Different geographical areas (World, Region, Country or River basin)
- Different sectors (water, power, etc.)
- A variety of stakeholders (lenders’ community, civil society organizations, corporate organizations, etc)

The whole decision-making process includes different levels: General Policy Level, Strategy Level and the practical decision-making at operational level. All three levels interact with the context and the whole system needs to operate as a closed loop. For example, the operational level is strongly influenced by the context, but it may also lead to some changes to that context through the lessons learned by application.

In term of development and sustainability of water and hydropower projects there have been major changes at all levels over the last two decades. Some changes in Global Policy and Strategy Levels are briefly set out below, resulting from an analysis of a few key documents.

4.1.1.1 Key Documents and General Policy Level

Ensuring environmental sustainability and ensuring a global partnership for development are goals assigned by the United Millennium Declaration. The role of hydropower as a renewable energy source has been recognized at different occasions, such as the Johannesburg World Summit on Sustainable Development (September 2002), the 3rd World Water Forum in Kyoto (March 2003) and the Bonn Conference for Renewable Energies (June 2004). Developing hydropower in all forms, including R&U, should thus contribute to meet the Kyoto Protocol commitments, UNFCCC or other international agreements aiming at sustainable development.

4.1.1.2 Key Documents and Strategy Level

The Water Resources Sector Strategy from the World Bank, complemented by the “Infrastructure Scale-up Policy” document, is largely based on the assertion that water resources management and development is central to sustainable growth and poverty reduction. In particular, the record shows that there is a major need in all countries for improving the benefits from existing infrastructure. This is the motivation for the World Bank’s re-engagement in infrastructure projects and to assisting countries in developing and maintaining appropriate stocks of hydraulic infrastructure which perform well and to mobilising public and private financing, whilst meeting environmental and social standards.

The White Paper from the IHA focuses on the implementation of appropriate systems for decision-making. Amongst others, the motivation comes from the contradiction between multi-stakeholder processes being increasingly adopted in many countries and longer-term planning being on the decline, as well as the failure to reach decisions within a reasonable time frame. Sustainability Guidelines issued by the IHA cover the following five elements: Policy Framework, Evaluation of alternatives, Hydropower and environmental management, Social sustainability and Economic sustainability. Prioritizing the upgrading of existing facilities is one of the criteria that should be used in comparing energy options and hydro alternatives.

The New Framework for decision-making issued by the World Commission on Dams has identified five core values and seven strategic priorities intended to assist in sustainable development of water and energy resources.

4.1.1.3 Changes in the Context

Changes that have an impact on the development and management of water and power resources and infrastructures can be noted, including, but not limited to:

Increasing concern for sustainable development: In particular, public interest has become more wide-ranging and gives more weight to the rights, risks and responsibilities of people affected by projects, pays more attention to distribution of costs and benefits, and puts more emphasis on inter-generational equity. For example, the Stakeholder Involvement from the Global Policy Level down to the local level is one of the most visible signs of this increasing concern.

Water and Power Sector changes: Governments are changing from their traditional role as the sole service provider to that of regulators and facilitators. Consequently, many countries are currently facing major changes in the water sector, and most in the power sector. These changes lead to a different approach for the development and management of infrastructures, and require more efficiency by increasing reliability and improving the response to system requirements.

Conservation of storage capacity: Dams and associated water reservoirs are ageing. Reservoir ageing is mainly caused by sediment accumulation (an order of magnitude of 0.5 percent of the total reservoir storage capacity lost annually is frequently observed as a result of sedimentation). Ensuring the sustainability of existing infrastructures for future generations by conserving existing water storage capacity is a priority for the 21st century, together with the development of new storage capacity as required.

Addressing climate change: Addressing climate change is progressively becoming a key issue in ensuring the sustainability of existing water/power infrastructures. Not only may climate change impact the revenue of the projects but also it may require reassessment of extreme hydrological events and subsequent spillway design in order to ensure dam safety and flood control. The fundamental role of storage in mitigating the effects of floods and droughts should be maintained by appropriate reservoir conservation measures.

Growing interest for regional approaches: This may be regarded as one component of the power system change, which improves power stability, emergency power and diversity, and generally reduces overall investment by sharing reserves. Such changes may require some specific performance characteristics to operate in a synchronous network. It also makes decision-making more complex, as Options Assessment needs to give more consideration to the import/export of energy and transboundary water issues.

Scarcity of funds: Projects face increasing difficulties in obtaining adequate finance, in association with risk allocation and the period of reimbursement. However, as mentioned by the Water Resources Sector Strategy from the World Bank (2003), there has been a recent positive change in the lenders' community attitude regarding dam and hydropower project financing.

Scarcity of water: Both power and water need optimized management in view of sustainable development goals. However, energy options are more numerous than water options, whilst water needs are most likely to increase in future decades. Optimized water management is an absolute priority.

4.1.1.4 A brighter future for dam and hydro plant projects

All the aforementioned changes and their potential impact on dam and hydro-plant projects can be looked at from different perspectives. Whilst it cannot be denied that there are more parameters to be taken into account for decision-making, there are also good reasons to expect a future, which is better than what has been observed during the last two decades for water and hydropower projects.

4.2 OBJECTIVES OF THE RANKING

The objective of the ranking HPPs projects is:

- To identify within each country Sudan and Ethiopia sets of hydropower projects having similar evaluation mark and to sequence the projects. This identification is based on a simplified analytical tool using a summarized set of data for each HPP.
- These information will be used in the planning model (Module M6) to sequence the commissioning of HPPs projects by sets of projects having similar evaluation mark (from higher mark to lower mark).
- To eliminate, if it is justified, in coordination with Sudanese and Ethiopian representatives few projects.
- Not an inter-comparison between HPPs projects of different ENTRO countries. There is definitely no competition between Ethiopian and Sudanese projects because each power system will need, in the long term, the development of the quasi-totality of the HPPs projects identified in Module M3.

The Consultant proposes a methodology for scaling and weighting the different criteria in order to establish a global evaluation mark for each HPP candidate.

The Consultant has obtained an extensive experience in ranking/screening projects:

- in the framework of consultancy services (for institutional Clients, utilities, lenders, developers and funding agencies) worldwide and in particular in tropical and equatorial area,

- also for its own needs in many countries (Europe/ South America, Africa and Asia) for due diligences used by EDF Special Purpose Investment Committee for decisions concerning IPPs development.

The Consultant approach was based on six families of criteria divided in several sub-criteria.

When enough data is available, sub-criteria are quoted using a precise scale. The classes of these scales are widely used, nevertheless they are customized to the HPP projects of the present study. It means that the ranges (minimum and maximum values) depend on the actual characteristics of the projects identified.

The six families of sub-criteria, as well as scales, used in the ranking are presented in 3.2. For each criteria the quotation is in the range **[1 (low) to 5 (high)]**.

Some criteria cannot be quoted due to the lack of data. It is important to notice that the data are really lacking *ie* they do not exist (for example data on Sudanese HPP). A global statistical profile is presented in 4.2 for each project. The missing quotations can induce some bias in the global quotation and this (limited) risk is discussed in 4.2. The bias is quite limited since all families are quoted, except some specific projects and social criteria.

In order to obtain a global evaluation mark, a relative weighting is necessary between all families of criteria. This stage is always controversial. Therefore the Consultant made different combinations to highlight and identify the “higher quoted” set of hydro projects regarding:

- pure economic criteria,
- pure socio-environmental criteria,
- pure technical criteria,
- balanced technico-economic criteria,
- linear combination with all criteria, keeping a high weight for economic criteria and giving preference to socio environmental criteria compared to technical criteria,
- linear combination with all criteria, keeping a high weight for economic criteria and giving preference to technical criteria compared to socio environmental criteria.

4.3 PROPOSED CRITERIA

Six families of criteria were identified:

- General,
- Environnemental,
- Social,
- Political,
- Economic / Financial,

- Technical.

For each specific family, the following sub-criteria are described hereafter.

4.3.1 GENERAL CRITERIA

Level of studies (level of knowledge about the project i.e. Identification, Pre-feasibility, Feasibility - reliability and accuracy of data – field investigations).

For this criteria the following scale was used:

Detailed design	5
Feasibility study	4
Pre-Feasibility study	3
Preliminary study or profile from Master plan	2
First Identification	1

Table 4.3-1 - Scale used for general criteria

The score can be fitted (+/- 1) according to the appreciation on the quality of the study and data.

4.3.2 ENVIRONMENTAL CRITERIA

This family includes 4 sub-criteria :

- Greenhouse gas reductions (global and regional scale).

For this sub-criteria it is proposed to connect the GHG reduction with the energy output and to introduce a penalization (-1 or –2) to take into account the possible flooded forest surface.

For this sub-criteria the following scale was used:

> 2 TWh	5
1,5 TWh < < 2 TWh	4
1 TWh < < 1,5 TWh	3
0,5 TWh < < 1 TWh	2
< 1 TWh	1

Table 4.3-2 - Scale used for greenhouse gas reduction sub criteria

- Upstream impact: land reduction for agriculture, health, archaeology, Flora and Fauna (known, rare, threatened or vulnerable species and their habitat, high quality habitats), protected ecosystems, natural sites, impacts on protected sensitive and fragile ecosystems, including internationally classified sites such as RAMSAR…

- Downstream impact: sedimentation (management and assessment of reservoir half-life in case of storage options), floods, cumulative impacts and likely indirect impacts, Flore and Fauna (known, rare, threatened or vulnerable species and their habitat, high quality habitats), protected ecosystems, natural sites, Impacts related to changes in river flows including environmental flow needs and/or securing of possibility for artificial flood (e.g. due to climatic variability and due to hydraulic infrastructure…), impacts on protected sensitive and fragile ecosystems, including internationally classified sites such as RAMSAR…

For these two above mentioned sub-criteria, the quotation is evaluated according to available information in the existing reports using the following scale:

Very low negative impact	5
Low negative impact	4
Medium negative impact	3
Important negative impact	2
Very important negative impact	1

Table 4.3-3- Scale used for upstream and downstream sub-criteria

- Ratio Reservoir area / Energy output.

For this sub-criteria the following scale was used:

< 0,001 km^2/GWh	5
0,001 < < 0,05 km^2/GWh	4
0,05 < < 0,08 km^2/GWh	3
0,08 < < 0,1 km^2/GWh	2
> 0,1 km^2/GWh	1

Table 4.3-4 - Scale used for reservoir area/energy output sub criteria

4.3.3 SOCIAL CRITERIA

This family includes 2 sub-criteria:

- o Resettlement: quantitative impact for population displacement and qualitative impact for vulnerable communities (ethic/religious minorities, indigenous people, most uneducated communities, etc…), impact on cultural and spiritual sites, requirements of population, households, perennial and annual crops, pasture, other livelihood assets.

The Beneficiary/Affected people ration is not known for the majority of HPP projects, so it was not considered. The preferred methods of sharing project benefits (revenue sharing, development funds, equity sharing, tax levies, preferential fees, etc…) with affected people (in addition to compensation) were neither taken into account.

The balance small (local benefits) and large projects (national/regional growth) can not be considered at this stage: it will be one the results of Module 6 model.

For this sub-criteria the following scale was used (the household are those located in the reservoir area and to be resettled):

0 household	5
0 < < 100 households	4
100 < < 300 households	3
300 < < 600 households	2
> 600 households	1

Table 4.3-5 - Scale used for resettlement sub criteria

For this sub-criteria it was proposed to induce a penalization (-1) to take into account the loss of agricultural land or presence of vulnerable communities.

- o Multipurpose benefit: irrigation, flood control, fisheries, navigation or tourism, competing water uses.

For this above mentioned sub-criteria, the quotation is evaluated according to available information in the existing reports (a special attention was paid to the irrigation benefit) using the following scale:

Very important multipurpose benefit with irrigation	5
Important multipurpose benefit with irrigation	4
Medium multipurpose benefit	3
Limited multipurpose benefit	2
No multipurpose benefit	1

Table 4.3-6 – Scale used for multipurpose benefit sub-criteria

4.3.4 POLITICAL/MACROECONOMICS CRITERIA

This family includes 2 sub-criteria:

- Trans-boundary benefits and cooperation, conflict resolution, trust building potential, sub regional integration,
- Poverty reduction, balancing benefits between rural and urban populations, level of services (transport infrastructures, water supply and sanitation, health, education, communications,…), sub-regional integration, mechanisms for benefits sharing, contribution of project to poverty reduction in the area in the proximity to project.

For these two above mentioned sub-criteria, the quotation is evaluated according to available information in the existing reports and using the following scales:

Very important Trans-boundary benefit	5
Important Trans-boundary benefit	4
Medium Trans-boundary benefit	3
Limited Trans-boundary benefit	2
No Trans-boundary benefit	1

Table 4.3-7- Scale used for Trans-boundary sub-criteria

Very important poverty reduction	5
Important poverty reduction	4
Moderate poverty reduction	3
Limited poverty reduction	2
No poverty reduction	1

Table 4.3-8- Scale used for Poverty sub-criteria

4.3.5 ECONOMIC/FINANCIAL CRITERIA

This family includes 2 sub-criteria:

- Capacity cost (includes construction cost, transmission line costs, O&M cost, cost of environmental and social mitigation measures),

For this sub-criteria the following scale was used:

< 1000 USD/kW	5
1000 < < 1500 USD/kW	4
1500 < < 2000 USD/kW	3
2000 < < 2500 USD/kW	2
> 2500 USD/kW	1

Table 4.3-9 - Scale used for capacity cost sub-criteria

- o Generation cost (includes construction cost, transmission line costs, O&M cost, cost of environmental and social mitigation measures ; calculated with a 12% discount rate).

The sub-criteria gestation period in delivering benefits, macro-economics considerations, microeconomic considerations (including mechanisms for benefit sharing) and life cycle assessment can not be considered at this stage because there is no knowledge for quotation.

The quality of power production (suitability to provide base load, suitability for seasonal peak load, suitability for daily peak load was not considered at this stage. The module 6 will bring information regarding these aspects.

For this sub criteria the following scale was used:

< 45 USD/MWh	5
45 < < 55 USD/MWh	4
55 < < 70 USD/MWh	3
70 < < 80 USD/MWh	2
> 80 USD/MWh	1

Table 4.3-10 - Scale used for generation cost sub-criteria

4.3.6 TECHNICAL CRITERIA

This family includes 6 sub-criteria:

- o Hydro-generation risk (energy output / hydrological inflow),

For this sub-criteria, the ratio firm energy/average energy was calculated and the following scale was used:

98 < < 100%	5
98 < < 95%	4
92 < < 95%	3
85 < < 92%	2
< 85%	1

Table 4.3-11 - Scale used for hydro-generation sub-criteria

- Reservoir filling time (assuming an independent development of the project),

Obviously this sub-criteria is a key one: a long filling time has negative effect downstream and impacts the financial income for the first years.

For this sub-criteria the following scale was used:

< 0,5 year	5
0,5 < < 1 year	4
1 < < 2 years	3
2 < < 2,5 years	2
> 2,5 years	1

Table 4.3-12 - Scale used for reservoir filling time sub-criteria

- Construction risk (geological risk, presence of underground works),

This sub-criteria was appreciated with an appraisal on existing geological reports and the quotation used the following table:

Very low risk	5
Low risk	4
Moderate risk	3
High risk	2
Very high risk	1

Table 4.3-13- Scale used for Construction risk sub-criteria

- Accesses/Lines (length of new accesses roads and transmission line to be built to link the grid),

For this sub-criteria the following scale was used (the total length of accesses and lines to be built were considered):

< 40 km	5
40 < < 100 km	4
100 < < 300 km	3
300 < < 500 km	2
> 500 km	1

Table 4.3-14 - Scale used for accesses/lines sub-criteria

- Grid integration (significance of the power supply from the project in the national context and regional context including interconnections),

The idea is to evaluate the integration of the project within the grid. The approach consist in:

- quantifying the regional national, or international benefit,
- determining the distance from consumption centres,
- estimating the interest of the project for the balance of existing grid.

The scale used to quote this sub-criteria is the following:

Very important benefit for grid integration	5
Important benefit for grid integration	4
Medium benefit for grid integration	3
Limited benefit for grid integration	2
Low benefit for grid integration	1

Table 4.3-15- Scale used for Grid integration sub-criteria

- Hydraulic link (hydraulic cascade scheme on the river or rivers if the project comprises transfers).

The idea is to give a higher quotation to a project which provide regulation on the downstream HPPs. Usually, the upstream dam is expensive (large dam and big storage), but gain is obtained on the following project downstream.

The scale used to quote this sub-criteria is the following:

Very important benefit for downstream projects	5
Important benefit for downstream projects	4
Medium benefit for downstream projects	3
Limited benefit for downstream projects	2
Low benefit for downstream projects	1

Table 4.3-16- Scale used for Hydraulic link sub-criteria

5. DRAFT APPLICATION OF THE MULTI-CRITERIA RANKING METHODOLOGY

The purpose of this paragraph is to evaluate and mark each hydropower candidates on the basis on the previous methodology.

5.1 JUSTIFICATION FOR EACH PROJECT

5.1.1 "FULA" PROJECT

	Criteria N°	CRITERIA	Quotation	Justification
General	1	Level of studies	2	LTPSPS : ACRES 1993
Environmental	2	GHG reduction	5	95% Firm energy 2300 GWh
	3	Upstream impacts		not available
	4	Downstream impacts	3	Low siltation problems
	5	Reservoir area/energy	4	0,0437 km^2/GWh
Social	6	Resettlement		not available
	7	Multipurpose benefit		not available
Political / Macroeconomics	8	Transboundary benefit	1	none
	9	Poverty reduction	3	In the case of a programme involving local population ; electrification dissemination
Economical / Financial	10	Capacity cost	2	1830 USD2006/kW (720 MW)
	11	Generation cost	4	49.1 USD2006/MWh
Technical	12	Hydro-Generation risk	4	Average energy = 4119 GWh Firm = 2300 GWh - White Nile inflows have low seasonality
	13	Reservoir filling time		not available
	14	Constr. risk		not available
	15	Accesses/Lines	1	transmission line to main grid not expected before 2020
	16	Grid insertion	2	Support the development of the southern part of Sudanese grid
	17	Hydraulic link (e.g. cascade)	5	The first upstream project in Sudan followed by Shukoli

Table 5.1-1 - Fula Project

5.1.2 “SHUKOLI” PROJECT

	Criteria N°	CRITERIA	Quotation	Justification
General	1	Level of studies	2	LTPSPS : ACRES 1993
Environmental	2	GHG reduction	2	95% Firm energy 914 GWh
	3	Upstream impacts		not available
	4	Downstream impacts	3	Low siltation problems
	5	Reservoir area/energy	4	0,01 km^2/GWh
Social	6	Resettlement		not available
	7	Multipurpose benefit		not available
Political / Macroeconomics	8	Transboundary benefit	1	none
	9	Poverty reduction	3	In the case of a programme involving local population ; electrification dissemination
Economical / Financial	10	Capacity cost	3	2000 USD2006/kW (210 MW)
	11	Generation cost	5	45 USD2006/MWh
Technical	12	Hydro-Generation risk	4	Average energy = 1420 GWh, Firm energy = 914 GWh - White Nile inflows have low seasonality
	13	Reservoir filling time		not available
	14	Constr. risk		not available
	15	Accesses/Lines	1	transmission line not expected before 2020 ; 10 MUSD2006
	16	Grid insertion	2	Support the development of the southern part of Sudanese grid
	17	Hydraulic link (e.g. cascade)	4	14 km downstream from Fula

Table 5.1-2 - Shukoli Project

5.1.3 “LAKKI” PROJECT

	Criteria N°	CRITERIA	Quotation	Justification
General	1	Level of studies	2	LTPSPS : ACRES 1993
Environmental	2	GHG reduction	2	95% Firm energy 912 GWh
	3	Upstream impacts		not available
	4	Downstream impacts	3	Low siltation problems
	5	Reservoir area/energy	4	0,01 km^2/GWh
Social	6	Resettlement		not available
	7	Multipurpose benefit		not available
Political / Macroeconomics	8	Transboundary benefit	1	none
	9	Poverty reduction	3	In the case of a programme involving local population ; electrification dissemination
Economical / Financial	10	Capacity cost	2	2040 USD2006/kW (210 MW)
	11	Generation cost	4	46 USD2006/MWh
Technical	12	Hydro-Generation risk	4	Average energy = 1415 GWh, Firm energy = 912 GWh - White Nile inflows have low seasonality
	13	Reservoir filling time		not available
	14	Constr. risk		not available
	15	Accesses/Lines	1	transmission line not expected before 2020 ; 11.9 MUSD2006
	16	Grid insertion	2	Support the development of the southern part of Sudanese grid
	17	Hydraulic link (e.g. cascade)	3	24 km downstream from Shukoli

Table 5.1-3 - Lakki Project

5.1.4 "BEDDEN" PROJECT

	Criteria N°	CRITERIA	Quotation	Justification
General	1	Level of studies	2	LTPSPS : ACRES 1993
Environmental	2	GHG reduction	4	95% Firm energy 1850 GWh
	3	Upstream impacts		not available
	4	Downstream impacts	3	Low siltation problems
	5	Reservoir area/energy	4	0,04 km^2/GWh
Social	6	Resettlement		not available
	7	Multipurpose benefit	4	irrigation of the Bahr et Jebel area
Political / Macroeconomics	8	Transboundary benefit	1	none
	9	Poverty reduction	3	In the case of a programme involving local population ; electrification dissemination
Economical / Financial	10	Capacity cost	2	2200 USD2006/kW (400 MW)
	11	Generation cost	4	49 USD2006/MWh
Technical	12	Hydro-Generation risk	4	Firm energy = 1850 GWh, average energy = 2700 GWh - White Nile inflows have low seasonality
	13	Reservoir filling time		not available
	14	Constr. risk		not available
	15	Accesses/Lines	1	transmission line not expected before 2020 ; 32.8 MUSD2006
	16	Grid insertion	2	Support the development of the southern part of Sudanese grid
	17	Hydraulic link (e.g. cascade)	2	66 km downstream from Lakki

Table 5.1-4 - Bedden Project

5.1.5 "RUMELA" PROJECT

	Criteria N°	CRITERIA	Quotation	Justification
General	1	Level of studies	3	F/S completed (SOGREAH)
Environmental	2	GHG reduction	1	95% Firm energy 35 GWh
	3	Upstream impacts	4	No permanent households
	4	Downstream impacts	5	Reservoir downstream Khasm Elsirba
	5	Reservoir area/energy	4	
Social	6	Resettlement	4	No permanent households
	7	Multipurpose benefit	5	Regulation for downstream irrigation - Project having high priority for irrigation purposes
Political / Macroeconomics	8	Transboundary benefit	1	none
	9	Poverty reduction	5	Development of a local associated programme involving local population
Economical / Financial	10	Capacity cost	1	6400 MUSD2006/kW (30 MW)
	11	Generation cost	1	340 USD2006/MWh
Technical	12	Hydro-Generation risk	1	Firm energy = 35 GWh, average energy = 82 GWh (Atbara river)
	13	Reservoir filling time	5	1 month
	14	Constr. risk	4	No major risks
	15	Accesses/Lines	5	Few km from grid and roads
	16	Grid insertion	5	Good effect to balance
	17	Hydraulic link (e.g. cascade)	5	Reservoir downstream Khasm Elsirba

Table 5.1-5 - Rumela Project

5.1.6 "SHEREIQ" PROJECT

	Criteria N°	CRITERIA	Quotation	Justification
General	1	Level of studies	4	Feasibilty Hydroproject & Dar Consult 1999
Environmental	2	GHG reduction	4	95% Firm energy 1936 GWh
	3	Upstream impacts	4	impact on fish migration ; reduction of agriculture land
	4	Downstream impacts	3	Regulation, sediment trapping ; impact on fish migration ; reduction of agriculture recession
	5	Reservoir area/energy	1	386 km² / 1536 GWh (average energy) = 0.25 km²/GWh
Social	6	Resettlement	2	Flooding of settlements and cultivated lands ; densely populated area between Abia and Atbara
	7	Multipurpose benefit	4	irrigation ; fishery in the case of a development programme ; considered as first priority by Dams Implementation Unit of Sudan
Political / Macroeconomics	8	Transboundary benefit	3	Reduction of silt transportation to Egypt
	9	Poverty reduction	3	In the case of a programme involving local population ; electrification dissemination
Economical / Financial	10	Capacity cost	1	3780 USD2006/kW (315 MW)
	11	Generation cost	1	122 USD2006/MWh
Technical	12	Hydro-Generation risk	1	Firm energy = 80 % of average energy
	13	Reservoir filling time	4	6 months during the low water period
	14	Constr. risk	3	Low geological risk. Good dam foundations, no undergrounds works.
	15	Accesses/Lines	4	transmission cost 7 MUSD2006
	16	Grid insertion	4	National context
	17	Hydraulic link (e.g. cascade)	5	Impact on Nile cascade : Dagash, Merowe, Kajabar, Dal, etc.

Table 5.1-6 - Shereiq Project

5.1.7 "DAGASH" PROJECT

	N°	CRITERIA	Quotation	Justification
General	1	Level of studies	2	LTSP Study ACRES 1993
Environmental	2	GHG reduction	5	95% Firm energy 3836 GWh
	3	Upstream impacts	1	relocation 65km railway (in service) ;
	4	Downstream impacts		not available
	5	Reservoir area/energy		not available
Social	6	Resettlement		not available
	7	Multipurpose benefit		not available
Political / Macroeconomics	8	Transboundary benefit	2	Reduction of silt transportation to Egypt
	9	Poverty reduction	3	In the case of a programme involving local population ; electrification dissemination
Economical / Financial	10	Capacity cost	1	3680 USD2006/kW (285MW)
	11	Generation cost	1	109 USD2006/MWh
Technical	12	Hydro-Generation risk	4	Nile river hydrology, just dowstream of Sheireq (lower risk thanks to regulation from Sheireq)
	13	Reservoir filling time		not available
	14	Constr. risk		not available
	15	Accesses/Lines	4	transmission cost 6MUSD2006
	16	Grid insertion	4	National context
	17	Hydraulic link (e.g. cascade)	4	Impact on Nile cascade : Merowe, Kajabar, Dal, etc.

Table 5.1-7 - Dagash Project

5.1.8 "KAGBAR" PROJECT

	Criteria N°	CRITERIA	Quotation	Justification
General	1	Level of studies	4	F-S
Environmental	2	GHG reduction	3	Low benefit at regional scale / Average energy 1307 GWh/y
	3	Upstream impacts	3	No critical issue for acquatic and terrestrial ecology. Moderate flooded area. Barrier for fish migration (If Mandaya is not developed, 80% storage loste in 7 years)
	4	Downstream impacts	3	No critical issue for acquatic and terrestrial ecology. Gross storage 0.03 x MAR. High evaporation loss
	5	Reservoir area/energy	1	Ratio = 0.154 km2/Gwh
Social	6	Resettlement	2	Significant inundation of population and loss of resources (flooded land)
	7	Multipurpose benefit	2	Fisheries could be developed
Political / Macroeconomics	8	Transboundary benefit	1	No downstream benefit
	9	Poverty reduction	2	No direct national benefit (except power)
Economical / Financial	10	Capacity cost	1	5200 USD/kW (high)
	11	Generation cost	1	107 USD/MWh (high)
Technical	12	Hydro-Generation risk	2	Firm power 176 MW, Firm 98 %
	13	Reservoir filling time	5	< 1 month @ 50% of inflow (very short)
	14	Constr. risk	4	Low geological risk. Good dam foundation. No underground works. Good rock mass quality
	15	Access/Lines	5	Transmission line 220 kV under construction. Acess road under construction.
	16	Grid insertion	4	Low capacity but close to Egypt, Regional context, transmission line 220 kV under construction
	17	Hydraulic link (e.g. cascade)	2	Downstream of Merowe, adversely affected by Merowe sediment flushing operation

Table 5.1-8 - Kagbar Project

5.1.9 "LOW DAL" PROJECT

	Criteria N°	CRITERIA	Quotation	Justification
General	1	Level of studies	3	Pre F-S on going
Environmental	2	GHG reduction	2	Low benefit at regional scale / Average energy 1944 Gwh/y
	3	Upstream impacts	3	No critical issue for acquatic and terrestrial ecology. Low flooded area. Barrier for fish migration
	4	Downstream impacts	5	No critical issue for acquatic and terrestrial ecology. Some sediment trapping. Gross storage 0.03 x MAR. High evaporation loss
	5	Reservoir area/energy	1	Ratio = 0.154 km2/Gwh
Social	6	Resettlement	2	Significant inundation of population and loss of resources (flooded land)
	7	Multipurpose benefit	2	Fisheries could be developed
Political / Macroeconomics	8	Transboundary benefit	3	No downstream benefit
	9	Poverty reduction	2	No direct national benefit (except power trade with Egypt and Sudan)
Economical / Financial	10	Capacity cost	2	2000 USD/kW (high) - to be confirmed in the current Pre-feasibility Study
	11	Generation cost	2	75 USD/MWh (high) - to be confirmed in the current Pre-feasibility Study
Technical	12	Hydro-Generation risk	4	Firm power 298 MW, Firm 98 %
	13	Reservoir filling time	5	< 1 month @ 50% of inflow (very short)
	14	Constr. risk	4	Low geological risk. Good dam foundation. No underground works. Good rock mass quality
	15	Access/Lines	5	Close to transmission line under construction (220 kV). Access road under construction.
	16	Grid insertion	4	Low capacity but close to Egypt, Regional context, transmission line 220 kV under construction
	17	Hydraulic link (e.g. cascade)	2	Downstream of Merowe, adversely affected by Merowe sediment flushing operation

Table 5.1-9 - Low Dal Project

5.1.10 “HALELE WORABESA” PROJECT

	Criteria N°	CRITERIA	Quotation	Justification
General	1	Level of studies	4	feasability studies (aug. 2000 & dec 2004)
Environmental	2	GHG reduction	5	firm energy : 2 TWh
	3	Upstream impacts	4	the project won't adversely affect any known endangered species of plants or animals
	4	Downstream impacts	3	Increased generation at GebeIII,~5%(including the completonof gojeb)
	5	Reservoir area/energy	1	0,14 km2/GWh (total) ; 0,09 for stage I, 0,61 for stage II
Social	6	Resettlement	1	635 households; reservoir will flood 280 km2 of which 13 are productive
	7	Multipurpose benefit		not available
Political / Macroeconomics	8	Transboundary benefit	1	national context
	9	Poverty reduction	3	improve transport to town, will stimulate local trade
Economical / Financial	10	Capacity cost	4	1123 $/kW (2260 $/kW for stage I ; 790 $/kW for stage II)
	11	Generation cost	5	40$/MWh (75 $/MWH for stage I ; 25 $/MWh for stage II)
Technical	12	Hydro-Generation risk	2	Stage I : firm energy = 93 % of average energy ; Stage II : firm energy = 90 % of average energy(needs to be evaluated in a system context or contribution of the plant to the overall system generation)
	13	Reservoir filling time	4	< 1 year
	14	Constr. risk	1	dam foundation : heterogeneous volcanic layers. Underground work in basalt (important length). Uncertainties
	15	Accesses/Lines	4	30 km of transmission line 230 kV and 30 km of transmission line 115 kV ; 40 km of roads
	16	Grid insertion	4	national context

Table 5.1-10 - Halele Worabesa Project

5.1.11 “CHEMOGA-YEDA” PROJECT

	Criteria N°	CRITERIA	Quotation	Justification
General	1	Level of studies	4	feasability study
Environmental	2	GHG reduction	3	firm energy : 1350 GWh
	3	Upstream impacts	3	no specific impact on andegered species of plants or animals. 63 km2 of land flooded in a region intensively cultivated with high demand for land
	4	Downstream impacts	3	no specific impact on andegered species of plants or animals. Important water supply demand dowstream (human and livestock). Recommendation to construct water supply points
	5	Reservoir area/energy	4	0,02 km2/GWh
Social	6	Resettlement	1	1462 households, lost of cultivated and grazzing land
	7	Multipurpose benefit	5	significant potential for irrigation in the area
Political / Macroeconomics	8	Transboundary benefit	3	none
	9	Poverty reduction	3	transport improvement, local rural electrification
Economical / Financial	10	Capacity cost	4	1400 $/kW
	11	Generation cost	5	37 $/MWh (55 $/MWh for Chemoga Yeda I ; 32 for Chemoga -Yeda II)
Technical	12	Hydro-Generation risk	4	firm energy = 97 % of average energy (driest year production : 90 % of firm energy),compare it in a system context)
	13	Reservoir filling time	3	2 wet seasons
	14	Constr. risk	3	6 km of tunnel for stage I ; 12 km for stage II (including tailrace); underground powerhouse for stage II. Quite poor rockmass quality. Powerhouse in good gneiss. Presence of landslides for stage II
	15	Accesses/Lines	4	70 km of new road; 45 km of transmission line (230 kV)
	16	Grid insertion	3	regional context
	17	Hydraulic link (e.g. cascade)	2	low impact (project on tributaries of the Abbay river)

Table 5.1-11 – Chemoga-Yeda Project

5.1.12 "ALELTU EAST" PROJECT

	Criteria N°	CRITERIA	Quotation	Justification
General	1	Level of studies	4	Feasability study (feb 95)
Environmental	2	GHG reduction	2	firm energy : 780 GWh
	3	Upstream impacts	4	No critical issue for acquatic and terrestrial ecology. lost of cultivated and grazing land ; localised but significant impact on microclimate ; eutrophication highly probable
	4	Downstream impacts	3	No critical issue for acquatic and terrestrial ecology. impact on water users downstream the chacha reservoir
	5	Reservoir area/energy	3	0,05 km2/GWh
Social	6	Resettlement	2	460 households
	7	Multipurpose benefit	3	better water availability for livestock; improved access from gorges tio plateau
Political / Macroeconomics	8	Transboundary benefit	3	none
	9	Poverty reduction		not available
Economical / Financial	10	Capacity cost	2	2200 $/kW
	11	Generation cost	1	$95 /MWh (high)
Technical	12	Hydro-Generation risk	2	firm production = 92 % of average production
	13	Reservoir filling time	3	2 years
	14	Constr. risk	3	dam foundation : poor for Chacha, fair for Rikicha. Tunnels (12 km) poor rock mass quality. Underground works reduced.
	15	Accesses/Lines	3	no new road needed. 94 km of new transmission line (230 kV)
	16	Grid insertion	3	regional context
	17	Hydraulic link (e.g. cascade)	2	low impact (project on tributaries of the Abbay river)

Table 5.1-12 - Aleltu East Project

5.1.13 "ALELTU WEST" PROJECT

	Criteria N°	CRITERIA	Quotation	Justification
General	1	Level of studies	3	prefeasability study (jan 94)
Environmental	2	GHG reduction	2	firm energy 983 GWh
	3	Upstream impacts	3	continual availability of water (positif for agriculture, negatif for health)
	4	Downstream impacts	4	regulation of flows will improve habitat of present species and perhaps attract other species
	5	Reservoir area/energy	3	0,08 km2/GWh
Social	6	Resettlement	3	many old orthodox churches in the area
	7	Multipurpose benefit		not available
Political / Macroeconomics	8	Transboundary benefit	3	none
	9	Poverty reduction	3	21 M$ for agricultural support programm associated and the families displaced acompanying
Economical / Financial	10	Capacity cost	2	2000 $/kW w/o transmission
	11	Generation cost	1	$85 $/MWh
Technical	12	Hydro-Generation risk	4	firm production = 94 % of average production
	13	Reservoir filling time		not available
	14	Constr. risk	3	uncertainties (low level of field investigations) dam foundations : fair. Long tunnels, rock mass quality : fair
	15	Accesses/Lines		not available
	16	Grid insertion	3	national context
	17	Hydraulic link (e.g. cascade)	4	low impact (project on tributaries of the Abbay river)

Table 5.1-13 - Aleltu West Project

5.1.14 "GEBA I & II" PROJECT

	Criteria N°	CRITERIA	Quotation	Justification
General	1	Level of studies	4	feasability study
Environmental	2	GHG reduction	2	firm energy : 1700 GWh. Inundation of 30 km2 of rainforest
	3	Upstream impacts	2	reduction of rainforest area is a very significant impact that cannot be mitigated. Eutrophication higly probable
	4	Downstream impacts	3	flows regulation may have an impact on Gambela national park (wetland considered as important bird area)
	5	Reservoir area/energy	3	0,065 km2/GWh (0,13 for Geba I)
Social	6	Resettlement	3	115 households, 2000 ha of grazing land, 39 ha of cultivated land
	7	Multipurpose benefit	3	no possibilities of irrigation in Geba region but development possible in Gambela plain. Very limited impact on floods in Gambela
Political / Macroeconomics	8	Transboundary benefit	3	no transboundary impact
	9	Poverty reduction	3	new roads increase local trade opportunities
Economical / Financial	10	Capacity cost	4	1400 $/kW
	11	Generation cost	5	35 $/MWh (Geba I : 55 $/MWh ; Geba II : 25 $/MWh)
Technical	12	Hydro-Generation risk	2	only 2 years of data on Geba river. Sor hydrology has been used with simple proportional relationship. Limited data on floods
	13	Reservoir filling time	4	1 year
	14	Constr. risk	3	Geba I : dam, tunnels (10 km) and powerhouse in basalt formation (poor quality). Geba II : powerhouse in crystalline rock (good quality). Tunnels in crystalline rock
	15	Accesses/Lines	3	difficult acces to project area. new road : 43 km. New transmission line : 220 km
	16	Grid insertion	2	far from consumption centers
	17	Hydraulic link (e.g. cascade)	4	Geba II benefits from Geba I regulation

Table 5.1-14 - Geba I & II Project

5.1.15 "BARO I & II" PROJECT

	Criteria N°	CRITERIA	Quotation	Justification
General	1	Level of studies	4	faisability study
Environmental	2	GHG reduction	4	firm energy : 2800 GWh ; inundation of rainforest
	3	Upstream impacts	2	inondation of 38 km2 of rainforest and 2 km2 of wetland
	4	Downstream impacts	4	no significant downstream effect
	5	Reservoir area/energy	4	0,016 km2/GWh
Social	6	Resettlement	3	240 households, 280 ha of grazzing land, 30 ha of arable land
	7	Multipurpose benefit	1	none
Political / Macroeconomics	8	Transboundary benefit	4	flow regulation can increase irrigation and firm energy in Sudan
	9	Poverty reduction	2	access roads
Economical / Financial	10	Capacity cost	4	1200 $/kW
	11	Generation cost	5	42 $/MWh (90 $/MWh for Baro I ; 20/25 $/MWh for Baro II)
Technical	12	Hydro-Generation risk	1	firm energy = 85 % of average energy
	13	Reservoir filling time	4	26 weeks
	14	Constr. risk	3	Favorable geological conditions. Underground powerhouses. Baro I dam : gneiss. Tunnel : good rock mass quality. Baro II : weathered basalt (poor)
	15	Accesses/Lines	1	transmission line to Roseires : 548 km ; 80 km of road development
	16	Grid insertion	2	Project intended for power export to Sudan and Egypt
	17	Hydraulic link (e.g. cascade)	5	regulation of Baro flows will increase production in Sudan (135 GWh)

Table 5.1-15 - Baro I & II Project

5.1.16 "GENALE VI & III" PROJECT

	Criteria N°	CRITERIA	Quotation	Justification
General	1	Level of studies	2	pre faisability (Genale III prefaisability study not available, but most impats and costs are linked with this first stage)
Environmental	2	GHG reduction	5	firm energy = (1010+1200)GWh / y
	3	Upstream impacts	4	none (second equipment in a cascade). Genale III impacts not available
	4	Downstream impacts	4	Genale VI does not alter regulation from Genale III
	5	Reservoir area/energy	4	0, 004 km2/ GWh
Social	6	Resettlement	5	no resettlement
	7	Multipurpose benefit	2	none
Political / Macroeconomics	8	Transboundary benefit	4	Export to KENYA
	9	Poverty reduction		not available
Economical / Financial	10	Capacity cost	3	1686 $/kW
	11	Generation cost	4	40 / 60 $/MWh
Technical	12	Hydro-Generation risk	5	firm energy = 98 % of average energy
	13	Reservoir filling time	5	6 days
	14	Constr. risk	2	Uncertainties. 16 km of tunnel, large surge tank. Open air powerhouse. Presence of karst (dans foundations and reservoir)
	15	Accesses/Lines	4	84 km of transmission line to Genale III
	16	Grid insertion	2	production exportation to Kenya
	17	Hydraulic link (e.g. cascade)	2	benefits from regulation of Genale III

Table 5.1-16 - Genale VI & III Project

5.1.17 "GOJEB" PROJECT

	Criteria N°	CRITERIA	Quotation	Justification
General	1	Level of studies	5	Detailed design and bid documents completed
Environmental	2	GHG reduction	1	Low benefit at regional scale / firm energy 420 GWh/y, Average energy 594 Gwh/y
	3	Upstream impacts	3	No critical issue for acquatic and terrestrial ecology. Moderate flooded area. Barrier for fish migration
	4	Downstream impacts	3	No critical issue for acquatic and terrestrial ecology. Partial regulation. Sediment trapping.
	5	Reservoir area/energy	3	Ratio = 0.062 km2/Gwh
Social	6	Resettlement	3	Small number of permanent households inundated (55) and loss of resources (flooded land)
	7	Multipurpose benefit	2	Fisheries could be developed
Political / Macroeconomics	8	Transboundary benefit	1	none
	9	Poverty reduction	2	No direct national benefit (except power)
Economical / Financial	10	Capacity cost	3	1600 USD/kW (high)
	11	Generation cost	1	95 USD/MWh (very high)
Technical	12	Hydro-Generation risk	1	Firm power 48 MW, Firm energy = 70 % of average
	13	Reservoir filling time	3	2 years
	14	Constr. risk	3	Low geological risk. Good dam foundation. Surface powerhouse.
	15	Access/Lines	3	Transmission line from Gojeb 50 KM to Jima ,95KM to G.Gibe,125KM to Wolita Sodo,all 230KV
	16	Grid insertion	2	National context
	17	Hydraulic link (e.g. cascade)	1	None

Table 5.1-17 - Gojeb Project

5.1.18 "KARADOBI" PROJECT

	Criteria N°	CRITERIA	Quotation	Justification
General	1	Level of studies	4	Pre F-S, F-S on going
Environmental	2	GHG reduction	5	High benefit at regional scale / average enegy 8293 GWh/y
	3	Upstream impacts	3	No critical issue for acquatic and terrestrial ecology. Large flooded area. Barrier for fish migration
	4	Downstream impacts	4	No critical issue for acquatic and terrestrial ecology. Regulation. Sediment trapping. Flood alleviation. Filling time = crutial. Navigation improved downstream
	5	Reservoir area/energy	4	Ratio = 0,046 km2/Gwh
Social	6	Resettlement	4	No permanent household but loss of ressources (flooded land)
	7	Multipurpose benefit	3	Fisheries could be developped
Political / Macroeconomics	8	Transboundary benefit	4	Downstream benefit in Sudan (Flood, inflow, sedimentation)
	9	Poverty reduction	2	No direct national benefit (except power trade with Egypt and Sudan)
Economical / Financial	10	Capacity cost	5	1390 USD/kW (low)
	11	Generation cost	4	50 USD/MWh (low)
Technical	12	Hydro-Generation risk	5	Firm energy = 94 % of average
	13	Reservoir filling time	1	3 years (long)
	14	Constr. risk	4	Low geological risk. Good dam foundation (gneiss). Large cavern for powerhouse. Tunnel lenth reduced. Good rock mass quality
	15	Accesses/Lines	1	Transmission line 480 km to Roseires (500 kV). Important access roads to be built.
	16	Grid insertion	3	Regional context
	17	Hydraulic link (e.g. cascade)	3	Regulation not needed for downstream projects (Mandaya, Border) but benefit for Roseires in case of Karadobi alone.

Table 5.1-18 - karadobi Project

5.1.19 "MABIL" PROJECT

	Criteria N°	CRITERIA	Quotation	Justification
General	1	Level of studies	1	Identification studies only (1964, USBR)
Environmental	2	GHG reduction	3	Moderate benefit at regional scale / average energy 5314 GWh/y, Firm energy estimated at 2500 Gwh/y
	3	Upstream impacts	3	No critical issue for acquatic and terrestrial ecology. Fairly large flooded area. Barrier for fish migration
	4	Downstream impacts	3	No critical issue for acquatic and terrestrial ecology. Sediment trapping. Flood alleviation. Navigation improved downstream
	5	Reservoir area/energy	4	Ratio = 0.046 km2/Gwh
Social	6	Resettlement	4	No permanent household but loss of resources (flooded land)
	7	Multipurpose benefit	2	Fisheries could be developed
Political / Macroeconomics	8	Transboundary benefit	3	Small downstream benefit in Sudan (Flood, inflow, sedimentation)
	9	Poverty reduction	2	No direct national benefit (except power trade with Egypt and Sudan)
Economical / Financial	10	Capacity cost		not available
	11	Generation cost		not available
Technical	12	Hydro-Generation risk	1	Firm energy < 50 % of average
	13	Reservoir filling time	3	1.5 years @ 50% of inflow (medium)
	14	Constr. risk	4	Fairly low geological risk. Good dam foundation (gneiss). Large cavern for powerhouse. Good rock mass quality
	15	Access Lines	2	Transmission line 320 km to Roseires (500 kV). Important access roads to be built.
	16	Grid insertion	3	Regional context
	17	Hydraulic link (e.g. cascade)	1	Site flooded by Mandaya FSL 800m. Refer to new replacement site Beko Abo. Upstream regulation (Karadobi) needed for maximum firm energy. No significant benefit for downstream projects (Mandaya, Border, Roseires)

Table 5.1-19 - Mabil Project

5.1.20 "MANDAYA" PROJECT

	Criteria N°	CRITERIA	Quotation	Justification
General	**1**	**Level of studies**	**3**	Pre F-S on going
Environmental	**2**	**GHG reduction**	**5**	High benefit at regional scale / average energy 16 000 GWh/y (12 119 if no upstream large dam)
	3	**Upstream impacts**	**3**	No critical issue for acquatic and terrestrial ecology. Large flooded area. Barrier for fish migration
	4	**Downstream impacts**	**4**	No critical issue for acquatic and terrestrial ecology. Regulation. Sediment trapping. Flood alleviation. Gross storage 1.54 x MAR, Filling time = 3 years @ 50% of inflow. Navigation improved downstream
	5	**Reservoir area/energy**	**4**	Ratio = 0.066 km2/Gwh
Social	**6**	**Resettlement**	**5**	600 people
	7	**Multipurpose benefit**	**2**	Fisheries could be developed
Political / Macroeconomics	**8**	**Transboundary benefit**	**4**	Downstream benefit in Sudan (Flood, inflow, sedimentation)
	9	**Poverty reduction**	**2**	No direct national benefit (except power trade with Egypt and Sudan)
Economical / Financial	**10**	**Capacity cost**	**5**	1000 USD/kW (low)
	11	**Generation cost**	**5**	35 USD/MWh (low)
Technical	**12**	**Hydro-Generation risk**	**3**	Firm energy = 92 % of average
	13	**Reservoir filling time**	**3**	3 years @ 50% of inflow (long)
	14	**Constr. risk**	**4**	Low geological risk. Good dam foundation (gneiss). Surface power station. Few underground works. Good rock mass quality
	15	**Access/Lines**	**2**	Transmission line 260 km to Roseires (500 kV). Important access roads to be built.
	16	**Grid insertion**	**3**	Regional context
	17	**Hydraulic link (e.g. cascade)**	**5**	Floods site of Mabil dam upstream but new site (Beko Abo) selected to replace Mabil. Regulation benefit for downstream projects (Border) and benefit for Roseires in case of Mandaya alone.

Table 5.1-20 - Mandaya Project

5.1.21 "BORDER" PROJECT

	Criteria N°	CRITERIA	Quotation	Justification
General	**1**	**Level of studies**	**3**	Pre F-S on going
Environmental	**2**	**GHG reduction**	**3**	Fairly high benefit at regional scale / firm energy 3966 GWh/y, Average energy 6011 Gwh/y
	3	**Upstream impacts**	**3**	No critical issue for acquatic and terrestrial ecology. Large flooded area. Barrier for fish migration
	4	**Downstream impacts**	**4**	No critical issue for acquatic and terrestrial ecology. Regulation. Sediment trapping. Flood alleviation. Filling time = crutial. Navigation improved downstream
	5	**Reservoir area/energy**	**1**	Ratio = 0.145 km2/Gwh
Social	**6**	**Resettlement**	**1**	Estimated 14,000 persons and loss of resources (flooded land)
	7	**Multipurpose benefit**	**2**	Fisheries could be developed
Political / Macroeconomics	**8**	**Transboundary benefit**	**4**	Some downstream benefit in Sudan (Flood, inflow, sedimentation)
	9	**Poverty reduction**	**2**	No direct national benefit (except power trade with Egypt and Sudan)
Economical / Financial	**10**	**Capacity cost**	**5**	1000 USD/kW (low)
	11	**Generation cost**	**5**	35 USD/MWh (low)
Technical	**12**	**Hydro-Generation risk**	**1**	Firm energy = 66 % of average
	13	**Reservoir filling time**	**4**	< 0.5 years @ 50% of inflow (very short)
	14	**Constr. risk**	**4**	Very low geological risk. Good dam foundation (granite). Surface powerhouse. No underground works. Good rock mass quality
	15	**Access/Lines**	**3**	Transmission line 140 km to Roseires (500 kV). Important access roads to be built.
	16	**Grid insertion**	**3**	Regional context
	17	**Hydraulic link (e.g. cascade)**	**2**	Needs regulation from upstream downstream projects (Mandaya, Karadobi) for maximum firm energy benefits

Table 5.1-21 - Border Project

5.2 RESULTS AND ANALYSIS OF THE RANKING

5.2.1 AVAILABILITY OF INFORMATION

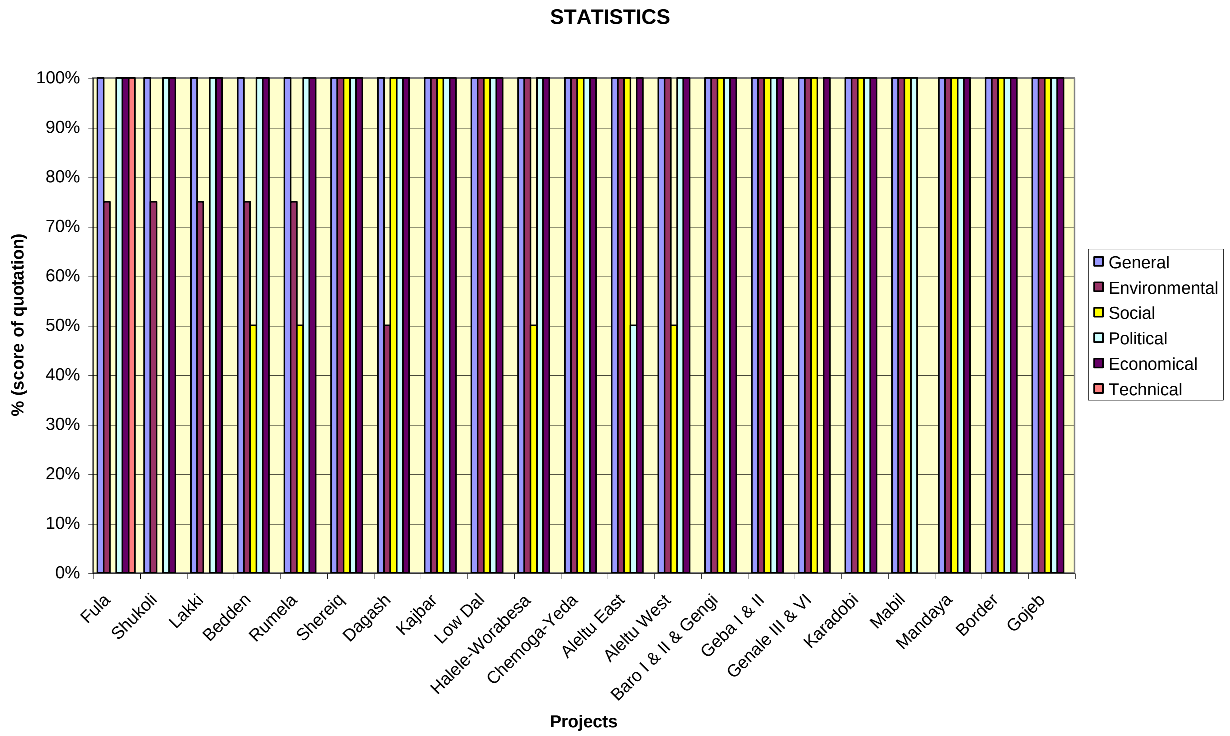
First of all, it is important to give a statistical description of the number of criteria which the Consultant was able to quote for each project (24 projects: 9 in Sudan and 15 in Ethiopia) on the basis of available information.

The statistics of quoted criteria (by family of criteria and by project) are presented below:

	CRITERIA						
Project Name	**General**	**Environmental**	**Social**	**Political**	**Economical**	**Technical**	**Average**
Fula	100%	75%	0%	100%	100%	66%	74%
Shukoli	100%	75%	0%	100%	100%	66%	74%
Lakki	100%	75%	0%	100%	100%	66%	74%
Bedden	100%	75%	50%	100%	100%	66%	82%
Rumela	100%	75%	50%	100%	100%	50%	79%
Shereiq	100%	100%	100%	100%	100%	100%	100%
Dagash	100%	50%	100%	100%	100%	66%	86%
Kajbar	100%	100%	100%	100%	100%	100%	100%
Low Dal	100%	100%	100%	100%	100%	100%	100%
Halele-Worabesa	100%	100%	50%	100%	100%	100%	92%
Chemoga-Yeda	100%	100%	100%	100%	100%	100%	100%
Aleltu East	100%	100%	100%	50%	100%	100%	92%
Aleltu West	100%	100%	50%	100%	100%	66%	86%
Baro I & II & Gengi	100%	100%	100%	100%	100%	100%	100%
Geba I & II	100%	100%	100%	100%	100%	100%	100%
Genale III & VI	100%	100%	100%	0%	100%	100%	83%
Karadobi	100%	100%	100%	100%	100%	100%	100%
Mabil	100%	100%	100%	100%	0%	100%	83%
Mandaya	100%	100%	100%	100%	100%	100%	100%
Border	100%	100%	100%	100%	100%	100%	100%
Gojeb	100%	100%	100%	100%	100%	100%	100%
Average	88%	80%	67%	81%	83%	77%	**79%**

Table 5.2-1 – Statistics of criteria quoted

The following graphs illustrate the statistics.



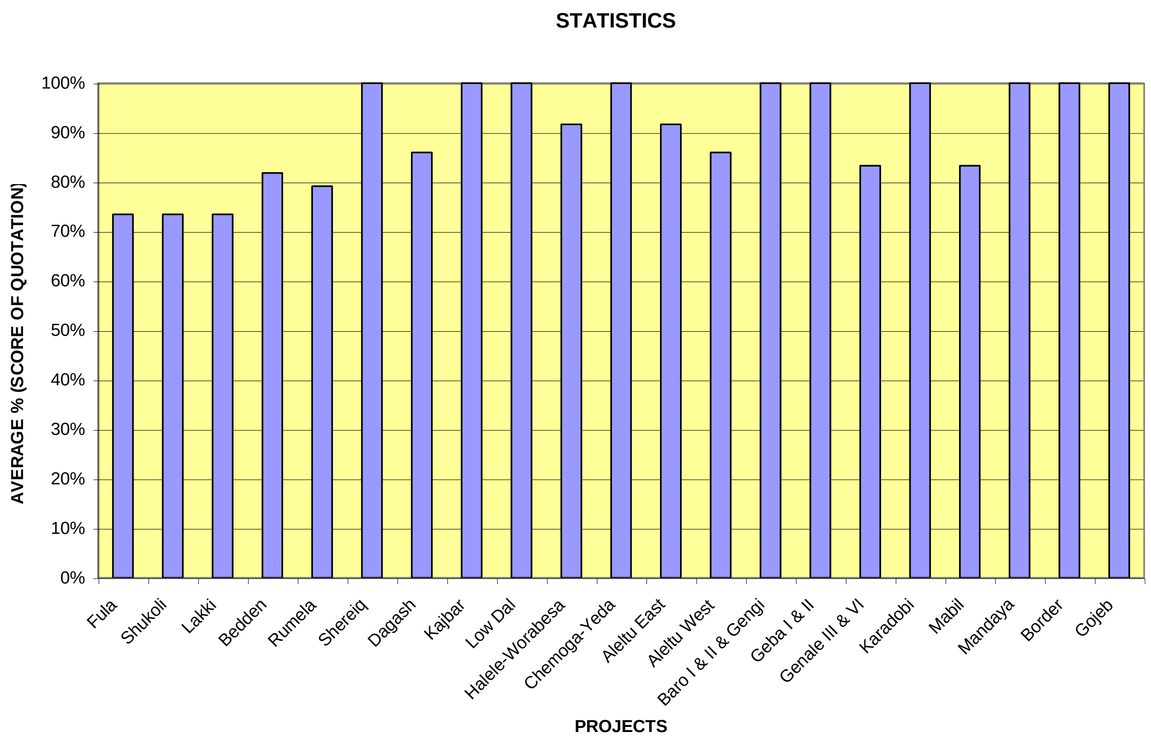


Figure 5.2.1-1- Statistics of criteria quoted

The results show that:

- available information allows to properly quote criteria except social one for some projects in Sudan (no existing EIA/SIA and no indicative information about impacts),
- all other criteria present quotation score greater than 77% which is good and guarantees a good consistency for the analysis,
- concerning projects, only South Sudan projects are characterized by incomplete database which leads to low percentages in quotation score average, other Sudanese projects have at least a 79% score of quotation which is satisfactory,
- In Ethiopia, except Mabil and Genale, all projects have a score greater than 86%.

5.2.2 RESULTS AND ANALYSIS

5.2.2.1 Case simulation

Following the ENTRO Workshop N°3, the following projects were removed from the list (project recently committed, abandoned or very small): Neshe, Awash IV and Wabe Shebele 18.

Relative weighting is necessary between the different families of criteria. This stage is always controversial. Therefore the Consultant made six different combinations to highlight and identify the "higher quoted" set of hydro project. The weighting considered 6 different combinations of criteria:

- Case 1: pure economic criteria,
- Case 2: pure socio-environmental criteria,
- Case 3: pure technical criteria,
- Case 4: balanced technico-economic criteria,
- Case 5: linear combination with all criteria, keeping a high weight for economic criteria and giving preference to socio environmental criteria compared to technical criteria,
- Case 6: linear combination with all criteria, keeping a high weight for economic criteria and giving preference to technical criteria compared to socio environmental criteria.

An analysis is proposed in the following paragraphs:

Case 1: pure economic criteria:

This “simulation” is illustrated in fig. 4.2.1. below:

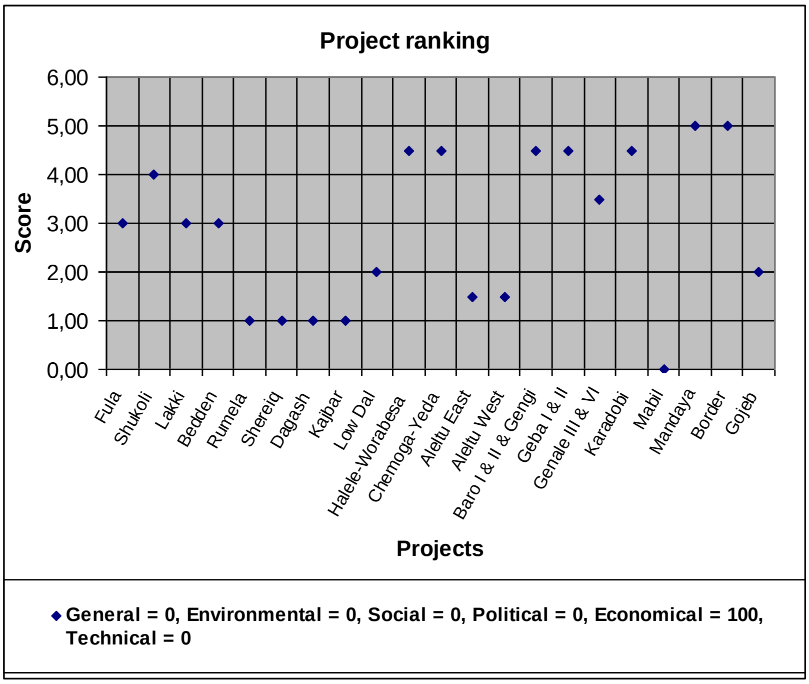


Figure 5.2.2-1 - Project ranking with only economic criteria

The “higher quoted” projects (characterized by evaluation mark greater than 2,5) are in this case:

For Sudan:

- Fula
- Shukoli
- Lakki
- Bedden

For Ethiopia:

- Halele-Worabesa
- Chemoga-Yeda
- Baro I & II & Gengi
- Geba I & II
- Genale III & VI
- Karadobi
- Mandaya
- Border

Case 2: pure socio-environmental criteria:

This “simulation” is illustrated in fig. 4.2.2. below:

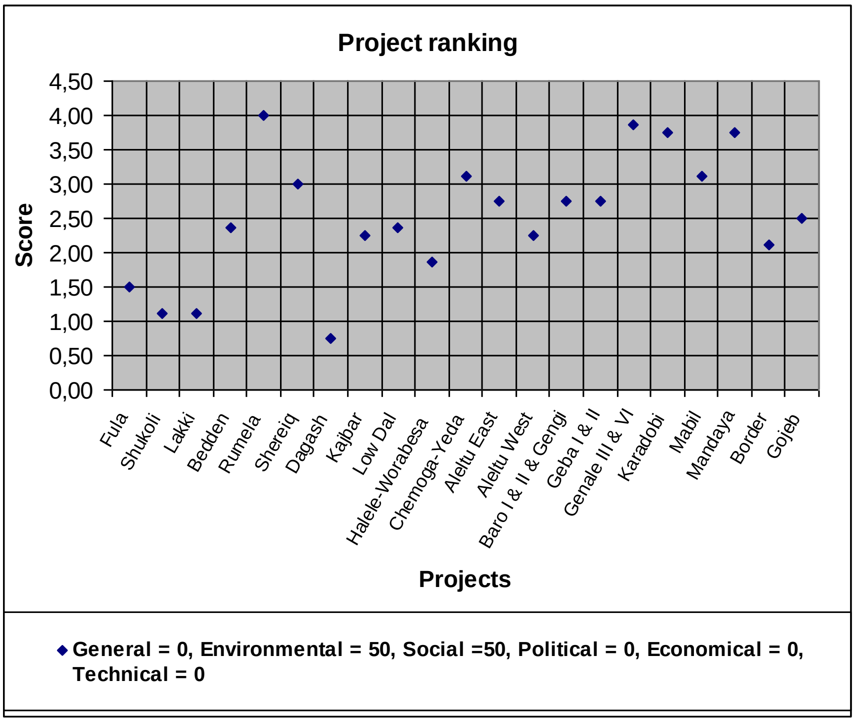


Figure 5.2.2-2 - Project ranking with only socio-environmental criteria

The “higher quoted” projects (characterized by evaluation mark greater than 2,5) are in this case:

For Sudan:

- Rumela
- Shereiq

For Ethiopia

- Chemoga-Yeda
- Aleltu East
- Baro I & II & Gengi
- Geba I & II
- Genale III & VI
- Karadobi
- Mabil
- Mandaya

Case 3: pure technical criteria:

This “simulation” is illustrated in fig. 4.2.3. below:

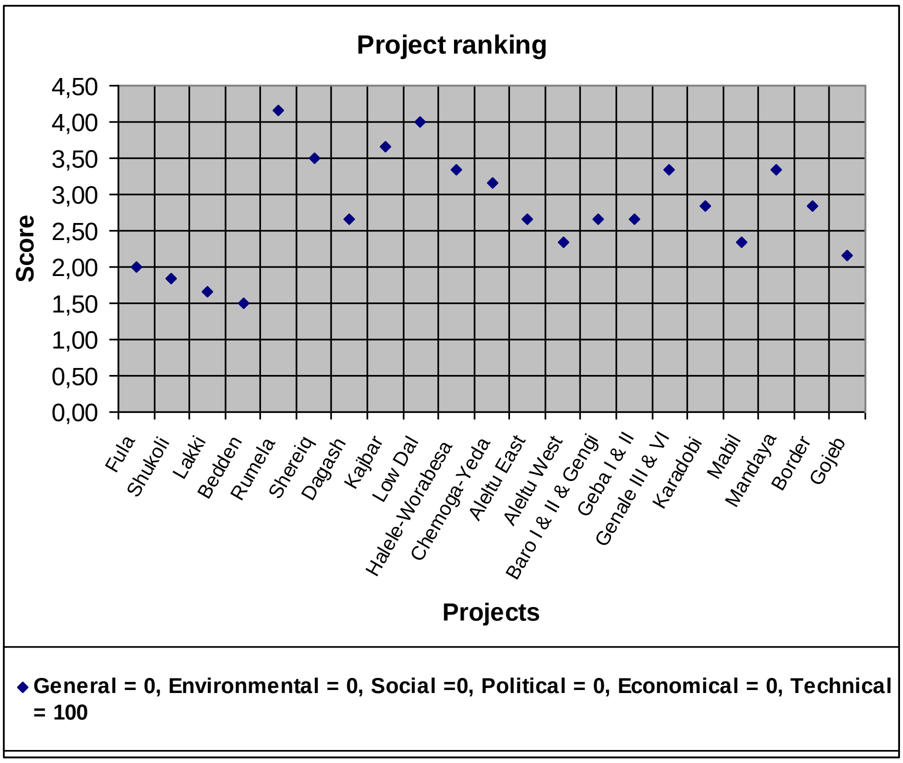


Figure 5.2.2-3 - Project ranking with only technical criteria

The “higher quoted” projects (characterized by evaluation mark greater than 2,5) are in this case:

For Sudan:

- Rumela
- Shereiq
- Dagash
- Kajbar
- Low Dal

For Ethiopia:

- Halele-Worabesa
- Chemoga-Yeda
- Aleltu East
- Baro I & II & Gengi
- Geba I & II
- Genale III & VI
- Mandaya
- Border

Case 4: balanced technico-economic criteria:

This “simulation” is illustrated in fig. 4.2.4. below:

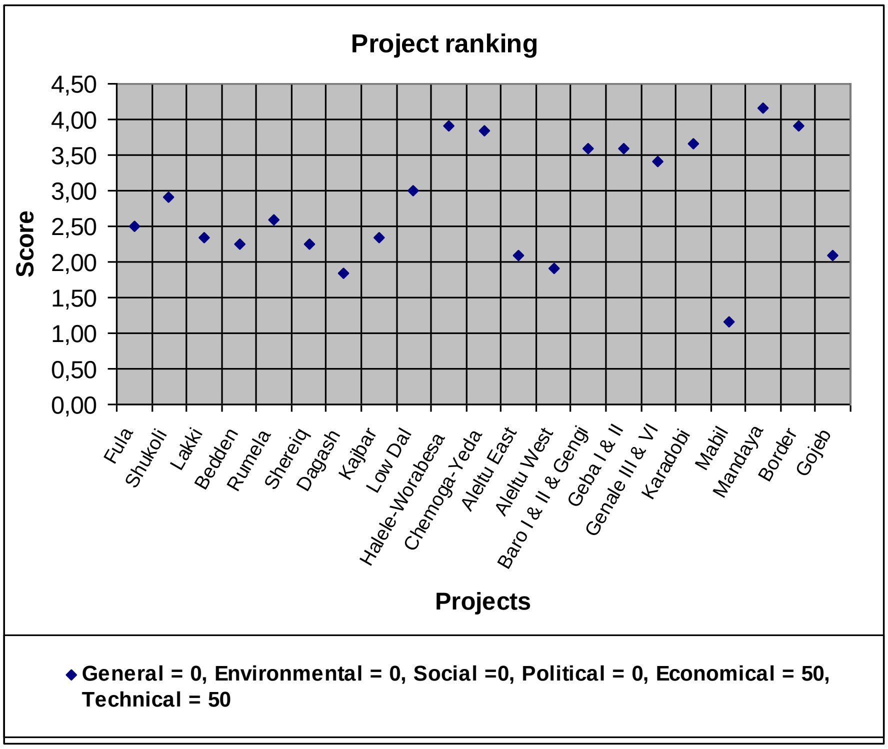


Figure 5.2.2-4 - Project ranking with balanced technico-economic criteria

The “higher quoted” projects (characterized by evaluation mark greater than 2,5) are in this case:

For Sudan:

- Fula
- Shukoli
- Rumela
- Low Dal

For Ethiopia:

- Halele-Worabesa
- Chemoga-Yeda
- Baro I & II & Gengi
- Geba I & II
- Genale III & VI
- Karadobi
- Mandaya
- Border

Case 5: linear combination with all criteria, keeping a high weight for economic criteria and giving preference to socio-environmental criteria compared to technical criteria.

This "simulation" is illustrated in fig. 4.2.5. below:

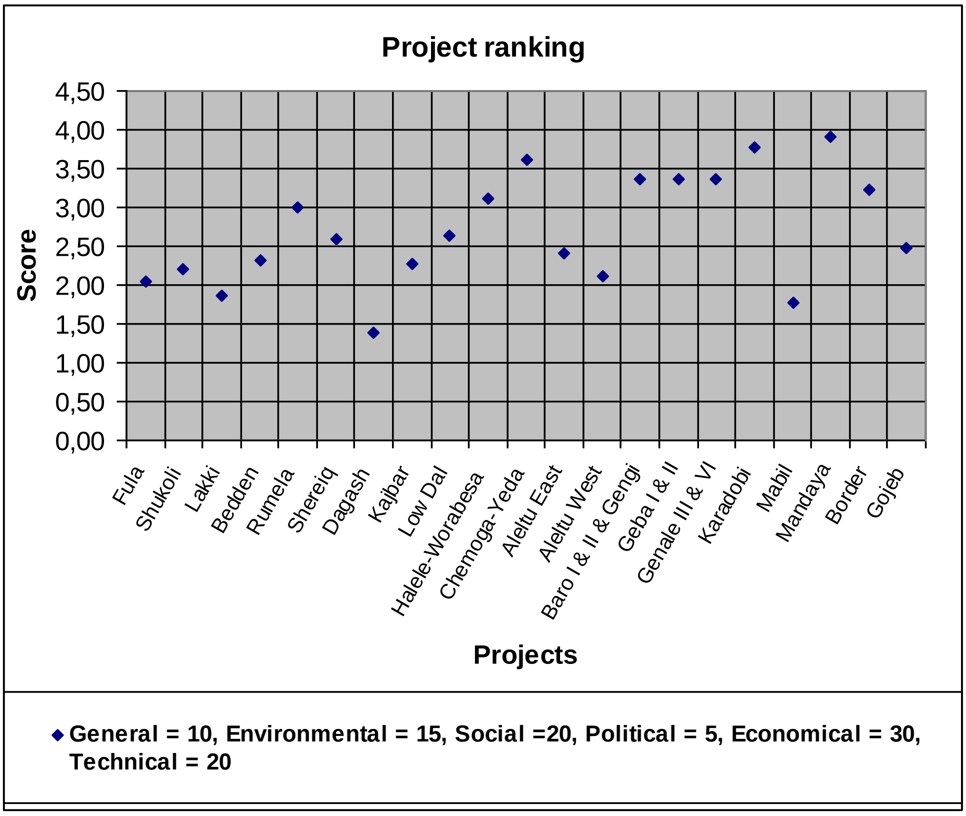


Figure 5.2.2-5 - Project ranking with linear combination of all criteria and preference for socio-environmental and economic criteria

The "higher quoted" projects (characterized by evaluation mark greater than 2,5) are in this case:

For Sudan:

- Rumela
- Shereiq
- Low Dal

For Ethiopia:

- Halele-Worabesa
- Chemoga-Yeda
- Baro I & II & Gengi
- Geba I & II
- Genale III & VI
- Karadobi
- Mandaya
- Border

Case 6: linear combination with all criteria, keeping a high weight for economic criteria and giving preference to technical criteria compared to socio environmental criteria.

This "simulation" is illustrated in fig. 4.2.6. below:

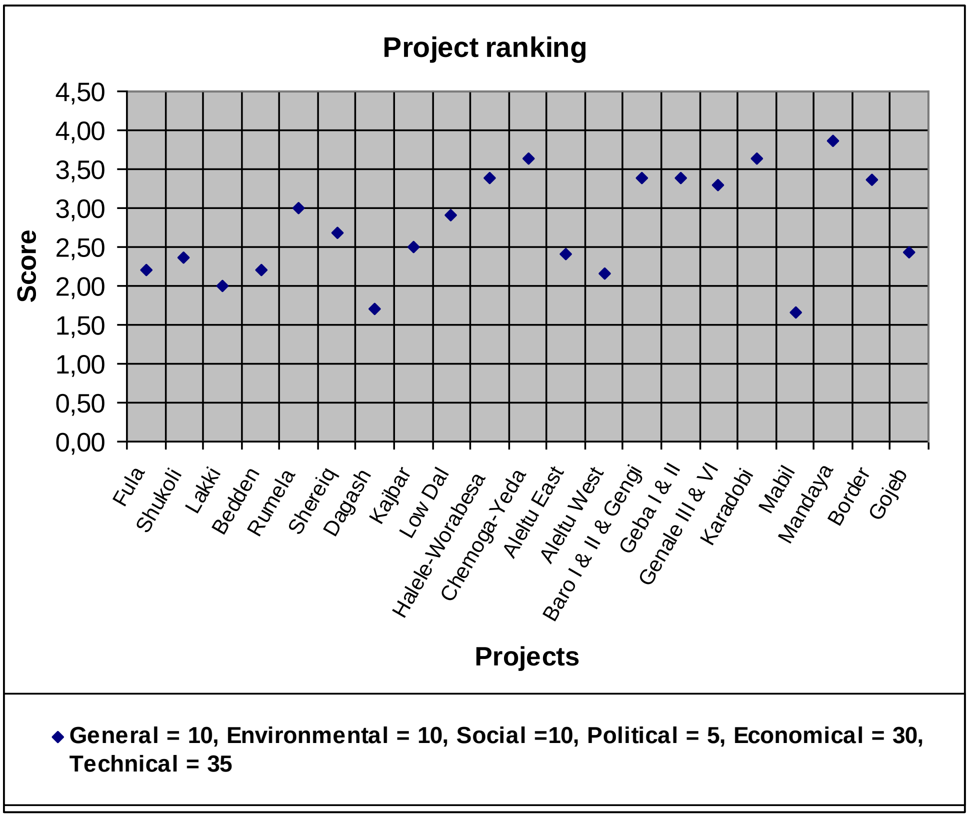


Figure 5.2.2-6 - Project ranking with linear combination of all criteria and preference for technical and economic criteria

The "higher quoted" projects (characterized by evaluation mark greater than 2,5) are in this case:

For Sudan:

- Rumela
- Shereiq
- Kajbar
- Low Dal

For Ethiopia:

- Halele-Worabesa
- Chemoga-Yeda
- Baro I & II & Gengi
- Geba I & II
- Genale III & VI
- Karadobi
- Mandaya
- Border

5.2.2.2 Global representation

A balanced quotation between Socio-environmental, Technical and Economic was also done and the here below graph is an illustration (for the three criteria):

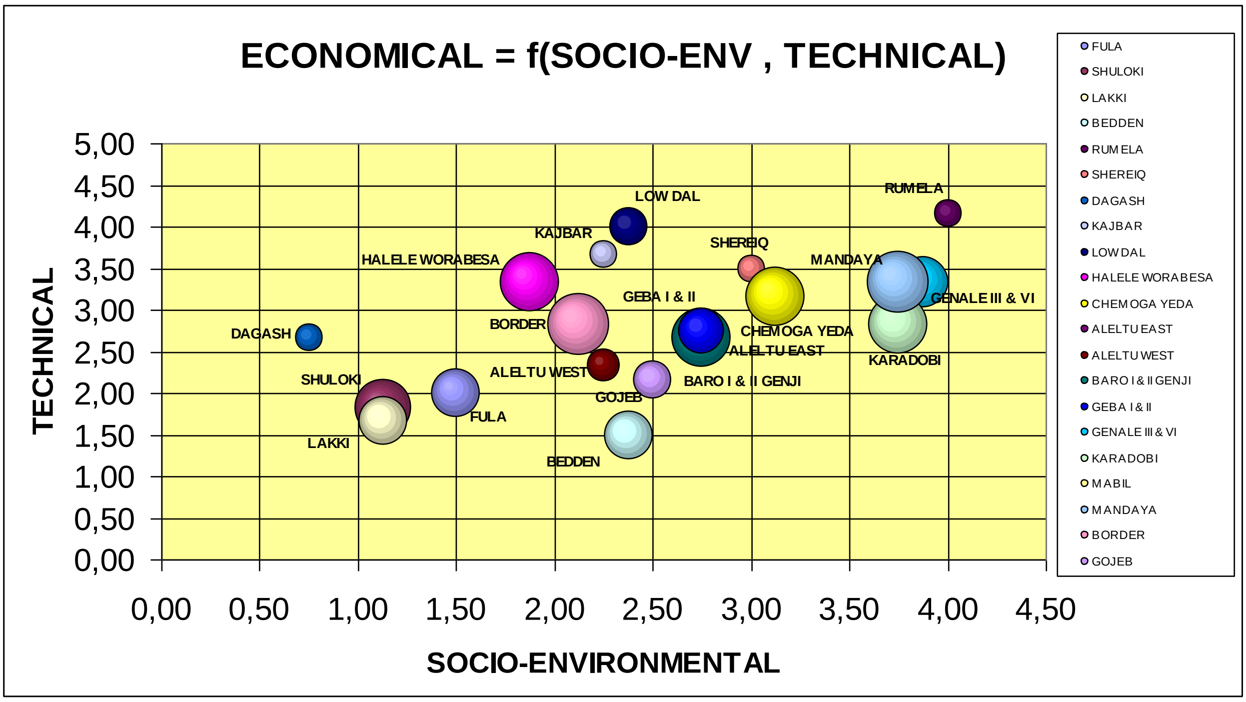


Table 5.2-2- Economic criteria vs Socio-environmental and Technical criteria

5.2.2.3 Conclusion

The two last "simulations" (Case 5 and 6) show that almost the same projects are "short listed". This means that the quotation is robust and that the projects are good ones whatever the weighting used for the criteria families.

The Gojeb project was removed following discussion with Ethiopian representatives and the Mabil project was also removed (flooded by Mandaya).

The conclusion can be summarized with the following sequencing for each country using the previous simulations and representations:

Sequencing	SUDAN
1	Rumela
2	Shereiq
3	Low Dal
4	Kajbar
5	Dagash
6	Southern HPP projects

Table 5.2-3 Sudanese project sequencing

The southern HPP project can not be ranked at this stage due to the very low level of information and study. There is no negative impact for the sequencing because the commissioning of these project is planned for 2020.

Sequencing	ETHIOPIA
1	Mandaya
2	Genale
3	Karadobi
4	Chemoga Yeda
5	Baro
6	Geba
7	Border
8	Halele Worabesa
9	Aleltu East
10	Aleltu West

Table 5.2-4 Ethiopian project ranking

The quotation of the economic criteria of Mandaya and Border will have to be secured after cost estimates completed of these project.

6. GENERATION AND TRANSMISSION PLANNING CRITERIA

The purpose of this paragraph is to:

- review the criteria used in the Egypt, Ethiopia and Sudan for generation and transmission planning,

- propose common generation and transmission planning criteria to be adopted for the combined system for the purposes of the present Study.

6.1 EXISTING CRITERIA FOR GENERATION PLANNING

In this paragraph, an overview of the common criteria used for generation planning is presented, then the criteria used in each country is presented. These criteria are later discussed in the next paragraph concluding with recommended criteria for the present Study.

6.1.1 GENERAL OVERVIEW

6.1.1.1 Objective function

The general purpose of generation investment planning is to determine the least cost schedule of commissioning of new generation units over a given period of time within acceptable level of reliability of power supply.

More precisely, the objective cost function is:

Min [NPV (Investment costs + O & M cost + Fuel costs + Unserved energy cost + Externalities)]

where:

NPV: Net Present Value over the planning period (2007-2030).

Investment costs: generation and interconnection investment costs over the planning period.

O & M cost: O&M cost of generation and interconnection over the planning period.

Fuel cost: fuel cost of generation (TPP) over the planning period.

Unserved energy cost: cost of unserved (i.e. unsupplied) energy over the planning period.

Externalities: other costs or benefits such as mitigation costs, irrigation benefits, etc.

6.1.1.2 Reliability of power supply

One of the first steps in electric generation expansion planning is to establish the objective level of reliability which is expected for the future generation system. This level determines the total amount of generation capacity required to be installed. A high level of reliability meaning a need for an increased total capacity at the expense of larger investment cost.

LOLP:

The Loss of Load Probability (LOLP) index provides a consistent and sensitive measure of generation system reliability. It indicates the number of days per year with expected capacity shortage (i.e. the expected number of days per year where the capacity of the generation system is lower than the demand). It is the most widely accepted approach to measure the level of power supply reliability.

The evaluation of the LOLP required the use of a probabilistic planning model taking into account a description of the generation mix under study.

Cost of unserved energy (USD/MWh):

The reliability objective of a generation system is linked to an economic concept called the cost of unserved energy (CUE, also referred as failure cost).

The introduction of the CUE allows to address the basic question which reliability standard is most favourable and appropriate, considering the costs associated with both investment in new generation facilities and the effects of the interruptions experienced by the customers and more generally to the economy of the country. In this respect, there is an optimum trade-off between these two costs:

- A higher value of the CUE means a need for higher capacity investments in order to minimise the economic consequences of power shedding, and consequently results in a higher reliability level of the generation system.

- A lower value of the CUE means that less capacity investments are required because the economic consequences of load shedding are lower.

The values for the CUE of unserved energy used in the various international studies vary significantly ranging from 150 to 15 000 USD/MWh. An accurate value can be established through detailed economic studies analysing the cost of capacity shortage to the different sectors of the national economy (heavy and light industry, service industry, foreign investments, etc.).

In the absence of such studies, the ratio between the Gross Domestic Product of the country and the annual electric generation is often used to get a rough estimate of the CUE.

Relation between LOLP and CUE:

The LOLP and the CUE are linked through the following relation (see justification in Appendix M4):

$$CUE \times H = A + P \times H$$

where:

- H: expected yearly duration of shortage (H),
- A: investment annuity of peak load generation (A),
- P: proportional cost of peak load generation (P)

This relation means that it is economically profitable (resp. non profitable) to build a peak load generation unit only if its expected duration of operation is greater (resp. lower) than H hours per year. In other words, if load shedding duration is longer than H, then the cost of power shedding for the economy of the country is greater than the cost of adding new peak load generation unit in the power system. Accordingly more peak load generation are need. The economic balance is reached when the duration of load shedding is equal to H (=LOLP).

<u>Margin ratio</u>:

The margin ratio is the ratio of installed capacity in excess to the peak demand, a larger margin ratio meaning an improved reliability of power supply.

The margin ratio provides a simple guiding rule to determine a simplified generation investment plan. However, it should be emphasized that the reliability of power supply is not only dependant on the margin ratio but also on:

- the hydro / thermal composition of the generation mix,
- the variability of the hydro inflows (annual and inter annual),
- the outage rate of the power plants (schedule and forced outage rate),
- the relative size of generation units compared to the total installed capacity.

For instance, a lower forced outage rate will lead to a higher reliability. A greater number of units for a given total installed capacity will lead to a higher reliability. A large amount of HPP with large inter annual inflow variability would lead to decreased reliability.

Accordingly, for a given level of reliability, the associated value of margin ratio depends heavily on the characteristics a generation mix. A 15% margin ratio might be convenient for a purely thermal generation mix, while a 30% margin ratio might not be sufficient for a hydro power system exposed to large variability of hydro inflows.

As the result, the Loss of Load Probability (or the CUE) is definitely a more pertinent criterion to determine the level of reliability of power supply.

6.1.1.3 Discount rate

Strictly speaking, the discount rate is not a criterion for generation planning but rather an economic parameter. However, because of its importance in the economic calculation, and the need for a common value to be used in the Study, the Consultant proposes to discuss it in the present Module.

<u>Definition and related notions</u>:

In an economic study, the discount rate "a" allows to calculate the present value of future revenues or expenditures. Its value indicates the preference for investors to get an immediate revenue rather than a future revenue of the same nominal value. Thus, a revenue (or expenditure) "R" obtained in n years has the same present value as an immediate revenue equal to: $\frac{R}{(1+a)^n}$

The related economic notion, the Net Present Value (NPV), is the discounted sum of the cash flows over the economic life time of a project (including construction phase):

$$\text{NPV} = \sum_1^n \frac{(R_i - E_i)}{(1+a)^i}$$

where

Ri = revenue for year i

Ei = expenditure (i.e. construction cost, O&M, etc) for year i

A project is economically profitable when its NPV > 0. Its profitability increases when its NPV increases.

An other useful economic concept is the Economic Internal Rate of Return (IRR) of a project, which is by definition the value of the discount rate such as NPV = 0. This means that a project is economically profitable when its IRR > a. In other words, "a" is the minimum profitability rate required by the investor.

A high discount rate, giving less weight to long term, will favour short term, while a low discount rate will favour large capital projects with long term economic return.

<u>Determination of the discount rate</u>:

The (economic) discount rate used in economic studies (like the determination of the least cost investment planning in Module 6) should not be confused with the (financial) discount rate used in banking, which is the interest rate at which a Central Bank in a country lends to commercial Banks or financial institutions.

The "bank" discount rate is set by the Central Bank according to the exchange rate of the national currency, commercial exchange balance, amount of the different monetary aggregates in the country, inflation rate, etc. It may change on short term steps depending on the international and national financial situation.

On the other hand, the "economic" discount rate used for investment choices of state-owned companies is usually established by the government depending on economic, financial and social constraints. In case of a private owned company, the value of the discount rate depends on the availability of funds (equity, debts, loan rates), the profitability objective of the company and the risks of the project (and more generally the risks on the company, country and activity where the investment is made).

The discount rate could be given in real or nominal term (i.e. without or with inflation).

Its typical value ranges from 8% to 12% according to the country. Upper values reflect a scarcity of financial resources and high investment risks (investment type or country) disfavouring investments with high expenditures at the beginning of their economic life (e.g. hydropower plants) and favouring investments with short pay back duration.

The value commonly recommended by the World Bank for economic studies is in the range of 10 to 12%, with sensitivity to plus or minus 5%.

6.1.2 EGYPT

The criteria used for generation planning by EEHC in Egypt are:

- Discount rate: 7% in real term. This value seems to be on the low side for this region. For comparison, typical values greater than 8% are used by Utilities in Western European countries with large financing capabilities and cost recovering tariffs. Nevertheless, the discussion of the discount rate used by EEHC is beyond the scope of the present studies provided the 7% refers to the discount rate used in economic studies.

- Capacity margin ratio: 15% to 23%.

- LOLP: 8 hours / year.

- Unserved energy: 900 USD/MWh.

Optimisation planning model: Electric Generation Expansion Analysis System (EGEAS) from Electric Power Research Institute (EPRI -USA)

6.1.3 ETHIOPIA

The criteria used for generation planning by EPCO in Ethiopia are:

- Discount rate: 12% in real term, sensitivity analysis are carried out with 9% and 15%.

A first stage of analysis of installed capacity requirement is carried out on the basis of:

- Margin ratio: 20% (based on HPP firm capacity)
- Firm energy for HPP: 97.3% reliability (1 year out of 37).

The second stage of the determination of the least cost GEP is based on a detailed simulation:

- Cost of unserved energy: 520 USD/MWh.
- LOLP: 10 days/year.

Optimisation planning model: ACRES Reservoir Simulation Package (ARSP) and Generation System Simulation Package (GENSIM) for the calculation of the NPV from probabilistic simulations.

6.1.4 SUDAN

The criteria used for generation planning by NEC in Sudan are:

- Discount rate: base: 12% in real term sensitivity analysis are carried out with 10% and 15%.
- LOLP: 3.65 days / year.
- Cost of unserved energy: not used explicitly in the planning model.
- Firm energy HPP: 95% reliability

Optimisation planning model: PB Power ASPLAN (Analytic Solutions – USA – developed from WASP) and RAPSO for the simulation of hydro reservoir and calculation of firm energy.

6.1.5 COMPARISON TABLE

The following table makes a comparison of the generation planning criteria:

	Egypt	Ethiopia	Sudan
Discount rate	7%	12% (9% & 15%)*	12% (10% & 15%)*
LOLP	8 hour / year	10 days / year	3.65 day / year
Cost of unserved energy	900 USD /MWh	520 USD/MWh	not used explicitely
Margin ratio	15 to 23%	20%	not used
HPP firm energy	not relevant	97.3% reliability	95% reliability
Planning model	EGEAS	GENSIM + ARSP	ASPLAN + RAPSO

Table 6.1-1: criteria used for generation planning in Egypt, Ethiopia and Sudan

Note : * values used for sensitivity analysis

6.2 EXISTING CRITERIA OF TRANSMISSION SYSTEM PLANNING

6.2.1 EGYPT

The planning criteria adopted to develop the transmission system were communicated during a meeting held in Cairo on the 10th of December 2006, and in a specific document send by EPS on February 2007. They are described hereafter.

To develop the 220 kV network, the N-2 criterion is adopted. This implies that the transmission system must be able to supply the loads within the operational limits following the outage of two elements of the power system.

To develop the 500 kV network, the N-1 criterion is adopted.

The operational voltage limits are:

<u>In normal condition</u>: the voltage at each bus bar must be kept within 95% and 105% of its nominal value.

<u>In emergency condition</u>: (in N-1 or N-2 situations) the voltage at each bus bar must be kept within 90% and 105% of its nominal value.

For the analysis of the planned Egyptian transmission system, the planning criteria are:

<u>In normal conditions</u>: the flows must be kept below the thermal rating of each network element. The generators must operate within their reactive capabilities (generation and absorption).

In emergency situation: (in N-1 or N-2 situations) the thermal rating of any equipment should not be exceeded. Immediately after a circuit tripping, the rating for transformers can be increased when specified by the manufacturer, while corrective measures are being under-taken.

In transient state: the power system must remain stable following a three-phase fault normally cleared by operation of the protection. The generators must operate in synchronism without sustained oscillations, power and voltage oscillations must be quickly damped.

Frequency limits:

Under frequency load shedding scheme: threshold of the first stage 49.~~5~~ 2 Hz

Tripping of the interconnection with Libya: 49.5 Hz

Tripping of the interconnection with Jordan: 49 Hz

Over frequency limit: 51 Hz (High Dam generators)

6.2.2 ETHIOPIA

The planning criteria adopted to elaborate the “Power System Expansion Master Plan” was the “N-1 Criterion”. This criterion implies that the transmission system must be able to supply the loads within the operational limits following the outage of one and only one element of the power system, so call emergency situation.

The operational limits, in normal and emergency situations, are described hereafter.

In normal condition: the flows must be kept below the thermal limit of each network element. The voltage at each bus bar must be kept within 95% and 105% of its nominal value. The generators must operate within their reactive capabilities (generation and absorption).

In emergency situation: (outage of one element:) the flows are allowed to increase up to 120% of the thermal rating of each element. The voltage dip can reach 10% of the nominal value.

In transient state: the power system must remain stable following a three-phase fault. The generators must operate in synchronism without sustained oscillations, power and voltage oscillations must be quickly damped.

Frequency limits:

Under frequency load shedding scheme: threshold of the first stage 48.6 Hz

Over frequency limit: 52 Hz

6.2.3 SUDAN

The planning criteria adopted to perform the “Long-term Power System Planning Study” was the “N-1 Criterion”. The transmission network was planned such that an outage of any component (e.g; overhead lines, transformers,...) or any generating unit can be accommodated. Thermal ratings of equipment should not be exceeded during the outage of an item of plant.

The thermal rating of the lines is based on the following conditions:

Ambient temperature = 40°C; Maximum conductor temperature = 75°C; Intensity of solar radiation = 1200 W/m²; wind velocity = 1 mph.

To develop its transmission system, NEC has adopted ACSR conductors, 2x 240 mm² for 220 kV lines and 4x280 mm² for 500 kV lines, which the thermal rating is as follows.

Voltage (kV)	Conductor Type	Thermal rating (MVA)	Thermal rating (A)
220	2x240 mm²	370	972
500	4x280 mm²	1 843	2 128

Table 6.2-1 – Thermal rating

The operational limits, in normal and emergency situations, are described hereafter.

In normal conditions: the flows must be kept below the thermal rating of each network element. The voltage at each bus bar must be kept within 95% and 105% of its nominal value. The generators must operate within their reactive capabilities (generation and absorption).

In emergency situation: (outage of one element:) the thermal rating of any equipment should not be exceeded. The voltage should be kept within 90% and 105% of its nominal value.

In transient state: the power system must remain stable following a three-phase fault cleared within 120 ms. The generators must operate in synchronism without sustained oscillations, power and voltage oscillations must be quickly damped.

Frequency limits:

Under frequency load shedding scheme: threshold of the first stage 49.2 Hz

Over frequency limit: 52 Hz (3 s)

6.3 PROPOSED CRITERIA FOR THE STUDY

6.3.1 CRITERIA FOR GENERATION PLANNING

6.3.1.1 Discount rate

Considering the value of 12% used in the last Generation Expansion Plan in Ethiopia and Sudan, the 10% to 12% range commonly recommended by World Bank for the area, the 10% to 12% commonly observed by the Consultant in this region for economic studies, the discussions relative to the discount rate during the Minutes of Meeting following Workshop N°2 in Khartoum (January 2007), the Consultant recommends to apply a12% discount rate for the base case, and a 10% discount rate for the sensitivity analysis.

6.3.1.2 LOLP and cost of unserved energy

Egypt:

In 2005, the ratio GDP/ electricity sales was 89.3 GUSD / 90 300 GWh = 980 USD/MWh. This value is consistent with the CUE of 900 USD/MWh used by EEHC.

If this value was used as an input to the planning model, the corresponding value of LOLP is given by the relation (see justification in appendix M4):

LOLP = Investment annuity of peak load generation unit / CUE

If a 600 USD/kW investment cost is considered for peak load generation unit in Egypt, with a life duration of 25 years and a discount rate of 7%, then the investment annuity is equal to 76000 USD per guaranteed MW, resulting in a LOLP of 76 000 / 900 = 84 hours / year or 3.5 days / year.

A LOLP of 8 hours / year is equivalent to European standards. For comparison, the value used for generation investment planning in France is 4 hours / year. A LOLP of 8 hours / year, would be equivalent to a CUE given as an input to planning model equal to :

CUE = 76 000 / 8 = 9 500 USD/MWh

Ethiopia:

In the case of Ethiopia, the ratio GDP / annual electricity sales is not a relevant way to approximate the CUE because of the large amount a population (an economy not provided with electricity. Furthermore, the 520 USD/MWh used by EEPCO was updated recently in the Tariff Study carried out in 2005.

Considering a 130 USD/kW investment annuity for an OCGT in Ethiopia (see Module 3 Vol3), the classic equation :

LOLP = Investment annuity of peak load generation unit / CUE provides a LOLP equal to 130 000 / 520 = 250 hours / year which is basically identical to the 10 days/ year provided by EEPCO.

Sudan:

As for Egypt, the investment cost of peak load OCGT in Sudan in close to 600 USD/kW (see Module 3 Vol4). Accordingly, a 3.65 day / year LOLP is consistent with a 108 000 / (3.65 x 24h) = 1 200 USD/MWh CUE.

Recommendation for the present Study:

The connection of the three countries though a high voltage interconnection will raise the three power systems to the same level of reliability of power supply (this is one of the technical benefit of an interconnection).

Accordingly, the Consultant proposes to set this value to a target value of 8 hours / year for the LOLP, which corresponds to a Cost of Unserved Energy to be considered by the planning model equal to 13 000 USD/MWh (for a discount rate of 12%).

NB:

The margin ratio criteria will not be used in the present Study (see presentation of the stochastic planning model in Module M6).

6.3.2 PROPOSED CRITERIA FOR THE INTERCONNECTION

6.3.2.1 General considerations

The interconnections between the three power systems must respect some rules to comply with technical and economic constraints. These rules are listed hereafter.

As the distances between the transmission systems are consequent and huge power exchange could be profitable, the AC interconnection links must be designed with the highest voltage used in the countries in order to maximise the power transfer capacity and minimise the transmission losses.

The interconnection links must be connected close to a huge power station in the exporting country and close to a main load centre in the receiving country to minimise the impact of the power exchanges on the internal networks.

AC links are technically and economically feasible whether the distance does not exceed 500 or 600 km. For longer distance beyond 800 km without tapping substations, DC solution has to be recommended.

The interconnection must follow the shortest route to minimise the investment cost and the transmission losses. Moreover to facilitate the construction of the line and the maintenance during its operation, the line route must be kept close to roads or tracks.

6.3.2.2 Proposed planning criteria

Principle: the interconnected system must satisfy the N-1 criterion, that is the planning criterion used in the three countries.

In normal and in emergency situations, the operation of the interconnection must not adversely affect the operation of the three interconnected systems. Whatever the situation, the electrical parameters of these systems (currents, voltages, frequency,...) must be kept within their operation limits recalled in the previous paragraphs, §5.2.1, §5.2.2 and §5.2.3.

Moreover, as each system complies with N-1 criterion, any single outage in one of the three systems must not adversely affect the operation of the interconnection and of the two other systems.

The two interconnection links between Ethiopia and Sudan, and then Sudan and Egypt, must be properly linked together with a robust interconnection, subjected to the same planning criteria.

<u>Emergency situation for the interconnection</u>:

It consists in the outage of one element of the interconnection link:

One circuit for an AC line,

One pole for a DC line,

Blocking of one pole of a converter.

Following the outage, the interconnected system shall operate without the faulted element.

<u>Technical constraint on the power exchange</u>:

The transfer capacity of the interconnection will be deduced from the results of Economic Study, the interconnection will be sized to transmit all the profitable power exchanges, taking into account the benefit due to fuel substitution and the transmission cost.

In N-1 situation, the power exchange could be affected by the outage of one element of the interconnection link according to the design of the interconnection: single circuit line, double circuit line or double pole DC link or several circuit link. The following cases could be examined:

- <u>Single circuit link</u> (AC single circuit line or DC single pole link)
  The outage of the interconnection entails the loss of the whole power exchange. In this situation, there is a shortage of generation in the receiving country, and consequently a frequency drop. The under frequency load shedding scheme in the receiving country must not be activated. In the exporting country, the frequency surge due to the extra generation must not activate the over frequency protection of the generating units. To respect these limits – under frequency and over frequency – the power exchange will have to be limited.

- <u>Double circuit line</u>

    - AC double circuit line: following the outage of one circuit, two situations can appear:

  - The power exchange is not affected; the N-1 criterion is satisfied. The remaining circuit will be sized to transmit the whole power exchange.

  - The power exchange has to be reduced; the N-1 criterion is not totally satisfied. The remaining circuit will be sized to be temporarily overloaded, until the decrease of the power exchange will be effective.

- DC double pole link: Following the outage of one DC pole, half of the initial power exchange is lost. As in the situation “Single circuit link”, the receiving system must avoid the activation of the under frequency load shedding scheme and the exporting system must avoid over frequency.

- Multi circuit link: the interconnection satisfies the N-1 criterion; following the outage of one circuit, the power exchange is not affected.

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- Tropics (Ethiopia)
- YAM (Sudan)

ENTRO

EASTERN NILE POWER TRADE PROGRAM STUDY

AfDB

MODULE 4:

PLANNING AND EVALUATION CRITERIA

APPENDIX

30 MARCH 2007

LIST OF APPENDICES

TABLE OF CONTENTS

0. SAMPLE OF SPREADSHEET

Project Name	Level of studies	GHG reduction	Upstream impacts	Downstream impacts	Reservoir area/energy	Average	Resettlement	Multipurpose benefit	Average	Transboundary benefit	Poverty reduction	Average	Capacity cost	Generation cost	Average	Hydro-Generation risk	Reservoir filling time	Constr. risk	Accesses/ Lines	Grid insertion	Hydraulic link (e.g. cascade)	Average	
	10%					10%			10%			5%			30%							35%	100%
WEIGHT	2					2			2			1			6							7	20
	General	Environmental					Social			Political / Macroeconomics			Economical / Financial			Technical							TOTAL SCORE
Fula	2,00	5	0	3	4	3,00	0	0	0,00	1	3	2,00	2	4	3,00	4	0	0	1	2	5	2,00	2,20
Shukoli	2,00	2	0	3	4	2,25	0	0	0,00	1	3	2,00	3	5	4,00	4	0	0	1	2	4	1,83	2,37
Lakki	2,00	2	0	3	4	2,25	0	0	0,00	1	3	2,00	2	4	3,00	4	0	0	1	2	3	1,67	2,01
Bedden	2,00	4	0	3	4	2,75	0	4	2,00	1	3	2,00	2	4	3,00	4	0	0	1	2	2	1,50	2,20
Rumela	3,00	1	4	5	4	3,50	4	5	4,50	1	5	3,00	1	1	1,00	1	5	4	5	5	5	4,17	3,01
Shereiq	4,00	4	4	3	1	3,00	2	4	3,00	3	3	3,00	1	1	1,00	1	4	3	4	4	5	3,50	2,68
Dagash	2,00	5	1	0	0	1,50	0	0	0,00	2	3	2,50	1	1	1,00	4	0	0	4	4	4	2,67	1,71
Kajbar	4,00	3	3	3	1	2,50	2	2	2,00	1	2	1,50	1	1	1,00	2	5	4	5	4	2	3,67	2,51
Low Dal	3,00	2	3	5	1	2,75	2	2	2,00	3	2	2,50	2	2	2,00	4	5	4	5	4	2	4,00	2,90
Halele-Worabesa	4,00	5	4	3	1	3,25	1	0	0,50	1	3	2,00	4	5	4,50	2	4	1	4	4	5	3,33	3,39
Chemoga-Yeda	4,00	3	3	3	4	3,25	1	5	3,00	3	3	3,00	4	5	4,50	4	3	3	4	3	2	3,17	3,63
Aleltu East	4,00	2	4	3	3	3,00	2	3	2,50	3	0	1,50	2	1	1,50	2	3	3	3	3	2	2,67	2,41
Aleltu West	3,00	2	3	4	3	3,00	3	0	1,50	3	3	3,00	2	1	1,50	4	0	3	0	3	4	2,33	2,17
Baro I & II & Gengi	4,00	4	2	4	4	3,50	3	1	2,00	4	2	3,00	4	5	4,50	1	4	3	1	2	5	2,67	3,38
Geba I & II	4,00	4	2	4	4	3,50	3	1	2,00	4	2	3,00	4	5	4,50	1	4	3	1	2	5	2,67	3,38
Genale III & VI	2,00	5	4	4	4	4,25	5	2	3,50	4	0	2,00	3	4	3,50	5	5	2	4	2	2	3,33	3,29
Karadobi	4,00	5	3	4	4	4,00	4	3	3,50	4	2	3,00	5	4	4,50	5	1	4	1	3	3	2,83	3,64
Mabil	1,00	3	3	3	4	3,25	4	2	3,00	3	2	2,50	0	0	0,00	1	3	4	2	3	1	2,33	1,67
Mandaya	3,00	5	3	4	4	4,00	5	2	3,50	4	2	3,00	5	5	5,00	3	3	4	2	3	5	3,33	3,87
Border	3,00	3	3	4	1	2,75	1	2	1,50	4	2	3,00	5	5	5,00	1	4	4	3	3	2	2,83	3,37
Gojeb	5,00	1	3	3	3	2,50	3	2	2,50	1	2	1,50	3	1	2,00	1	3	3	3	2	1	2,17	2,43

1. SCREENING CURVES

• INTRODUCTION

The use of screening curves is a classic and useful tool to provide a quick evaluation of the relative economic potential of various thermal candidates. These curves represent the evolution of total annual generation cost of one guaranteed kW according to the number of hours of generation per year. The different underlying concepts are presented hereafter.

• GOING TO ANNUAL COST

Comparing different types (or technologies) of generation units often implies comparison between generation units or projects having different economic life durations. The first step to provide a fair comparison is to annualize the investment cost.

In order to do this, we have to find the constant annual value "A" such as the NPV of the annual values of "a" over the economic life time is equal to investment "I". In other words, it is equivalent to pay the value "I" in one time step (construction) or to pay the value "a" every year of the economic life. Accordingly the relation linking "I" and "a" is:

$$I = \sum_{i=1}^{d} \frac{a}{(1+r)^i}$$

where r = discount rate

I = investment

a = investment annuity

d = economic life time of the investment

The resulting value a is given by the relation: $a = \frac{I}{K(r,d)}$

where the amortization factor K is given by the relation :

$$K(r,d) = \frac{r \times (1+r)^d}{(1+r)^d - 1}$$

Once the investment cost is annualized it is possible to compare, on the same annual basis, projects having different economic lives.

- **GOING TO INVESTMENT COST PER INSTALLED KW TO INVESTMENT COST PER GARANTEED KW**

Some definitions are helpful to consider these issues:

Installed capacity:

The installed capacity of a thermal plant is the nominal output, measured at the generator terminals, given by the constructor under standard conditions (usually 15°C temperature and sea level pressure conditions).

Gross available capacity:

The gross available capacity is the installed capacity less de-rating to account for age and actual temperature and pressure conditions.

Net available capacity:

The net available capacity is the gross available capacity less the power consumed by the auxiliaries. This is also referred to as "send out capacity".

Planned Outage Rate (POR):

Is the time spent on planned maintenance expressed in days per year or in percentage.

Forced Outage Rate (FOR):

Is the expected time that a generation unit is expected to be out of service for unplanned repair or maintenance, expressed as a percentage of the maximum expected days a unit should be available to generated (i.e. days of year less the number of days undergoing planned maintenance).

Annual availability:

Is the fraction of the year that a generating unit is expected to be available for service:

$$((365 - POR) \times (1 - FOR)) / 365$$

In order to make a fair comparison between investments it is necessary to consider the fact that one installed MW does not provide one available (or guaranteed) MW.

Accordingly, the comparison should be made on the basis of the investment cost of:

Net Capacity / k_{avail}

where:

k_{avail} = availability factor (considering forced and planned outage rate).

- **ANNUAL GENERATION COST**

The global cost of a thermal generation unit over its economic life depends on:

- fixed costs: construction cost (more precisely cash flow schedule during construction) and annual O&M cost,

- variable cost: fuel cost and variable O&M cost,

- the economic life time of the unit.

The annual generation costs of an available kW of a thermal unit i according to the number of hour generation per a year is given by the equation:

$$C_i\ (h) = A_i + K_i * h$$

where:

A_i = anticipation cost of an <u>available</u> kW [$/kW/year]

K_i = proportional cost (fuel, lubricant, proportional O&M) of unit i [$/kWh]

h = number of hours of generation per year [h/year]

The anticipation cost[1] of one guaranteed kW is equal to the sum of the fixed annual costs of the facility:

$$A_= (a + Kfix) / k_{avail}$$

where:

a = investment annuity of one installed kW = (construction cost + IDC) / K (r,d).

$Kfix_i$ = annual O&M cost.

k_{avail} = availability factor (considering forced and planned outage rate).

IDC = interest during construction.

r = discount factor.

d = economic life duration.

K (r,d) = amortization factor.

In this way, it is possible to compare the total costs of thermal generation units having different economic lives and different outage rates.

[1] Called "anticipation cost" because it is also equal to the additional fixed cost paid when the commissioning of the facility i is anticipated by one year.

- **SCREENING CURVES**

The diagram of screening curves presents on the same figure the evolution of the annual generation cost of a set of thermal plants (usually the thermal candidates) according to the annual generation duration (hour / year) of each unit.

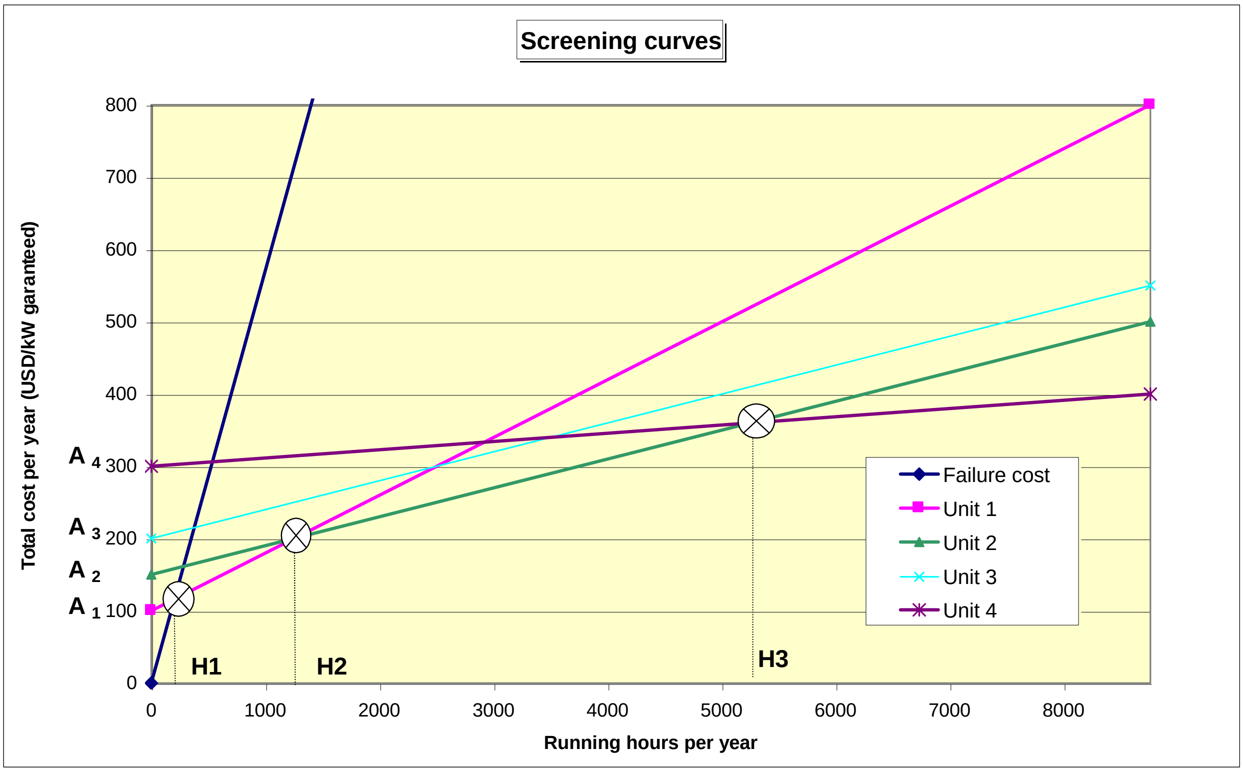

Figure 1-1 – Evolution of the annual generation cost

In the example above:

- unit 1 has a low investment cost (anticipation cost A1 = 100), but a high proportional cost, this is typical of peak generation units (e.g. OCGT),

- unit 2 has a greater investment cost (anticipation cost A 2 = 150), but a slightly lower proportional cost,

- unit 3 has a greater investment cost (anticipation cost A 3 = 200), but a lower proportional cost,

- unit 4 has the greatest investment cost (anticipation cost A 3 = 300), but the lowest proportional cost, which is typical of base load generation.

- **WHAT IS THE LEAST COST OPTION FOR WHAT ANNUAL GENERATION DURATION ?**

From the previous figure, it is clearly apparent that:

- for a number of generation hours per year > H3, unit 4 is the one resulting in the lowest generation cost.

- from H2 hours of generation per year to H3 hours, the least cost unit is unit 2.

- for less than H2 hours of generation per year, unit 1 is the least cost option.

Unit 4 is always more expensive than one of the other units whatever the annual generation duration.

- **BALANCE TIME BETWEEN TWO TYPES OF THERMAL UNITS**

The balance time hij between two types of thermal facilities i and j is defined as the annual utilization time for which the two facilities reach the same generation costs.

$$A_i + K_i \cdot h_{ij} = A_j + K_j \cdot h_{ij}$$

$$h_{ij} = (A_i - A_j) / (K_j - K_i)$$

It also provides the break even value between load, semi-base and peak generation among thermal facilities. In the previous example:

- unit 4 is the base load generation unit for annual generation duration > H3. If more base load generation is required because of the expansion of the system, then more units of unit1 type are to be committed,

- unit 2 is the semi-base load generation unit for annual generation duration between H2 et H3,

- unit 1 is the peak load generation unit for annual generation duration shorter then H2.

- **OPTIMALITY OF A GENERATION MIX (PART 1):**

In order to be optimal (i.e. least cost option) a generation mix should satisfy a certain number of conditions. One of these conditions is that there should be a certain balance between base, semi-base and peak units.

In the example above, the generation mix would not be optimal if the peak unit (Unit 1) was be used more than H2 hours per year. Indeed, it would be more economical in this case to commit an another semi-base unit (Unit 2) which would be less expensive.

Basically, each generation units should be called within the limits of the annual balance time described above.

- **LINK BETWEEN THE COST OF UNSERVED ENERGY AND THE LOLP**

The cost of unserved energy (CUE) is the cost of power shortage to the different sectors of the national economy (heavy and light industry, service industry, etc).

The CUE has a relation with the amount and the cost of generation units to be installed in a generation mix. If, in order to reduce power shedding, the cost of generation would be greater than the CUE, then the optimal choice for the economy of the country is to have power shedding rather than build a new power unit. On the other hand, if it is possible to build a power unit having a cost lower than CUE, then the best choice is to build this unit to reduce power shedding.

Obviously this comparison of costs should also consider the duration of generation (or the duration of power shedding). This is what is presented in the following figure:

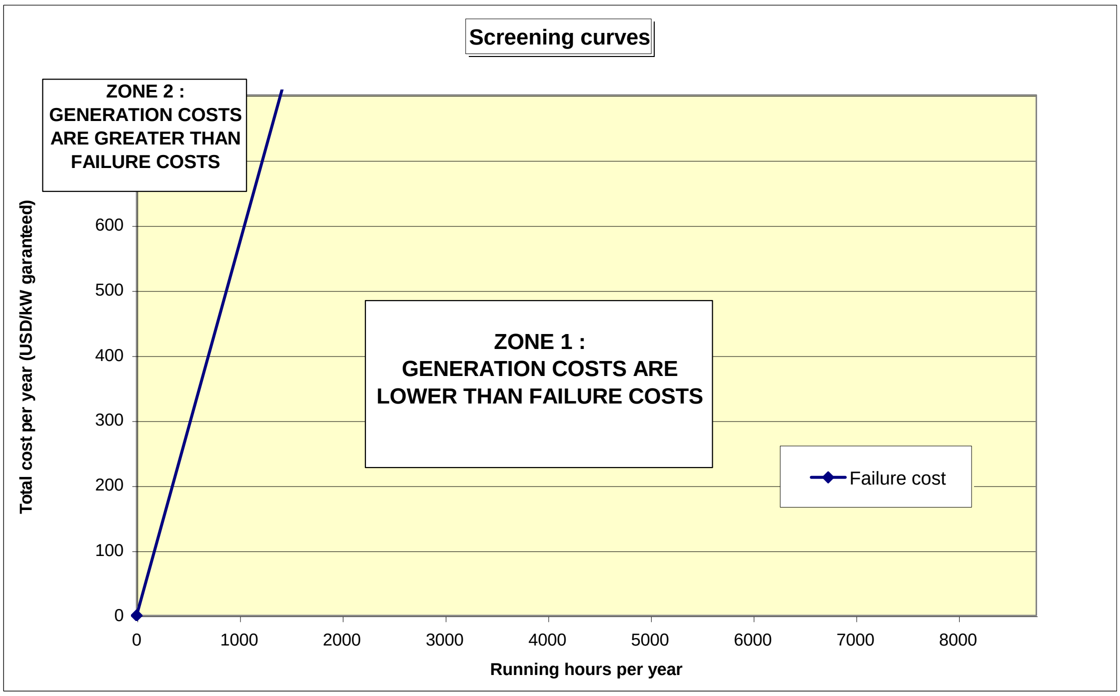

Figure 1-2 - Total generation cost

A generation unit having an annual generation cost in zone 2, have a cost greater than CUE and could not be profitable to the economy of the country.

The relation between CUE and LOLP can be found when the failure cost line is drawn on the screening curves diagram:

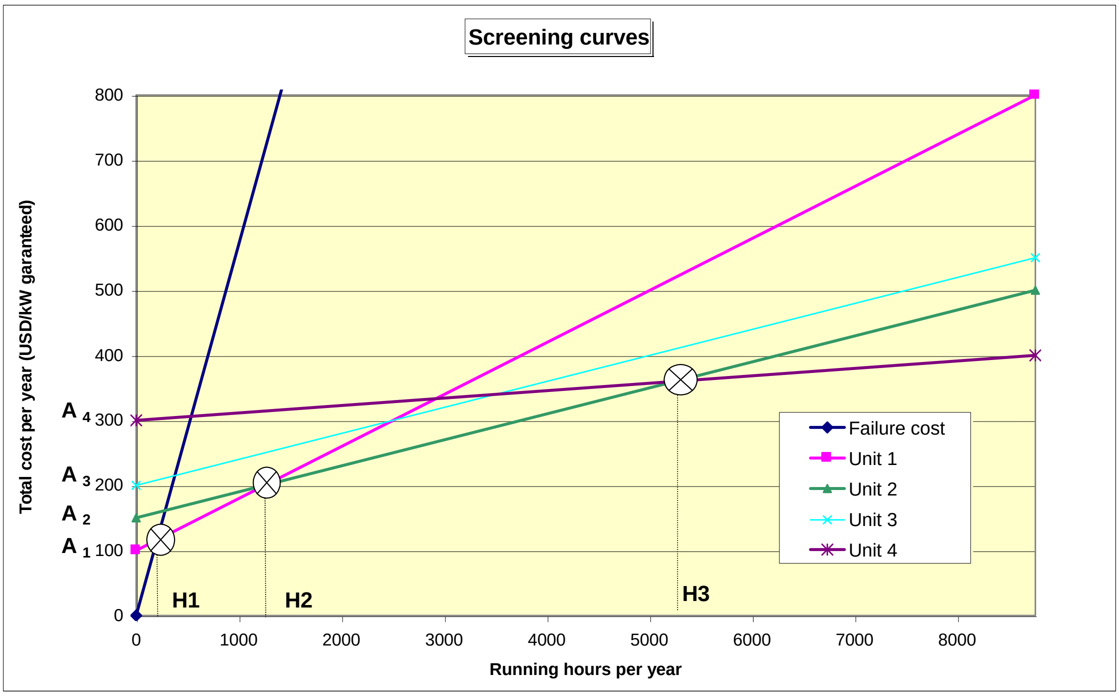

Figure 1-3 - ??

For annual duration lower than H1 hours / year, the cost of generation from unit 1 (peak unit) is greater than the failure cost. This means that is not economically justified to build unit 1 if this unit is used less than H1 hours / years, it is more economical to have power shedding.

In other words, the economic duration of power shedding, given the value of the CUE, and given the characteristics of the peak unit 1, is H1. Accordingly, H1 is the value of the LOLP expressed in hours per year.

The relation linking these different quantities is:

CUE x LOLP = A1 + K1 x LOLP

where:

CUE = cost of unserved energy	[USD/MWh)
LOLP = average annual duration of power shedding	[hours /year]
A1: anticipation cost of peak generation unit	[USD/MW]
K1: proportional cost of peak generation unit	[USD/MWh]

The term K1 x LOLP being very small with respect to A, the useful relation is:

CUE x LOLP = A1 + K1 x LOLP

Example:

If the anticipation cost of the peak generation unit is 130 USD/kW and the Cost of Unserved Energy is 520 USD /MWh, then LOLP = 130 000 / 520 = 250 hours per year.

- **OPTIMALITY OF A GENERATION MIX (PART 2):**

According to the previous discussion an optimal (i.e. least cost) generation mix should satisfy the two following conditions:

- The total installed capacity should be such as the shortage duration is equal to the target LOLP. This means that the target level of reliability is reached.

- The total installed capacity for each group of generation units (base, semi-base, peak) should be such than the balance times between the different groups are respected.