ENTRO

EASTERN NILE POWER TRADE PROGRAM STUDY

AfDB

ENERGY SECTOR PROFILE & PROJECTIONS

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with participation of:

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



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PHYSICAL UNITS AND CONVERSION FACTORS

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

General Conversion Factors for Energy

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

ABBREVIATIONS AND ACRONYMS

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

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

1. EXECUTIVE SUMMARY

1.1 EGYPT

1.1.1 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.

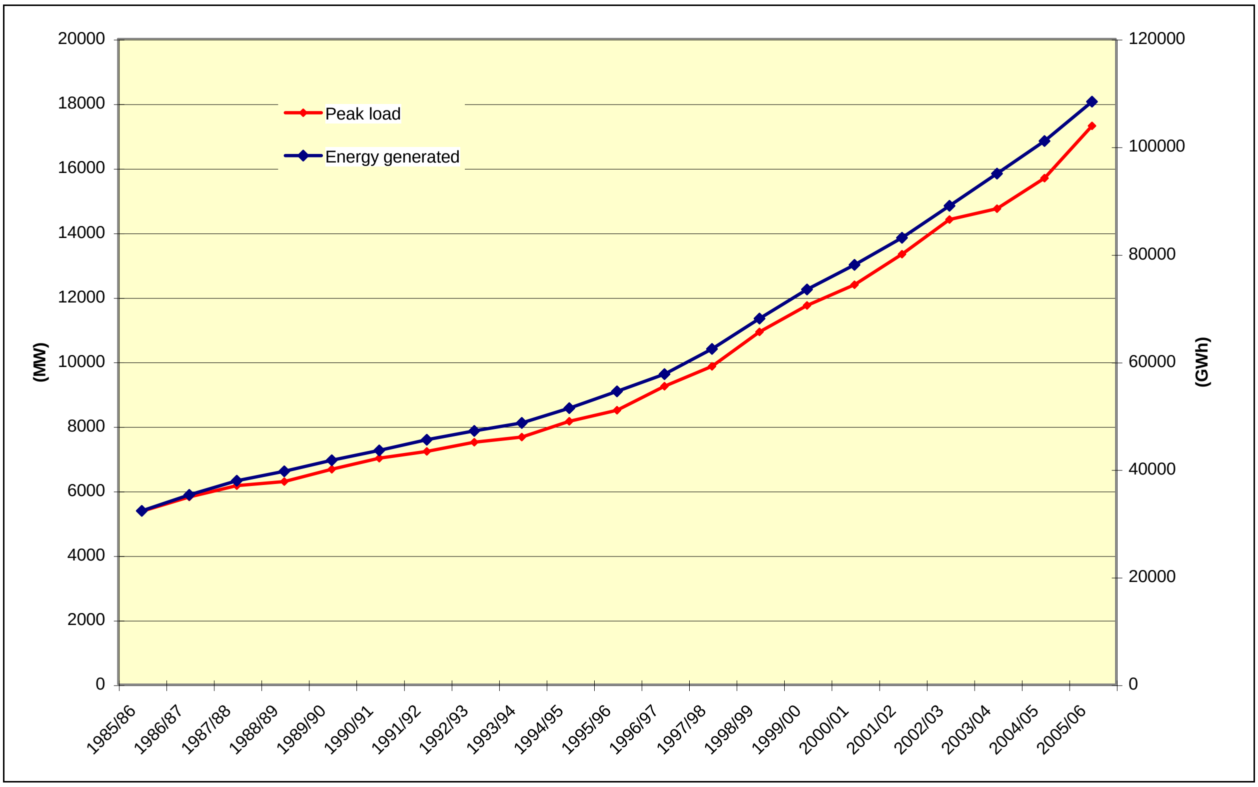

Figure 1.1-1- Historical evolution of Egyptian demand (MW and GWh)

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 1.1-1 - Historical evolution of Egyptian Peak load

1.1.2 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 1.1-2 - Demand forecast for Egypt 2008-2030

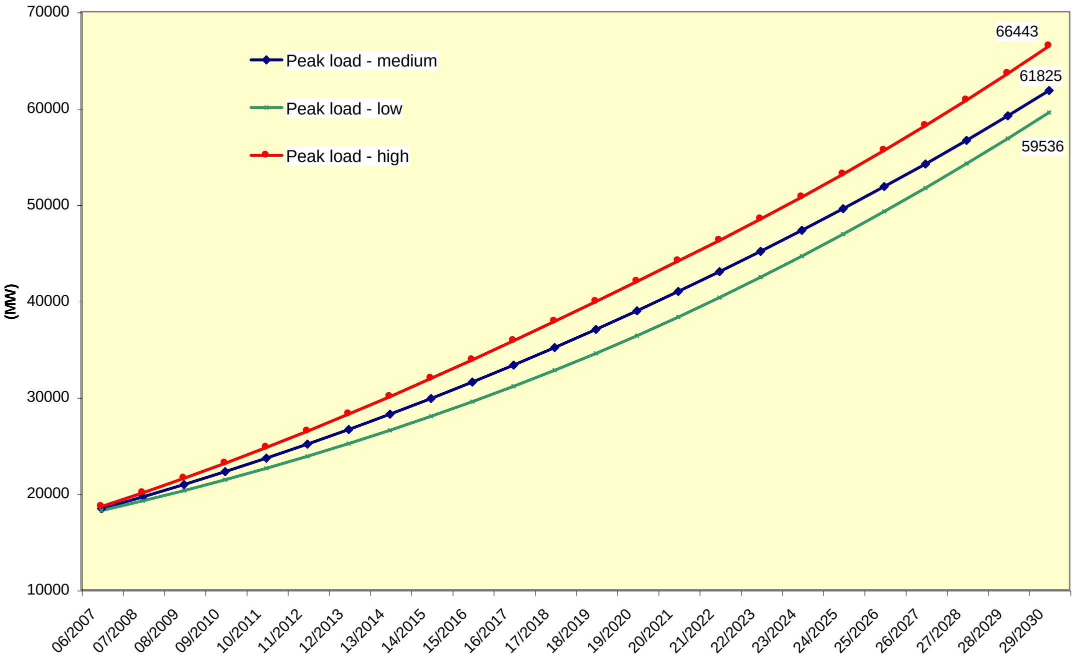

Figure 1.1-2 - Peak load projections for Egypt (2006/2007 to 2029/2030)

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%.

1.1.3 POWER TRADE OPPORTUNITIES

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 a positive export balance;
- ✓ Exports will be quite similar in both directions;
- ✓ Energy power exports will remain stable over the planning period according to the future long term contracts.

A conservative power export hypothesis is considered in the present Study:

Annual balance	2007		2008		2009		2010		2015		2020		2030	
	(GWh)	(MW)	(GWh)	(MW)	(GWh)	(MW)	(GWh)	(MW)	(GWh)	(MW)	(GWh)	(MW)	(GWh)	(MW)
Egypt -> Libya	800	200	800	200	800	200	800	200	800	200	800	200	800	200
Egypt -> Jordan	800	200	800	200	800	200	800	200	800	200	800	200	800	200

Table 1.1-3 - Power export hypothesis for Egypt

1.1.4 GENERATION SUPPLY OPTIONS

Considering the large availability of natural gas in Egypt, the thermal candidates identified for new generation investment 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 1 000 MW units for Dabaa nuclear plant from 2016 until 2027.

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

1.1.5 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 1.1-4 - EEHC Generation Expansion Plan from 2008 until 2027.

1.1.6 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.

1.1.7 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 Dabaa, and in the Delta Zone, with the creation of North Delta 500/220 kV substation. Two new 500/220 kV substations are created in Heliopolis (Cairo) 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 ETHIOPIA

1.2.1 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 1.2-1 - Main characteristics of the three demand projections for Ethiopia

1.2.2 POWER TRADE OPPORTUNITIES

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	369 GWh	369 GWh
(7000h base load export)	0	21 MW	45 MW	47 MW	53 MW	53 MW	53 MW
Kenya	0	0	0	200 MW	400 MW	600 MW	1 200 MW
(5000 h export)	0	0	0	1 000 GWh	2 000 GWh	3 000 GWh	6 000 GWh
Sudan	0	0	200 MW max	200 MW max	Result of M6	Result of M6	Result of M6

Table 1.2-2 - Power export projection for Ethiopia

1.2.3 IDENTIFICATION OF GENERATION OPTIONS

1.2.3.1 Thermal candidates

The candidate thermal plants identified are:

- 20 MW Medium Speed Diesel burning lowest grade of residual fuel oil,
- 70 MW Combustion Turbine burning diesel oil,
- 190 MW Combined Cycles burning diesel oil.

1.2.3.2 Hydropower candidates

Ethiopia has abundant water resources and 122 km^3 of water flow through 12 large and medium sized river basins. Approximately 85% of the water resources are in the western part of the country, in the major basins of Abay, Omo-Gibe and Baro-Akobo.

The corresponding economically exploitable potential is estimated to be about 30,000 MW (160 TWh) with 20,000 MW for the three major basins.

The following table presents the main characteristic of the hydro projects relevant for the present Study. The comparison and ranking of these projects will be carried out within Module 4:

Project name	Level of study (&date of study)	Installed capacity MW	Average energy GWh/year	Firm energy GWh/year	Project cost USD_{06} M	Economic cost USD_{06}/MWh (discount rate 10%)	Economic cost USD_{06}/MWh (discount rate 12%)	Comments
Halele Worabesa	F (2000 & 2005)	420	510 + 1735	460 & 1570	232 & 275	60 & 21	73 & 26	financed project ?
Chemoga-Yeda	F (2005)	162 + 118		780 + 568	285 & 127	49 & 31	61 & 39	
Aleltu East	F (1995 ?)	186	800	780	438	77	95	
Aleltu West	PF (1994 ?)	265	1 050	983	560	76	93	
Baro I & II & Gengi	F (2005)	200 + 500 + 200	904 + 385 + 920	770 & 2 085	487, 350 & 139	78 & 20 & 22	95 & 25 & 27	
Geba I & II	F (2005)	215 + 157	935 + 853		295 & 124	45 & 19	55 & 23	multi purpose
Genale III & VI	F & PF (2006)	254 + 256	1 200 + 1 000	1 200 & 1 010	? & 383	34 & 50	40 & 60	possible HVDC link to Kenya
Karadobi	PF (2006) F (2007?)	1 600	8 600 (with BELES)	8 300 (with Beles)	2 231	40	50	+ 2.6 TWh downstream
Mabil	PF (?)	1 200	5 300					Incompatible with Mandaya
Mandaya	PF (2007)	2 000	12 100	11 200	2 477	29	36	Pre-feasibility studies carried out in Module 5
Border	PF (2007)	1 200	6 000 (wo Mandaya)	4 000 (wo Mandaya)	1 442	34	42	Pre-feasibility studies carried out in Module 5
Gojeb	D (1997)	153	520	364	287	74	91	IPP ?
Awash IV	F (2006)	38	160	144	49	36	42	irrigation

Table 1.2-3 - Main characteristics of the Ethiopian hydropower projects

1.2.3.3 Other types of power candidates

Opportunities in geothermal or wind projects exist in Ethiopia. However, considering the relatively low capacities involved (compared to large scale hydro projects) and the scope of the present Study, no development of geothermal or wind energy will be considered in the present Study.

1.2.4 REVIEW OF THE GENERATION EXPANSION PLAN

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	N° of units x Capacity	System Dependable capacity (MW)	ICS Peak Demand - Medium scenario (MW)	ICS Peak Demand - Target scenario (MW)	Margin ratio for Target Demand scenario
2008	GILGEL GIBE II	4 x 105	1 135			
2008	TEKEZE	4 x 75	1 435	826	900	59%
2009	BELES	4 x 105	1 855	967	1 079	72%
2010	YAYU COAL	2 X 50	1 955	1 125	1 286	52%
2011	GIBE III (Phase 1)	4 x 226	2 857	1 266	1 485	92%
2012	GIBE III (Phase 2)	4 x 226	3 759	1 418	1 705	120%
2013						
2014	HALELE WORABESA	2 x 48,5 + 4 x 81,5	4 181	1 765	2 229	88%
2015	CHEMOGA YEDA	2 x 81 + 2 x 59	4 461	1 967	2 544	75%

Table 1.2-4 - Ethiopian Generation Expansion plan to year 2015

It can be noticed that the system dependable capacity is significantly greater than the target peak demand projection which results in good opportunities for power exports to neighbouring countries.

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, Mandaya and Border.

1.2.5 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 - 420 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.

1.3 SUDAN

1.3.1 DEMAND FORECAST

The demand forecast study has formed the basic input data to Sudan Long Term Power Plan Study 2006 (LTPPS).

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 1.3-1 - Main assumptions for the base case demand projection for Sudan

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.

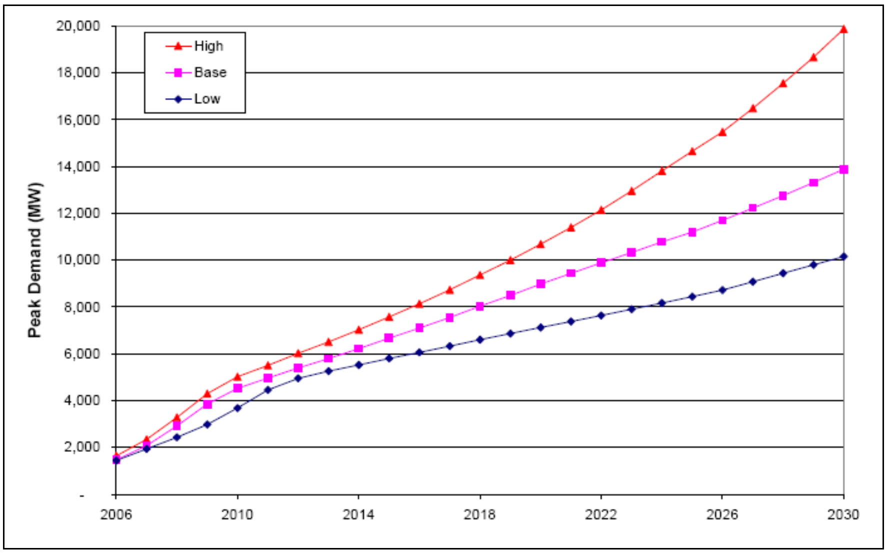

Figure 1.3-1 - Peak demand projection for Sudan (2006-2030)

	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 1.3-2 - Main characteristics of the demand projection for Sudan

1.3.2 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 (i.e. capacity >200 MW).

1.3.3 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 in Sudan LTPPS 2006.

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

1.3.3.1 Thermal candidates

In line with Sudan Long Term Power Plan Study 2006 study, 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.

1.3.3.2 Hydropower 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	Average generation GWh/year	Comments
Rumela	Atbara river	M&M/Gibb 1979	30	193	82	Irrigation pupose
Sabakola	Main Nile	Acers 1993	120	596	691	Might flood Khartoum
Shereiq	Main Nile	F (1990)	315	1 190	1 546	Prioritary
Dagash	Main Nile	Acers 1993	285	1 048	1 476	
Kajbar	Main Nile	F (Hydroproject 1997)	300	1 125	1 400	
Dal Low	Main Nile	On going PF	340	1 118	1 944	cost currently updated in PF
	Sub Total		1 360			
Fula Alt 1	Barh el jebel	Acers 1993	720	1 319	4 119	limited information
Shukoli	Barh el jebel	Acers 1993	210	420	1 422	available
Lakki	Barh el jebel	Acers 1993	210	429	1 415	comm. date > 2020
Bedden	Barh el jebel	Acers 1993	400	880	2 761	(Pre-Feasibility : starting in 2007)
	Sub Total		1 540			

Table 1.3-3 - List of hydro candidates for Sudan

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

1.3.4 REVIEW OF THE GENERATION EXPANSION PLAN

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

For the base case, the main hypothesis are:

- planning period from 2006 to 2030,
- discount rate: 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.

1.3.5 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 VHV 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 VHV reinforcement in the Korfdofan and Darfur areas.

1.4 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 1.4-1 - 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 1.4-2 - Natural gas price projections

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

1.5 INTERCONNECTION VIEWS FOR THE INTERCONNECTED SYSTEM

Four views have been selected to interconnect the systems, two AC options and two DC options. The interconnection points are the following:

- In Egypt: High Dam for the AC alternatives and Assiut for the DC alternative.
- In Ethiopia: Border HPP and Mandaya HPP for the AC alternatives and Mandaya HPP for the DC alternatives.
- In Sudan: Merowe HPP and Hasaheisa 500 kV substation for AC views. One DC view passes through Sudan without taping station, the other one with a tapping station in Khartoum (Markhiat 500 kV substation).

View A1:

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.

View A2:

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 1 000 MW, is guaranteed in N-1.

View A3a:

Consists in a ± 500 kV double pole line between Mandaya HPP and Assiut. One AC/DC 1 200 MW converter is installed at Mandaya and one at Assiut. The power exchange is equal to 1 200 MW, only 600 MW are guaranteed in N-1.

View A3b:

Same as A3a but with a DC/AC tapping station located at Khartoum (300 MW), the station in Assiut is reduced to 900 MW.

The investment cost of the three alternatives 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 A3a	V A3b
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 (Sudan 300 MW Egypt 900 MW)
Transfer capacity in N-1 situation	0 MW	1 000 MW	600 MW	600 MW

Table 1.5-1 - First views of interconnection costs and characteristics

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.

1.6 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 views of interconnection options 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.

The economic costs of generation and transmission depend on investment cost, operation cost (fuel and O&M) and also on discount rate. A high value of discount rate would give more weight to short term, and would disfavour large and long term investments (e.g. HPP and interconnection) compared to lower investments with short economic lives (e.g. CCGT).

The reference discount rate for the economic Study carried out in Module 6 is 10% (see justification in Module 4). A 12% rate will be considered in the sensitivity analysis.

From the first views of the interconnection (technology, route, capacity, etc), it is found that:

a- For the reference discount rate used in this Study (10%), power exports from Ethiopia – Sudan area supplied from a 35 USD/MWh HPP (typical value of the lowest cost HPP identified in Module 3 Vol 3 and 4), would become competitive when the natural gas price in Egypt is greater than a range of 5.0 to 5.5 USD/MBTU. This value is significantly exceeded in the 2015, which is the earliest date of commissioning of the interconnection, in both reference and high projection of natural gas price. This means that the interconnection would become profitable from its earliest possible date of commissioning. If the natural gas price remains low, economic profitability of power export to Egypt from a 35 USD/MWh HPP would not be achieved before 2025-2030, even for the lowest cost interconnection options.

b- For a 12% discount, which could be considered as a conservative value, the typical value of the lowest cost HPP is 40 USD/MWh in he Sudan / Ethiopia area. Hydro power exports would become competitive when the price of natural gas in Egypt is greater than a range of 6.0 to 6.2 USD/MBTU.

This value is exceeded in the 2015, for the two lower cost options identified for the interconnection for both high and reference natural gas price projection. In the high price gas projection, the most expensive interconnection option, 500 kV AC 1 000 MW, would become competitive from about 2015.

If the natural gas price remains low, then it is not possible to expect any economic profitability of power export to Egypt from a 40 USD/MWh HPP, even in 2030.

At this stage of the Study, these figures and results 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. ORGANISATION OF MODULE 3 REPORT

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

This Module is organized in five Volume:

- Volume 1: Executive summary of Module M3
- Volume 2: Energy Sector Profile & Projections for Egypt
  - Review and update of previous demand forecast.
  - Potential trade opportunities.
  - Review of the existing Generation Expansion Plan.
  - Identification of generation supply options.
  - Review of existing transmission master plan.
- Volume 3: Energy Sector Profile & Projections for Ethiopia
  - Review and update of previous demand forecast.
  - Potential trade opportunities.
  - Review of the existing Generation Expansion Plan.
  - Identification of generation supply options.
  - Review of existing transmission master plan.
- Volume 4: Energy Sector Profile & Projections for Sudan
  - Review and update of previous demand forecast.
  - Potential trade opportunities.
  - Review of the existing Generation Expansion Plan.
  - Identification of generation supply options.
  - Review of existing transmission master plan.
- Volume 5:
  - Fuel prices Projections.
  - Interconnection options.
  - First evaluation of economic profitability of exports from Sudan-Ethiopia.