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Ministry of Industry, Energy and Mines
Société Tunisenne de l'Electricite et du Gaz

Data Collection Survey On Power Sector In Tunisia

Final Report

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Abbreviation

AFD	:	Agence Française de Développement
AfDB	:	African Development Bank
ASPSPP	:	Ajustable Speed Pumped Storage Power Plan
BESS	:	Battery Energy Storage System
B/S	:	Balance Sheet
C/P	:	Counter Part
DPF	:	Investment, Competitiveness and Inclusion Development Policy Financing
EBRD	:	European Bank for Reconstruction and Development
EFF	:	Extended Fund Facility
EMS	:	Energy Management System
ESMAP	:	Energy Sector Management Assistance Program
EIRR	:	Economic Internal Rate of Ruturn
FIT	:	Feed-In-Tariff
GDP	:	Gross Domestic Product
GF	:	Governor-Free
GIZ	:	Deutsche Gesellschaft fur InternationaleZusammenarbeit
IBRD	:	International Bank for Reconstruction and Development
IFC	:	International Finance Corporation
IFRS	:	International Financial Reporting Standards
IMF	:	International Monetary Fund
IPP	:	Independent Power Producer
JICA	:	Japan International Cooperation Agency
METI	:	Ministry of Economy, Trade and Industry
MEIM	:	Ministere de I'Enrgie des Mines et des Enegies renouvelables
PDM	:	Project Design Matrix
PIP	:	Performance Improvement Plan
PPA	:	Power Purchase Agreement
P/S	:	Profit and Loss Statement
PSPP	:	Pumped Storage Power Plant
PSS/E	:	Power System Simulator for Engineering
PV	:	Photovoltaic
RE	:	Renewable Energy
SAIDI	:	System Average Interruption Duration Index
SAIFI	:	System Average Interruption Frequency Index
SCADA	:	Supervisory Control And Data Acquisition
SCR	:	Short Circuit Ratio
SM	:	Smart Meter
STEG	:	Société tunisienne de l'électricité et du gaz
TD	:	Tunisia Dinar
UFR	:	Under Frequency Relay
UTICA	:	Tunisian Confederation of Industry, Trade and Handcrafts
VPP	:	Virtual Power Plant
VRE	:	Variable Renewable Energy
WB	:	World Bank

WS	:	Work Shop
WT	:	Wind Turbine

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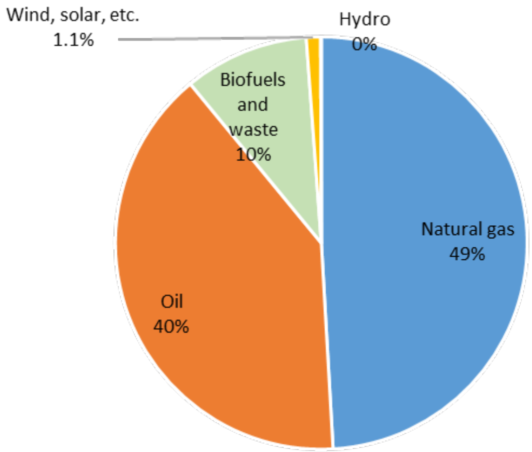
Chapter 1 Introduction

1.1 Background

Tunisia relies heavily on oil and natural gas for its domestic primary energy. Imports have increased due to a decrease in domestic production of oil and natural gas and an increase in demand since 2000, and at present, the majority of all energy is dependent on imports. In the electric power sector as well, in addition to the conventional issue of compensating for a loss margin of electricity prices, the burden will increase due to the increase in energy imports, and the uncollectible cost due to non-technical loss will increase, and energy-related spending will be occupied more than half of the government's budget deficit. Reform and efficiency improvement of the electric power sector has become a major issue.

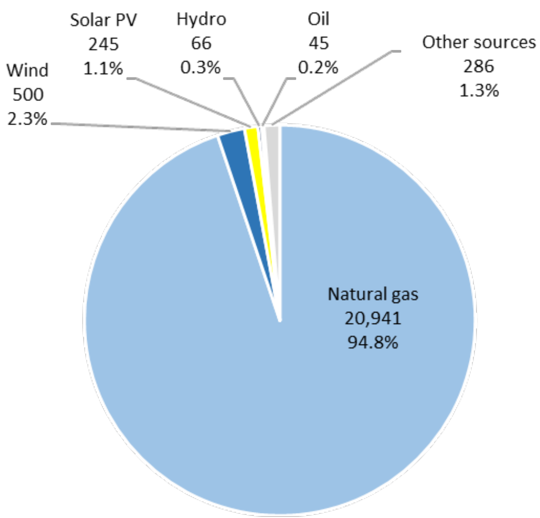
Primary energy supply and power generation by source are shown in Figure 1-1 and Figure 1-2 respectively.



Source	Energy[TJ]	Rate [%]
Natural gas	229,757	49.09
Oil	186,911	39.94
Biofuels and waste	45,864	9.80
Wind, solar, etc.	5,259	1.12
Hydro	237	0.05

(Source:IEA, Total energy supply by Source (2019))

Figure 1-1 Composition of primary energy supply (2019)



Source	Energy[kWh]	Rate[%]
Natural gas	20,941	94.83
Wind	500	2.26
Solar PV	245	1.11
Hydro	66	0.30
Oil	45	0.20
Other sources	286	1.30

(Source:IEA, Electricity generation by source (2019))

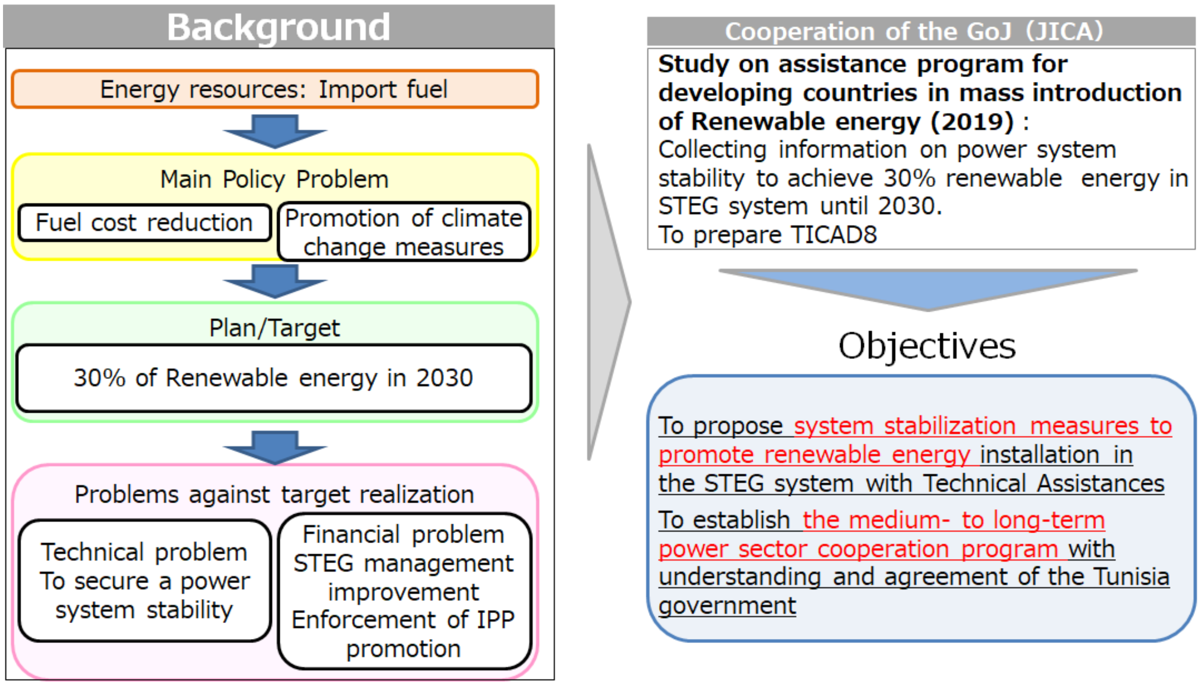
Figure 1-2 Electricity generation by source (2019)

To remedy this situation, the Tunisian government has decided to cover 30% of its electricity with renewable energy (RE) such as wind power (WT) and solar power (PV) in 2030 under its national energy strategy. This strategy has a policy of utilizing independent power generation companies (IPPs) for more than two-thirds of the introduction of renewable energy. The introduction of IPP requires strengthening the capacity of financial services such as project finance related to renewable energy investment. Since the financial risk caused by the budget deficit of the Tunisian Electricity and Gas Corporation (STEG: Société tunisienne de l'électricité et du gaz) is directly linked to the payment risk of IPP companies, management improvement is an important issue.

The "Survey and Research on Support for Developing Countries in the Era of Mass Introduction of Renewable Energy" (The past JICA study) conducted in FY2019 clarified the problems in the power system due to the expansion of the introduction of renewable energy, and it is necessary to deal with short-term and long-term frequency fluctuations, voltage fluctuations, etc.

1.2 Purpose of the survey

In this survey, we re-analyzed the development effects and trends of other donors by solving the above issues, and collected and analyzed basic information to consider to identify issues, schemes to be prioritized, and approaches, and materialize cooperation programs, business plans, and individual projects. In addition to responding to traditional issues such as reducing power loss, we also investigated the possibility of cooperation with next-generation power distribution systems such as distributed power sources and energy management systems (EMS). Through these, the study team collected and analyzed the information necessary to promote discussions and consensus-building between Tunisian government officials and the organization regarding the direction of future cooperation in the electric power sector and business plan proposals.



(Source: JICA study team)

Figure 1-3 Outline of the background and purpose of the study

1.3 Survey content and implementation method

This survey work was carried out during FY2020 by conducting a survey in Tunisia utilizing remote web conferencing operated by a local Tunisia consultant and working in Japan. From April 2021, considering the impact of COVID-19 infection prevention measures, the study was carried out through two (2) field surveys including training of PDPAD2 in Tunisia.

1.4 Flow chart of survey work

Table 1-1 Flow chart of survey work summarizes the outline of this work in a flow.

Table 1-1 Flow chart of survey work

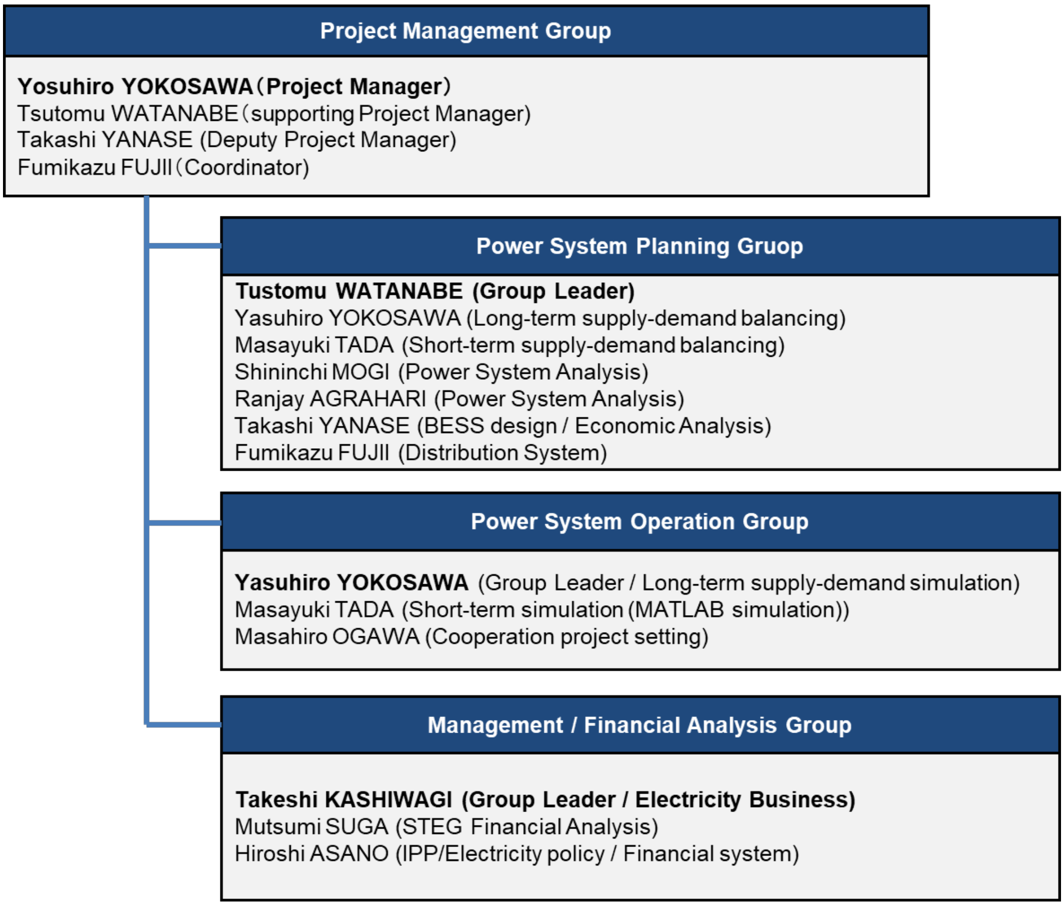
Year	2020		2021												2022		
Month	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3
Remote Kick-off meeting	▲																
Preparation of ItR1			↔	↔	↔												
Preparation of ItR2						↔	↔	↔	↔	↔							
Preparation on System Stability Analysis	↔	↔	↔	↔	↔												
Examination on System Stabilization Measures						↔	↔	↔	↔	↔	↔						
Examination Power Sector Cooperation Project											↔	↔	↔				
1st Field survery - Explanation of ItR2													↔	↔			
Preparation of DfR1														↔			
2nd field survery - Training of PDPAT2 - Demonstration of AGC30 model - Explanation of DFR1															↔		
Submission of DFR2 (Mid-Feb, 2022)																▲	
Finalizing Report																↔	↔
Submission of FR (Mid-March, 2022)																	▲

(Source: JICA study team)

1.5 Personnel Assignment

JICA experts were assigned to four groups to carry out the survey efficiently: Project Management / Power System Planning / Power System Operation / Management & Financial Analysis Group. In carrying out the survey, a system was established in which the four groups cooperate to promote their work efficiently.

In this survey, a wide range of evaluations and examinations of electric power systems in general were conducted based on information collection and analysis. Establish a survey system that appoints the METI survey experienced person who was conducted before to the core post in order to proceed with the work efficiently. Experienced Tunisian consultants were assigned to support field surveys for smooth remote survey implementation.



(Source: JICA study team)

Figure 1-4 Organization of the study team

Chapter 2 Power Sector in Tunisia

2.1 Organization of Power sector

2.1.1 Related organizations and institutions

(1) Related organizations and institutions

The electricity sector in Tunisia is under the jurisdiction of the Ministry of Industry, Energy and Mines (MIEM, MINISTÈRE DE L'INDUSTRIE, DE L'ÉNERGIE ET DES MINES). In the electric power sector, the ministry has jurisdiction over the institutions and companies shown in Table 2-1.

Table 2-1 Organizations under the jurisdiction of the MIEM

Entity	Acronym
Société Nationale de Distribution des Pétroles	SNDP
Compagnie Tunisenne de Forage	CTF
Société Tunisenne du Gazoduc Trans-Tunisien	SOTUGAT
Compagnie des Transports par Pipelines au Sahara	TRAPSA
Société de Transport Des Hydrocarbures Par Pipelines	SOTRAPIL
Enterprise Tunisenned'ActivitesPetrolieres	ETAP
Société Tunisenne de I'Electricite et du Gaz	STEG
Société Tunisenne des Industries de Raffinage	STIR
Agence Nationale pour Maitrise I'Energie	ANME

(Source: https://www.energiemines.gov.tn/fr/ministere/entreprises-et-etablissements-sous-

(a) STEG

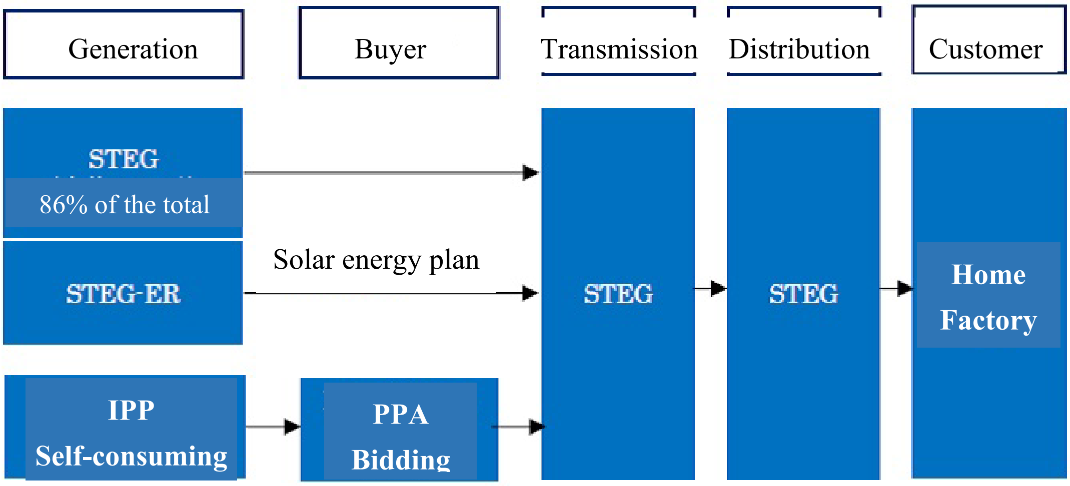
The state-owned Tunisian Electricity and Gas Corporation (STEG), established in 1962, is a vertically integrated operator engaged in the transmission and distribution business and the supply of natural gas. The Government of Tunisia liberalized the power generation business in 1996 so that independent power generation companies (IPPs) in Tunisia and overseas could also carry out the power generation business that was previously monopolized by STEG. In addition, STEG ER (Energies Renouvelables) is in charge of the renewable energy field. The main roles of STEG ER are the promotion of photovoltaic power generation plans, FS (Feasibility Study) for project development, project realization, and maintenance.

(b) ANME

Established in 1985 under the jurisdiction of the Ministry of Energy, it formulates energy-saving and renewable energy policies. It consists of two sections, one focusing on renewable energy projects and the other focusing on energy efficiency. Under ANME, Energy Conversion Fund (FTE) has jurisdiction over subsidies for renewable energy equipment for self-consumption.

(2) Electric power supply system

Tunisia's electricity supply system is as follows. STEG is responsible for 86% of the total power generation, and STEG-ER is an organization that implements the government policy (solar energy plan) on renewable energy. IPP and private power generation account for around 14% of power generation, and in the case of power generation by them, transmission and distribution will be carried out with the intervention of buyers. On the other hand, STEG is still responsible for power transmission and distribution.



(Source: RES4MED, Country Profiles-Tunisia, November 2016)

Figure 2-1 Electric power supply system in Tunisia

2.1.2 Related policies / Laws / regulations for power sector

(1) Environmental policy

The Tunisian government submitted a Draft Promise (INDC) to the United Nations Framework Convention on Climate Change (UNFCCC) Secretariat in September 2015. INDC has set a goal of reducing CO2 emission intensity by 41% compared to 2010 by 2030. In addition, it will promote energy conversion centered on the introduction of renewable energy and energy saving, and will reduce CO2 emission sources in the energy sector by 46% from 2010 levels by 2030. A total of $ 20 billion is required to invest in climate change measures, but Tunisia says it will raise funds through an international support framework to meet its emission reduction targets. The country signed the Paris Agreement in April 2016 and ratified it in February 2017.

(2) Policy of Renewable energy

The Tunisian government plans to meet the increasing energy demand and improve energy security by promoting renewable energy in the future. The "Tunisia Solar Project" announced by ANME in 2012 sets out to increase the share of renewable energy in the electricity supply to 30% by 2030. ANME estimates that the breakdown will be wind power: 15%, solar power: 10%, and solar heat: 5%, and the installed capacity will need to introduce 3,725,000 kW of renewable energy by 2030. The Renewable Energy Act for Electricity Production was enacted in April 2015. This law plans to promote investment in renewable energy and achieve the above-mentioned renewable energy ratio target. It also aims to increase investment in the power sector, create 10,000 jobs, reduce STEG's debt and improve the environment (reduce air pollutants).

(3) Resource and energy security

The Tunisian government contributes to energy security by developing natural gas import routes from neighboring countries such as Libya and Algeria, and as a transit country for large-scale export gas pipelines from Algeria to Sicily Island, Italy. In addition, the policy is to help security by strengthening regional interdependence through power interchange plans between AMU (Arab Maghreb Union) countries.

(4) Electricity market reform / liberalization policy

The Tunisian government has actively promoted the economy under President Ben Ali (then) by market reforms and liberalization. Substantial privatization of state-owned enterprises since the 1990s, attractions of new private enterprises, introductions of foreign private capital, and establishments of JVs are in line with the movement. The degree of privatization in 2006 was 72%. Tunisia joined the GATT (General Agreement on Tariffs and Trade) and became a member of the WTO (World Trade Organization) in 1990. These global frameworks became the driving force for promoting these privatization and liberalization policies.

The Tunisian government liberalized the power generation business in 1996 so that the power generation business, which STEG previously monopolized, could be carried out by overseas IPPs. There is no discussion about retail liberalization. In addition, to extend the introduction of renewable energy, we are considering improving access conditions to the power grid, adding purchase obligations to electric power companies, and establishing independent regulatory bodies.

2.1.3 Electric Tariff

Electricity tariff and their categories in Tunisia are as follows.

Table 2-2 House usage Low Overall Voltage (2019/6/1)

Price	Sector	Power Charge (mill/kVA /month)	Energy price for each monthly consumption band (mill/kWh)					
			1-50	51-100	101-200	201-300	301-500	501 and +
Economic slice (1 and 2 kVA and C°≤ 100kWh/ month)	Residential	700	62					
	Residential		96					
	Non Residential		104					
Economic slice (1 and 2 kVA and C°≤ 100kWh/ month)	Residential	700	176			218	341	414
Normal section (> 2kVA)	Non Residential	700	195			240	333	391

(Source: STEG home page (https://www.steg.com.tn/fr/clients_res/tarif_electricite.html))

Table 2-3 House usage Special Low Voltage (2019/6/1)

Prices		Fee		Energy price (mill/kWh)			
		Subscription (mill/Ab /month)	Power (mill/kVA /month)	Day	Morning	Evening	Night
Public lighting		-	900	234			
Water heater		500	-	341	Erasing	Erasing	341
Heating and air conditioning		-	700	414			
Imigation	Uniform	300	700	164			
	Three Hourly Positions	1,000	-	121	NA	391	106

(Source: STEG home page (https://www.steg.com.tn/fr/clients_res/tarif_electricite.html))

Table 2-4 Industrial Voltage levels: MV (2019/6/1)

Average Voltage Rates	Power Charge (mill/kW/month)	Energy price (mill/kWh)			
		Day	Morning	Evening tip	Night
Uniform	5,000	251			
Hourly positions	11,000	240	366	329	188
Pumping for irrigation	-	279	NA	Erasure	225
Agricultural irrigation	-	189	Erasure	195	138
help	6,000	264	407	365	200

(Source: STEG home page (https://www.steg.com.tn/fr/clients_res/tarif_electricite.html))

Table 2-5 Industrial Voltage levels: MV, INTERRUPTIBLE RATE (2019/6/1)

Rate Level	Price	Power subscribed interruption	Variable compensation (mill/kWh not consumed)	Fixed compensation (mill/interruptible kW/month)
Medium voltage	Hourly positions	< 400 kW	212	1,050
		≥ 400kW	416	
	Uniform	< 400kW	212	500
		≥ 400kW	465	

(Source: STEG home page (https://www.steg.com.tn/fr/clients_ind/tarifs_mt.html?tknfv=678B2868DEFGHIJKMNOPQRSTUV018411))

Table 2-6 Industrial Voltage levels: HV (2019/6/1)

Price	Power Charge (mill/kW/month)	Energy price (mill/kWh)			
		Day	Morning	Evening tip	Night
Four hourly positions	10,000	207	309	279	160
help	5,200	225	350	315	168

(Source: STEG home page (https://www.steg.com.tn/fr/clients_res/tarif_electricite.html))

Table 2-7 Industrial Voltage levels: HV, INTERRUPTIBLE RATE (2019/6/1)

Rate Level	Price	Power subscribed interruption	Variable compensation (mill/kWh not consumed)	Fixed compensation (mill/interruptible kW/month)
High tension	Hourly positions	< 3 MW	204	900
		≥3 MW	410	

(Source: STEG home page (https://www.steg.com.tn/fr/clients_res/tarif_electricite.html))

In addition to the above, there are tariffs for cement for HV and MV.

Electricity charges for low voltage are mainly classified by monthly power consumption rates, and special rates for different purposes such as water heaters and air conditioners are also offered. Electricity tariff for medium-pressure consumers mainly consists of four types: standard, TOU, agricultural irrigation, and emergency. Electricity tariff for high-voltage consumers consists of two types: TOU and emergency.

In Tunisia, all energy products such as oil, LPG, natural gas, and electricity are covered by subsidies. The distribution ratio of subsidies is electricity (34%), LPG (25%), diesel (19%), and natural gas (12%). The amount of subsidies in 2017 is estimated to be 2.3% of GDP, accounting for more than one-third of the budget deficit. STEG has been in the red since 2010, with a total of 15.8 billion TND of subsidies from 2008 to 2017, however, in 2017, even after the subsidy was put in, it was insolvent with a deficit of 1.2 billion TD, and cumulative debt of 6.4 billion TD (mainly denominated in foreign currencies). STEG became the company with the most significant deficit among state-owned enterprises in Tunisia in 2016.

The Tunisian government has been undertaking subsidy reforms since 2012; for example, industrial electricity subsidies were reduced by 50% in 2014 and abolished in 2015. Indirect subsidies for oil and gas used for refining and power generation were abolished in 2016.

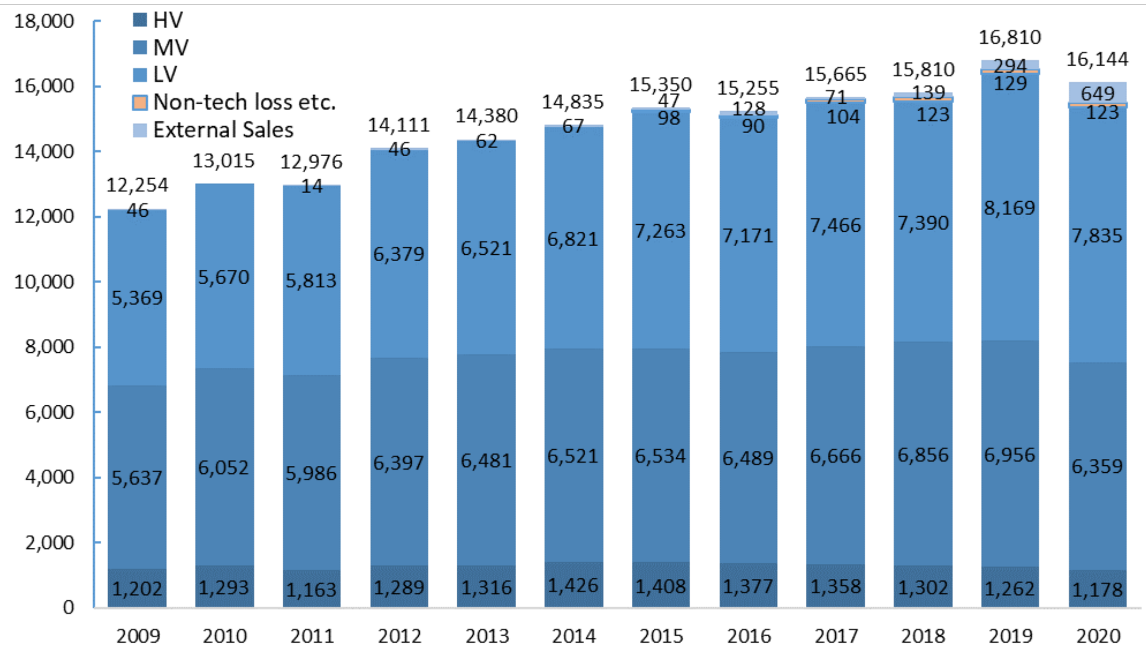
The Tunisian government is gradually rising electricity and gas prices with the ultimate goal of abolishing subsidies in 2026. A roadmap for phasing out subsidies and curbing demand through energy efficiency was approved by the Tunisian government in 2018. However, the current situation is that the adjustment of electricity prices has not caught up with the rise in international fuel prices and the depreciation of domestic currencies.

2.2 Current power system in Tunisia

2.2.1 Electricity Demand

Electricity demand is increasing year by year in Tunisia. As shown below figure, around 28% increase is in recent ten years from 2010 to 2020.

However, electricity sales for the year 2020 have fallen by 4% compared to 2019, going from 16,810 GWh in 2019 to 16,144 GWh in 2020. STEG explains that this decrease was caused by the effect of the COVID 19 pandemic.[1]

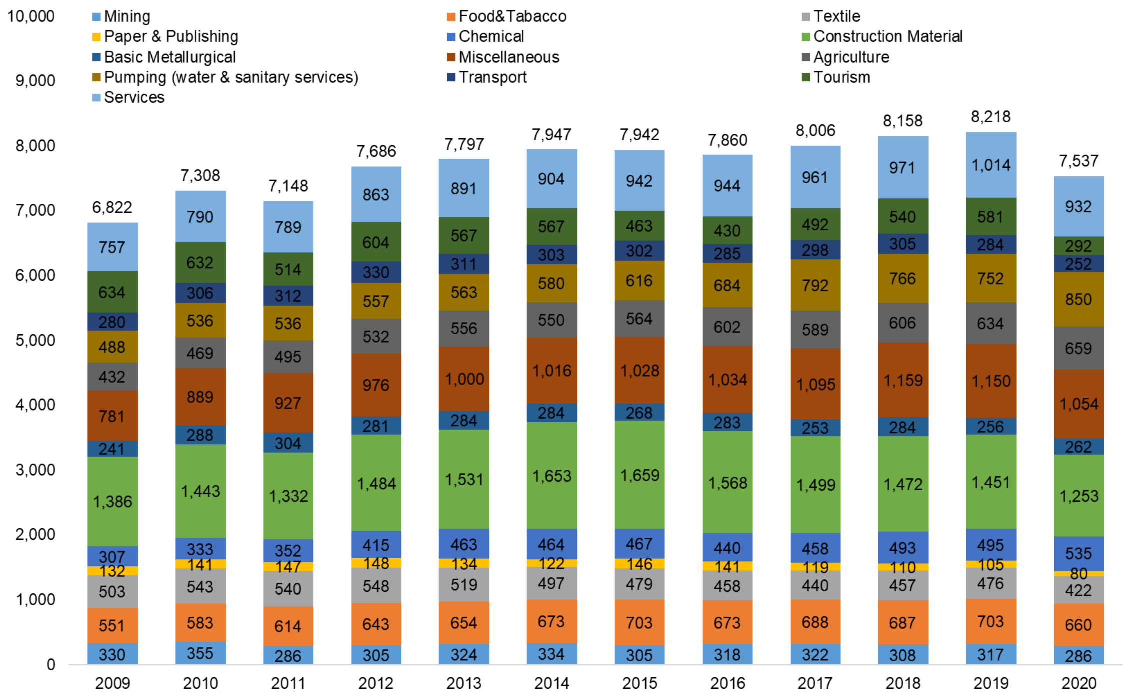


(Source: STEG Annual Report 2009-2020)

Figure 2-2 Electricity Sales

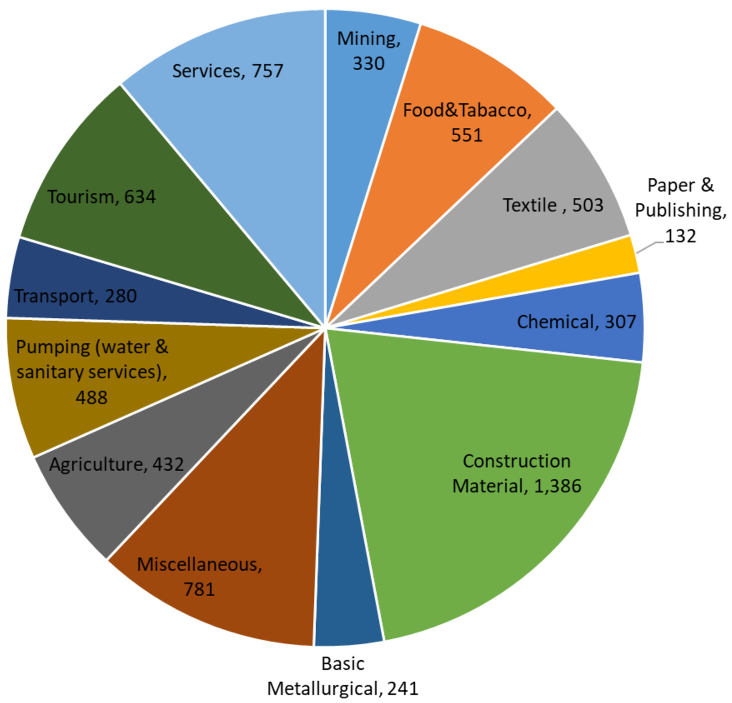
The below figure shows HV-MV electricity sales by economic sector. From 2019 to 2020, it is decreasing as well as total sales. As shown in the figure, the increase for pumping and sanitation services is 13 %, and that for chemical industries is 8%. While, for all other sectors such as tourism (-50%), paper and publishing industries (-24%), building materials (-14%) and textile industries and transport (-11%) are decreasing. These decrements are due to COVID-19, which affected electricity demand.

[1] STEG Annual Report 2020



(Source: STEG Annual Report 2009-2020)

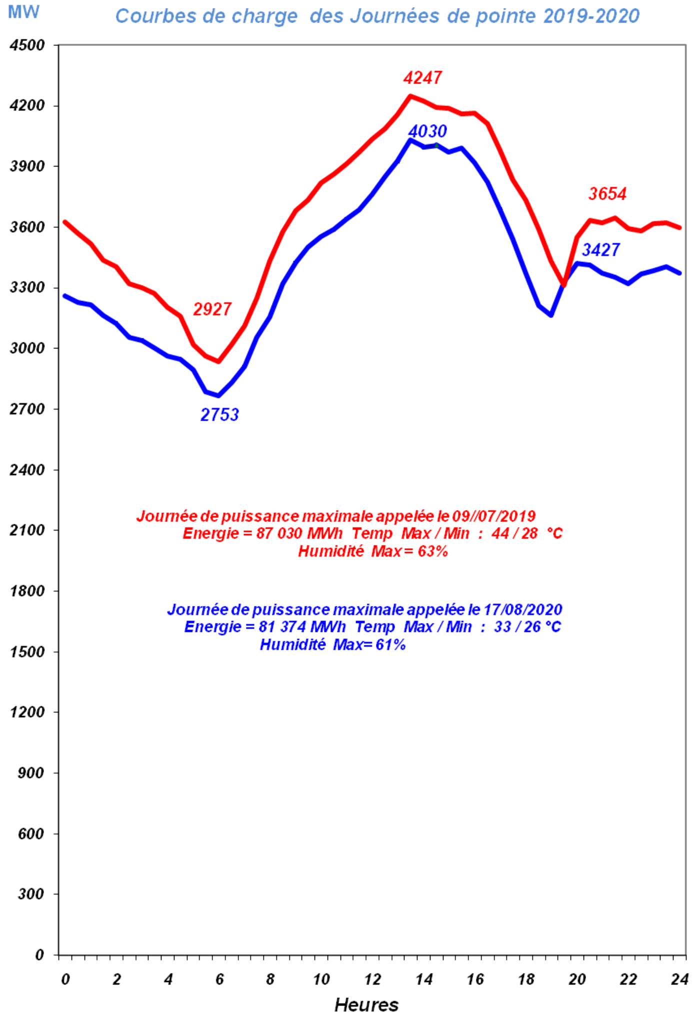
Figure 2-3 Electricity Sales in HV/MV



(Source: STEG Annual Report 2020)

Figure 2-4 Electricity Sales of HV/MV by type of customer (as of 2019)

Day load curve on maximum demand date in 2019 (red line) and 2020 (blue line) is shown below. The maximum demands were recorded around 2:00 p.m., and the minimum demands were recorded around 6:00 a.m. in 2019 and 2020. The maximum demand of 4,030 MW was recorded at 1:40 p.m. on Monday, August 17, 2020, and that of 4,247 MW was recorded at 1:41 p.m. on Tuesday, July 9, 2019.



(Source: STEG Annual Report 2020)

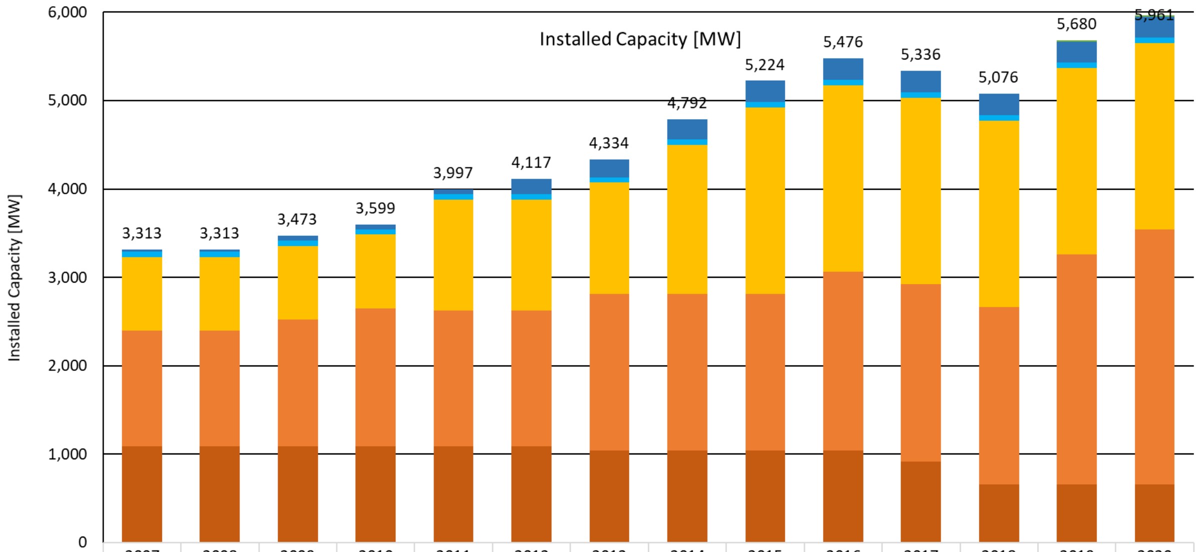
Figure 2-5 Day load curve on maximum demand date

2.2.2 Power Generation facilities

The configuration of Tunisia's power generation facilities is shown in Figure 2-6. As of 2020, 94% of power generation facilities are thermal power generation facilities, and wind power generation and hydroelectric power generation account for the remaining 6%. Of the thermal power plants, conventional thermal power generation (BTG) is gradually decreasing, and gas turbine (GT) and combined cycle power generation (CC) are being newly installed and increased. In addition, although there is no immediate development of hydro power generation, the number of wind power generation facilities is increasing slightly.

Table 2-7 show the actual amount of power generated by type of fuel. The amount of power generated by the combined cycle (CC) is increasing year by year, and in 2020, it accounted for 66% of the total amount of power generated.

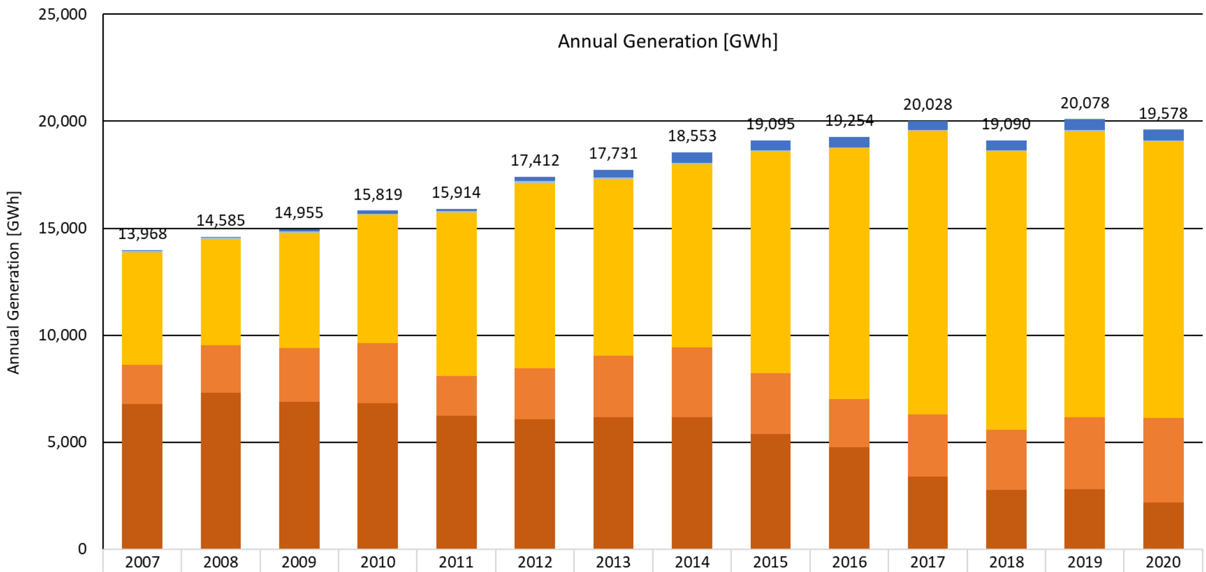
A list of power generation facilities is shown in Table 2-8.



	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Total	3,313	3,313	3,473	3,599	3,997	4,117	4,334	4,792	5,224	5,476	5,336	5,076	5,680	5,961
PV													10	10
Wind	19	19	53	53	53	173	200	233	240	240	240	240	240	240
Hydro	62	62	62	62	62	62	62	62	62	62	62	62	62	62
CC	835	835	835	835	1,260	1,260	1,260	1,685	2,110	2,110	2,110	2,110	2,110	2,110
GT	1,307	1,307	1,433	1,559	1,532	1,532	1,772	1,772	1,772	2,024	2,004	2,004	2,598	2,879
BTG	1,090	1,090	1,090	1,090	1,090	1,090	1,040	1,040	1,040	1,040	920	660	660	660

(Source: STEG Annual Report)

Figure 2-6 Generation installed capacity



	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Total	13,968	14,585	14,955	15,819	15,914	17,412	17,731	18,553	19,095	19,254	20,028	19,090	20,078	19,578
PV													0.15	0.2
Wind	43	39	98	139	109	196	358	507	448	474	449	453	500	465
Hydro	49	38	79	50	54	110	60	56	69	45	18	16.5	65.9	46
CC	5,265	4,980	5,384	6,010	7,662	8,662	8,272	8,552	10,345	11,733	13,269	13,038	13,331	12,928
GT	1,807	2,223	2,505	2,797	1,851	2,370	2,870	3,270	2,852	2,231	2,890	2,812	3,362	3,956
BTG	6,804	7,305	6,889	6,823	6,238	6,074	6,171	6,168	5,381	4,771	3,402	2,770	2,819	2,183

(Source: STEG Annual Report)

Figure 2-7 Generation results by fuel type

Table 2-8 List of generation plants

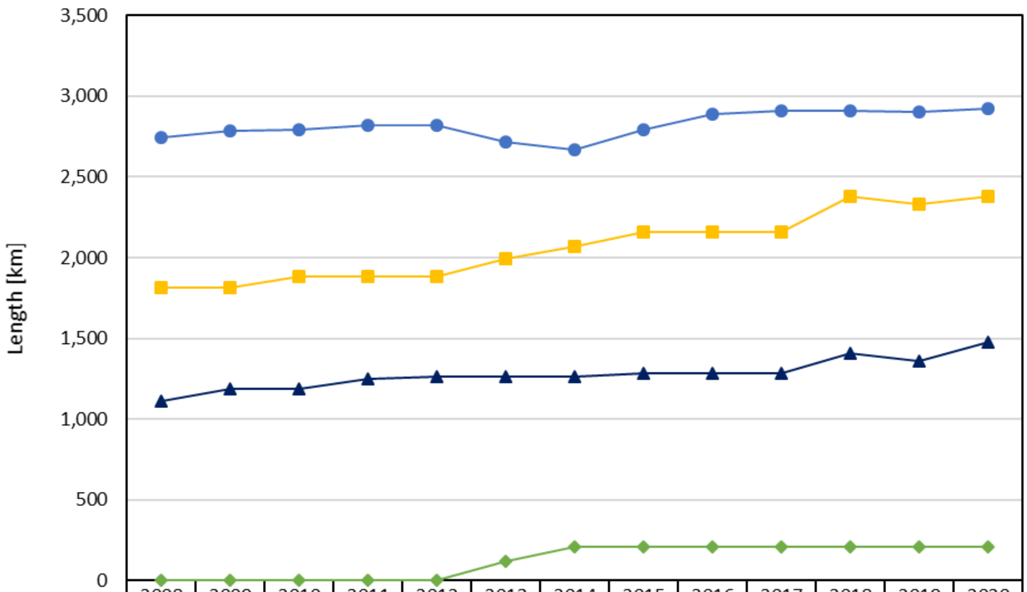
Type	Plant name	Unit	Commissioning year	Retirement year	Type of Facility	Installed capacity	Available capacity (MW)		Notes
							Winter	Summer	
Hydropower	SIDI SALEM		1983		hydro	36.0			
	FERNANA		1958/1962		hydro	9.7			
	NEBER		1956		hydro	13.0			
	AROUSSA		1956		hydro	4.80			
	KASSEB		1969		hydro	0.66			
	SEJANA		2003		hydro	0.6			
	BOUHERTMA		2003		hydro	1.2			
						65.96			
Thermal Power	RADES A	1	1985	2025	BTG		145	125	
		2			BTG		145	125	
	RADES B	3		2033	BTG		150	135	
		4			BTG		150	135	
	SOUSSE B	-	1995	2030	CC	684	350	309	
	GHAN-NOUCH	-	2011	2041	CC	425	412		
	SOUSSE C	-	2014	2044	CC	425	424	358	
	SOUSSE D	-		2045	CC	425	424	360	
	RADES C	-	2019-20	2050	CC	427	450		
	BOUCHEMMA	3	1977/1999	2029	GT	178	120	97	
		4		2046	GT		120	97	
		5		2046	GT		120	97	
	GOLLETTE	1	2005	2035	GT	120	120	97	
	THYNA	1	2004	2034	GT	358	120	97	
		2	2007	2037	GT		120	97	
		3		2040	GT		120	97	
	FERIANA	1	2005	2035	GT	240	120	97	
		2	2009	2039	GT		120	97	
	BIR MICHERGUA	1	1998	2028	GT	476	120	97	
		2	1998	2028	GT		120	97	
		3	2013	2043	GT		120	97	
		4	2013	2043	GT		120	97	
	BOUCHEMMA	1&2		2021	GT		30		
	KASSERINE	1&2	1984	2021	GT	68	30		
	SFAX	1&2	1977	2021	GT	44	20		
	TUNIS SUD	1,2& 3	1975/1978	2021	GT	66	20		
	KORBA	1&2	1978/1984	2021	GT	56	20,30		
	MENZEL BOURGUBA	1&2	1978	2021	GT	44	20		
	ZARZIS	1	1983/1999	2021	GT	34	30		
	ROBBANA	1	1984	2021	GT	34	30		
	RADES 2 (IPP)	1	2002	2032	CC	471	471	409	
	ZARZIS (IPP)	1	2003		GT	30			
	GHANOUCH	1	1973	2041	CC	412			
						5,017	**4,891.0**	**3,217.0**	
Solar									
						0.00	**0.00**	**0.00**	
Wind	SIDIDAOUD		2000/2007			54.0			
	KACHBTA		2012			94.0			
	METLINE		2012			95.0			
						243.00	**0.00**	**0.00**	
Biomass									
						0.00	**0.00**	**0.00**	
Others									
						0.00	**0.00**	**0.00**	

(Source: STEG)

2.2.3 Transmission facilities

The power system in Tunisia consists of voltage classes of 400kV, 225kV, 150kV and 90kV. The center of demand is Tunis, the capital city located in the north, with thermal power plants located along the east coast. Algeria, which is next to the west, forms a voltage loop that is interconnected with a 400kV transmission line for one line, a 225kV transmission line for one line, and a 150kV transmission line for one line, a 90kV transmission line for two lines and the interconnections are used mainly for reliability and emergency purposes. These lines are equipped of watt metric protections. So, if the currents exceed the fixed thresholds, the lines will be opened before being overloaded. It is also connected to Libya, which is adjacent to the southeastern part, by a 225kV transmission line, but there is almost no power exchange.

The length [km] of each transmission line is shown below. The transmission loss in 2020 is 2.3%.



	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
400kV	0	0	0	0	0	117	208	208	208	208	208	208	210
225kV	2,741	2,787	2,792	2,821	2,821	2,717	2,669	2,790	2,885	2,910	2,910	2,902	2,921
150kV	1,812	1,812	1,883	1,883	1,883	1,993	2,067	2,157	2,157	2,157	2,382	2,331	2,377
90kV	1,108	1,188	1,189	1,249	1,266	1,266	1,266	1,285	1,285	1,285	1,406	1,360	1,479

(Source: STEG Rapport Annual 2008-2020)

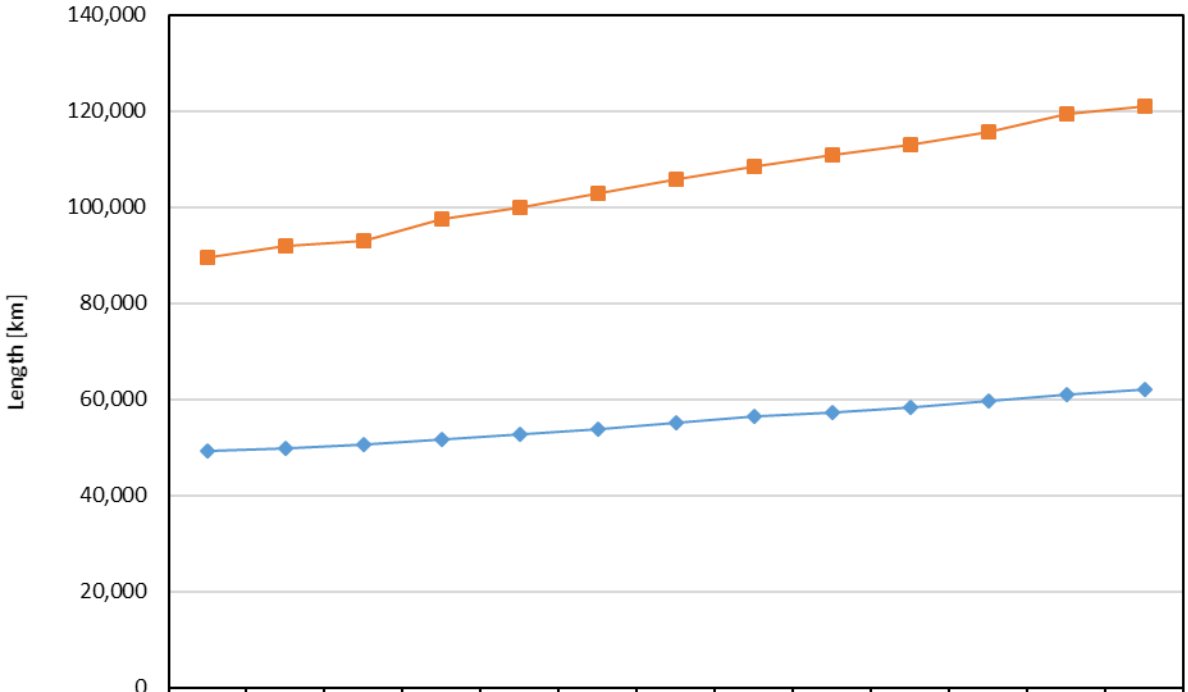
Figure 2-8 Transmission line length

(Source: STEG)

Figure 2-9 Transmission system in Tunisia

2.2.4 Distribution facilities

The distribution line system consists of medium pressure 30kV, 15kV, 10kV and low voltage 220 / 380V. The electrification rate of Tunisia in 2018 was 99.8%, and the development of the domestic power grid is almost complete.



	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
MV (km)	49,309	49,712	50,634	51,699	52,783	53,885	55,049	56,576	57,270	58,417	59,691	60,966	62,115
LV (km)	89,489	91,859	92,860	97,413	99,926	102,70	105,85	108,51	110,83	112,89	115,69	119,45	121,07

(Source: STEG Rapport Annuel 2008-2020)

Figure 2-10 Distribution line length

2.2.5 Electric Power Import/Export with neighboring countries

The transmission grid is currently interconnected with Algeria via one 400 kV line, one 225 kV line, one 150 kV line, and two 90 kV lines. Electricity trade with countries in the region represents less than 1% of national consumption, and the interconnections are used mainly for reliability and emergency purposes[2].

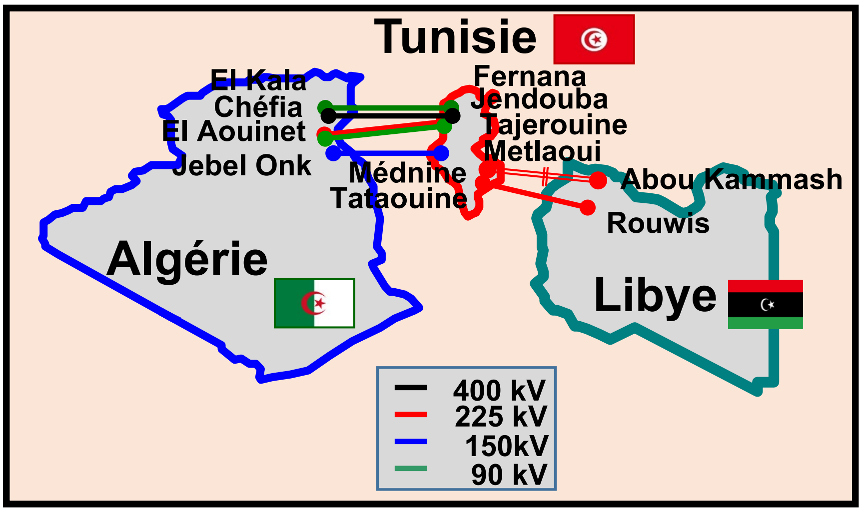
According to the Energy Profiles issued by United Nations, electricity import/export volume in Tunisia is reported in Table 2-9.

Table 2-9 Electricity import/export

[unit: GWh]

	2015	2016	2017	2018
Imports	403	134	450	382
Exports	500	255	483	484

(Source: UN Electricity Profiles 2018 https://unstats.un.org/unsd/energystats/pubs/eprofiles/)



(Source: STEG)

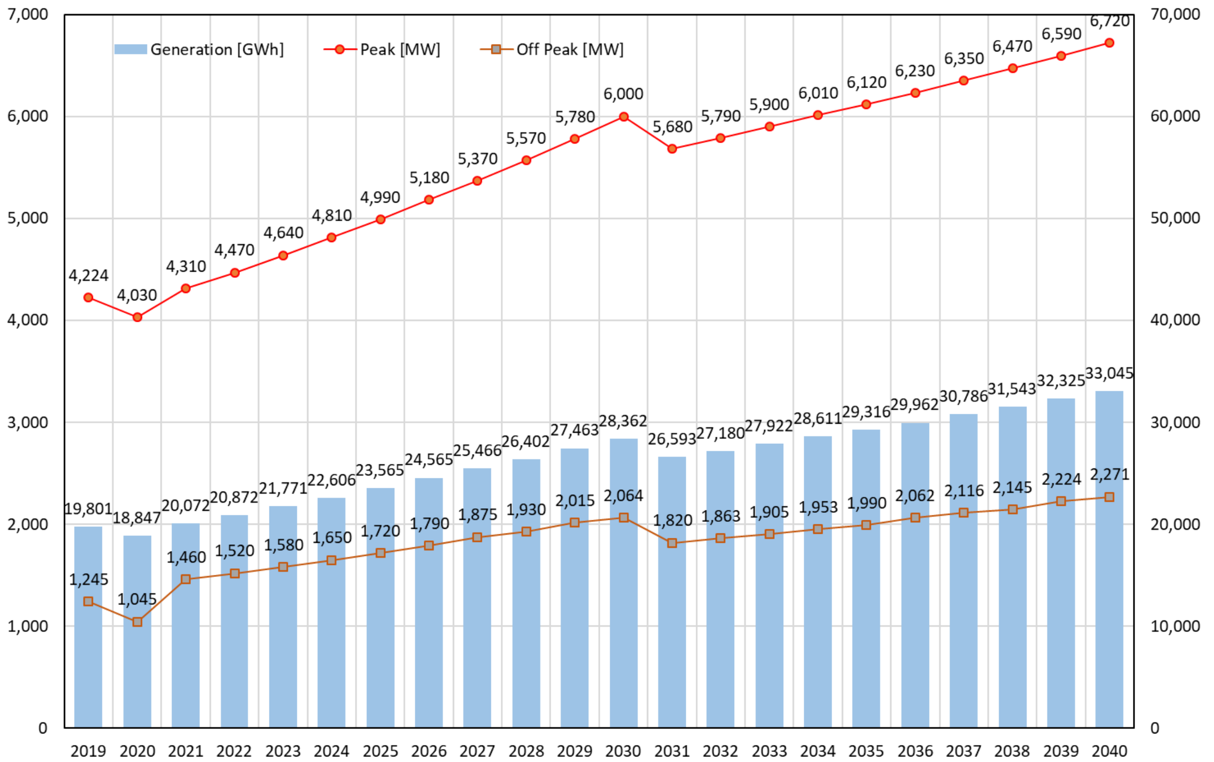
Figure 2-11 Electric interconnections in the North African region.

2 STEG (Tunisian Company of Electricity and Gas), Annual Report 2018, Tunisian Company of Electricity and Gas, Tunis, www.steg.com.tn/fr/institutionnel/publication/rapport_act2018/Rapport_Annuel_steg_2018_fr.pdf.

2.3 Power System Plan in Tunisia

2.3.1 Power Demand Forecast

The current demand forecast in STEG is only the basic case which is the one based on the current trend. The forecasted electricity demand is 24,565GWh in 2026 and 28,362GWh in 2030. Compared to the 2019 actual records, the annual growth rate is 3.2%. The peak demand is forecasted to be 5180 MW in 2026 and 6000 MW in 2030. It is expected to grow by 3% in 2026 and 3.3% in 2030.



(Source: STEG)

Figure 2-12 Demand forecast in STEG

2.3.2 Generation Plan

The candidate sites for power plant development are planned as shown in Table 2-10. STEG is constructing a combined cycle power plant and plans to build four new power plants with a maximum output of 450 MW by 2030. As for gas turbine power plants, STEG is planning to build a new power plant with a maximum output of 60 MW in 2030.

Hydro power plant development plan is shown in Table 2-11. The operation of these hydroelectric power plants is under the jurisdiction of the Ministry of Agriculture. In addition to Table 2-11, STEG is proceeding with a plan to build two new 200 MW pumped storage power plants (PSPP) in 2029.

Table 2-10 Planned power plants candidate sites

Technology	Power Plant Name	Unit	Pmax: Maximum Power/Unit (MW)	Decommissioning	Fuel
Gas Turbine	Mornaguia	TG1	300	2049	Gas
		TG2		2050	
	Bouchemma	TG3	120	2029	
		TG4		2046	
		TG5		2046	
	Bir_Mcherga	TG1		2028	
		TG2		2028	
		TG3		2043	
		TG4		2043	
	Feriana	TG1		2035	
		TG2		2039	
	Thyna	TG1		2034	
		TG2		2037	
		TG3		2040	
	Goulette	TG1		2035	
	Kasserine	TG1	30	2021	
		TG2			
	Sfax	TG1	20		
		TG2			
	Tunis_Sud	TG1	20		
		TG2			
		TG3			
	Korba	TG1	20		
		TG2	30		
	Bouchemma	TG1	30		
		TG2			
	Robbana	TG1	30		Gasoil
	Zarzis	TG1	30		
	Menzel_Bouguiba	TG1	20		
		TG2			
Steam Turbine	RadesA	TV1	145	2025	Gas
	RadesA	TV2			
	RadesB	TV1	150	2033	
	RadesB	TV2			
Combined Cycle	SousseB	CC1	350	2030	Gas
	IPPrades	CC1	471	2032	
	Ghannouch	CC1	412	2041	
	SousseC	CC1	424	2044	
	SousseD	CC1	424	2045	
	RadesC	CC1	450	2050	

(Source: STEG)

Table 2-11 Conditions for a Hydro power plant plan

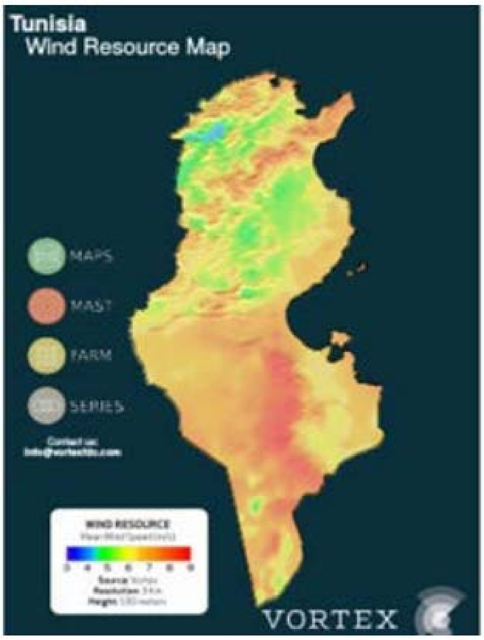
No.	Plant name	Unit	Installed Capacity (MW)	Type	COD	Annual Generation (GWh)
1	Sidi_Salem	NA	33	Reservoir	NA	
2	Nebeur	NA	13.2	Reservoir	NA	
3	Aroussia	NA	4.8	Reservoir	NA	
4	Fernana	NA	9.7	Reservoir	NA	
5	Kasseb	NA	0.825	Reservoir	NA	
6	Bouherthma	NA	1.2	Reservoir	NA	
7	Sejnane	NA	0.6	Reservoir	NA	
		Total	63.325MW			55

(Source: STEG)

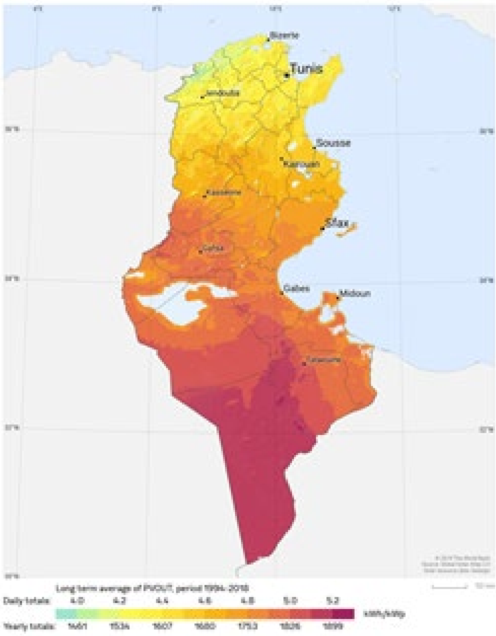
2.3.3 Renewable energy development plan

In the National Stratégie Energétique Horizon 2030, the renewable energy ratio will be set at 30% in 2030 as an energy mix with primary energy from the viewpoint of energy security, which is positioned as an integrated policy.

Tunisia has high potential for wind and solar power generation. The wind conditions are blessed along the northern coast and in the central and southern regions, and with regard to sunlight, annual solar radiation of about 2,000 to 2,300 kWh / m2 can be obtained, mainly in the southern regions.



(Source:Tunisia: Derisking Renewable Energy Investment 2018, UNDP)



(Source:2020 The World Bank, Global Solar Atlas 2.0, Solar resource data: Solargis)

Figure 2-13 Potential map (left: wind, right: solar)

The table below shows the existing Wind and PV installed capacity in 2020, additional development plans from 2021 to 2026, and development plans from 2027 to 2030. Auto production means self-consumption with reverse power flow.

The capacity factor of wind power generation is 21% for existing equipment, but the capacity factor of newly developed equipment is expected to be 35%, incorporating the improvement of equipment utilization rate through improvement of wind power generation technology and efficient maintenance.

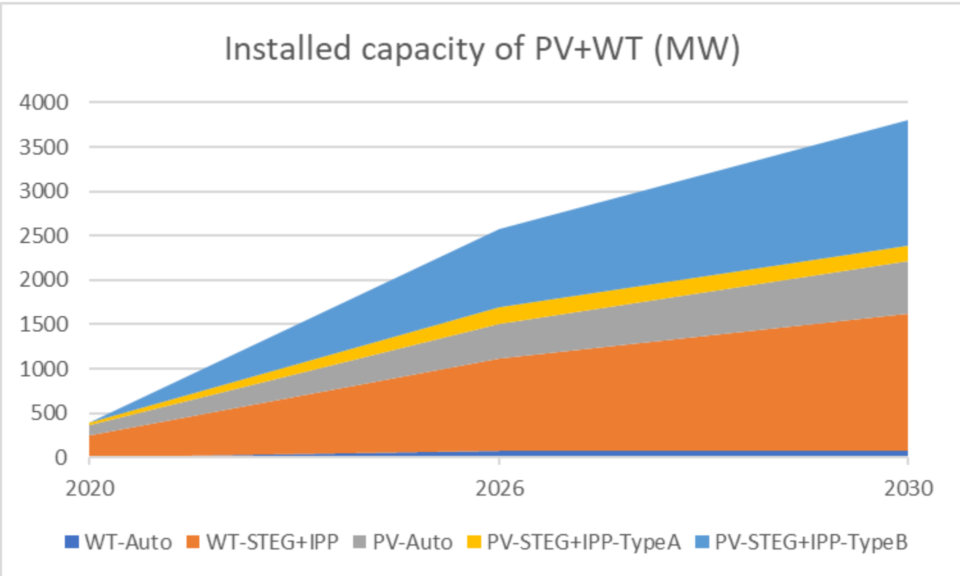
Regarding the capacity factor of solar power generation, the existing type A is 19% and the new technology type B is 26%. Type A is an existing technology that uses a conventional single crystal PV module. Type B is equipped with a PV module on the back of the panel, which can generate electricity from the reflected light from around the ground, and is equipped with a mechanism for tracking the position of the sun.

Table 2-12 Additional development plan of WT and PV

Additional Development (MW)	2020	2026	2030
WT-Auto production	0	80	0
WT-STEG+IPP	242	800	500
PV-Auto production	125	265	200
PV-STEG+IPP-TypeA	31	144	0
PV-STEG+IPP-TypeB	0	881	540
Total	398	2,170	1,240

(Source: STEG)

The total installed capacity of WT and PV will be 2568 MW in 2026 and 3808 MW in 2030.



(Source: STEG)

Figure 2-14 Installed capacity of WT and PV

2.3.4 Transmission facilities

As part of the "Tunisia Solar Energy Program" project, a total of 4 billion euros "ELMED" project was announced between STEG and Terna in Italy in September 2009, including the construction of a revised transmission line between Tunisia and Italy. The plan consisted of two projects, a 200-kilometer submarine high-voltage direct current (HDVC) line facility connecting Cape Bon in Tunisia and Sicily Island in Italy, and a 1,200 MW power plant on the Tunisian side. Due to the difficulty of implementing the plan in the year, it was revised to a simpler plan to abandon the construction of a 1,200 MW power plant and maintain the 600 MW HVDC line jointly funded by Tunisia and Italy.

In 2016, the project was added to the Terna's National Electricity Transmission Grid Development Plan and was adopted by the European Network of Transmission Operators (ENTSO-E) 10-year plan. The World Bank, which plans to fund the project, has begun FS research and support since 2018 and is expected to complete the survey by the end of 2021. The project consists of (a) land and sea feasibility studies, (b) environmental and social impact studies and relocation action plans, (c) financial models, and (d) transaction advisory activities. It is $ 13.4 million and is borne by the Global Infrastructure Facility (GIF), Energy Sector Management Assistance Program (ESMAP), European Investment Bank (EIB) and STEG.

(Source: Development of Renewable Energy in Tunisia Challenges and Prospects, STEG (2017))

Figure 2-15 ELMED Power grid plan

2.3.5 Distribution facilities

(1) Reduction status of non-technical loss

STEG's power loss is about 9% for non-technical loss (non-payment, power theft) and about 9% for technical loss (technical loss of power transmission and distribution system), for a total of 18%. The level of technical loss is not extremely bad. On the other hand, although the toll collection rate has improved to 92%, it is required to further improve the toll recovery rate by reducing non-technical losses to improve the financial position.

The French Development Agency (AFD) backed smart grid (meter) program aims to improve toll recovery and prevent electricity theft by installing smart meters in medium- and high-voltage consumers. The interview at second visit to Tunisia confirmed that STEG expects to reduce non-technical loss through the smart meter to be installed.

(2) Measures to reduce power transmission and distribution loss (non-technical loss)

As general non-technological reduction measures, (i) whether the watt-hour meter is properly "sealed," (ii) changing from bare wires to covered wires creates a situation where it is difficult to steal electricity, (iii) smart meters (SM) will be installed.

As a measure to reduce the non-technical loss, STEG has a plan to introduce smart meters. They expect to reduce the electricity theft and miss-reading of watt-hour meter by the installation of smart meter.

1) Latest non-technical loss data and calculation method

As the result of interview to STEG, total losses were about 18% (generated power amount; 19,623,653MWh, total losses; 3,602,000MWh) in 2020. The breakdown is the followings; 12.2% (440,212MWh) for High voltage, 26.0% (937,213MWh) for Medium voltage, and 61.8% (2,224,575MWh) for Low voltage. It is said that non-technical loss is 9 %. Generally, non-technical losses are calculated by subtracting technical losses from total losses.

2) Non-technological factors

Electricity theft, miss-reading of watt-hour meter, and uncollected charges are considered as non-technological factors. Especially, 5% or 6% of 9% for non-technical losses come from electricity theft and miss-reading of the meter.

3) Non-techloss reduction measures currently being implemented and future plans

As aforementioned, STEG plans to install 400,000 smart meters to reduce non-technical losses.

4) Smart meter functions

As the result of interview to STEG, the project whose donor is French Development Agency is now underway.

The French Development Agency is funding a smart grid project that introduces 400,000 smart meters (120 million euros, repayment over 20 years, 7-year grace period) that are 20,000 units for medium- and high-voltage customers and 380,000 units for low voltage customers. In this project, smart meters will be installed mainly in SFAX, and the others will be installed on SIDI BOUZID, BEJA, and LE KRAM.

At present, STEG is reviewing the result of the Bidding and the works will be implemented from the end of the first quarter or the beginning of the second quarter of 2022.

On the other hand, STEG has another project whose donor is CEA, but it is a pilot and small smart meter project.

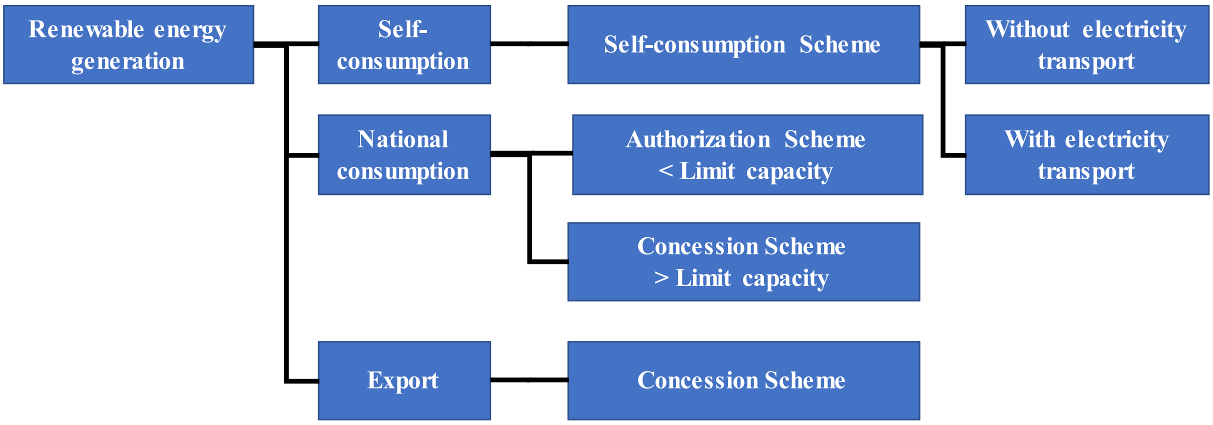
When a smart meter system is installed and introduced, if the meter is crafted for power theft, STEG staff and the workers can recognize that by the alarm on the host system monitor and send someone to the site for confirmation. Also, if a smart meter is installed on the secondary side of the distribution transformer, the total value of the smart meter measurement value and the smart meter measurement value of the important house supplied from the transformer will be compared, and if there is a difference, somewhere. It means that the power is being stolen, and it can also be used as a trigger to have the workers confirm the site. In addition, a method of narrowing down the area where electricity theft is occurring by installing a smart meter and using the actual load estimation method (if there is a discrepancy between the load estimation for each load pattern and the actual electricity usage, there is a power theft. Judgment that it has occurred) is also possible.

Chapter 3 Measures Necessary to Promote the Introduction of Renewable Energy IPPs

3.1 Current status of IPP-related policies and systems

According to the web site of the Ministry of Energy, Mines and Renewable Energy, Law n°2015-12 is the main text regarding renewable energy in Tunisia. It was enacted on the 11th of May 2015 and has established a legal framework governing the development of renewable energy projects. According to this law, electricity generated from renewable energy resources can be used for either of self-consumption, national consumption and export. Pursuant to the law, there are the following three schemes applicable to the development of renewable energy resources with private participation:

1. Self-consumption scheme
2. Authorisation scheme
3. Concession scheme



Source: GIZ, "PROJETS D'ÉNERGIE RENOUVELABLE EN TUNISIE" (2019)

Figure 3-1 Use and applicable development schemes for renewable energy generation

Table 3-1 Renewable energy development regimes

Type	Scale	Selection method
Self-consumption	Solar power generation and wind power generation for private power generation	-
Authorisation	Solar power generation of 10 MW or less, wind power generation of 30 MW or less	Select a business operator by competitive bidding
Concession	Solar power generation and wind power generation on a scale exceeding the above authorisation target	Select a business operator by competitive bidding

Source: JICA Study Team

(1) Self-consumption scheme

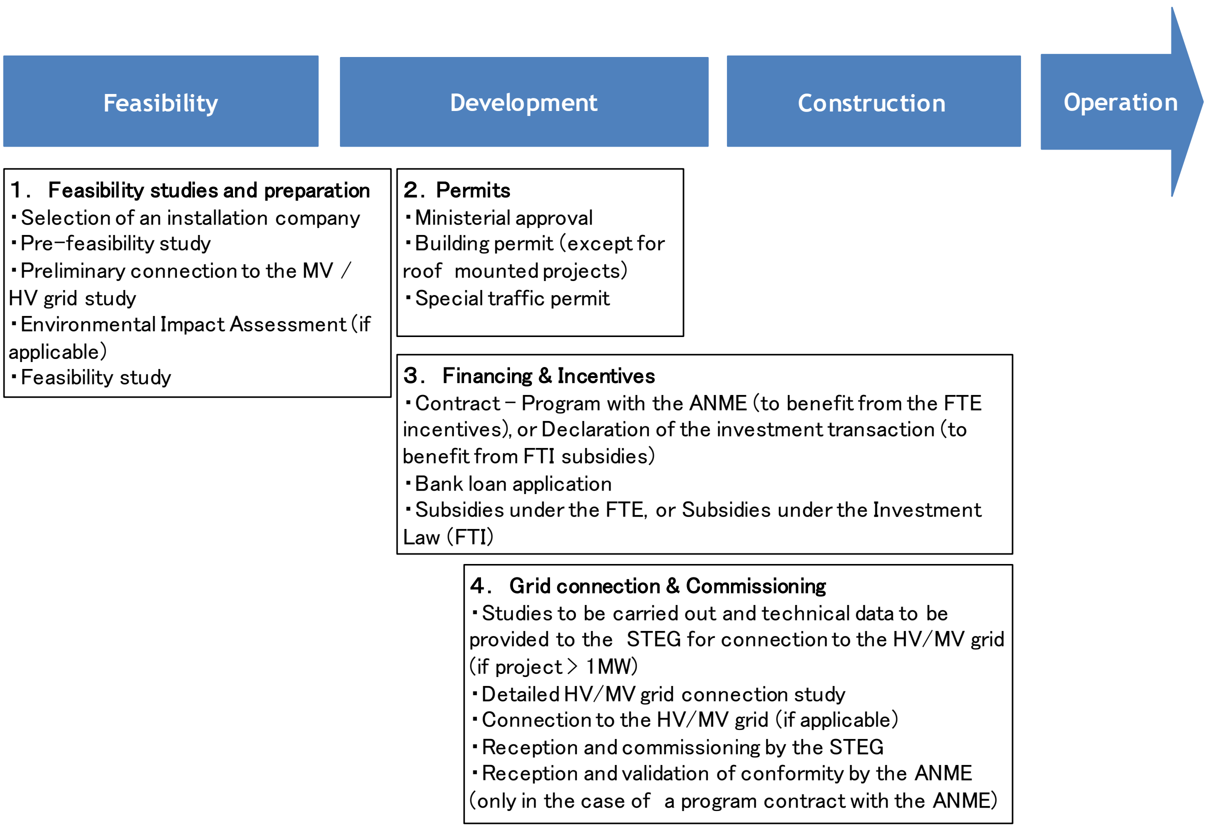
The implementation of a project under the self-consumption scheme connected to STEG's MV/HV grid is subject to an authorisation by the Ministry in charge of energy. The validity of the ministerial authorisation is two years for solar PV projects and three years for wind projects. An extension of one year is possible for both.

Self-consumption projects provide the possibility to consume one's own produced electricity instantly, thus saving payments of electricity bills, and the possibility to sell excess electricity generation to STEG, which commits to purchasing the excess electricity based on an agreement.

This excess electricity purchase agreement is signed for a period of 20 years and automatically renewed for a period of one year unless terminated by either of the parties.

The possible configurations for a self-consumption project include a project without electricity transmission on the STEG grid. In this case, the electricity generation site is coincident with the consumption site.

The overview of major procedures for the development of an on-site self-consumption project, where the electricity generation site is coincident with the consumption site, is shown in Figure 3-2.

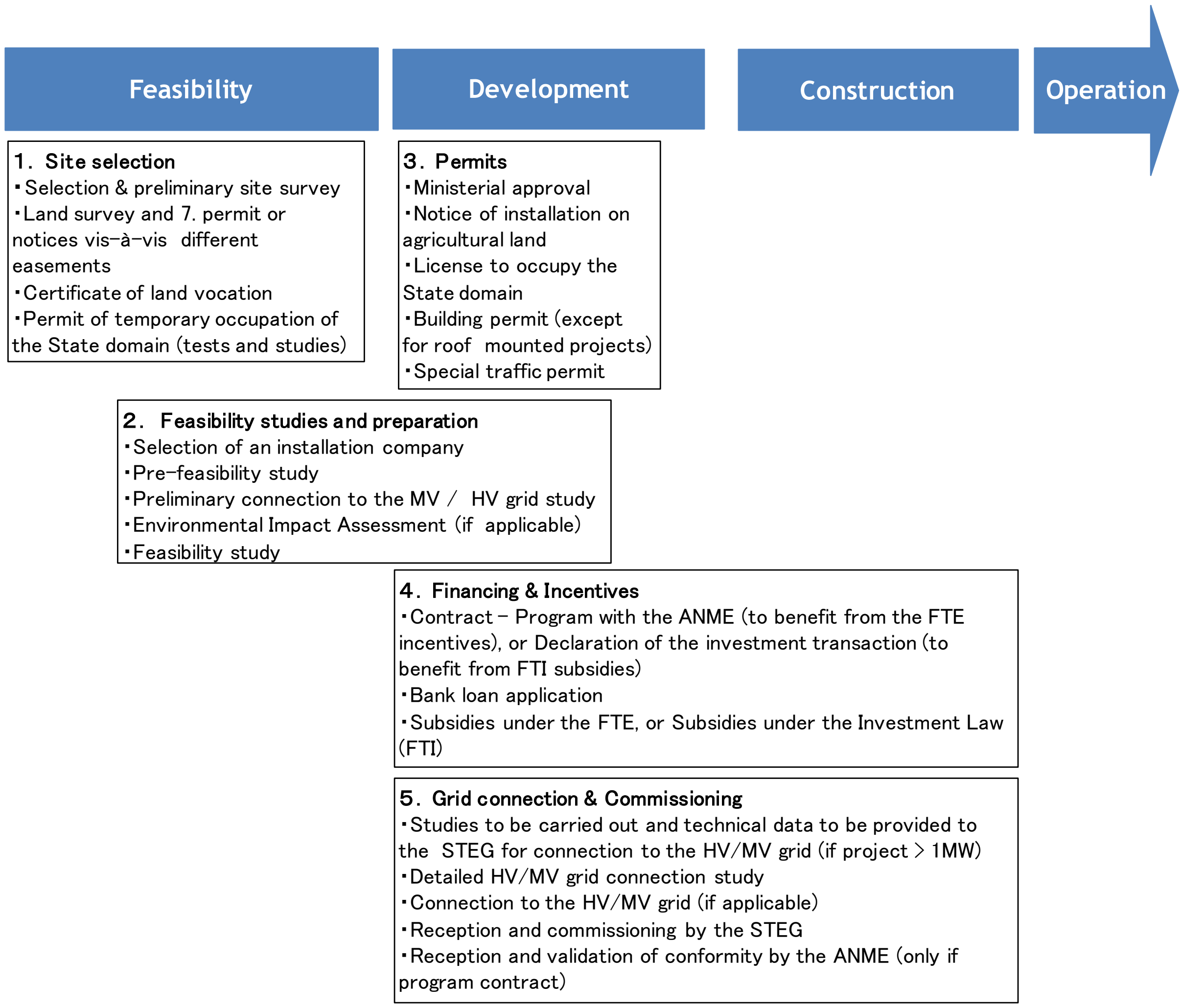


Source: GIZ, "PROJETS D'ÉNERGIE RENOUVELABLE EN TUNISIE" (2019)

Figure 3-2 On-site self-consumption project development procedures

In off-site projects where the electricity generation site is not identical with the consumption site, the terms and conditions of excess electricity tariffs and a purchase contract are similar to those for on-site self-consumption projects. However, in the case of a project which requires electricity transmission through the STEG grid, one must take into account that electricity wheeling from the generation site to the consumption site is to be charged by STEG.

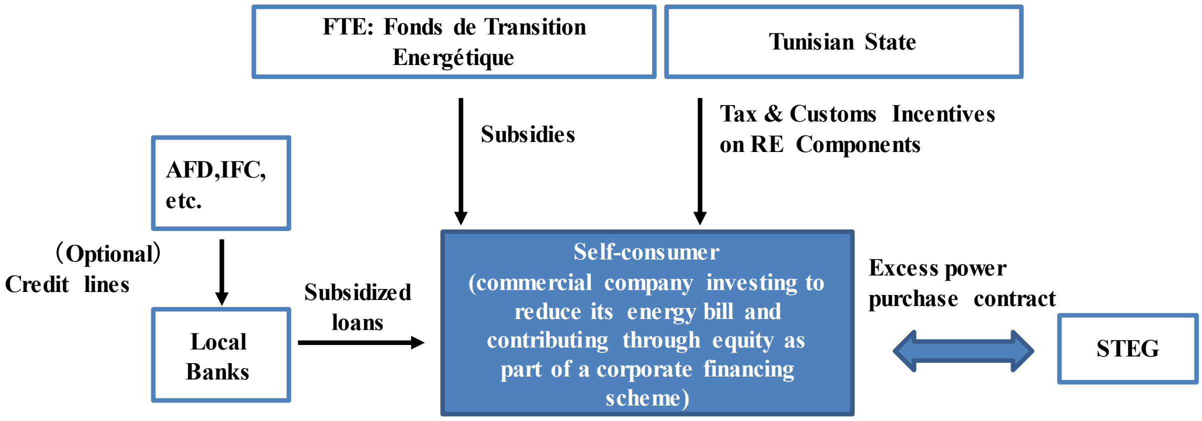
The overview of major procedures for the development of an off-site self-consumption project is shown in Figure 3-3.



Source: GIZ, "PROJETS D'ÉNERGIE RENOUVELABLE EN TUNISIE" (2019)

Figure 3-3 Off-site self-consumption project development procedures

The general business scheme applicable to the self-consumption scheme is as follows:



Source: GIZ, "PROJETS D'ÉNERGIE RENOUVELABLE EN TUNISIE" (2019)

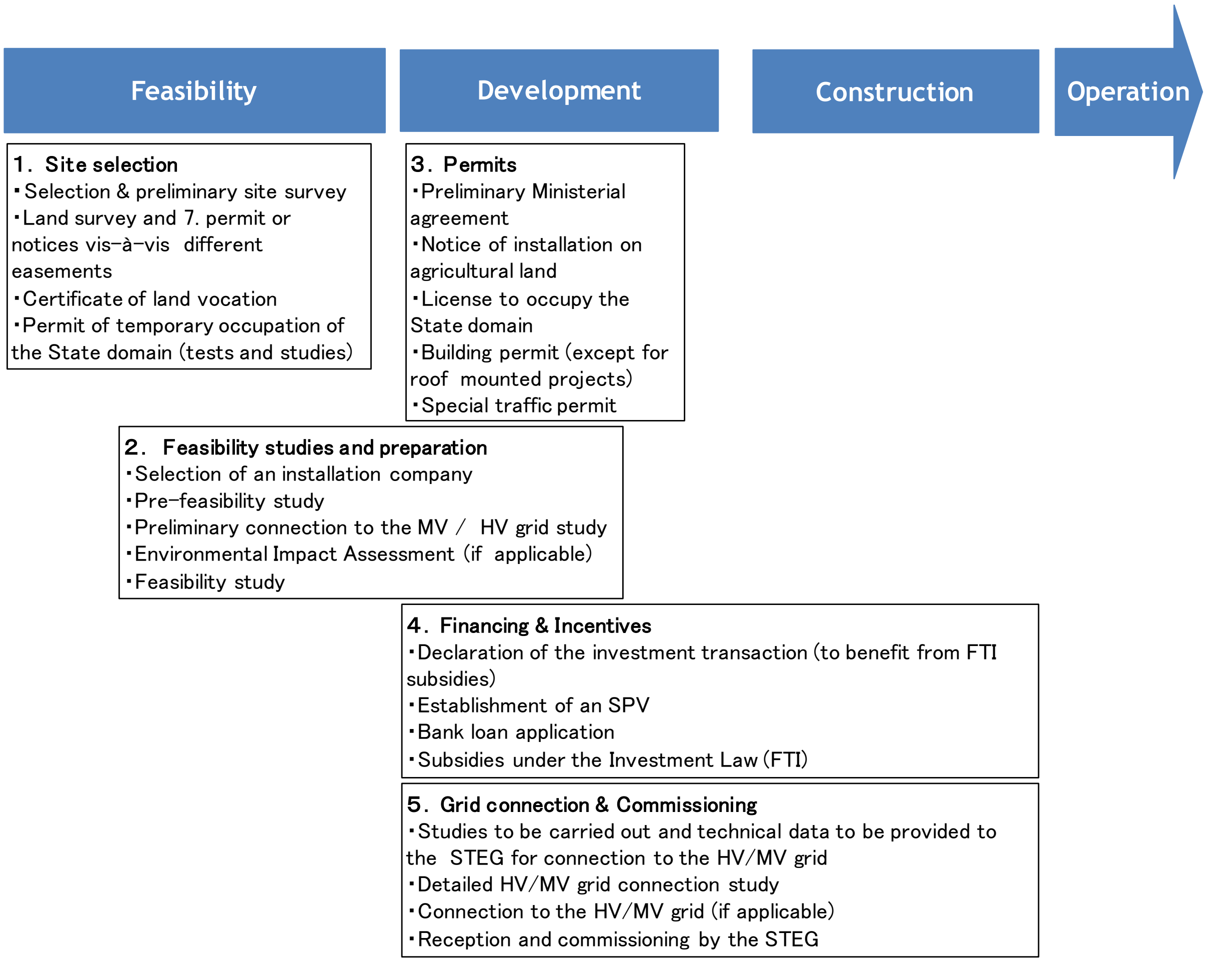
Figure 3-4 Typical project structure for a self-consumption project

(2) Authorisation scheme

Authorization is a scheme for implementing projects with less than the statutory capacity of 10 MW for solar, 30 MW for wind, 15 MW for biomass and less than 5 MW for other renewables. In order to develop a renewable energy project intended to satisfy the needs of the Tunisian consumption, a request needs to be made to the Ministry in charge of energy.

The granting of a preliminary agreement by the Ministry allows the producer to establish a project company in the form of a resident company with limited responsibility (SARL) or a limited company (SA). The validity of the preliminary agreement is two years for solar PV projects and three years for wind projects. An extension of one year is possible for both.

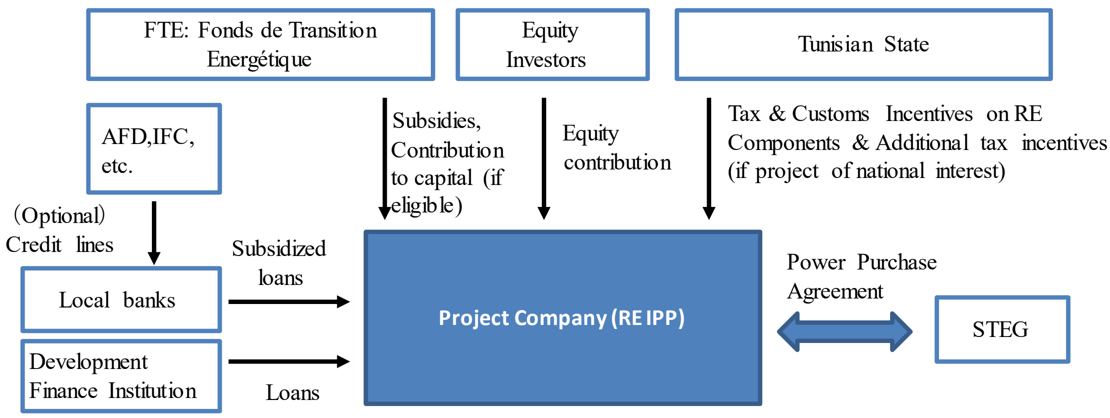
The overview of major procedures for the development of an authorisation scheme project is shown in Figure 3-5.



Source: GIZ, "PROJETS D'ÉNERGIE RENOUVELABLE EN TUNISIE" (2019)

Figure 3-5 Authorisation scheme project development procedures

The general business scheme applicable to the authorisation scheme is as follows:



Source: GIZ, "PROJETS D'ÉNERGIE RENOUVELABLE EN TUNISIE" (2019)

Figure 3-6 Typical project structure for an authorisation scheme project

(3) Concession scheme

Projects with a rated capacity exceeding the statutory limits (10 MW for PV, 30 MW for wind) for the authorisation scheme, fall under the concession scheme.

Under the concession scheme projects shall be subject to a public tender procedure by the Government of Tunisia and various conventions relating to the grant of each project need to be approved by a special committee at the People's Assembly.

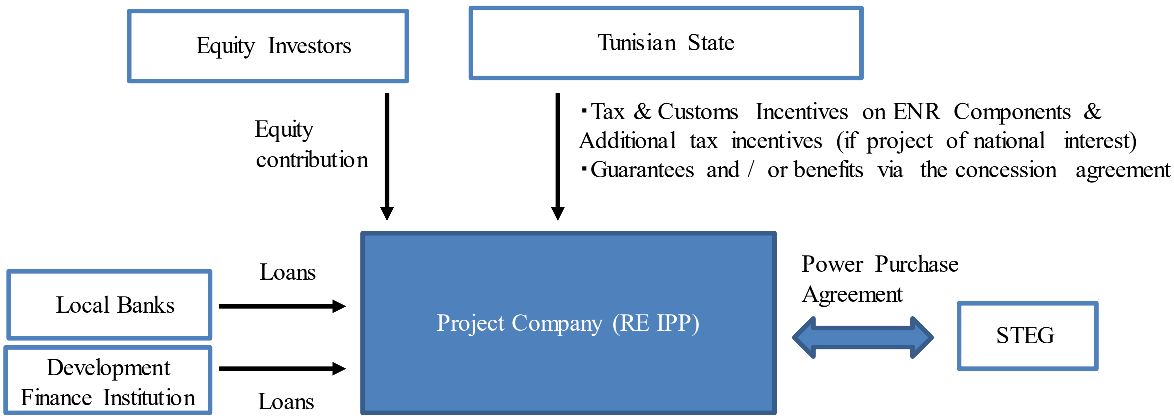
The overview of major procedures required for the concession scheme is as follows:

Selection of the Sponsor	• Prequalification call for tender based on technical and financial references • Implementation of a restricted call for tenders with pre-qualified candidates and submission of an offer by each candidate and for each site • Evaluation and selection of the best offer based on the proposed price and technical and financial requirements
Finalization of Project Agreements	• Finalization and signature by the selected sponsor of the Concession Agreement, the Power Purchase Agreement, the Land Use Agreement (if the site is on the State domain) and any other contract necessary to the successful completion and operation of the project (Direct Agreements with Lenders, etc.) • Enforcement of the various conventions after approval by the Assembly of People's Representatives and promulgation of the JORT approval law
Establishment of a Project Company and financial closing	• Creation by the sponsor of a company under Tunisian law, whose object will be the generation of electricity • Novation (transfer) of the different Project Agreements for the benefit of the Project Company • Organization of the financing by the project sponsor, realization and financial closing
Realization and operation of the project	• Finalization of the studies, construction and commissioning of the project by the project company and its subcontractors, according to a schedule specific to each project • Operation of the plant for the duration of the concession (20 years, renewable 5 years after agreement of the parties) • Sale of energy to STEG for the duration of the concession

Source: GIZ, "PROJETS D'ÉNERGIE RENOUVELABLE EN TUNISIE" (2019)

Figure 3-7 Concession scheme project development procedures

The general business scheme applicable to the concession scheme is as follows:



Source: GIZ, "PROJETS D'ÉNERGIE RENOUVELABLE EN TUNISIE" (2019)

Figure 3-8 Typical project structure for a concession scheme project

3.2 Current status of IPP projects

The renewable energy development schemes in Tunisia include the Concession scheme for large-scale projects, the Authorization scheme for medium-scale projects and the Self-consumption which is premised on self-consumption. According to the latest information available on the web site of the Ministry of Energy, Mines and Renewable Energy, the status of the projects is as follows.

- Concession scheme

In May 2018, the Ministry of Energy, Mines and Renewable Energy conducted a solicitation for pre-qualification examinations for 500 MW of solar power generation, and as a result, 38 applications were submitted. In December 2019, the temporary successful bidders have been decided as follows.

Table 3-2 Temporary successful bidder for solar power generation by concession scheme

Project	Temporary successful bidder	Capacity（MW）	Price（Tunisian Dinar / MWh）
Tozeur (A)	SCATEC SOLAR	50	79.379
Sidi Bouzid (B)	SCATEC SOLAR	50	79.379
Kairouan (C)	TBEA/AMEA	100	97.920
Gafsa (D)	ENGIE/NAREVA	100	79.950
Tataouine (E)	SCATEC SOLAR	200	71,783

Source: Ministry of Energy, Mines and Renewable Energy HP

The Ministry of Energy, Mines and Renewable Energy also conducted a solicitation for pre-qualification examinations for wind power in May 2018, but the deadline for applications by potential bidders has been extended to the end of 2021.

➢ Authorisation scheme

In May 2017, May 2018, July 2019 and September 2020, the solicitations for authorization scheme projects are being conducted. In May 2017, 70 MW for solar power generation, 140 MW for wind power generation, 70 MW for solar power generation, 130 MW for wind power generation in May 2018, and 70 MW for solar power generation in 2019 have been decided.

➢ Self-consumption scheme

Two new projects are under preparation after 2020 for generating facilities connected to the low voltage network. One is the "Prosol Economique" project for consumers of 1,200 to 1,800 kWh / year, and the other is the "Prosol Social" project for consumers of less than 1200 kWh / year. Regarding the connection to the medium and high voltage network, the installation of 32 MW (172 projects) of solar power plants was approved by September 2020.

Carthage Power Company is a company that already has been operating the IPP business in Tunisia. Carthage Power Company is funded by Nebras Power (60%) and Marubeni (40%), and the Rades II plant is the largest power plant in Tunisia with an installed capacity of 471 MW (representing more than 8% of the total installed capacity in Tunisia in 2019). The plant comprises of two gas turbines and one steam turbine and has started commercial operation in 2002. All amount of electricity generated is purchased by STEG under a long term Power Purchase Agreement (PPA) until 2022[1].

3.3 Bottlenecks for the introduction of renewable energy IPPs

The challenge of introducing renewable energy by IPP is that it will take a lot of time to approve the project under the concession scheme. Actually, it took about a year and a half for the approval process.[2] Furthermore, in recent years, there have been cases where parliamentary approval has been delayed due to the COVID-19 pandemic.

Although local investors are paying close attention to renewable energy projects under the authorization scheme, there is an issue associated with funding that that the targeted project scale is larger for local banks and, on the other hand, smaller for international financial institutions. In addition, the issue is that the contents of a power purchase agreement (PPA) do not meet international standards.[3]

Regarding the self-consumption scheme, the main issue is that the sale of surplus electricity (reverse power flow) to the grid is limited to a maximum of 30% of the amount of electricity generated. This

[1] https://nebras-power.com/assets/listing/rades-ii?language_content_entity=en
[2] Interview with the World Bank
[3] Interview with EBRD

limitation is imposed taking account of the cost burden of STEG purchasing electricity instead of technical constraints of the power system.[4]

The issues in each scheme are summarized below.

Table 3-3 Major challenges for the introduction of renewable energy IPPs

Type	Challenges
Concession	・ It takes a considerable amount of time to approve the project. ・ No particular procurement conditions (The PPA is not guaranteed by the government, but the risk is mitigated by the government issuing a comfort letter and the commitment of the government because Ministry of Energy, Mines and Renewable Energy is a contracting party.)[5] ・ The existing grid capacity is not sufficient.
Authorisation	・ The PPA does not comply with international standards (there is no government guarantee, STEG does not compensate for grid restrictions, and all risks related to grid connection are borne by the operator, etc.) ・ Difficulty in financing by local banks (lack of liquidity due to central bank demanding a certain amount of deposit, lack of risk assessment ability, etc.) ・ No import duty exemption or VAT exemption[6] ・ The existing grid capacity is not sufficient.
Self-production	・ Sales of surplus electricity (reverse power flow) to the STEG system are limited to a maximum of 30% of power generation ・ Although the new investment law has made it possible to sell electricity to third parties via the STEG grid, detailed rules such as grid access rules and deregulation of surplus electricity sales limits are unknown. ・ No import duty exemption or VAT exemption[7]

Source: JICA Study Team

With respect to the concession scheme, the issues such as government guarantees for PPAs have been reasonably mitigated, and the tender carried out in 2019 has brought about competitive results. The remaining risks are mainly the foreign exchange and conversion risks. [8]

3.4 Solutions to these bottlenecks and support from other donors

Recently, EBRD has provided STEG with a sovereign-guaranteed loan of up to € 300 million to support the reform and development of Tunisia's electricity sector. The main objective is the reform and restructuring of STEG and the Tunisian energy sector to achieve long term sustainability. The Project will include a comprehensive corporate reform roadmap, including measures to improve the Company's corporate governance, financial management, strategy & risk, renewable energy integration and procurement. The outline of the project is as follows.[9]

4 Interview with the World Bank
5 https://openjicareport.jica.go.jp/670/670/670_000_12356184.html
6 https://openjicareport.jica.go.jp/670/670/670_000_12356184.html
7 https://openjicareport.jica.go.jp/670/670/670_000_12356184.html
8 https://openjicareport.jica.go.jp/670/670/670_000_12356184.html
9 https://www.ebrd.com/work-with-us/project-finance/project-summary-documents.html?1=1&filterCountry=Tunisia

Table 3-4 Support project by EBRD

Project Title	Approval date	Project Description	Total Project Cost
STEG Transmission	21 Sep 2016	A senior loan of up to EUR 85 million to STEG, to finance the reinforcement of the electricity transmission network in North-Eastern Tunisia.	Up to EUR 170 million
STEG Liquidity and Restructuring Facility	16 Dec 2020	Provision of a sovereign guaranteed loan to Societe Tunisienne de l'Electricite et du Gaz to assist the Company in its reforms and developing Tunisia's electricity sector. The Project combines long-term reform objectives with an immediate response to the COVID-19 crisis.	EUR 300,000,000.00 A portion of the project will be provided as liquidity support as an immediate response to the current COVID-19 crisis and another portion will be applied to refinance short-term debt.

Source: EBRD HP

It is supporting the Tunisian government with a technical and legal framework primarily for the concession scheme. Over the past two years, EBRD has been mandated for 400 MW of its 500 MW solar program, has been negotiating contracts with sponsors and the Tunisian government, and has finally been approved by the government.[10]

The World Bank plans to support US $ 151 million to strengthen Tunisian transmission system and improve STEG's commercial performance. The outline of the project is as follows.[11]

[10] Interview with EBRD
[11] https://projects.worldbank.org/en/projects-operations/projects-list?countrycode_exact=TN&os=0

Table 3-5 Support project by the World Bank

Project Title	Approval date	Project Description	Total Project Cost
Tunisia Energy Sector Improvement Project	June 24, 2019	The development objective of the Energy Sector Improvement Project for Tunisia is to: (i) strengthen Tunisia's electricity transmission system; and (ii) improve Tunisian Company of Electricity and Gas (STEG's) commercial performance. The project comprises of two components. The first component, strengthening the electricity transmission network will provide support for the expansion and reinforcement of Tunisia's power transmission system. The second component, commercial performance improvement will provide financing for payments under the eligible expenditure program in support of the strengthening of STEG's commercial performance.	151 (US$ Millions)

Source: the World Bank HP

It will provide technical assistance in simplifying and streamlining application procedures and training local banks in project evaluation capabilities to address the challenges of IPP's introduction of renewable energy. [12]

GIZ provides the Ministry of Mines, Energy and Renewable Energy of Tunisia with education and training support for the solar market development, support for developing the solar energy market, and support for implementing solar generation plans. [13]

Table 3-6 Support project by GIZ

Project Title	Implementation period	Project Description
Capacity and human resource building for solar market development in Tunisia	2015-2018	Support for an advanced training curriculum in the installation and maintenance of PV systems
Strengthening of the market for small and medium-sized PV systems	2017-2019	Supporting the Tunisian government's efforts to expand the market for distributed PV systems
Support the implementation of the Tunisian Solar Plan	2015-2021	Providing policy advice with the support of national and international technical, financial and legal experts

Source: GIZ HP

[12] Interview with the World Bank
[13] https://www.giz.de/en/worldwide/326.html

Chapter 4 Management reform of STEG

4.1 Current status of the energy subsidy of the Government of Tunisia and STEG

4.1.1 Current situation of STEG

According to "2021 Article IV Consultation – Press Release; Staff Report; and Statement by the Executive Director for Tunisia" (hereinafter referred to as "IMF Report") published by IMF on 26th February 2021, the COVID-19 pandemic has aggravated Tunisia's long-standing vulnerabilities and caused an economic downturn. The report highlighted that the Government of Tunisia should concentrate on the reform of inefficient state-owned enterprises (SOEs) including STEG which is one of the largest SOEs in Tunisia as well as the energy subsidy injected to STEG. The main points of the SOE reform referred to in the report are as follows:

- Enhancing monitoring and auditing of SOEs
- Strengthening the governance of SOEs
- Improving the transparency of SOEs' financial situation and SOEs' management through in-depth financial analysis

The draft of the amended SOE law stipulating i) the creation of an independent autonomous agency to supervise the SOE sector and ii) professionalizing the boards of SOEs is currently under review by the Tunisian authorities.

4.1.2 Current situation of the energy subsidy

As for the progress of the energy subsidy reform in Tunisia, certain progress was observed in 2018 and 2019. However, it came to a halt before the 2019 elections. Due to the frequent administration changes and the economic downturn caused by the COVID-19 pandemic, the reform process has not proceeded smoothly. Recently, the dialogue between the government and the World Bank on subsidy reform has finally resumed[1].According to the interviews with EBRD, the government aims to eliminate subsidies and increase electricity tariffs by 2026, and to introduce subsidy programs for the poor and low-income customers. EBRD is also monitoring the progress of the subsidy reform, which is still in the process of being implemented.

The outline of the most recent tariff increase is as follows

- Fuel prices were raised in September 2018
- Planned increases in fuel and utility tariffs for October and November 2018 were not implemented considering social tensions
- The government increased the prices of fuel and other oil products by around 6.0 percent in March 2019

[1] Interview with World Bank

- The government raised the prices of low-pressure natural gas and the electricity tariffs for low-voltage customers in May 2019.

4.2 Management reform of STEG and relevant assistance from other donners

4.2.1 Status of STEG's electricity facilities and business operations

(1) Management reform of STEG

1) Review of the structure and the current status of the power sector subsidies to STEG and the governmental spending

According to Annual Report 2018 of STEG, the subsidy granted by the State for the year 2018 was 1,200 MTD, including 717.3 MTD for the electricity business.

The selling price, cost and subsidy per unit for the electricity and gas businesses are shown in Table 4-1 and Table 4-2, respectively. Both businesses are deficit even with the subsidies.

Table 4-1 Impacts of subsidies on electricity business

	2017	2018
Average unit selling price per kWh distributed	189.6	206.3
Average unit cost per kWh distributed	235.4	286.7
Result excluding operating subsidies	-45.9	-80.3
Impact of operating subsidy	22.8	45.7
Result Taking into account operating subsidies	-23.1	-34.6
Gross profit margin without subsidy（1kwh per kWh distributed）	-24%	-39%
Gross profit margin with subsidy（1kwh per kWh distributed）	-12%	-17%

(in millimes / KWh)

(Source: STEG Annual Report 2018)

Table 4-2 Impacts of subsidies on gas business

	2017	2018
Average unit selling price	460.4	508
Average unit cost	638.1	864.9
Result excluding operating subsidies	-177.7	-356.9
Impact of operating subsidy	110.2	214.5
Result Taking into account operating subsidies	-67.5	-142.4
Gross profit margin without subsidy	-39%	-70%
Gross profit margin with subsidy	-3%	-7%

In MDT

(Source: STEG Annual Report 2018)

2) Examination of electricity tariffs from the perspective of STEG's financial soundness and their impacts on the Tunisian industry

From the perspective of financial soundness, it is desirable to design proper electricity tariffs, as described below. Since the COVID-19 pandemic has caused serious economic downturn in Tunisia, there might be difficulties to raise electricity tariffs.

3) Survey in STEG's revenue and expenditure structure, extraction of financial issues, and examination from the perspective of financial soundness

a) STEG's financial reporting system

According to the "Project Appraisal Document" (June 6, 2019) for the Energy Sector Improvement Project of the World Bank, the STEG's financial reporting system is as follows.

Table 4-3 STEG's financial reporting system

Function	System
Accounting	➢ STEG is using a computer software for recording accounting transactions and for generating financial statements. ERP will be implemented. ➢ STEG is using the national accounting standards for the private sector. STEG is also working on the implementation of International Financial Reporting Standards. STEG has the custome to create a dedicated unit for the implementation of a donor-funded project, staffed with financial management specialists.
Internal control/Intaernal audit	➢ STEG has well-organised internal control and internal audit systems (No significant risk has been identified for the implementation of the World Bank's Energy Sectro Improvement Project.)
Financila reporting	➢ The current financial statements are elaborated based on a mixture of the local accounting standards and the international financial reporting standards.
External Audit	➢ STEG is endowed with an adequate external audit arrangement.

(Source: the World bank, "Project Appraisal Document" for Energy Sector Improvement Project, etc.)

b) The structure of revenue and expenditure

The following observations concerning STEG's financial condition are based on the financial information disclosed in its 2018, 2019 and 2020 annual reports. The revenue and expenditure structure of STEG for 2019 is shown in Table 4-4, the one for 2020 is shown in Table 4-5.

The "Net financial charges" (which appear to be corresponding to foreign exchange gains / losses, interests, etc.) are described in net values, and in 2019, it was on the profit side. Therefore, STEG was able to record net profits. On the other hand, since it was △ 1,543 MDT in 2018, a net loss was recorded for STEG in 2018. In 2020, the cost of sales is significantly lower, but as discussed below, the majority of the cost of sales is fuel (natural gas), which is likely to benefit from the decline in natural gas prices (linked to Brent prices) in the first half of 2020 (Figure 4-1). The operating grant has also been compressed significantly.

Table 4-4 STEG's revenue and expenditure structure in 2019

Income Statement FY2019 in MDT

Cost		Revenue	
Cost of sales	7,014	REVENUES	5,474
		Operating grant	1,242
		Other exploitation products	77
Administration fees	62	Net financial charges	646
Other operating expenses	261	Investment income	7
Other ordinary losses	11	Other ordinary earnings	14
Income tax	6	NET PROFIT FOR THE YEAR	106

(Source: STEG Annual Report 2019)

Table 4-5 STEG's revenue and expenditure structure in 2020

Income Statement FY2020 in MDT

Cost		Revenue	
Cost of sales	5,225	REVENUES	5,282
Administration fees	65	Operating grant	100
Other operating expenses	239	Other exploitation products	281
Net financial charges	171	Investment income	1
Other ordinary losses	34	Other ordinary earnings	15
Income tax	6		
NET LOSS FOR THE YEAR	60		

(Source: STEG Annual Report 2020)

The prices of natural gas being used as major fuel for power generation, are linked to the Brent prices, which have fallen significantly due to the lockdown caused by the COVID-19 pandemic in the first half of 2020. This is expected to have reduced fuel costs in 2020, leading to lower cost of sales. However, with Brent prices rising in 2021, the cost of sales may have increased again, leading to higher losses.

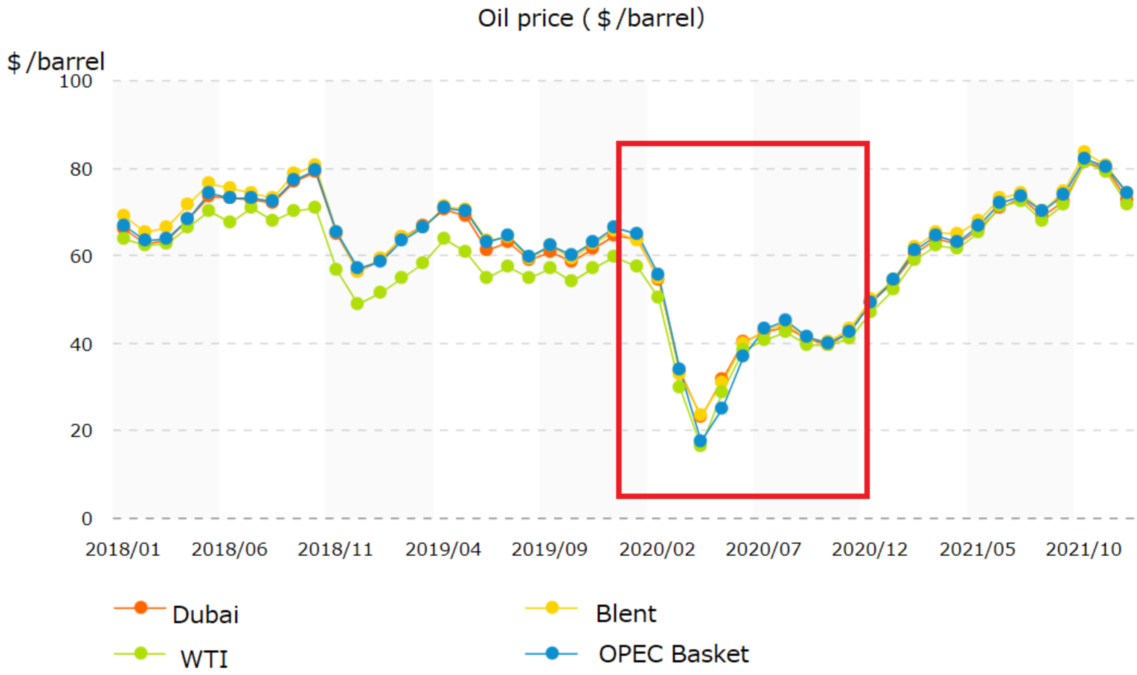


Figure 4-1 Brent Crude Price Trends

An overview of STEG's balance sheet, which indicates that STEG is insolvent, is as follows.

Table 4-6 Overview of STEG's balance sheet（as of 2020）

Balance sheet FY2020			in MDT
ASSETS		EQUITY AND LIABILITIES	
Intangible assets:	1	Loans	6,996
Tangible fixed assets completed	6,605		
		Guarantee deposits	432
investments in progress	1,173	Provisions for risks and charges	598
Financial fixed assets	111	Other non-current liabilities	1
Non-Current Assets total	7,889	Non-Current Liabilities total	8,027
Stocks	326	Accounts payable	2,600
Customers and related accounts	2,031		
Other current assets	186		
Other financial assets	16	Other current liabilities	821
Cash and cash equivalents	447	Bank overdrafts and other financia	1,727
Current Assets total	3,006	Current Liabilities total	5,147
Total Assets	10,895	Total Liabilities	13,174
		Dotation funds	75
		Legal reservations	0
		Other equity	1,590
		Results reported	-3,884
		Total equity before profit some ex	-2,219
		The result of the exercise	-60
		Total equity before allocation	-2,279

(Source: STEG Annual Report 2020)

c) Financial analysis

The "Efficiency of business operation of STEG" (Table 4-7) and the "Financial Soundness of STEG" (Table 4-8) were examined based on STEG's financial statement included in STEG annual report 2019.

In a comparative analysis among STEG and other electric utilities to examine the financial situation of STEG, although it would have been convenient to be able to use the indicators of the electric utilities in the same MENA region as Tunisia. It was difficult to obtain adequate financial data for other utilities. Accordingly, the financial indicators for the following companies, which have a certain similarity with STEG, were examined:

Engie (France), Enel (Italy), which are operating both electricity and gas business

Saudi Electricity Co (Saudi Arabia), Jordan Electric Power Co (Jordan), which are vertically-integrated electric utilities in MENA

Tenaga Nasional Bhd (Malaysia), which is a state-owned utility in a Muslim country.

Because some of these companies have different business portfolios from STEG (some are operating a telecommunications business, some are not operating a gas business, etc.), and the electricity market conditions are different country by country, it shall be noted that Table 4-7 and Table 4-8 are presented just for a reference purpose.

Table 4-7 Efficiency of business operation of STEG

Financial Indicator		STEG FY2018		STEG FY2019		STEG FY2020		Engie FY2020	Enel FY2020	Saudi Electricity Co FY2020	Jordan Electric Power Co FY2020	Tenaga Nasional Bhd FY2020	Comments
Return on Assets	Result of activities ordinary before tax	-2,088,257,817	-21.8%	112,721,336	1.1%	-54,067,416	-0.5%	(1.10)	1.56	0.43	0.99	1.99	In 2019, the company's ordinary income turned positive due to profits from financial charges that are not part of the company's core business (the breakdown of which is not available, but probably includes foreign exchange gains and losses, interest, etc.). However, in 2020, it is back in the red. Since the indicator is a measure of the company's overall profitability, it should continue to be positive. The average ROA of the four companies with positive ROA in 2020 is 1.24, which indicates that STEG's profitability is not sufficient. STEG should take some measures to hedge gas prices and exchange rate fluctuations, but STEG does not have the authority to manage risks, and the situation cannot be handled by STEG alone.
	Total asssts	9,563,753,285		10,333,347,343		10,895,133,784							
Return on Equity	Net profit for the year	-2,093,505,085	NA	106,409,910	NA	-60,170,126	NA	(5.56)	8.89	1.31	7.84	6.31	It is the profitability against equity capital. STEG has already fallen into excessive liabilities, and its equity capital is negative. Insolvency is a condition in which the amount of liabilities exceeds the amount of assets, indicating that STEG is in a difficult financial situation.
	Total equity	-2,341,811,915		-2,219,765,868		-2,279,099,383							
Gross profit margin	Gross margin	-380,701,779	-8.4%	-298,418,282	-5.5%	156,352,457	3.0%	37.28	34.32	11.78	12.73	27.03	It is the ratio of gross profit to net sales; for STEG, cost of sales exceeds net sales and is negative. It is necessary to bring sales and cost of sales to an appropriate level (e.g., increase the unit price of sales, make efforts to reduce the cost of sales, etc.). Although there will be an improvement in 2020 due to lower natural gas prices, it is still only 3%, which is still low compared to other countries and compared to the average of 24% for the five companies. Normally, some measures should be taken for gas price hedging, which constitutes a large part of the cost of sales, but STEG does not have the risk management authority, and STEG alone is unable to address this issue.
	Revenue	4,534,263,470		5,473,687,548		5,281,721,967							
Operating profit margin	Operating result	-552,802,401	-12.2%	-544,079,699	-9.9%	133,604,611	2.5%	6.66	18.36	11.94	3.83	16.55	It is an indicator that looks at the profitability of the core business; STEG is not profitable in its core business. Compared to other countries, the average of the five companies in 2020 is 11%, but STEG is still low, as it is only 2.5% even in 2020, the only positive year in the past three years.
	Revenue	4,534,263,470		5,473,687,548		5,281,721,967							
Ordinary profit margin	Result of activities ordinary before tax	-2,088,257,817	-46.1%	112,721,336	2.1%	-54,067,416	-1.0%	-	-	-	-	-	It is the profitability of ordinary income (including non-operating income and expenses); in 2019, it is positive because the company is profitable in Financial charge, which is not its core business. The profitability of ordinary income (including non-operating income and expenses) is the sum of non-operating income and expenses (income and expenses other than the core business, such as interest and foreign exchange gains/losses), and a negative figure indicates that the company is not making a profit. The company has not been able to secure profits.
	Revenue	4,534,263,470		5,473,687,548		5,281,721,967							

Financial Indicator		STEG FY2018		STEG FY2019		STEG FY2020		Engie FY2020	Enel FY2020	Saudi Electricity Co FY2020	Jordan Electric Power Co FY2020	Tenaga Nasional Bhd FY2020	Comments
Net profit margin	Net profit for the year	-2,093,505,085	-46.2%	106,409,910	1.9%	-60,170,126	-1.1%	(4.25)	4.19	3.05	1.08	8.17	In 2018, the company is in the red, but in 2019, it is back in the black due to a large profit from the financial charge; in 2020, the company is in the red, although the cost of sales may have improved due to lower natural gas prices. A review of electricity prices and costs other than cost of sales are considered necessary.
	Revenue	4,534,263,470		5,473,687,548		5,281,721,967							
Total assets turnover	Revenue	4,534,263,470	0.5	5,473,687,548	0.5	5,281,721,967	0.5	0.36	0.37	0.14	0.92	0.24	The higher the value of the total asset turnover ratio, the more effectively the assets are being used..STEG is slightly more efficient than other power companies in other countries, but it is possible that STEG is not actively investing in new projects in Tunisia because the country is a monopoly market.
	Total asssts	9,563,753,285		10,333,347,343		10,895,133,784							
Accounts receivable turnover	Revenue	4,534,263,470	2.8	5,473,687,548	3.2	5,281,721,967	2.6	3.78	4.96	1.89	1.64	13.08	The higher the value of the accounts receivables turnover ratio, the shorter the period between sales and the collection of receivables.STEG's accounts receivables turnover ratio is higher than that of power companies in the Middle East (Saudi Electricity Co. and Jordan Electric Power Co.), but there is still room for improvement compared to private companies such as Engie and Enel.
	Customers and related account	1,602,728,575		1,713,114,106		2,031,426,826							
Fixed assets turnover periode(month)	Total fixed aseets	7,376,526,418	4.6	7,855,564,594	4.6	7,889,407,969	3.9	–	–	–	–	–	The fixed asset turnover period is a measure of how long it takes for a company to recover its investment in fixed assets. The STEG is relatively efficient, with a result of less than five months.STEG can be considered relatively efficient with a result of less than five months, but it could also be that the investment in fixed assets is low to begin with because STEG almost dominates the market and can generate sales without new investment.
	Revenue per month	1,602,728,575		1,713,114,106		2,031,426,826							

(Source: STEG Annual Report 2019,2020 (for STEG), SPEEDA (for other utilities, as of Feburuary 18, 2022))

Table 4-8 Financial Soundness of STEG

Financial Indicator		STEG 2018		STEG 2019		STEG 2020		Engie (FY2020)	Enel (FY2020)	Saudi Electricity Co (FY2020)	Jordan Electric Power Co (FY2020)	Tenaga Nasional Bhd (FY2020)	Comments
Current ratio	Current assets	2,187,226,867	47.6%	2,477,782,749	46.1%	3,005,725,815	58.4%	111.20	82.69	64.37	109.34	96.53	The current ratio is an indicator of the safety of a company and should be above 100%.STEG's current liabilities (mainly payables) are almost twice as large as its current assets (cash and deposits, trade receivables, etc.), and depending on the timing of payments, the company may be short of funds, which could lead to short-term cash flow concerns.
	Current liabilities	4,598,626,073		5,372,740,460		5,147,486,794							
Quick assets ratio	Quick assets	1,860,874,817	40.5%	2,056,021,886	38.3%	2,478,517,948	48.2%	51.48	44.07	50.85	107.11	58.08	Current assets = cash and deposits + trade receivables. Since most of the current assets are cash and deposits and trade receivables, it shows the same trend as the current ratio. This is one of the indicators that looks at the short-term safety of funds, and STEG's average ratio for the past three years has been 42%, indicating that the ratio of current assets to current liabilities is low compared to other companies.
	Current liabilities	4,598,626,073		5,372,740,460		5,147,486,794							
Ratio of non-current assets to equity capital	Non-current assets	7,376,526,418	NA	7,855,564,594	NA	7,889,407,969	NA	321.63	455.08	177.44	338.02	275.16	The figure is negative because STEG is in a state of excessive debt. Insolvency is a condition in which the amount of liabilities exceeds the amount of assets, indicating that STEG is in a difficult financial situation.
	Equity	-2,341,811,915		-2,219,765,868		-2,279,099,383							
Non-current assets to long term capital ratio	Non-current assets	7,376,526,418	148.6%	7,855,564,594	158.4%	7,889,407,969	137.3%	-	-	-	-	-	This is above the level considered desirable (below 100%). Long-term liabilities are mainly Loan, accounting for nearly half of total liabilities. Taking into account the fact that equity capital is negative, we can see that fixed liabilities are particularly large. In general, it will be necessary to take steps to reduce fixed liabilities.
	Equity+Non-current liabilities	4,965,127,211		4,960,606,882		5,747,646,990							

Financial Indicator		STEG 2018		STEG 2019		STEG 2020		Engie FY2020	Enel FY2020	Saudi Electricity Co FY2020	Jordan Electric Power Co FY2020	Tenaga Nasional Bhd FY2020	Comments
Debt-equity ratio	Liabilities	11,905,565,199	NA	12,553,113,210	NA	13,174,233,167	NA	131.07	207.10	45.94	354.07	140.03	The figure is negative because STEG is in a state of excessive debt. Insolvency is a condition in which the amount of liabilities exceeds the amount of assets, indicating that STEG is in a difficult financial situation.
	Equity	−2,341,811,915		−2,219,765,868		−2,279,099,383							
Degree of indebtedness(leverage)	Loans	6,533,247,267	68.3%	6,345,901,310	61.4%	6,995,835,634	64.2%	－	－	－	－	－	The IMF's 2021 Country Report also points out that STEG is highly leveraged compared to SOEs in other countries, and the EBRD is providing debt restructuring support.
	Total assets	9,563,753,285		10,333,347,343		10,895,133,784							
Capital-to-asset ratio	Equity	−2,341,811,915	NA	−2,219,765,868	NA	−2,279,099,383	NA	18.90	17.33	51.04	12.48	30.77	STEG has fallen into insolvency. In order to get out of this situation, the company needs to become profitable. Excess liabilities are defined as the amount of liabilities exceeding the amount of assets, which indicates that STEG is in a difficult financial situation. Increasing electricity prices (to increase sales), managing costs by segment, and hedging gas prices and foreign exchange rates (to reduce costs) are essential.
	Total assets	9,563,753,285		10,333,347,343		10,895,133,784							

Net income figures for other companies in the same industry use figures before the deduction of income (loss) attributable to noncontrolling interests.

(Source: STEG Annual Report 2019 ,2020(for STEG), SPEEDA (for other utilities, as of Feburuary 18, 2022))

The major findings regarding STEG's revenue and expenditure are as follows:

Revenue

The cost of sales exceeds revenues through 2019, and even if subsidies are considered, the cost of sales is still larger. It is necessary to consider the optimization of electricity and gas tariff in relation with the subsidy reform. STEG does not have a right to determine its tariffs. The government is working with IMF to define tariff targets and to raise them.

The World Bank continues to provide support for the reduction of non-technical losses.

Cost

i) Electricity business

According to STEG's Annual Report 2018, the cost structure of the electricity business is as shown in Figure 4-2, with fuel costs accounting for 50-60% of the total cost in 2017 and 2018. According to the Project Appraisal Document of the World Bank's Energy Sector Improvement Project, the country is heavily dependent on imports of fuel (natural gas) for power generation. Most of natural gas is imported from Algeria and is denominated in US dollars.[2]

As for gas procurement contracts, they are affected by Brent prices and exchange rates, and accordingly, fuel costs are influenced by the fluctuations of international oil prices and currency exchange.

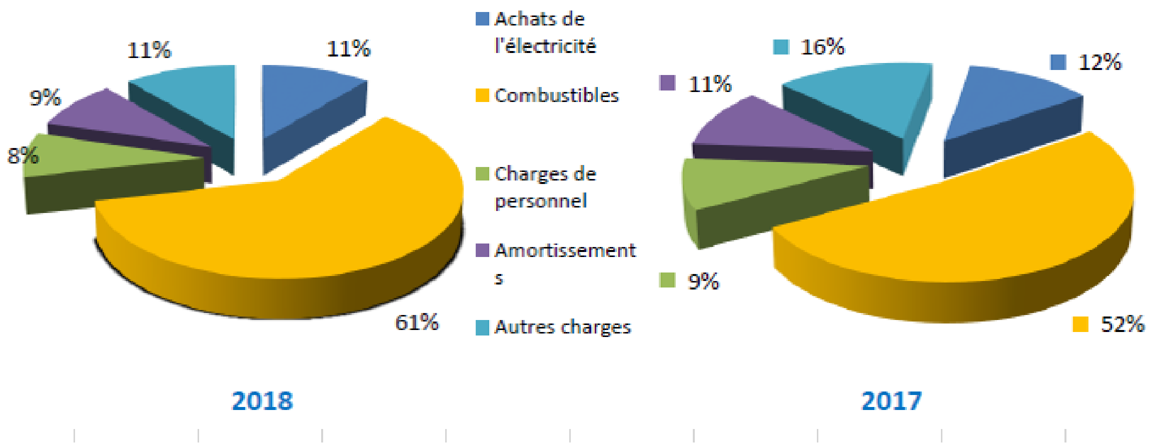


Figure 4-2 Cost structure of STEG's electricity business

[2] The World Bank "Project Appraisal Document" for Energy Sector Improvement Project, page 2
http://documents1.worldbank.org/curated/en/296941561687292260/pdf/Tunisia-Energy-Sector-Improvement-Project.pdf

In terms of costs by segment (i.e., electricity generation, distribution and transmission), the cost for electricity generation is the largest, accounting for 84.2% of the total cost.

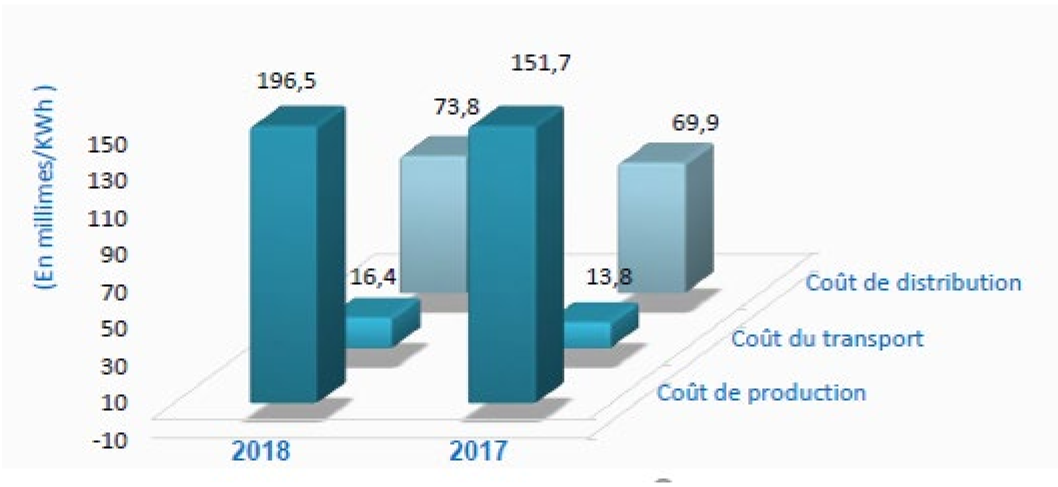


Figure 4-3 Cost components for electricity business (electricity generation, transmission, distribution)

ii) Gas business

The cost structure related to STEG's gas (natural gas and LPG) business is as follows. The procurement cost accounts for the majority of the total cost.

<Natural Gas>

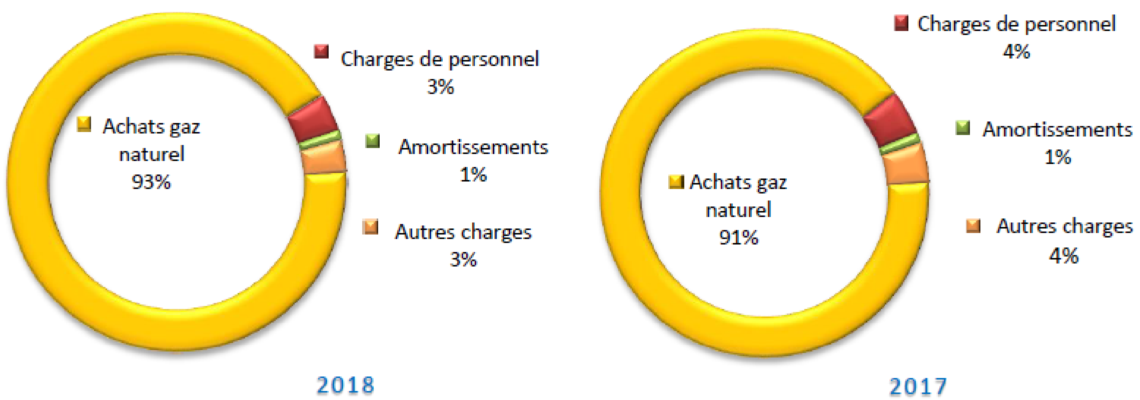


Figure 4-4 Cost structure of STEG's narural gas business

<LPG>

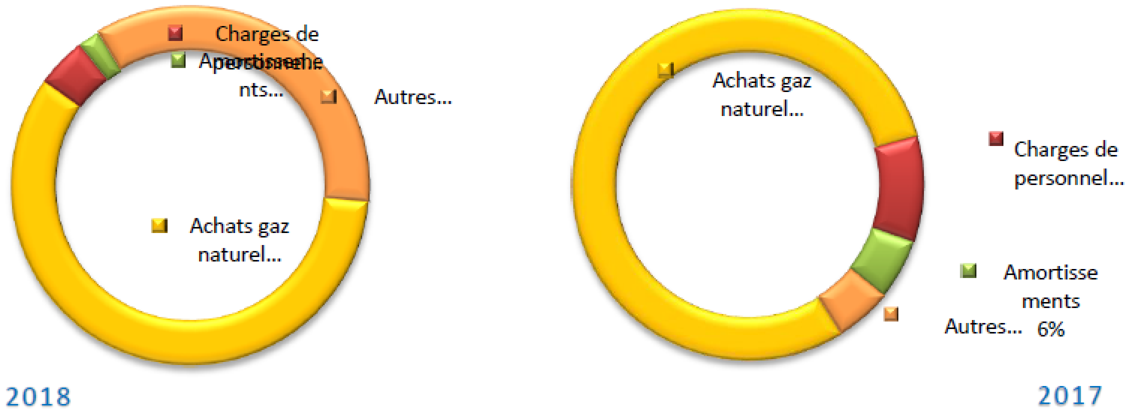


Figure 4-5 Cost structure of STEG's LPG business

While the personnel costs do not account for a large proportion of either the electricity business or the gas business, according to the IMF Report, the salaries of SOEs are, in general, higher than those of public officers and are rising year by year. In 2019, it was almost twice the nation's average salary. As such, it is envisaged that STEG's personnel costs are not so small.

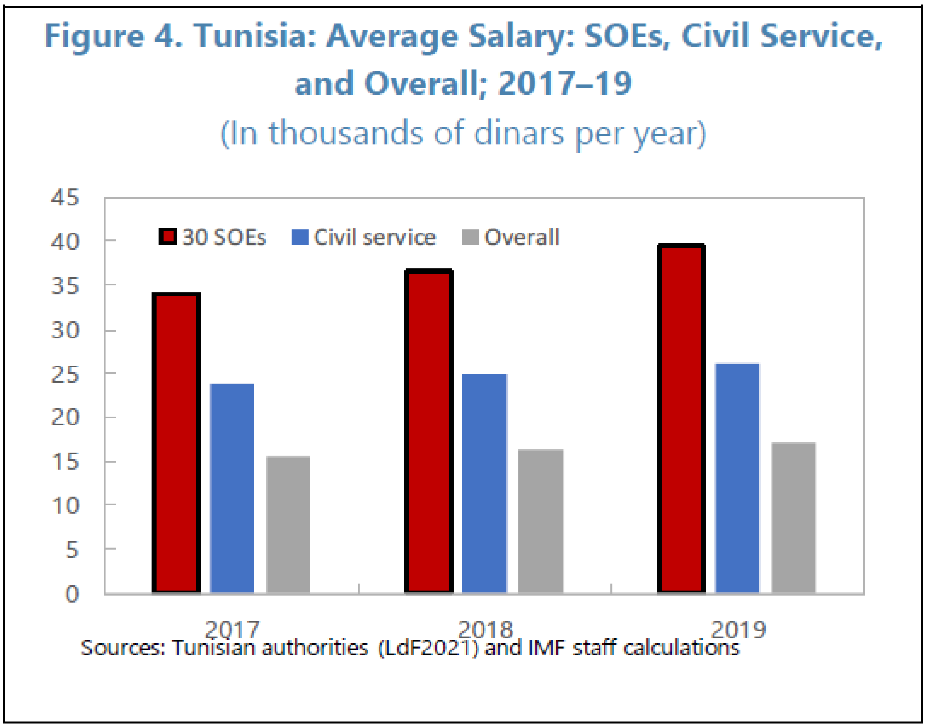


Figure 4-6 Tunisia: Average salary: SOEs,civil service and overall 2017-2019

Financial Charges

The financial charges of STEG appear to consist of foreign exchange gains and losses and financial expenses such as interests on loans. It is envisaged that the foreign exchange gains and losses account for the majority of the financial charges because the net figures for each year tend to fluctuate a lot.

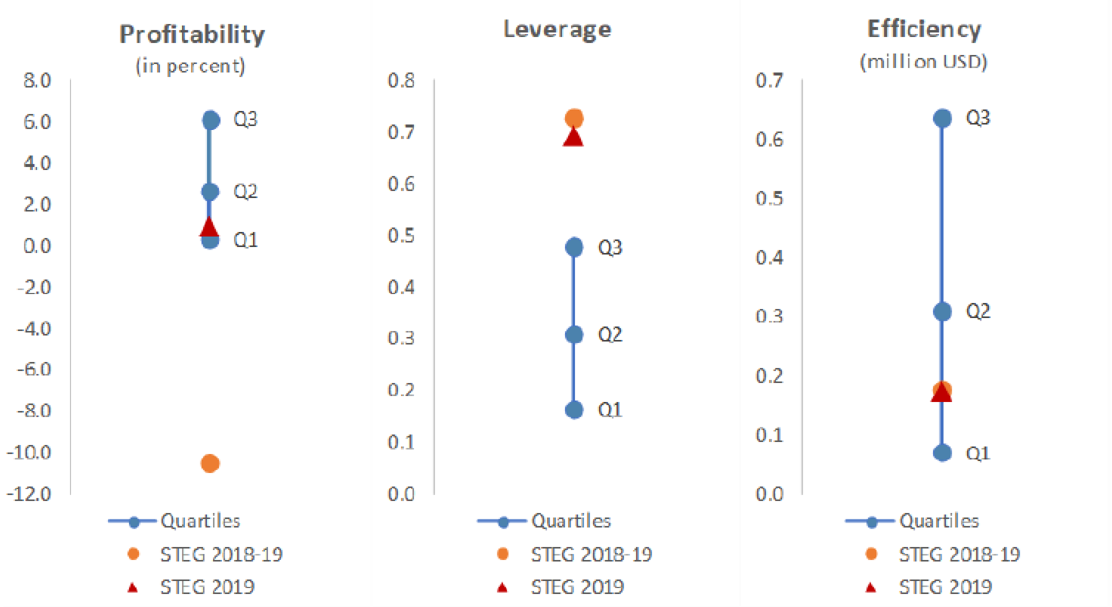
While the account receivables are denominated in Tunisian Dinar, the account payable for fuel is denominated in US dollars as mentioned above, and 99% of the borrowings are denominated in foreign currencies[3]. The foreign exchange gains and losses are resulted from those difference of currencies between the asset side and the liability side.

d) IMF's comparison with electricity SOEs in other countries

The IMF Report shows the results of its comparative analysis for typical financial indicators (ROA as Profitability, non-current liabilities to asset as Leverage, operating revenue per employee as Efficiency) of STEG and those of other SOEs in 58 countries. Compared to the SOEs in other countries, the profitability and efficiency of STEG are considerably low, and the leverage is significantly high. The IMF Report also mentioned that STEG's total debt accounted for 10.6 percent of GDP.

[3] The World Bank, "Project Appraisal Document" (for Eneryg Sector Improvement Project) http://documents1.worldbank.org/curated/en/296941561687292260/pdf/Tunisia-Energy-Sector-Improvement-Project.pdf

Figure 5. Benchmarking the STEG with Other Electricity SOEs



Sources: STEG 2019 financial statement and IMF staff calculations using Baum and others (2020).

Notes. STEG data are based on its 2019 financial statement. Profitability is measured by the return on assets; leverage by the ratio of non-current liabilities to assets and; efficiency by the ratio of operating revenue per employee. The blue dots are the median, top 75th and bottom 25th percentile of the distribution of each indicator in other countries. Operating revenue per employee is in millions of USD.

Note: Leverage was calculated as 'fixed liabilities / total assets',.on the analysis above. Meanwhile, "Degree of indebtedness (leverage)" in Table 4-8"Financial Soundness of STEG" is difined as 'loan / total assets'.

(Source: IMF Report)

Figure 4-7 Benchmarking STEG with other electricity SOEs

(2) Necessary undertakings to improve STEG's management

The following measures are considered necessary for financial improvement: (i) appropriate setting of electricity and gas tariff, (ii) cost reduction (improvement of fuel procurement, etc.), (iii) adoption of appropriate foreign exchange hedging instruments, and (iv) appropriate management of liabilities. However, EBRD and the World Bank are already in the process of providing relevant assistance and recommendations. It is desirable to continuously explore JICA's assistance opportunities in coordination with the World Bank and EBRD.

Chapter 5 Power System Stabilization for Massive Variable Renewable Introduction

5.1 Prospective of frequency and voltage fluctuations when introducing mass variable renewable energy and identification of issues

5.1.1 Issues of Massive Introduction of Variable Renewable Energy

In recent years, variable renewable energy (hereinafter referred to as "VRE (Variable Renewable Energy)"), such as photovoltaic power generation (PV) and wind power generation (WT), whose amount of power generation fluctuates greatly, has been introduced worldwide. Especially in the system, the frequency fluctuation becomes excessive, which is an immediate problem. The following two points cause the frequency fluctuation.

(1) Frequency Fluctuation of Power System

If the VRE, a fluctuated generation output (photovoltaic (PV) & wind turbine (WT)), massively connect to the electrical power system, the VRE power output fluctuation will overlap with the system load fluctuation, resulting in a more significant load fluctuation and increasing of the frequency fluctuation.

In order to check the frequency fluctuation when a large amount of VREs are connected to the power system, the following conditions are important to calculate the short-period frequency fluctuation in normal conditions.

・size of the fluctuation of electric power load
・size of the fluctuation of PV & WT output

In order to obtain accurate quantitative results, it is necessary these sizes are reasonable. Of course, if these sizes are large, severe results will be obtained.

However, at the moment, it is difficult to predict these sizes in the future accurately.

Therefore, to avoid underestimating the risk of increasing the frequency fluctuation, setting the power load fluctuation and output fluctuation of VRE to some extent is considered a rational choice.

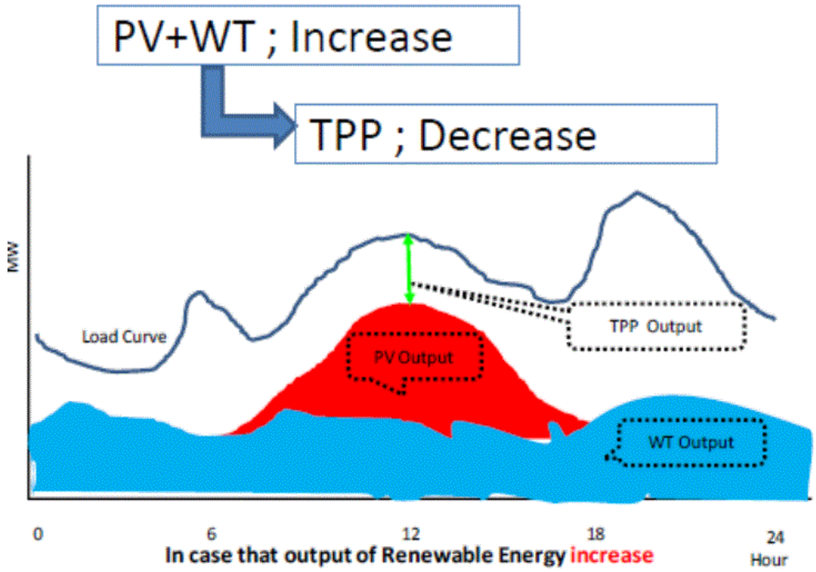
Based on the above, considering that this study is a feasibility study beforehand, the study team set load fluctuation and output fluctuation do not become too small.

(2) Decrease of TPP output

When a large number of VREs are connected to the grid, the output (MW) of thermal power plants (TPPs), which have the function of frequency regulation, needs to be suppressed in order to balance supply and demand, and the ratio (%) of thermal power output to grid capacity decreases.

As shown in the following equation and figure, the output of thermal power generator (TPP) decreases as PV and WT output increases.

Demand Load = TPP + PV + WT + others (PSPP, BESS)



(Source: JICA study team)

Figure 5-1 Load Curve

During the daytime holiday, the power demand load is small, and the output of PV (+ WT) is large, so the ratio of the output of the TPP decreases, and the frequency adjustment ability decreases.

Therefore, it is assumed that the risk of increasing the frequency fluctuation increases during holidays' daytime, and it is assumed that the daytime of holiday is the most severe case in which frequency fluctuation calculation should be executed.

5.1.2 Characterization of multiple power system stabilization measures

(1) Introduction of energy storage system (pumped storage power plant (PSPP), storage battery system (BESS))

In order to achieve the Tunisian government's target of a 30% share of renewable energy in electricity supply by 2030, it is considered realistic to supplement with the PSPP or adjustable speed pumped storage hydropower plant (ASPSPP) and BESS as a measure to reduce the frequency adjustment power due to the decrease in the operating amount of thermal power and hydroelectric generators. In Tunisia, there is a plan to introduce ASPSPP that has frequency adjustment capability during power generation and pumping, which is effective as a measure against frequency fluctuations associated with the mass introduction of VRE. However, it takes about 10 years to start operation, and it is not possible to deal with the immediate problems.

On the other hand, BESS can be introduced in about one year, and it is possible to set countermeasures such as plan contents and specifications, reflecting the latest situation. In addition, since there are few restrictions on the installation location, there is an advantage that it can contribute to improving the reliability of the power system by installing it at a location where not only frequency control but also voltage control and power flow control are required. Furthermore, although it is not suitable for large capacity, it has the advantage that it can be installed with a small capacity and can be relocated. In addition, the frequency adjustment effect of BESS does not depend on the installation location on the power system.

Therefore, in order to make the best use of BESS's multi-function, it is possible to propose measures such as selecting points to make the best use of BESS's voltage adjustment function. As will be discussed below, the MDHILLA substation on the north side of Lake Jerid, located in central Tunisia, is a one of promising candidate site.

Although there are many examples of the practical application of frequency control by BESS in the world, it is necessary to implement frequency control in consideration of the introduction status of VRE and the characteristics of each region. Therefore, it is not enough to simply introduce a general-purpose product, and fine adjustment is required especially for the control method.

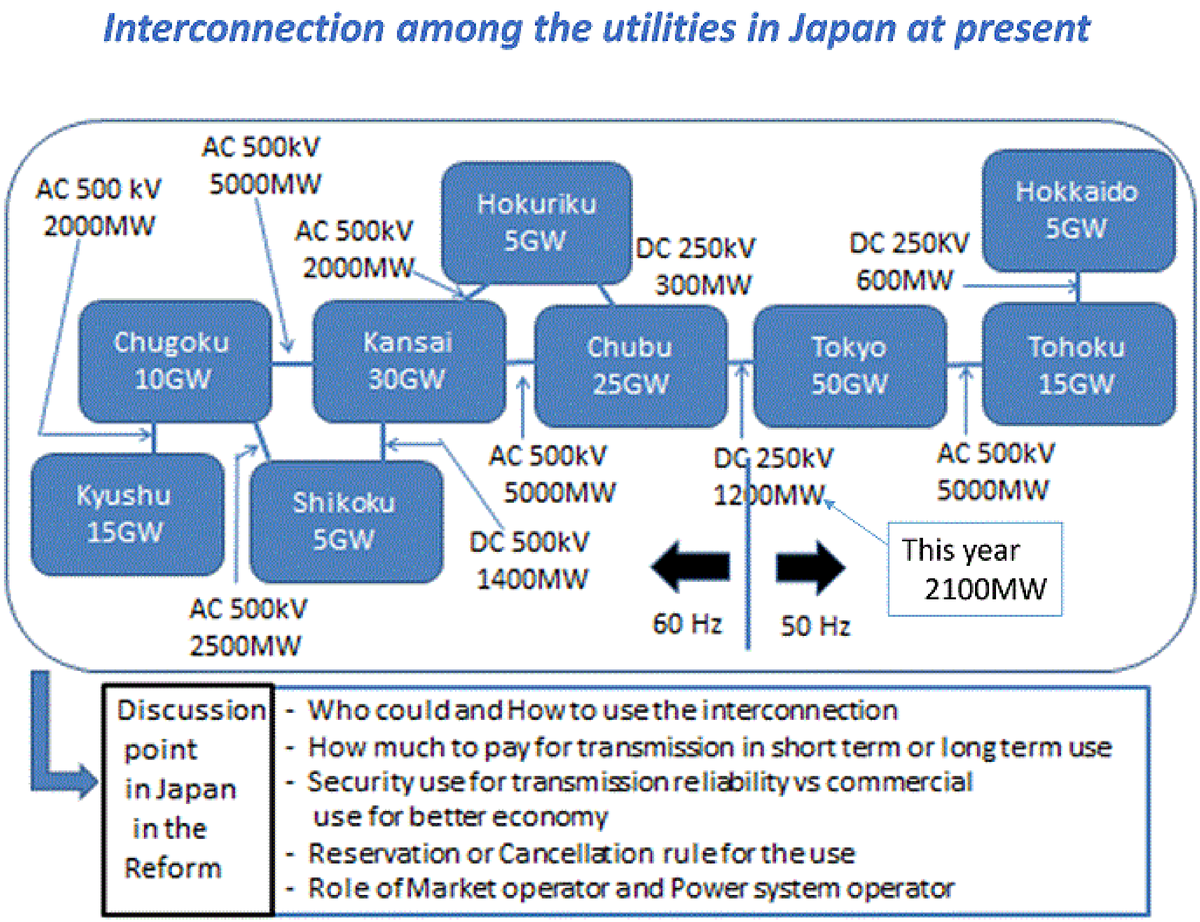
Therefore, it is important to accumulate such data in Tunisia, where there is no accumulation of short-period measured values of power demand fluctuation values and PV / WT output fluctuation values. In other words, it is desirable to aim to establish an efficient frequency control method utilizing BESS and ASPSPP by measuring various data and feeding back the results even after introducing the power storage equipment.

(2) Strengthening international grid interconnection

Strengthening the international interconnection line is an effective means to deal with the frequency fluctuation problem associated with the mass introduction of VRE, but political risks need to be considered. First, from the perspective of energy security, it is important to secure the frequency adjustment capability of the country.

Although there are two interconnection systems between Algeria and Libya, the interconnection with Libya has stopped its functions and usage of the interconnection between Algeria has been relatively low level for some reasons. The situations seems to be the one about 30 years ago in Japan when the transactions between the utilities were relatively low. In the case of Japan, Along with the development of interconnections and introduction of market mechanism (Power Sector Reform) accelerate the reform in power system operation.

Here, the history of the interconnection development is to be explained and its implication to Tunisia is briefly prospected.

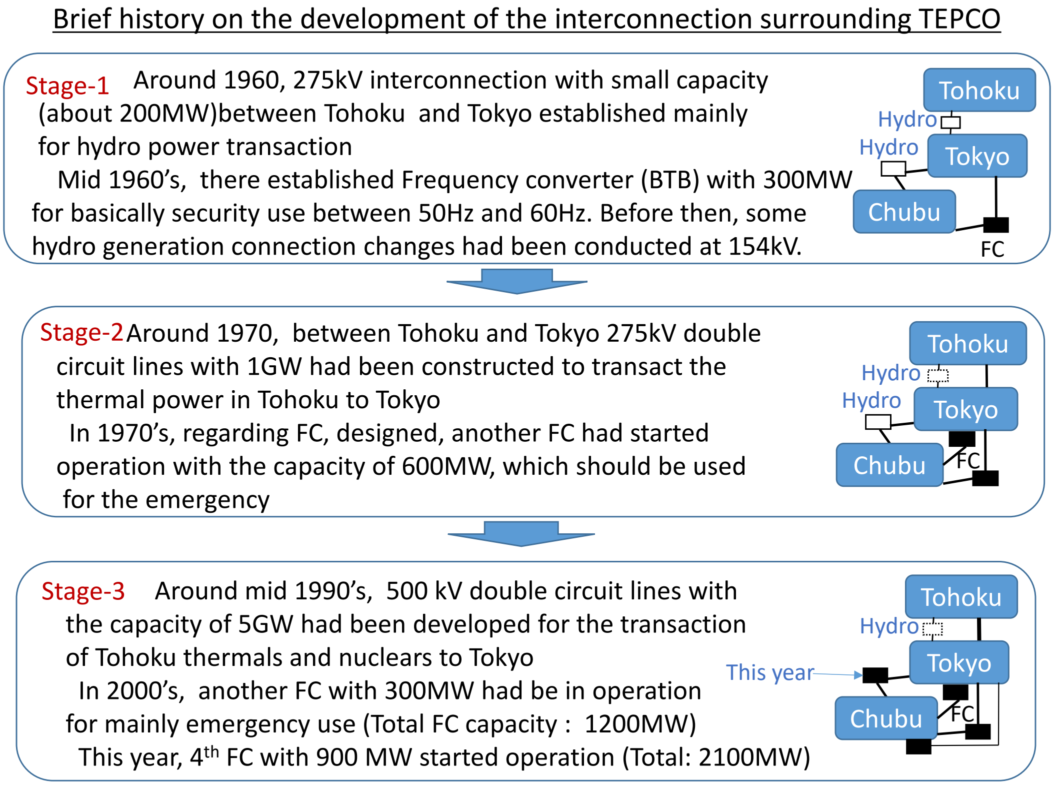


(Source: JICA study team)

Figure 5-2 Interconnection among the utilities in Japan at present

Each utility who control the frequency is almost same size as the system capacity in ENTSO (European Network of Transmission System Operators) and interconnection between utilities is almost same role of international interconnection. There should be no AC loop operation to avoid the loop flow problem as shown above.

Historically, the interconnections have been reinforced with step by step approach. In the case of Tokyo electric power system, the interconnections development is shown as follows.



(Source: JICA study team)

Figure 5-3 Brief history on the development of the interconnection surrounding TEPCO

Tokyo and Tohoku consist of the same frequency system, and the systems have been connected with AC interconnections while avoiding the loop flow.

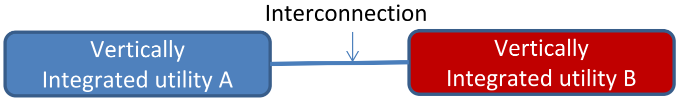
Tokyo and Chubu consist of 50 and 60Hz from the historical reasons, their interconnections have been developed by DC system (frequency convertor stations).

The usage of the interconnections has been transformed along with the Power Sector as shown below.

History on the development of Transaction through Interconnections-1

Utilities in Japan gradually have developed interconnection operation

➢ Before Deregulation : 5 type of transactions as shown below had been gradually developed.

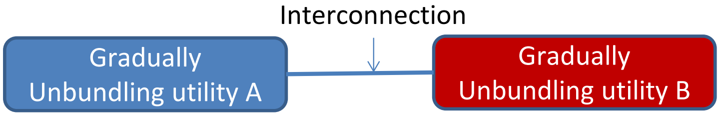


Transactions between A and B (Red: mainly generation dept., Blue: mainly operation dept.)

- ✓ a. Long-term* contracted transactions (*usually more than 10 years)
  such as Development of large generation plants to improve economy agreed by A and B
- ✓ b. Annual* base contracted transaction (*contracted in each year)
  such as to deal with the prospected short or surplus of generation powers in the year
- ✓ c. Economic improvement transaction (daily basis)
  In such case that generation reduction in A and generation increase B should bring about improvement in generation operation economy
- ✓ d. Emergency transaction (at any time if required, usually in short time (within several hours)
  In such case that unexpected large generation plant shut-down could cause power shortage
- ✓ e. Power system operation adjustment power between A and B
  In such case that to deal with the mismatch brought by the frequency controls in A and B

History on the development of Transaction through Interconnections-2

Utilities in Japan gradually have coped with new interconnection operation matched with the Reform requirements such as market transactions



➢ After Deregulation (Introduction of the market mechanism):

(1) Right after the introduction of the deregulation

" c. Economic improvement transaction (daily basis)" could be joined by new suppliers
Rest of 4 type transactions were conducted among the incumbent entities

(2) Some years after the introduction of the deregulation

" a. Long-term contracted transactions by new suppliers " were admitted
" b. Annual base contracted transactions by the incumbents " were abolished and over the counter (OTC*) transaction in the power exchange market was introduced to realize higher transparency (* Market Operator in Egypt seems to be OTC)
" c. economic improvement transaction were transformed into day-ahead spot-market in the power exchange market to realize higher market mechanism

(3) Latest situations

Transaction through interconnection could be conducted in the day ahead spot-market. Financial Transmission Right (FRT) is available for avoiding the contractual risks between the entity in A and the one in B. Ancillary service sharing for RE.

(Source: JICA study team)

Figure 5-4 History on the development of Transaction through Interconnections

As shown above, in order to effectively utilize electricity trading in the era of mass introduction of VRE, not only the strengthening of interconnection lines but also the introduction of market mechanisms and other electricity sector reforms have been implemented. Therefore, even in Tunisia, it should be modified not only by strengthening the international interconnection line but also by reforming the electric power sector such as introducing domestic and inter-country market mechanisms. The power system operator and planners, therefore, should prepare for the uncertainties in power transactions in Tunisia while setting the proper power system usage rules to avoid the adverse effects in the power system sound operation.

From the point of view of maintaining the power system security, there is a basic principle that when a system accident occurs in one system, the other systems can open their interconnection points with the objective of preventing the accident from spreading and collapsing together. Therefore, it is necessary to strengthen the security level of each system after the disconnection in each system that is interconnected as mutual reinforcement of each power system. Particularly in the case of the AC grid, power system operators need to be prepared for the worst-case scenario of stand-alone system operation after the disconnection of the AC grid for the purpose of preventing the spread of grid accidents. In the case of the DC interconnections, so called "power modulation control" system with the conventional DC control system might be applied to reinforce the security level of the power system. For example, in some DC system in Japan, emergency power supply system activating the power supply within some hundreds milliseconds to respond to the frequency rapid and deep drop in the one system. In another example, the automatic frequency control system in normal operation has been attached in DC control system to supply the ancillary services from one system to the other.

Tunisian power system planners along with the operators might make use of such experiences in Japan as described above and realize the most appropriate the interconnection functions while avoiding the possible adverse effects caused by the interconnection.

5.1.3 Methodology of the study for power system stabilization (necessity of BESS)

The problem of increased frequency fluctuations due to the mass introduction of PV / WT is the increase in output fluctuation sources and the decrease in the operating volume of thermal and hydroelectric generators that can suppress and control frequency fluctuations. Strengthening international interconnections is an effective means of addressing the frequency fluctuation problem associated with the mass introduction of VRE, but political risks need to be considered. First, from the perspective of energy security, it is essential to secure the frequency adjustment capability of the country. Adding pumped storage power generation (PSPP), variable speed pumped storage power generation system (ASPSPP), or BESS would be feasible. However, pumped storage power generation (PSPP) or variable speed pumped storage power generation system (ASPSPP) is very time-consuming to build.

On the other hand, BESS can be introduced in about one year, and measures such as plan contents and specifications can be set to reflect the latest situation. In addition, since there are few restrictions on the installation location, there is an advantage that it can contribute to improving the reliability of the power system by installing it in a location where not only frequency control but also voltage control and power flow control are required. For this reason, in this survey, we reviewed the existing grid plan and power development plan, examined grid stabilization measures for mass introduction of VRE based on the existing plan, and the possibility of BESS distributed installation.

5.1.4 Items of the study for power system stabilization

(1) Review of Power System plan / Power Development plan

Confirm the existing system plan with STEG and evaluate its validity and issues.

Receive power plan data for 2026 and 2030 from STEG and confirm the status of the plan. Information was additionally processed so that the supply and demand balance could be examined. Based on this data, we conducted a supply and demand simulation. The supply reliability for each year was calculated and evaluated.

(2) Study of short cycle constraints

As the amount of PV and WT introduced whose output fluctuates sharply with changes in the weather increases, the number of thermal and hydroelectric generators in operating and the ratio of thermal and hydroelectric generators will decrease, and the frequency adjustment capacity will decrease. Therefore, the frequency fluctuates greatly, which may lead to deterioration of power quality and damage to power generation equipment.

In order to maintain the frequency properly, it is necessary to carry out frequency control according to the power demand and the magnitude and cycle of PV / WT output fluctuations. In order to evaluate such a phenomenon, a frequency fluctuation simulation covering the control area of governor-free (GF) and load frequency control (LFC) is mainly required.

As a frequency fluctuation simulation tool, the "standard model of power supply and demand / frequency simulation" of the Institute of Electrical Engineers of Japan is used as necessary. In addition, since it is important to consider the duty cycle, which has a large effect on the life of BESS, it is necessary to set the control frequency and control sensitivity appropriately.

(3) Examination of long-period constraints

When formulating a long-term power development plan that assumes the mass introduction of PV / WT, it is necessary to consider its time output characteristics and seasonal output characteristics, and it is important to formulate an economic power supply plan every 8,760 hours through a year.

1) Review and analysis of power demand forecast

Organize related materials and review historical electricity demand information.

 Electric power demand (every hour, one year) was evaluated and analyzed, and future load profile (peak occurrence time, load factor, etc.) was evaluated.

- The growth rate and load factor of expected demand were reviewed.

2) Review, analysis and recommendations of medium- to long-term power development plan

Obtain the latest meddle- and long-term development plans for generation, transmission / substation, and distribution, and confirm the contents of each new development and renovation plan while paying attention to mutual consistency.

In the review and analysis of the power development plan, the actual supply capacity including PV / WT will be evaluated based on the actual situation such as the decrease in supply capacity due to aging deterioration, etc., and if necessary, a revision plan will be proposed.

Furthermore, supply/demand balancing simulations will be conducted based on the demand forecast and the power development plan. It is proposed that a revised development plan that adjusts for the excess and deficiency of the supply capacity required to secure the supply reliability target value (for example, LOLE 24 hours) for the planned target year. For the analysis, the supply/demand balancing simulation program PDPAT II is used, which can analyze the most economical power supply operation every 8,760 hours a year.

(4) Evaluation of the necessity of system voltage control and power flow control (examination of BESS distributed arrangement)

Evaluate the possibility of distributed installation of BESS from the necessity of system voltage control and power flow control.

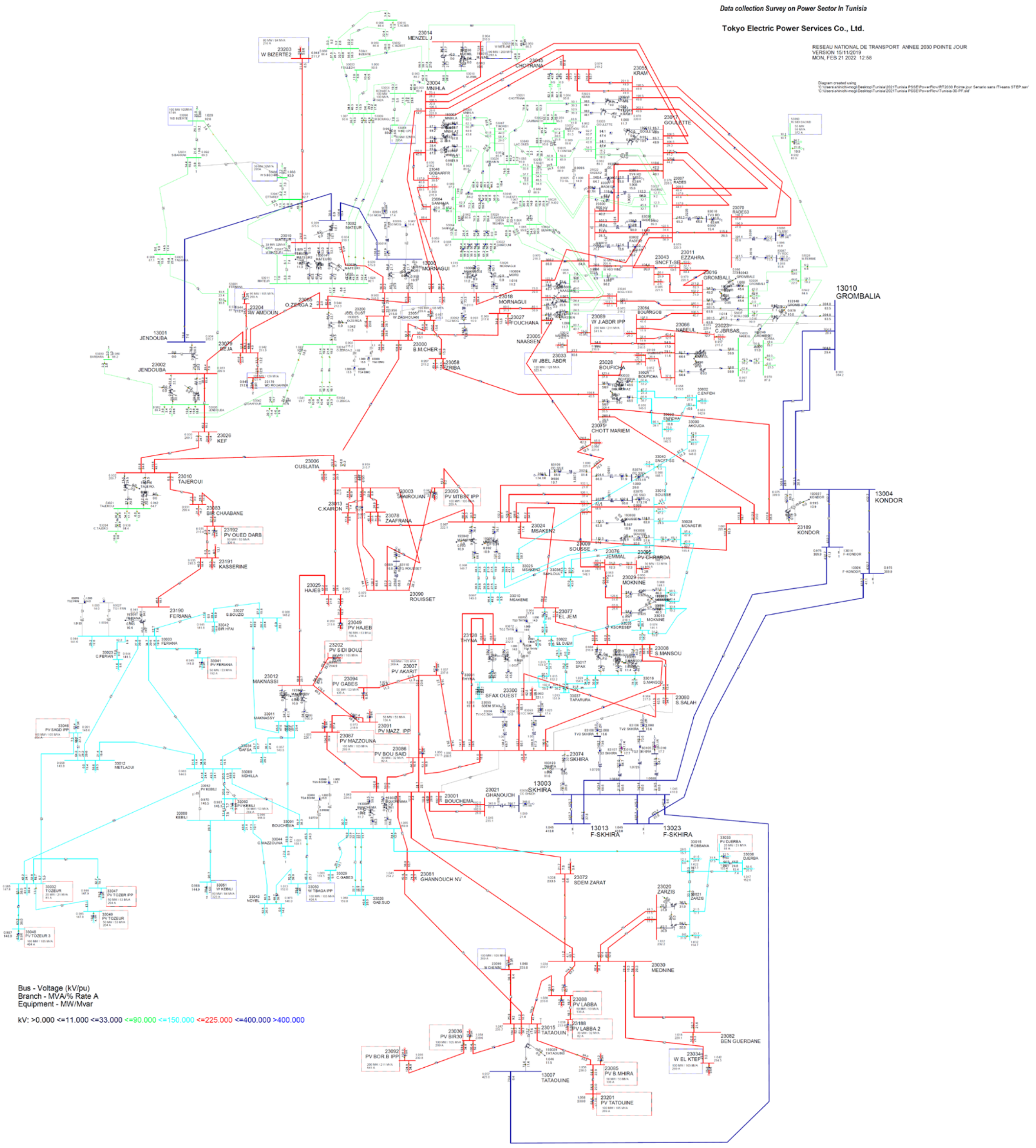
(5) Economic evaluation of system stabilization measures

Economic Analysis for grid stabilization measures is to be conducted.

5.2 Review for power system planning

5.2.1 Transmission system constraints (ie: transmission capacity shortage)

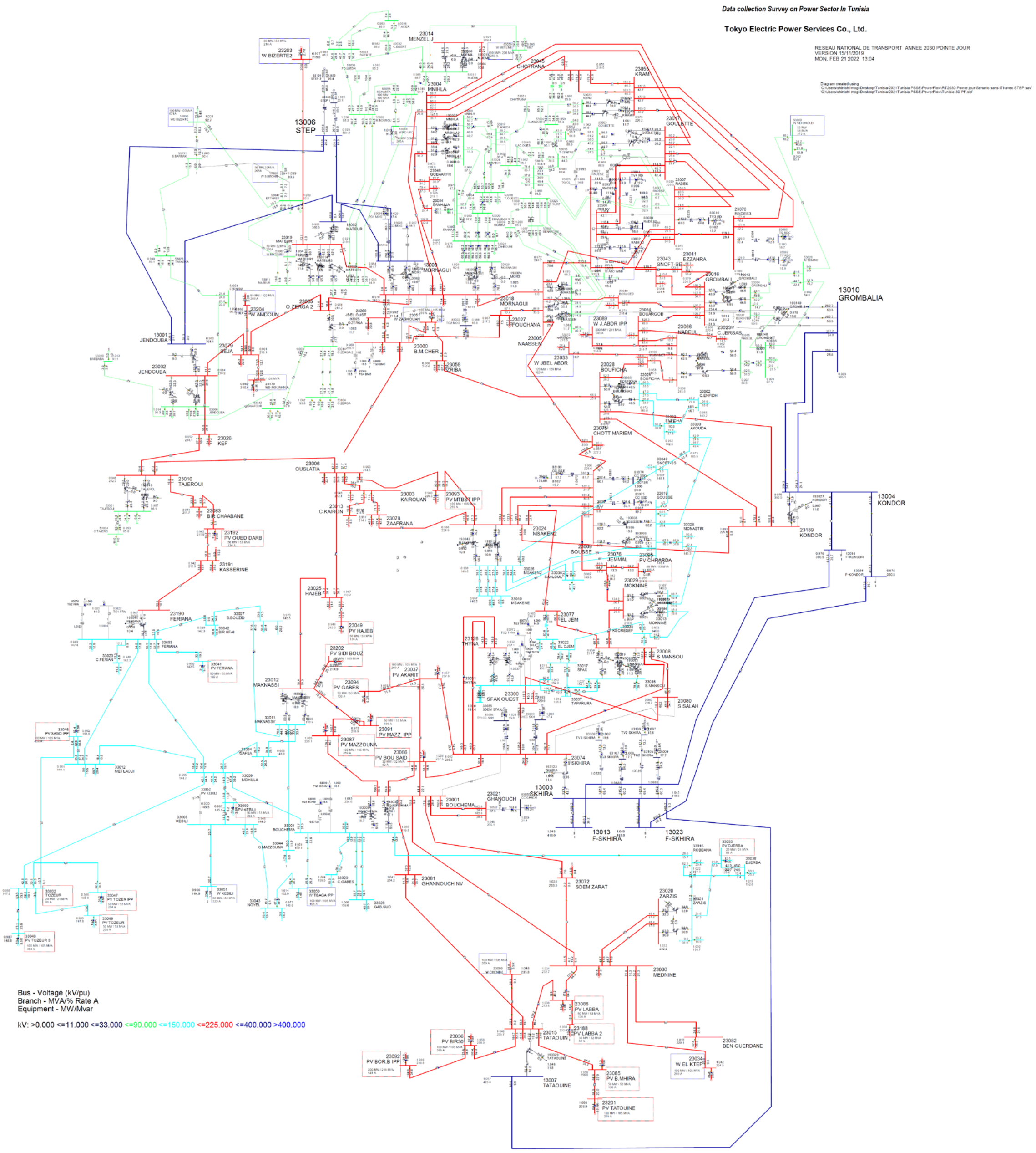
The power system analysis data at peak load in 2026 and 2030 (with/without PSPP) incorporating the generation development plans of Variable Renewable Energy (VRE) and PSPP was provided by STEG in August 2021. As a result of calculating the power flow for them, there was no equipment that would be overloaded (i.e.: transmission capacity shortage) even in the event of an N-1 single equipment accident contingency. Therefore, it is considered that a transmission planning corresponding to the power supply development has been made appropriately. Figure5-5 and Figure5-6 show the power flow calculation results in 2030 (without/with PSPP) at peak load when all equipment is sound. (See ANNEX 5-1 and 5-2 for details)



(Source: JICA study team)

Detailed map: ANNEX 5-1

Figure5-5 Power Flow diagram in 2030 without PSPP



(Source: JICA study team)

Detailed map: ANNEX 5-2

Figure5-6 Power Flow diagram in 2030 with PSPP

5.2.2 Transient stability

Using the network data received from STEG in August 2021, the study team examined the synchronism of the synchronous generator in the event of a three-phase short-circuit accident in the transmission line in 2026 and 2030. The dynamic data of newly added synchronous generators was assumed and was added to the data at the time of METI Study in 2019. The models of VRE were represented as negative constant current load models. For general loads, the active power component was treated as a constant current model, and the reactive power component was treated as a constant admittance model.

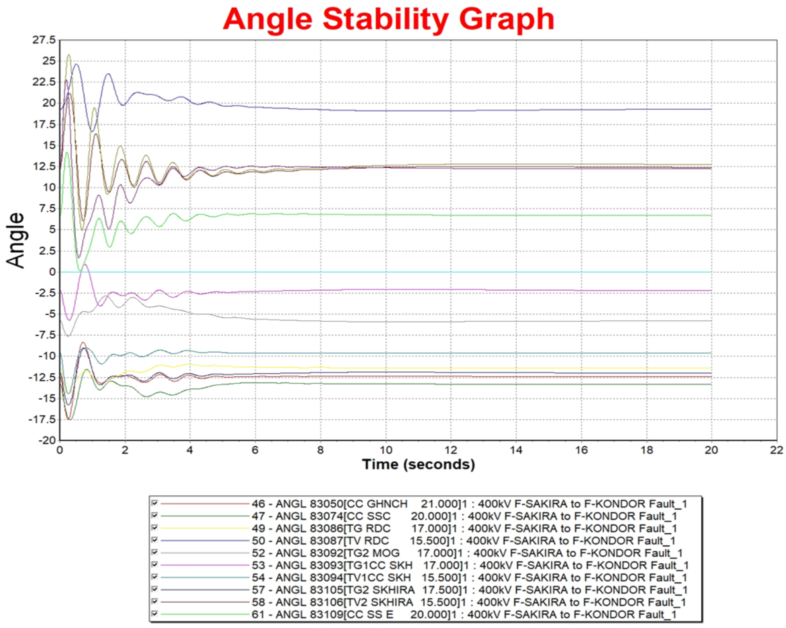
The transmission line with the largest phase difference at both ends of the transmission line was targeted for the accident. It was examined for 400kV, 225kV and 150kV systems respectively. In these simulations, as shown in Figure 5-7 to Figure 5-15, the angle swing of generators converged, and there were no issues in terms of transient stability as shown in Table 5-1.

Table 5-1 Transient stability simulation results (summary)

Year	PSPP	Target transmission line in one circuit fault							Type of fault	Fault clearance time (sec)	Simulation results
		Voltage	from point (fault side)			to end point					
2026		400 kV	13013	F-SKHIRA	-	13014	F-KONDOR		Three-phase short-circuit	0.07	Stable
		225 kV	23008	S.MANSOU	-	23074	SKHIRA		Three-phase short-circuit	0.07	Stable
		150 kV	33001	BOUCHEMA	-	33009	MDHILLA		Three-phase short-circuit	0.14	Stable
2030	without	400 kV	13013	F-SKHIRA	-	13014	F-KONDOR		Three-phase short-circuit	0.07	Stable
		225 kV	23008	S.MANSOU	-	23074	SKHIRA		Three-phase short-circuit	0.07	Stable
		150 kV	33001	BOUCHEMA	-	33009	MDHILLA		Three-phase short-circuit	0.14	Stable
2030	with	400 kV	13013	F-SKHIRA	-	13014	F-KONDOR		Three-phase short-circuit	0.07	Stable
		225 kV	23008	S.MANSOU	-	23074	SKHIRA		Three-phase short-circuit	0.07	Stable
		150 kV	33001	BOUCHEMA	-	33009	MDHILLA		Three-phase short-circuit	0.14	Stable

(Source: JICA study team)

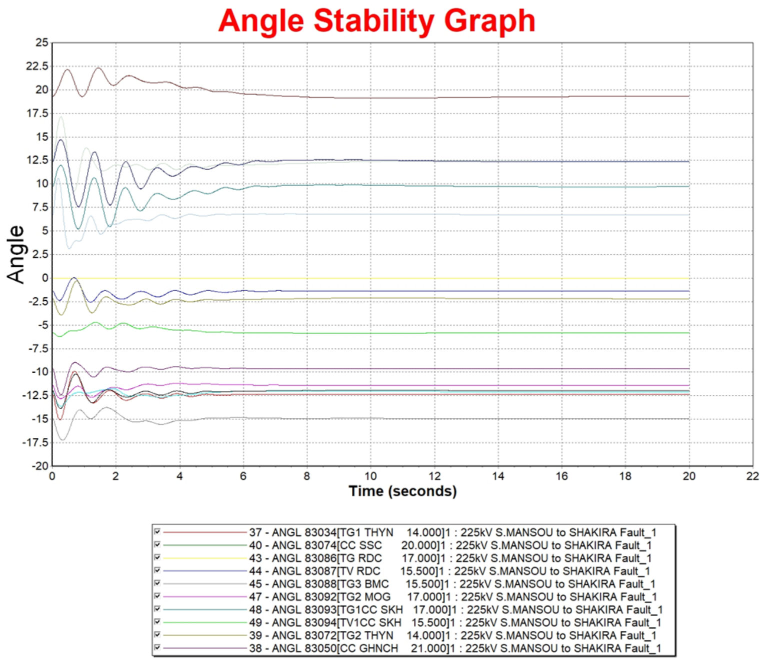
From Bus Number	From Bus Name	To Bus Number	To Bus Name	Id	Fault	Fault clearance
13013	F-SKHIRA 400.00	13014	F-KONDOR 400.00	1	3 Phase Short Circuit	0.07 second



(Source: JICA study team)

Figure 5-7 Transient stability simulation in 2026 (400 kV transmission line)

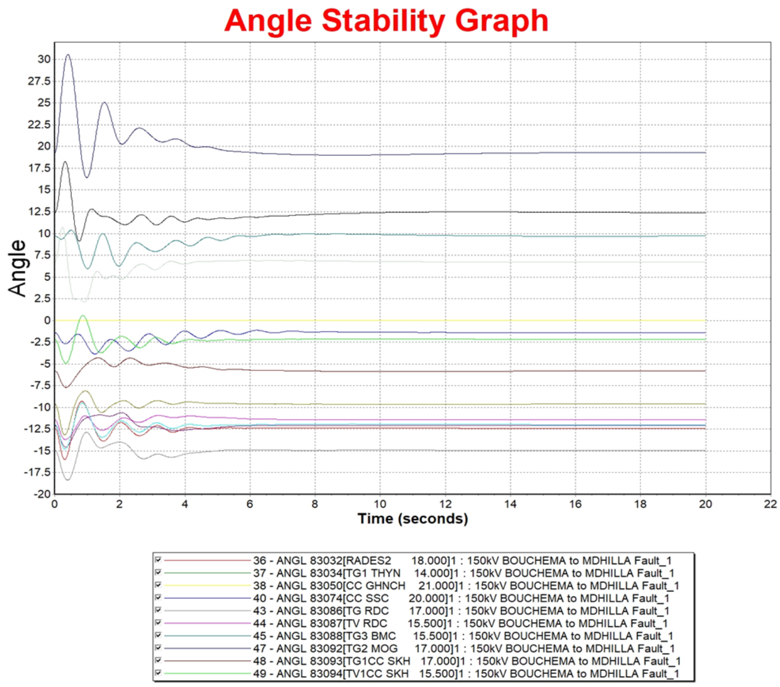
From Bus Number	From Bus Name	To Bus Number	To Bus Name	Id	Fault	Fault clearance
23008	S.MANSOU 225.00	23074	SKHIRA 225.00	2	3 Phase Short Circuit	0.07 second



(Source: JICA study team)

Figure 5-8 Transient stability simulation in 2026 (225 kV transmission line)

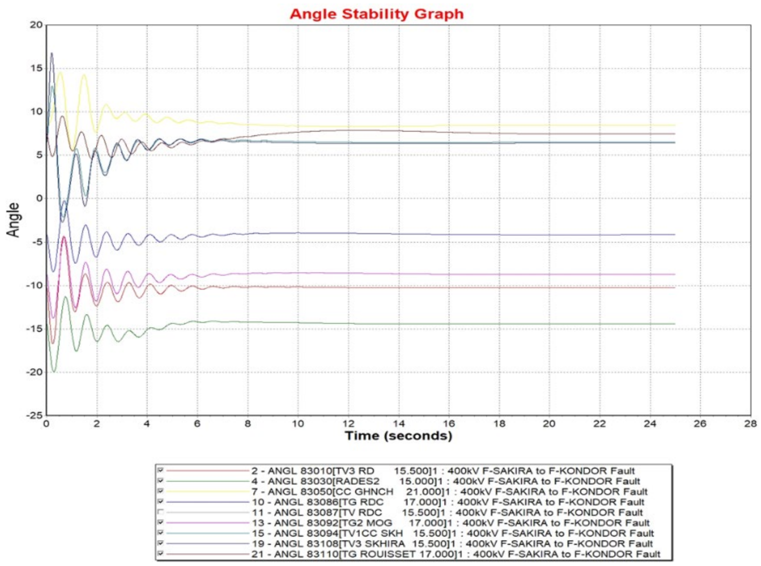
From Bus Number	From Bus Name	To Bus Number	To Bus Name	Id	Fault	Fault clearance
33001	BOUCHEMA 150.00	33009	MDHILLA 150.00	1	3 Phase Short Circuit	0.14 second



(Source: JICA study team)

Figure 5-9 Transient stability simulation in 2026 (150 kV transmission line)

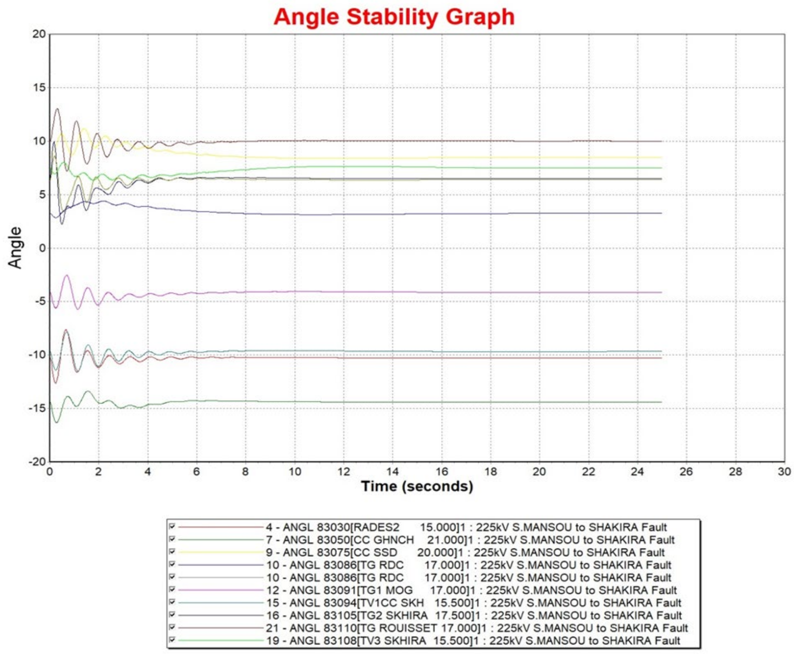
From Bus Number	From Bus Name	To Bus Number	To Bus Name	Id	Fault	Fault clearance
13013	F-SKHIRA 400.00	13014	F-KONDOR 400.00	1	3 Phase Short Circuit	0.07 second



(Source: JICA study team)

Figure 5-10 Transient stability simulation in 2030 without PSPP (400 kV transmission line)

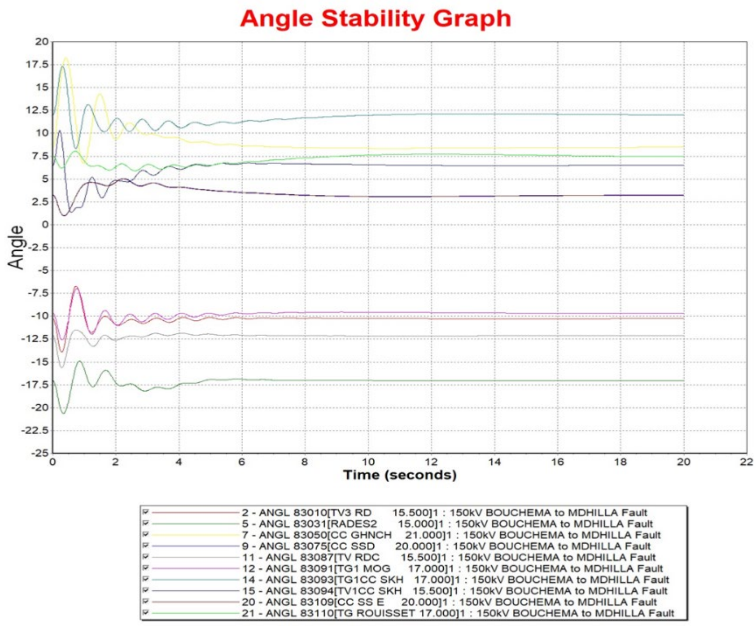
From Bus Number	From Bus Name	To Bus Number	To Bus Name	Id	Fault	Fault clearance
23008	S.MANSOU 225.00	23074	SKHIRA 225.00	2	3 Phase Short Circuit	0.07 second



(Source: JICA study team)

Figure 5-11 Transient stability simulation in 2030 without PSPP (225 kV transmission line)

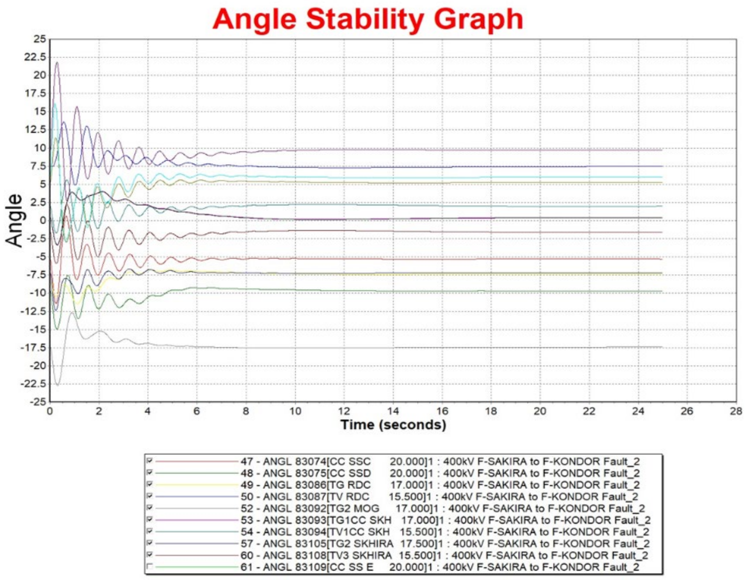
From Bus Number	From Bus Name	To Bus Number	To Bus Name	Id	Fault	Fault clearance
33001	BOUCHEMA 150.00	33009	MDHILLA 150.00	1	3 Phase Short Circuit	0.14 second



(Source: JICA study team)

Figure 5-12 Transient stability simulation in 2030 without PSPP (150 kV transmission line)

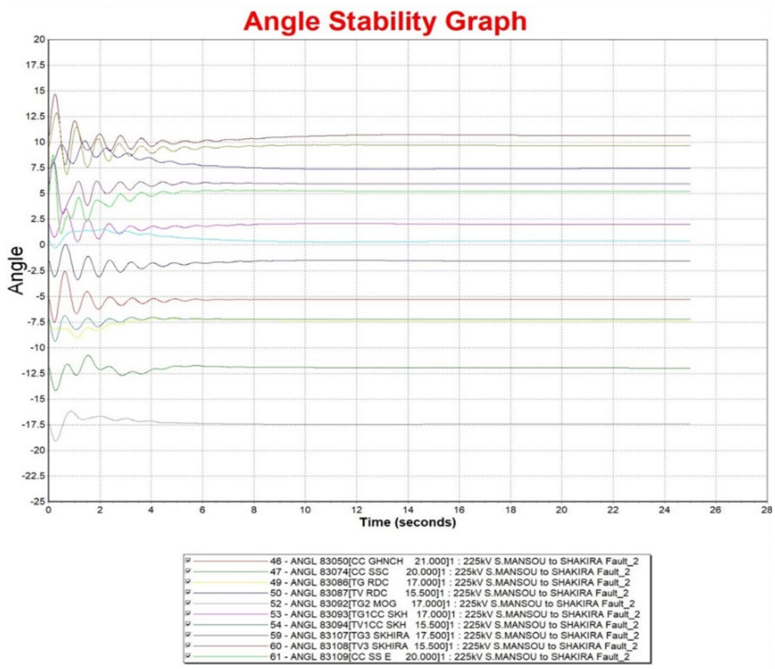
From Bus Number	From Bus Name	To Bus Number	To Bus Name	Id	Fault	Fault clearance
13013	F-SKHIRA 400.00	13014	F-KONDOR 400.00	1	3 Phase Short Circuit	0.07 second



(Source: JICA study team)

Figure 5-13 Transient stability simulation in 2030 with PSPP (400 kV transmission line)

From Bus Number	From Bus Name	To Bus Number	To Bus Name	Id	Fault	Fault clearance
23008	S.MANSOU 225.00	23074	SKHIRA 225.00	2	3 Phase Short Circuit	0.07 second



(Source: JICA study team)

Figure 5-14 Transient stability simulation in 2030 with PSPP (225 kV transmission line)

From Bus Number	From Bus Name	To Bus Number	To Bus Name	Id	Fault	Fault clearance
33001	BOUCHEMA 150.00	33009	MDHILLA 150.00	1	3 Phase Short Circuit	0.14 second

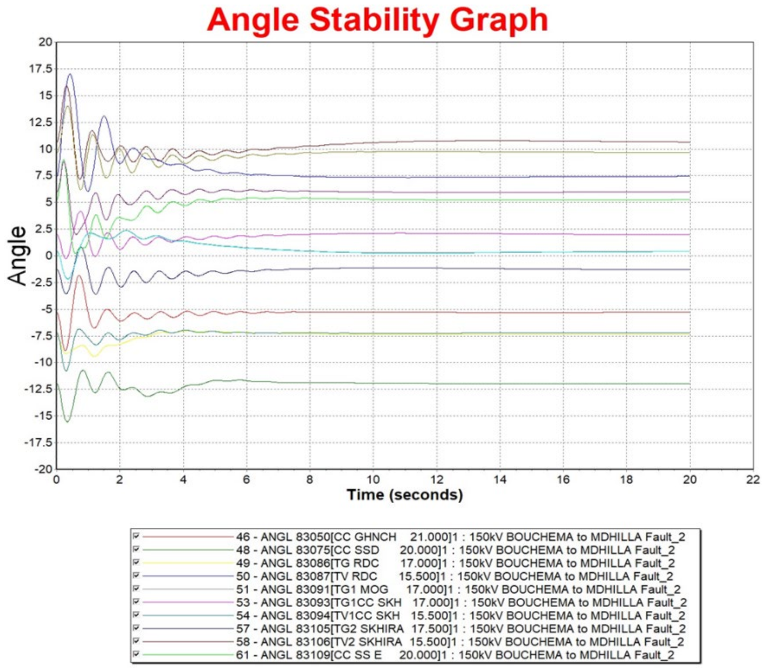
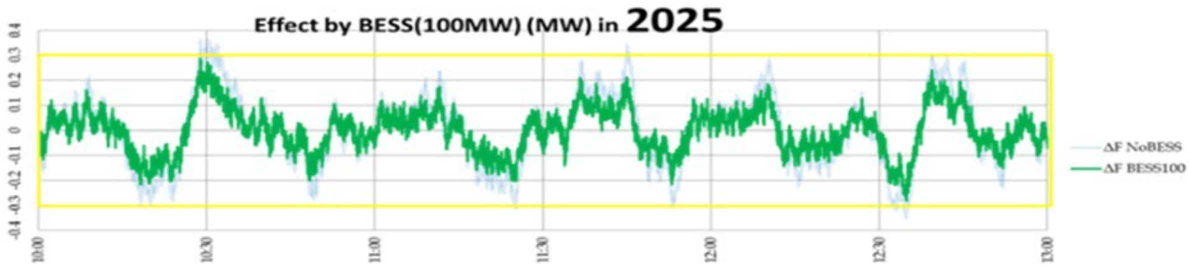


Figure 5-15 Transient stability simulation in 2030 with PSPP (150 kV transmission line)

5.3 Proposal of optimal stabilization measures from the viewpoint of effectiveness, cost effectiveness, etc.

5.3.1 Implementation of short-period fluctuation simulation analysis

This tool operates on MATLAB. Each element of the supply / demand / frequency control system (various generators, BESS, each control system, etc.) is prepared as a standard model, and standard data based on actual results is prepared for power demand and naturally fluctuating power supply data.



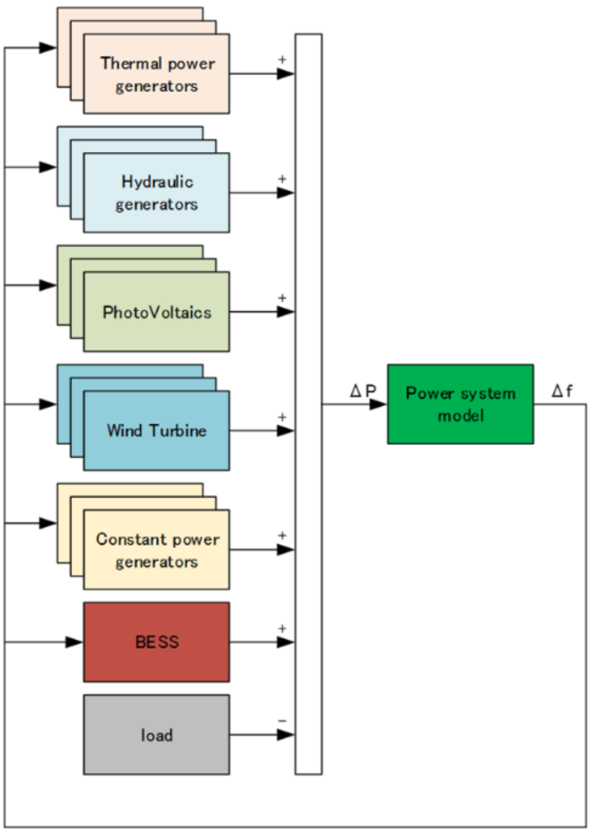
(Source: JICA study team)

Figure 5-16 Sample of power supply / demand / frequency simulation analysis

For the calculation of the frequency fluctuations in the power system, the frequency fluctuation calculation model using MATLAB/Simulink is used.

Focus on the point that the system frequency varies with the balance of load consumption and power generation and calculate the frequency fluctuation using the these active power of load consumption and all generators including the VRE source such as solar power and wind power generators that connected to the grid.

Figure on the right shows a conceptual calculation model by MATLAB/Simulink.



(Source: IEEJ, Technical Report No.1386, "Recommended practice for simulation models for automatic generation control")

Figure 5-17 Model of power supply / demand / frequency simulation

5.3.2 Necessary number of operating units of TPP

As mentioned above, when a large amount of VRE such as PV and WT is introduced, especially in the daytime of a holiday where electric power demand is small, in order to secure the load for operating TPP, It is necessary to take measures such as suppressing PV and WT output.

In carrying out this simulation, it is assumed the amount of load to be secured as follows.

It is assumed that five or more TPPs are always driven in order to reduce the influence on the power system when one of the TPPs drops out.

The need for 5 or more units can be explained as follows.

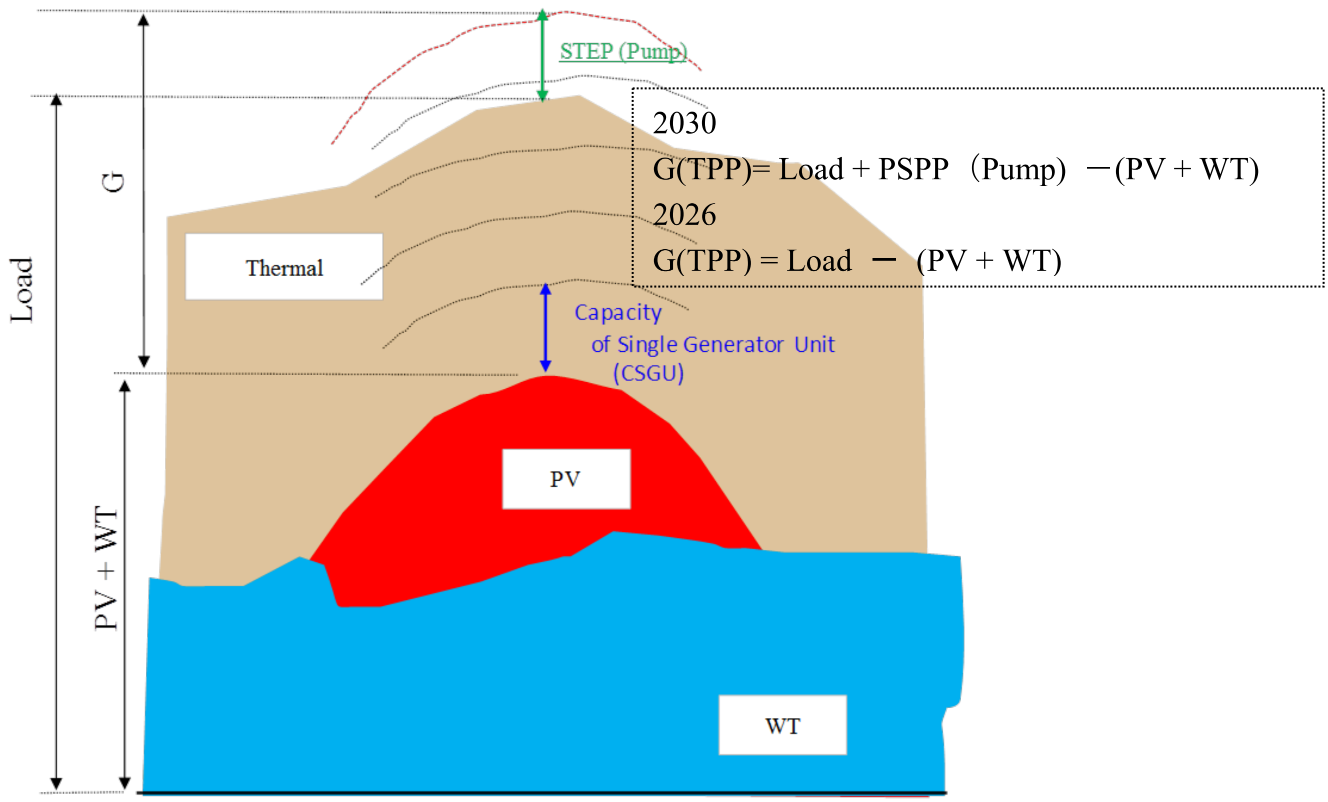
According to the materials provided from the dispatching center of STEG, the Tunisian power-frequency characteristic constant is 13 %MW/Hz.

If one unit drops out during the operation of five TPPs, the dropout ratio is 20%.

When the Power-frequency characteristic constant is 13%MW/Hz, which is given by STEG, if 20% of power generation dropout occurs, a frequency decrease of about 1.5 Hz occurs. (1.5Hz=20/13)

When a frequency decrease of 1.5 Hz occurs, load shedding (by UFR) might be activated to prevent frequency drop assuming that the frequency of load shedding is 48.5 Hz. Therefore, the condition under which load shedding is unnecessary should be that one TPP out during five TPPs in operation.

Therefore, the operation of five or more TPPs should be preserved to realize the reliable system operation.



(Source: JICA study team)

Figure 5-18 Power supply curve

5.3.3 Calculation Condition for short-period fluctuation simulation

(1) Main Power System condition

・Load-frequency characteristic constant :2 %MW/%Hz

・Assuming no frequency adjustment via International connection

(Tunisian domestic frequency fluctuations should be treated with Tunisian own measures)

・Peak Power Load and Installed Capacity of PV & WT

Table 5-2 Peak Power Load and Installed Capacity of PV & WT

Year	2026	2030
Peak Power Load (MW)	5,180	6,000
PV Installed capacity (MW)	1,446	2,186
WT Installed capacity (MW)	1,122	1,622

(Source: STEG)

(2) Demand load curve and output curve of PV & WT

1) "Load – PV – WT" Curve in 2030

From the power demand load, the output of PV and WT is subtracted, the demand to be supplied by the thermal power generation is sought, and "Load - PV - WT" curve for 1 year in 2030 is shown below.

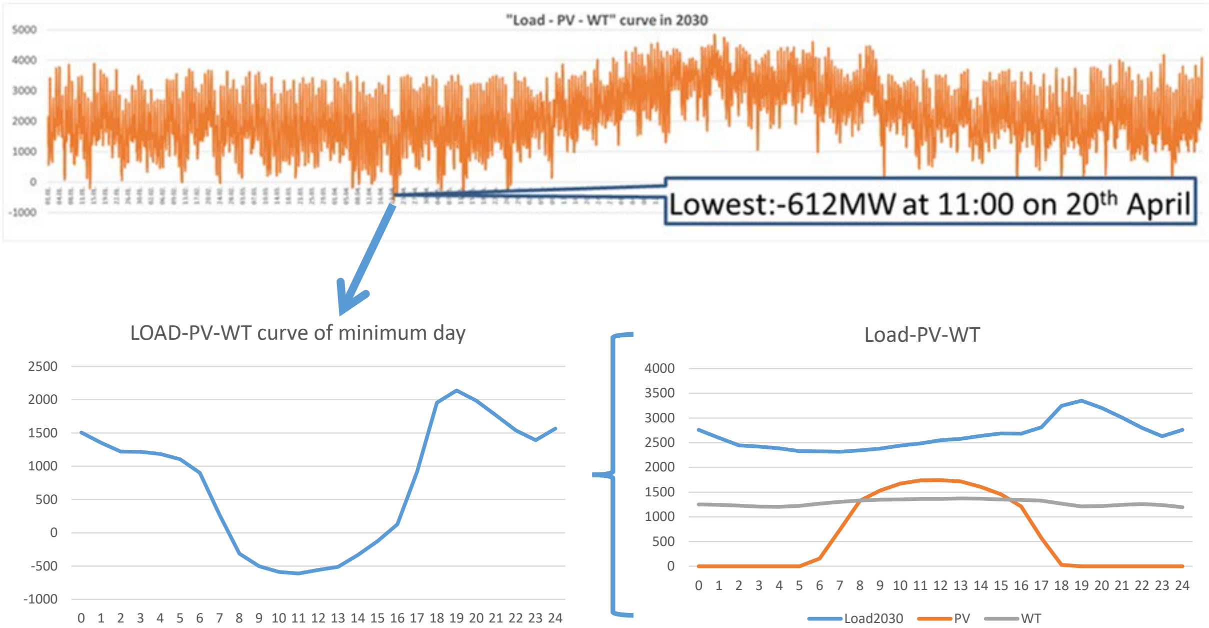
There are several cases where the load of "Load - PV - WT" becomes negative, and it can be confirmed that cases falling below 1,000 MW are frequent.

If the value of "Load-PV-WT" is small, it is necessary to limit the output of PV/WT, and if the adjustable speed pumped storage generator ASPSPP can be operated, it is also necessary to operate the pump of ASPSPP to secure the load to operate the thermal generator.

Basically, since the thermal generator implements the control of the suppression of short-period frequency fluctuation, the case where the number of thermal generators in operation is reduced becomes a more severe condition for the suppression of short-period frequency fluctuation.

Therefore, the value of the load demand "Load-PV-WT" to be supplied by the thermal generator is the smallest at 11:00, and this time period will be the most severe time period in the short-period frequency fluctuation.

In addition, since the ratio of PV and WT output to demand load is large, the double peak curve is not seen in the often seen such a day in such as Japan.

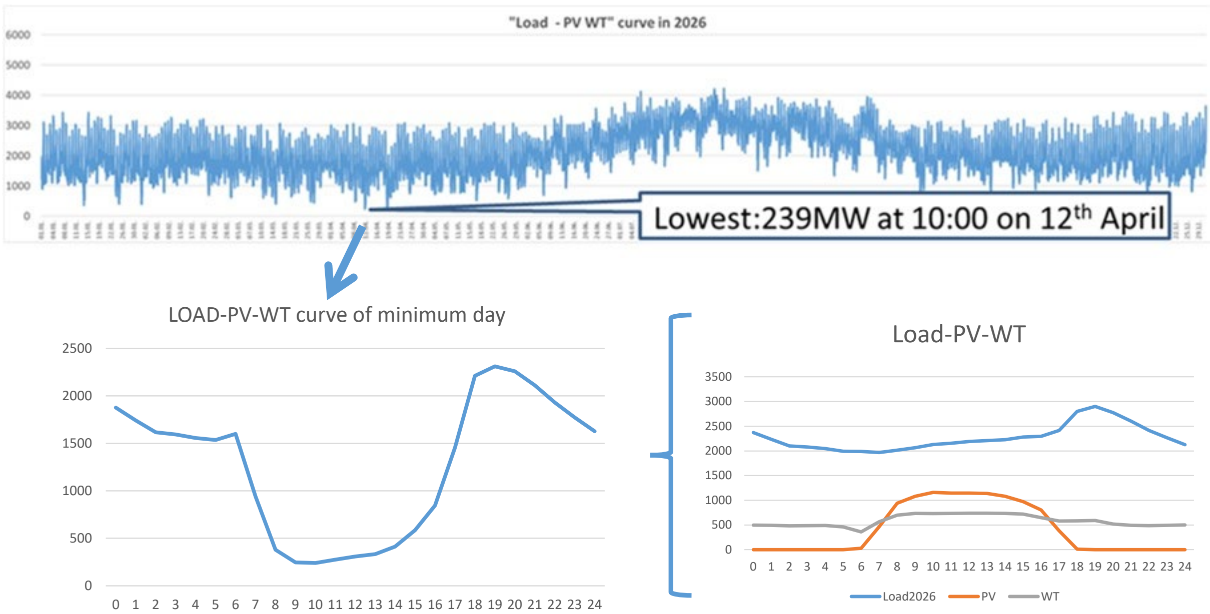


(Source: JICA study team)

Figure 5-19 "Load - PV - WT" Curve in 2030

2) “Load – PV – WT” Curve in 2026

From the power demand load, the output of PV and WT is subtracted, the demand to be supplied by the thermal power generation is sought, and "demand - PV - WT" curve for 1 year in 2026 is shown below.



(Source: JICA study team)

Figure 5-20 "Load - PV - WT" Curve in 2026

There are one case where the load of "Load - PV - WT" becomes negative, and it can be confirmed that cases falling below 1,200 MW are frequent.

If the value of "Load-PV-WT" is small, it is necessary to limit the output of PV/WT, and if the adjustable speed pumped storage generator ASASPP can be operated, it is also necessary to operate the pump of ASASPP to secure the load to operate the thermal generator.

Basically, since the thermal generator implements the control of the suppression of short-period frequency fluctuation, the case where the number of thermal generators in operation is reduced becomes a more severe condition for the suppression of short-period frequency fluctuation.

Therefore, even in 2026, the value of the load demand "Load-PV-WT" to be supplied by the thermal generator is the smallest at 11:00, and this time period will be the most severe time period in the short-period frequency fluctuation.

Since the value of "Load - PV - WT" is the lowest at 11 o'clock, 10 to 13 o'clock is set as 'target time zone' of this simulation.

In addition, since the ratio of PV and WT output to demand load is large, the double peak curve is not seen in the often seen such a day in such as Japan.

5.3.4 Demand load data

Create demand load data for calculation

Data for 1 second is required for frequency calculation in MATLAB / Simulink, so 60 minutes value of the minimum day is connected by a straight line, and the value is obtained every 1 second. In addition, this demand data is added for every 1 second for calculation by adding the short cycle fluctuation obtained from the real side value of Japan.

5.3.5 Supply balance

(1) Supply balance in 2030 Demand load curve for target timezone in this simulation

In the off-peak pattern of 2030, in order to secure the amount of power generated by five TPPs (CCGT), the output of PV / WT is assumed to be suppressed as shown in the table below.

In this simulation, it is assumed to preferentially suppress PV that is relatively easy to predict output. As a result, PV output is 0. The supply balance for 2030 used in the simulation is shown below.

Table 5-3 Supply Balance in 2030

Year: 2030	Capacity	Operation amount (Amount of sopped equipment)	Balance (No PSPP case)	Balance (400MW PSPP case)
TPP	CCGT: 5 units	-	1,200-1,500MW	1,500-1,800MW
PV	2,186MW	0 MW (Δ 2,186MW)	0 MW	0 MW
WT	1,622MW	1,322MW (Δ 300MW)	900-1,350MW	900-1,350MW
Generation total			2,400-2,600MW	2,750-2,950MW
ASPSPP	400MW	-	0 MW	350MW (±50MW)
Load			2,400-2,600MW	2,400-2,600MW

(Source: STEG)

The simulation also is carried out when pumping up ASPSPP (200 MW * 2 units) scheduled to start operation in 2029.

(2) PSPP (ASPSPP : Adjustable Speed Pumped Storage Power Plant) Supply balance in 2030

ASPSPP is modeled as follows.

・ASPSPP is a doubly-fed generator motor, and the electrical response during pumping operation can follow the input / output command of demand-supply / frequency control within the adjustable speed range.

・The adjustable speed pumped load range is generally 75 to 100%. (Because water flows backwards, extreme low load operation is not possible)

・Therefore, in this simulation, the operation command value during pumping operation of PSPP(ASPSPP : 200 MW × 2 units) is 350 MW (175 MW × 2: 87.5%), and the load fluctuation range corresponding to frequency fluctuation is assumed to be ± 50 MW (± 12.5%) .

(3) Supply Balance in 2026

In the off-peak pattern of 2026, in order to secure the amount of power generated by five TPPs (CCGT), the output of PV / WT is assumed to be suppressed as shown in the table below.

In this simulation, it is assumed to preferentially suppress PV that is relatively easy to predict output. As a result, PV output is 0. The supply balance for 2026 used in the simulation is shown below.

Table 5-4 Supply Balance in 2026

Year: 2026	Capacity	Operation amount (Amount of sopped equipment)	Balance
TPP	CCGT: 5 units	-	1,200-1,500MW
PV	1,446MW	0 MW (Δ 1,446MW)	0 MW
WT	1,122MW	922MW (Δ 200MW)	550-850MW
Generation total			2,000-2,200MW
ASPSPP	0MW	-	0 MW
Load			2,000-2,200MW

(Source: STEG)

5.3.6 Output curve of VRE

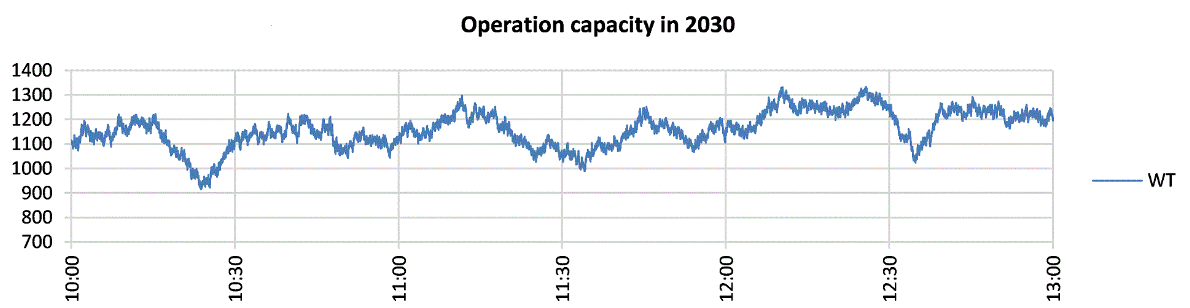
(1) Output curve of PV

This simulation assumes full PV curtailment and partial curtailment of WTs due to the need to keep more than 5 TPPs in operation. (PV output is zero)

(2) Output curve of WT

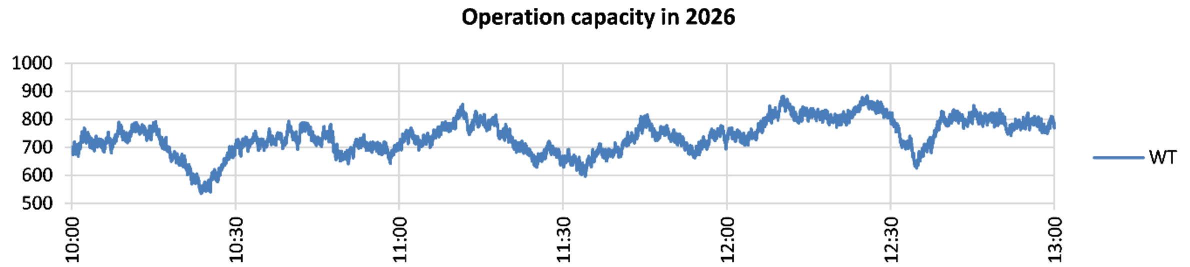
Approximately 95% of the equipment rated output was output, and output fluctuation was simulated based on actual results in Japan.

WT output curve for target time zone in 2030 and 2026 are shown below.



(Source: JICA study team)

Figure 5-21 WT Output Curve in 2030



(Source: JICA study team)

Figure 5-22 WT Output Curve in 2026

5.3.7 Result of frequency fluctuation calculation

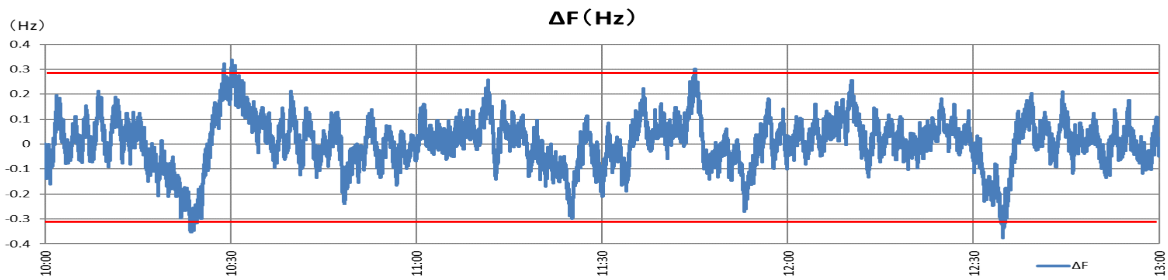
The optimal BESS capacity (MW) was determined by checking the amount of frequency variation at the most severe time.

The study team simulates frequency fluctuation during off-peak period in 2030 and 2026, using the installed capacity of BESS as a parameter. For 2030, the study team also simulates the case of pumping operation of ASPSPP (200 MW * 2 units).

The simulation results of frequency fluctuation for each case in 2030 and 2026 are shown below.

The vertical axis shows the deviation from 50 Hz, and the target is within ±0.3 Hz.

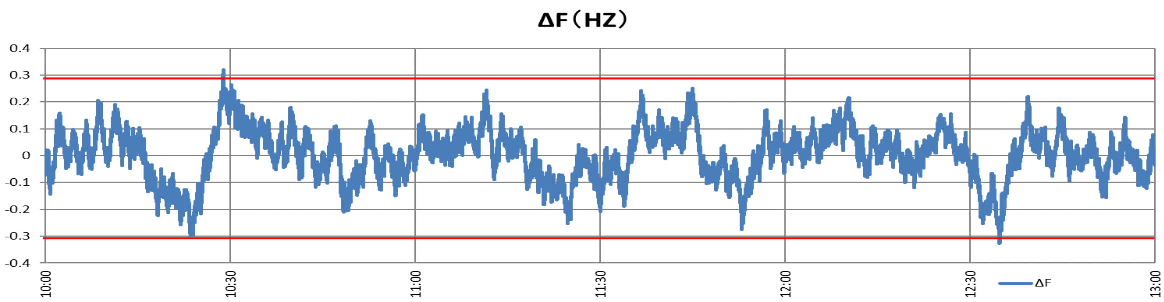
(1) Result of frequency fluctuation calculation in 2030 (BESS=50MW, PSPP=0MW)



(Source: JICA study team)

Figure 5-23 Case0 : ΔF in 2030 (BESS=50MW, PSPP=0MW)

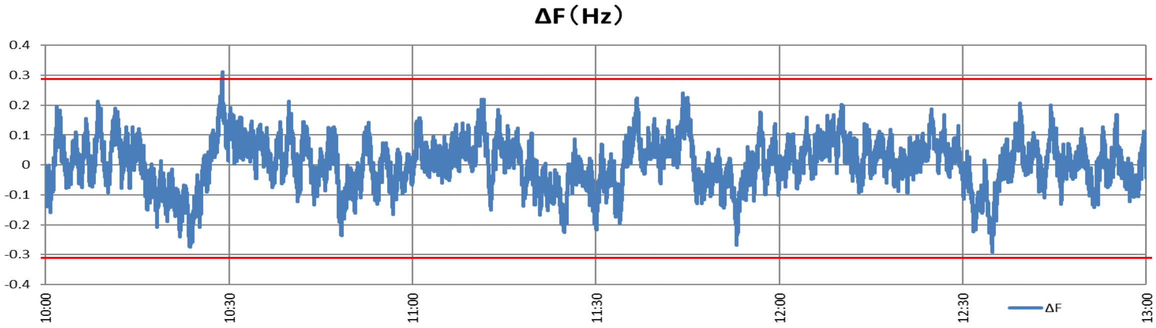
(2) Result of frequency fluctuation calculation in 2030(BESS=100MW, PSPP=0MW)



(Source: JICA study team)

Figure 5-24 Case1 : ΔF in 2030 (BESS=100MW, PSPP=0MW)

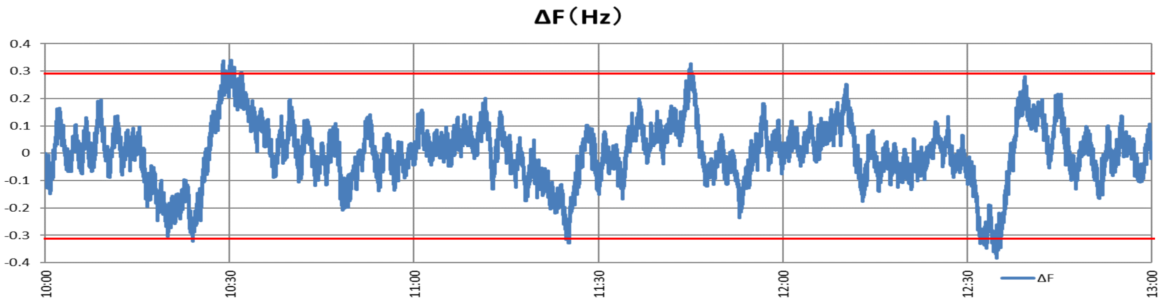
(3) Result of frequency fluctuation calculation in 2030 (BESS=150MW, PSPP=0MW)



(Source: JICA study team)

Figure 5-25 Case2 : Δ F in 2030 (BESS=150MW, PSPP=0MW)

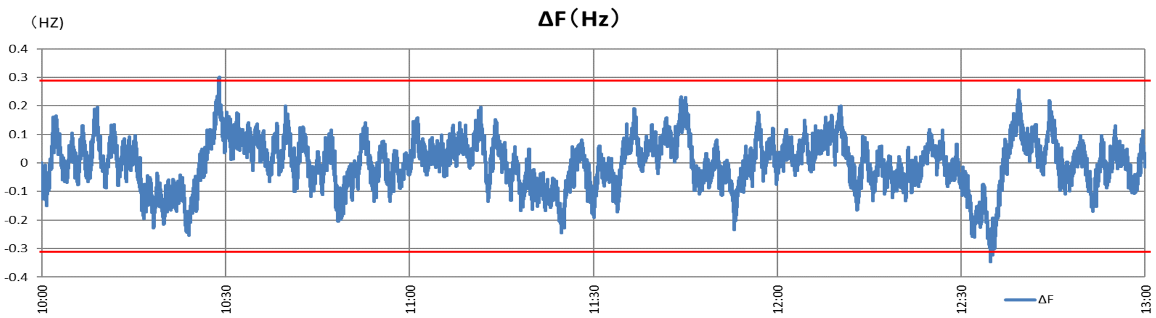
(4) Result of frequency fluctuation calculation in 2030 (BESS=50MW, PSPP=400MW)



(Source: JICA study team)

Figure 5-26 Case3 : Δ F in 2030 (BESS=50MW, PSPP=400MW)

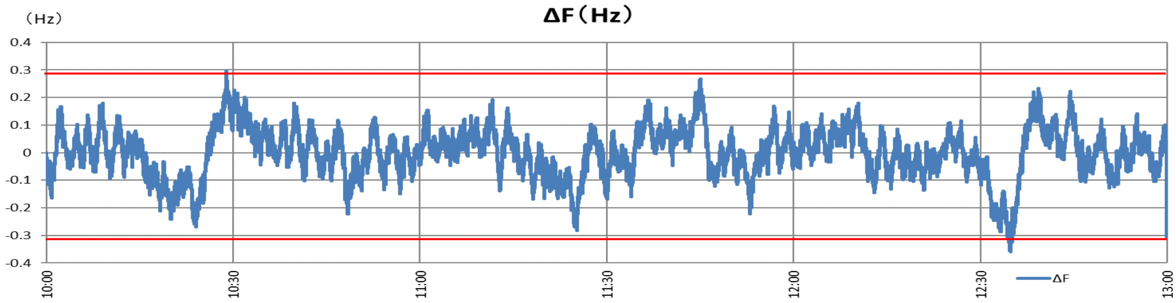
(5) Result of frequency fluctuation calculation in 2030 (BESS=100MW, PSPP=400MW)



(Source: JICA study team)

Figure 5-27 Case4 : Δ F in 2030 (BESS=100MW, PSPP=400MW)

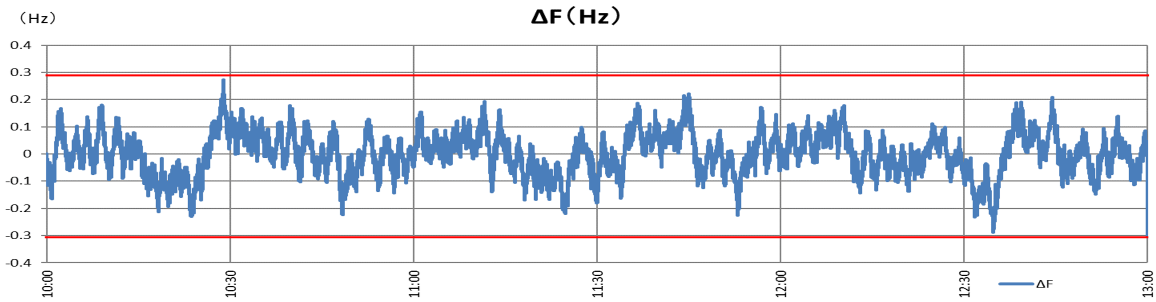
(6) Result of frequency fluctuation calculation in 2026 (BESS=50MW, PSPP=0MW)



(Source: JICA study team)

Figure 5-28 Case5: ΔF in 2026 (BESS=50MW, PSPP=0MW)

(7) Result of frequency fluctuation calculation in 2026 (BESS=100MW, PSPP=0MW)



(Source: JICA study team)

Figure 5-29 Case6 : Δ F in 2026 (BESS=100MW, PSPP=0MW)

The above calculation results are shown below. The target range of the frequency fluctuation of Tunisia is 50 ± 0.3 Hz.

Table 5-5 Frequency Fluctuation Calculation Result

CASE	0	1	2	3	4	5	6
Year	2030					2026	
ASPSPP (MW)	0	0	0	400	400	0	0
BESS(MW)	50	100	150	50	100	50	100
99.7 Percentile Value(Hz)	**0.3213**	**0.2778**	**0.2495**	**0.3343**	**0.2750**	**0.2976**	**0.2472**

(Source: JICA study team)

99.7 Percentile Value : Counted from the smaller ones, the value to be 99.7%- the population (absolute value)

(If the total number of population is 100, the 99.7 percentile value from the smaller value)

In the short-period frequency fluctuation, it is decided to evaluate with the goal of keeping 99.7% (equivalent to 3σ) within the target range of 50 ± 0.3Hz in the simulation in the above-mentioned severest case.

From the above results, it can be confirmed that the BESS& and ASPSPP effectively suppress the short-period frequency fluctuation.

As above result, in 2026, the required MW of BESS is 50 MW, and in 2030, it is 100 MW or more. In 2030, even if ASPSPP is in operation, the required MW of BESS is 100 MW or more.

5.3.8 State of Charge of BESS

The optimal BESS capacity (MWh) was determined by checking the stage of charge (SOC) in Case 1, Case 4 and Case 5, for which the BESS capacity [MW] was determined in Section 5.3.7.

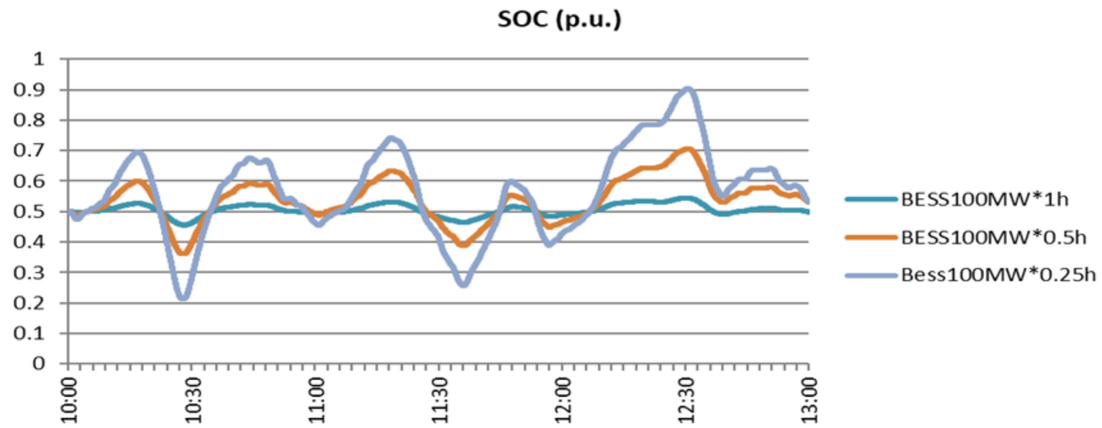
(1) SOC of BESS in 2030 (case 1)

In the case 1 (BESS: 100MW, ASPSPP: 0 MW), the transition of the SOC simulated with the following 3 types of 'MWh capacity' of BESS is shown in the figure below.

The fully charged state is defined as SOC=1p.u. and the fully discharged state as SOC=0p.u.

In BESS that supports short-period frequency fluctuations, the frequency adjustment function cannot be exerted in the fully charged state SOC = 1p.u. and the fully discharged state SOC = 0p.u, so the state of SOC = 0.5p.u. is the state in which the function can be most effectively exerted.

- 100MW, 25MWh (＝100MW×15min/60min)
- 100MW, 50MWh (＝100MW×30min/60min)
- 100MW, 100MWh (＝100MW×60min/60min)



(Source: JICA study team)

Figure 5-30 SOC in 2030 (BESS=150MW, ASPSPP=0MW)

In the case of 25 MWh, SOC reaches 20% and over 90%.

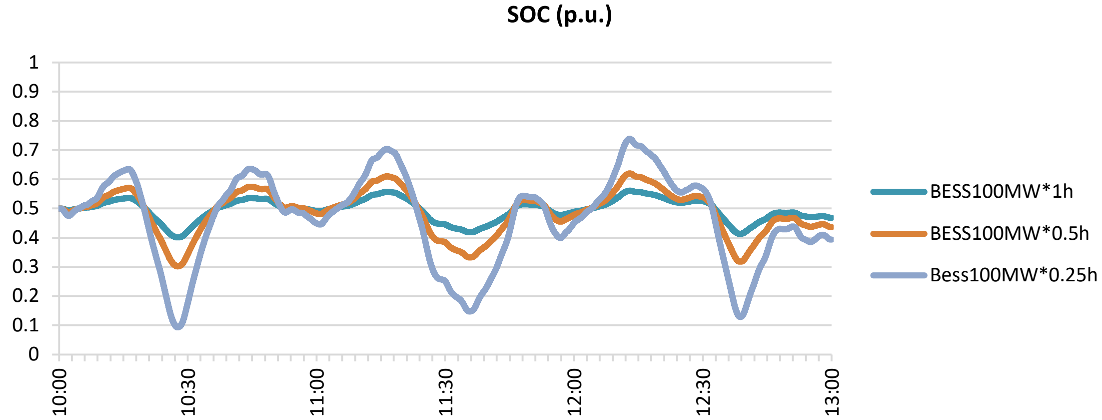
In the case of 50 MWh, SOC stays about 35 ～ 70%.

Based on the above, considering the margin, Required 'MWh capacity' is 75 MWh (= 150 MW × 30min/60min) or more.

(2) SOC of BESS in 2030 (case 4)

In the case 4 (BESS: 100MW, PSPP: 200 MW * 2 units), the transition of the SOC simulated with the following 3 types of 'MWh capacity' of BESS is shown in the figure below.

- 100MW, 25MWh (=100MW×15min/60min)
- 100MW, 50MWh (=100MW×30min/60min)
- 100MW, 100MWh (=100MW×60min/60min)



(Source: JICA study team)

Figure 5-31 SOC in 2030 (BESS=100MW, ASPSPP=400MW)

In the case of 25 MWh, SOC reaches over 70% and reaches under 10%.

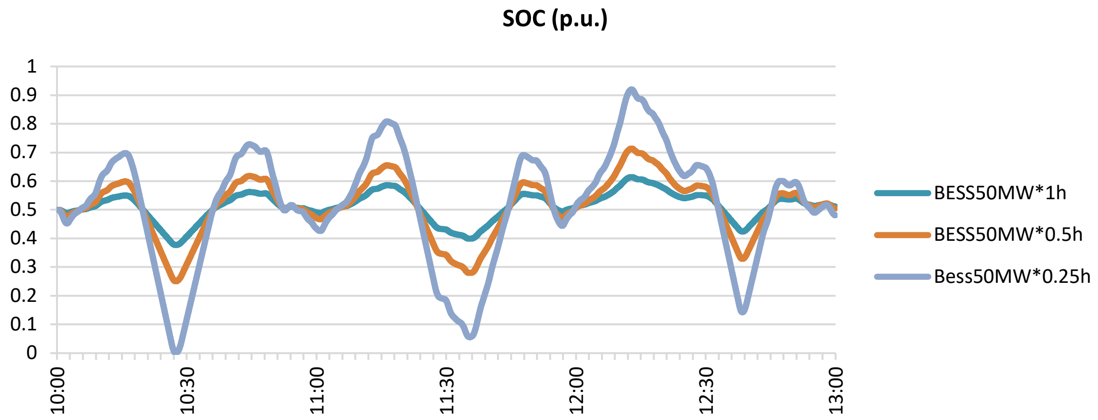
In the case of 50 MWh, SOC stays about 30 ～ 65%.

Based on the above, considering the margin, Required 'MWh capacity' is 50 MWh (= 50 MW × 30min/60min) or more.

(3) SOC of BESS in 2026 (case 5)

In the case 5, the transition of the SOC simulated with the following 3 types of 'MWh capacity' of BESS is shown in the figure below.

- 50MW, 12.5MWh (=100MW×15min/60min)
- 50MW, 25MWh (=100MW×30min/60min)
- 50MW, 50MWh (=100MW×60min/60min)



(Source: JICA study team)

Figure 5-32 SOC in 2026 (BESS=50MW, ASPSPP=0MW)

In the case of 12.5 MWh, SOC reaches over 90% and under 10%.

In the case of 25 MWh, SOC stays about 25 ～ 75%.

Based on the above, considering the margin, Required 'MWh capacity' is 25 MWh (= 50 MW × 30min/60min) or more.

5.3.9 Results of Short-period fluctuation simulations

Based on the results of the study in this section, the installed capacity of the BESS is recommended as follows.

・2030.

・MW capacity : 100MW (＝50MW×2units)

・MWh capacity : 50MWh (＝50MW×30min/60min×2units) or more

・2026.

・MW capacity : 50MW (＝50MW×1units)

・MWh capacity : 25MWh (＝50MW×30min/60min×1units) or more

・Even if ASPSPP (200 MW * 2) is available, it is necessary to additionally install 50 MWBESS in 2030.

・Based on the above, as for the installation of BESS after 2026, it is recommended that it should be decided after examining in detail the effect of two BESS(50MW＊2units), the introduction situation of PV / WT, the plan of installation of ASPSPP.

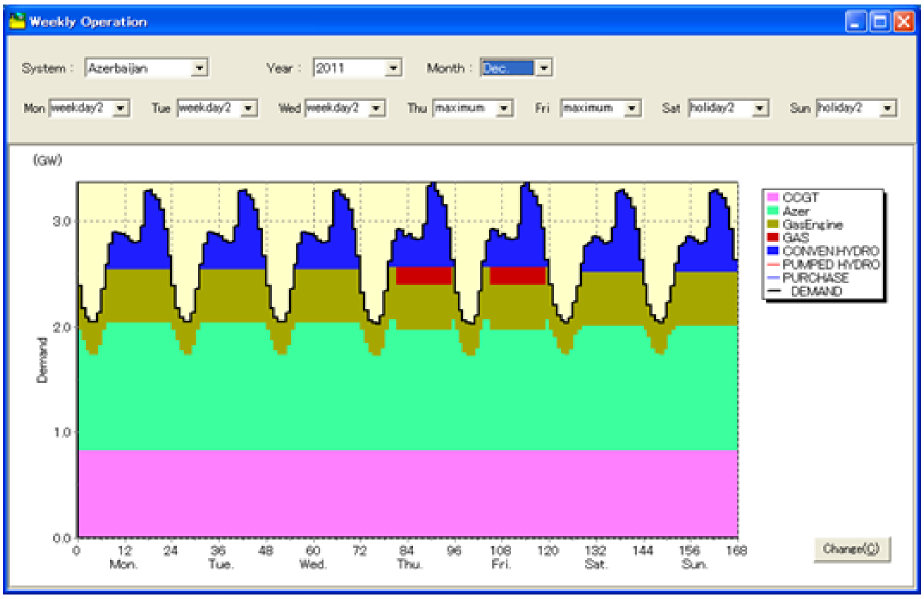
5.4 Examination of economic operation by supply / demand balancing simulation

5.4.1 Review, analysis and recommendations of medium- to long-term power development plan

Obtain the latest meddle- and long-term development plans for generation, transmission / substation, and distribution, and confirm the contents of each new development and renovation plan while paying attention to mutual consistency.

In the review and analysis of the power development plan, the actual supply capacity including PV / WT will be evaluated based on the actual situation such as the decrease in supply capacity due to aging deterioration, etc., and if necessary, a revision plan will be proposed.

Furthermore, supply/demand balancing simulations will be conducted based on the demand forecast and the power development plan. It is proposed that a revised development plan that adjusts for the excess and deficiency of the supply capacity required to secure the supply reliability target value (for example, LOLE 24 hours) for the planned target year. For the analysis, the supply/demand balancing simulation program PDPAT II is used, which can analyze the most economical power supply operation every 8,760 hours a year.

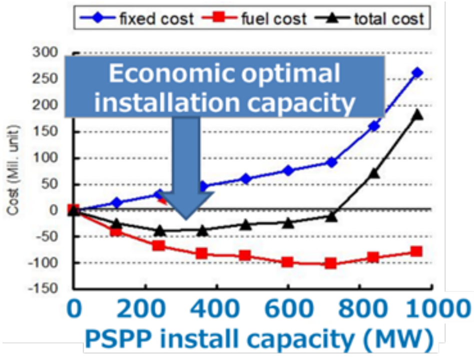


(Source: JICA study team)

Figure 5-33 Example of output of PDPAT II

(1) Examination of economic operation by supply / demand balancing simulation

Based on the long-term demand assumption, the economic efficiency in each assumed power development scenario is evaluated by keeping the supply reliability at the same level by the supply and demand simulation.



(Source: JICA study team)

Figure 5-34 Example of PSPP economic analysis

(2) Supply reliability

As the supply reliability standard, LOLE (Loss of Load Expectation), which is the expected value of the annual supply capacity shortage time, is used for examination.

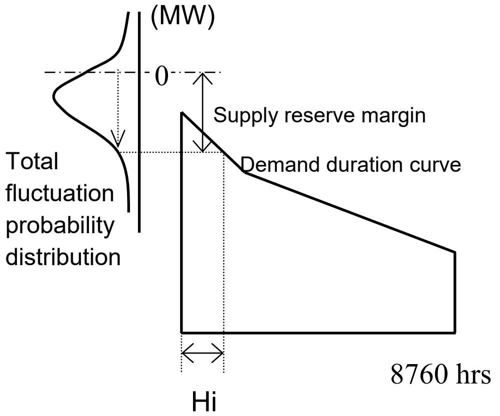
Confirming of the supply reliability standard of the power supply plan used by STEG, and convert it to LOLE before use.

Supply reliability standards (LOLE) are affected by accidental shutdowns of power sources, output fluctuations in hydropower and VREs such as PV and WT, and demand assumption errors. In addition, the grid interconnection is also affected by the supply and demand balance of the grid to which it is interconnected.

Power supply equipment accidents, VRE output fluctuations and demand assumption errors are defined in the form of probability distributions. The supply reliability (LOLE) is defined by the following equation between the output fluctuation probability distribution that integrates these probability distributions and the demand.

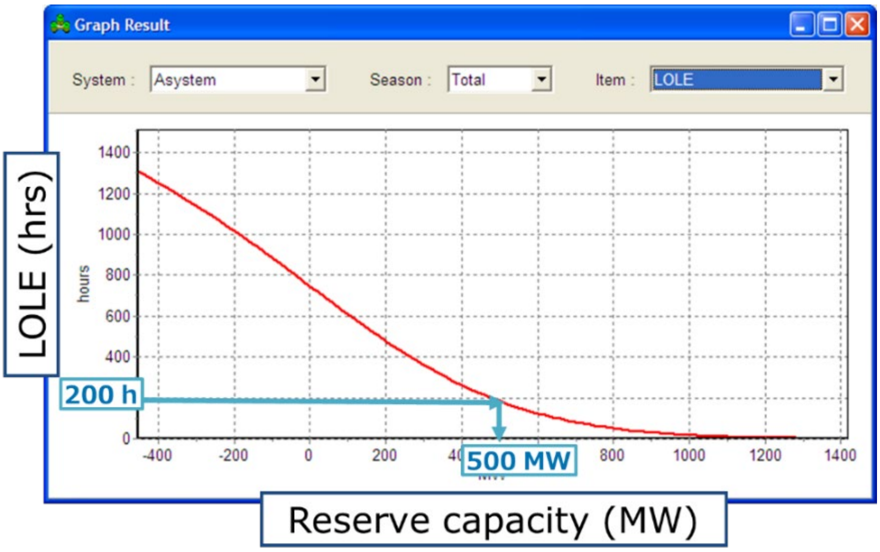
$$\text{LOLE} = \sum (\text{Pi} \times \text{Hi})$$

As can be seen from this figure, the supply reserve capacity and the supply reliability (LOLE) are uniquely determined for each system. (Refer to the figure below) Therefore, the relationship between supply reserve capacity and supply reliability differs depending on the supply and demand situation of each system. In other words, the supply reliability at the same supply reserve capacity differs depending on the amount of VRE introduced.



(Source: JICA study team)

Figure 5-35 Calculation of LOLE



(Source: JICA study team)

Figure 5-36 Relation between Reserve margin and LOLE

(3) Supply / demand balancing simulation

For the supply and demand simulation, we will use PDPATII[1], which can simulate daily operation and weekly operation. Simulation is performed by simulating PSPP pond operation and BESS charge / discharge in daily operation and weekly operation. Formulate an introduction scenario by comparing each system stabilization measure, and examine the economic efficiency of each by supply and demand simulation.

5.4.2 Conditions of the supply / demand balancing simulation

The simulations will be examined in 2026, when it is expected that system stabilization equipment can be installed in the shortest time in the future, and in 2030, when the VRE development plan is finalized.

(1) Setting a relaiblity criteria

The current supply reliability target with STEG.

LOLE ≤48hours

LOLP≤ 0.548

Reserve Margin: 10-15% of yearly power peak.

(2) Electric power demand forecast

The current demand forecast in STEG is only the basic case.

[1] This tool were developed by TEPCO when examining the economics of pumped storage power generation. It has a track record of being used in PDP formulation studies at TEPCO, Laos, Vietnam, Thailand, Cambodia, Myanmar, Bangladesh, etc.

The forecasted electricity demand is 24,565GWh in 2026 and 28,362GWh in 2030. It is forecasted to grow at an annual rate of 3.2% compared to the actual results in 2019. The peak demand is forecasted to be 5180 MW in 2026 and 6000 MW in 2030. It is expected to grow by 3% annually in 2026 and 3.3% annually in 2030.

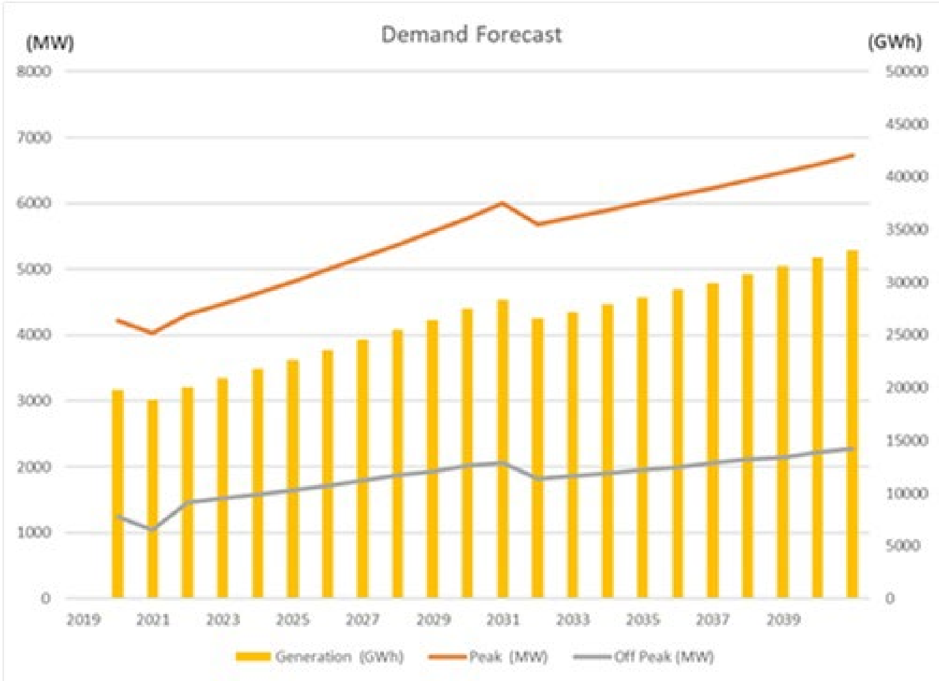
Looking at the demand forecast for 2030, the load factor is 54%, and it can be seen that the peak demand is expected to be nearly double the annual average power demand. Thus, there is room for measures such as DSM (Demand Side Management) to improve peak demand. Since STEG planned to develop 400 MW of pumped storage power generation (PSPP) in 2029 as a peak supply, the effect of PSPP will be evaluated by the supply and demand balance.

On the other hand, since measures to improve measurement accuracy, such as the introduction of smart meters, are being taken with the support of donors, this tendency may change in the future.

Demand forecasts in the power development plan are indicators that serve as the basis for formulating investment plans. Power development planning takes a lot of time to scale, fuel purchasing availability, design, environmental impact assessment, and land acquisition. It takes more than 10 years to secure a new site, depending on the scale, more than 30 years.

On the other hand, electricity demand is affected by population movements and economic trends, so it is difficult to look ahead 10 to 20 years.

For this reason, in addition to the basic case, two cases, a high demand case (corresponding to insufficient supply capacity) and a low demand case (corresponding to overinvestment), are prepared as risk analysis to deal with the investment risks of insufficient supply capacity and overinvestment. It is common in the United States and Japan to have a power development plan that can be done.



(Source: STEG)

Figure 5-37 Demand forecast in STEG

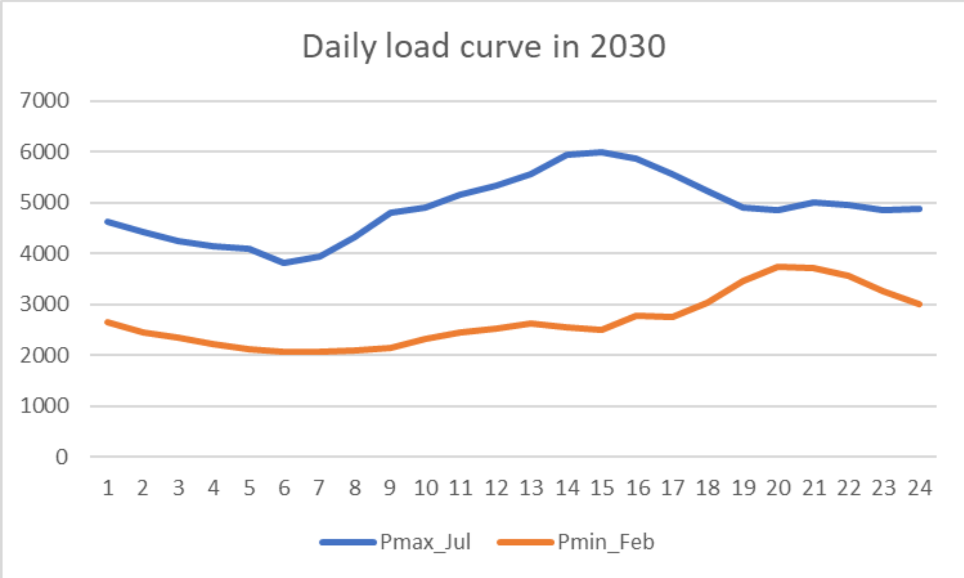
(3) Forecst of Daily load profiles

The load curves for each month from the demand forecast for 2026 and 2030 by STEG are analyzed.

Analysis of the daily load curve requires date day and holiday data for the 2026 and 2030 assumptions.

In 2030, it is predicted that a maximum power of 6000 MW will be generated around 15:00 during the daytime in July. The minimum power in 2030 is predicted to be 2064 MW around 7 am in February. The ratio of the minimum power to the maximum power is 34%.

Looking at the daily load curve of the lowest power generation date, the increase in demand is gradual, and the influence of the duck curve due to PV output is expected.



(Source: STEG)

Figure 5-38 Prediction of Daily load curve in 2030

(4) Power Development Plan

1) Generation facilities

The list of power generation facilities under confirmation is shown in tables below.

The Pumped Storage Hydro project is scheduled to start operation in 2029. A total of 400 MW is planned for two 200 MW units. Comprehensive efficiency is 75%. The maximum annual power generation is planned to be 920GWh. The capacity factor is planned to be up to 26.3%.

Assume a discount rate of 8% for annual expense calculations. Depreciation is assumed to be flat rate depreciation.

Thermal power plants will be installed 6,551MW in 2026 and retired 660MW before 2026. Total installed capacity is 5,891MW in 2026, the 960MW will be developed and be retired 360 MW between 2027 and 2030. Then, 6491MW will be installed in 2030.

The existing power plant of Mornaguia is composed by two gas turbines with:

Maximum capacity is 300 MW by unit in winter

Maximum capacity is 260 MW by unit in summer

Minimum capacity is 60 MW by unit

Table 5-6 Generation Plant List (Thermal power plants)

No.	Plant name	Unit	Boiler Turbine	Fuel Type	COD	Retirement	Minimum output (%)	Primary reserve per unit (MW)	Daily Start and Stop (DSS)	Weekly Start & Stop (WSS)	Monthly Start & Stop (MSS)	Heat rete 100% output (%)	Heat rete 75% output (%)	F.O.R (%)	Scheduled outage (days)
1	Mornaguia 1	300 (260)	GT	Gas	NA	2049	20.0% (11.5%)	21	Yes	Yes	Yes	35.9%	34.1%	7	18
2	Mornaguia 2	300 (260)	GT	Gas	NA	2050	20.0% (11.5%)	21	Yes	Yes	Yes	35.9%	34.1%	7	18
3	Bouchemma1	120 (97)	GT	Gas	NA	2029	33.0%	12	Yes	Yes	Yes	28.7%	26.9%	7	15
4	Bouchemma2	120 (97)	GT	Gas	NA	2046	33.0%	12	Yes	Yes	Yes	28.7%	26.9%	7	15
5	Bouchemma3	120 (97)	GT	Gas	NA	2046	33.0%	12	Yes	Yes	Yes	28.7%	26.9%	7	15
6	Bir_Mcherga1	120 (97)	GT	Gas	NA	2028	33.0%	12	Yes	Yes	Yes	28.7%	26.9%	7	15
7	Bir_Mcherga2	120 (97)	GT	Gas	NA	2028	33.0%	12	Yes	Yes	Yes	28.7%	26.9%	7	15
8	Bir_Mcherga3	120 (97)	GT	Gas	NA	2043	33.0%	12	Yes	Yes	Yes	28.7%	26.9%	7	15
9	Bir_Mcherga4	120 (97)	GT	Gas	NA	2043	33.0%	12	Yes	Yes	Yes	28.7%	26.9%	7	15
10	Feriana1	120 (97)	GT	Gas	NA	2035	33.0%	12	Yes	Yes	Yes	28.7%	26.9%	7	15
11.	Feriana2	120 (97)	GT	Gas	NA	2039	33.0%	12	Yes	Yes	Yes	28.7%	26.9%	7	15
12	Thyna1	120 (97)	GT	Gas	NA	2034	33.0%	12	Yes	Yes	Yes	28.7%	26.9%	7	15
13	Thyna2	120 (97)	GT	Gas	NA	2037	33.0%	12	Yes	Yes	Yes	28.7%	26.9%	7	15
14	Thyna3	120 (97)	GT	Gas	NA	2040	33.0%	12	Yes	Yes	Yes	28.7%	26.9%	7	15
15	Goulette	120 (97)	GT	Gas	NA	2035	33.0%	12	Yes	Yes	Yes	28.7%	26.9%	7	15

No.	Plant name	Unit	Boiler Turbine	Fuel Type	COD	Retirement	Minimum output (%)	Primary reserve per unit (MW)	Daily Start and Stop (DSS)	Weekly Start & Stop (WSS)	Monthly Start & Stop (MSS)	Heat rete 100% output (%)	Heat rete 75% output (%)	F.O.R (%)	Scheduled outage (days)
16	Kasserine1	30	GT	Gas	NA	2021	17.0%	0	Yes	Yes	Yes	21.5%	21.5%	10	21
17	Kasserine2	30	GT	Gas	NA	2021	17.0%	0	Yes	Yes	Yes	21.5%	21.5%	10	21
18	Sfax1	20	GT	Gas	NA	2021	25.0%	0	Yes	Yes	Yes	21.5%	21.5%	10	21
19	Sfax2	20	GT	Gas	NA	2021	25.0%	0	Yes	Yes	Yes	21.5%	21.5%	10	21
20	Tunis_Sud1	20	GT	Gas	NA	2021	25.0%	0	Yes	Yes	Yes	21.5%	21.5%	10	21
21	Tunis_Sud2	20	GT	Gas	NA	2021	25.0%	0	Yes	Yes	Yes	21.5%	21.5%	10	21
22	Tunis_Sud3	20	GT	Gas	NA	2021	25.0%	0	Yes	Yes	Yes	21.5%	21.5%	10	21
23	Korba 1	20	GT	Gas	NA	2021	25.0%	0	Yes	Yes	Yes	21.5%	21.5%	10	21
24	Korba 2	30	GT	Gas	NA	2021	17.0%	0	Yes	Yes	Yes	21.5%	21.5%	10	21
25	Bouchemma1	30	GT	Gas	NA	2021	17.0%	0	Yes	Yes	Yes	21.5%	21.5%	10	21
26	Bouchemma2	30	GT	Gas	NA	2021	17.0%	0	Yes	Yes	Yes	21.5%	21.5%	10	21
27	Robbana	30	GT	Gasoil	NA	2021	17.0%	0	Yes	Yes	Yes	20.5%	20.5%	10	21
28	Zarzis	30	GT	Gasoil	NA	2021	17.0%	0	Yes	Yes	Yes	20.5%	20.5%	10	21
29	Menzel_Bourguiba1	20	GT	Gasoil	NA	2021	25.0%	0	Yes	Yes	Yes	20.5%	20.5%	10	21
30	Menzel_Bourguiba2	20	GT	Gasoil	NA	2021	25.0%	0	Yes	Yes	Yes	20.5%	20.5%	10	21

No.	Plant name	Unit	Boiler Turbine	Fuel Type	COD	Retirement	Minimum output (%)	Primary reserve per unit (MW)	Daily Start and Stop (DSS)	Weekly Start & Stop (WSS)	Monthly Start & Stop (MSS)	Heat rete 100% output (%)	Heat rete 75% output (%)	F.O.R (%)	Scheduled outage (days)
31	RadesA1	145 (125)	ST	Gas	NA	2025	48.0%	7.25	No	No	Yes	34.4%	33.7%	11	30
32	RadesA2	145 (125)	ST	Gas	NA	2025	48.0%	7.25	No	No	Yes	34.4%	33.7%	11	30
33	RadesB1	150 (135)	ST	Gas	NA	2033	47.0%	7.5	No	No	Yes	34.4%	33.7%	11	30
34	RadesB2	150 (135)	ST	Gas	NA	2033	47.0%	7.5	No	No	Yes	34.4%	33.7%	11	30
35	SousseB	350 (309)	CCGT	Gas	NA	2030	51.0%	30.43	No	No	Yes	44.8%	42.8%	10	30
36	IPPrades	471 (409)	CCGT	Gas	NA	2032	55.0%	47	No	No	Yes	45.0%	42.6%	7	25
37	Ghannouch	412	CCGT	Gas	NA	2041	51.0%	0	No	No	Yes	51.5%	50.9%	9	25
38	SousseC	424 (358)	CCGT	Gas	NA	2044	59.0%	10.6	No	No	Yes	52.8%	51.8%	9	25
39	SousseD	424 (360)	CCGT	Gas	NA	2045	57.0%	10.6	No	No	Yes	52.8%	50.9%	9	25
40	Radès C	450 (392)	CCGT	Gas	NA	2050	50.0%	31.5	No	No	Yes	53.8%	52.1%	9	25
41	Skhira1	450 (427)	CCGT	Gas	2023	2053	44.0%	32	No	No	Yes	53.8%	52.1%	9	25
42	Skhira2	450 (427)	CCGT	Gas	2025	2055	44.0%	32	No	No	Yes	53.8%	52.1%	9	25
43	GT 1	300 (270)	GT	Gas	2027	2058	44.0%	32	No	No	Yes	53.8%	52.1%	9	25
43	CCGT 1	450 (427)	CCGT	Gas	2028	2058	44.0%	32	No	No	Yes	53.8%	52.1%	9	25
44	GT 2	300 (270)	GT	Gas	2028	2029	44.0%	32	No	No	Yes	53.8%	52.1%	9	25
44	CCGT 2	450 (427)	CCGT	Gas	2029	2059	44.0%	32	No	No	Yes	53.8%	52.1%	9	25
45	New GT	300 (270)	GT	Gas	2030	2060	20.0%	21	Yes	Yes	Yes	34.7%	33%	9	18

( ) is in summer output. (Source: STEG)

Hydropower is operated according to irrigation plans and varies widely from year to year. There is no control on the power side.

There is an annual electric power generation of 55GWh, including the average of the power generation amount actual from 2010 to 2019.

In addition, there is a PHS development plan by 2030. There is no other hydropower development plan.

Since these hydroelectric dams are used for irrigation and hydraulic control, they cannot be used for power supply and demand adjustment.

Table 5-7 Generation Plant List (Hydro power plants)

No.	Plant name	Unit	Installed Capacity (MW)	Type	COD
1	Sidi_Salem	NA	33	Reservoir	NA
2	Nebeur	NA	13.2	Reservoir	NA
3	Aroussia	NA	4.8	Reservoir	NA
4	Fernana	NA	9.7	Reservoir	NA
5	Kasseb	NA	0.825	Reservoir	NA
6	Bouherthma	NA	1.2	Reservoir	NA
7	Sejnane	NA	0.6	Reservoir	NA

(Source: STEG)

2) Fuel plan

Fuel costs, calorie and heat rate are organized each power plant and generator.

As for the gas price, the STEG forecast gas price (HHV) of 329 USD / TOE in 2026 and 386 USD / TOE in 2030 was used for the simulation.

3) Investment cost

For this reason, the fixed costs of power generation costs are being examined based on the following assumptions. For a detail study, it is necessary to investigate these investment cost data.

The discount rate was 8%/year.

- HPP: 1,300USD/kW,, life time:40-year
- GT: 600USD/kW-year, life time:30-year
- CCGT: 920 USD/kW-year, life time:30-year
- WT: 1,400USD/kW, life time: 25-year
- PV: 800USD/kW, life time: 25-year
- BESS: 700 – 1,000 USD/kW, life time:15-year

(5) VRE development plan

The table below shows the existing Wind and PV installed capacity in 2020, additional development plans from 2021 to 2026, and development plans from 2027 to 2030.

Wind plans to have a capacity factor of 21% for existing facilities and 35% for newly developed facilities.

In terms of PV, the capacity factor of existing PV and Type A is 19%, while that of Type B is 26%.

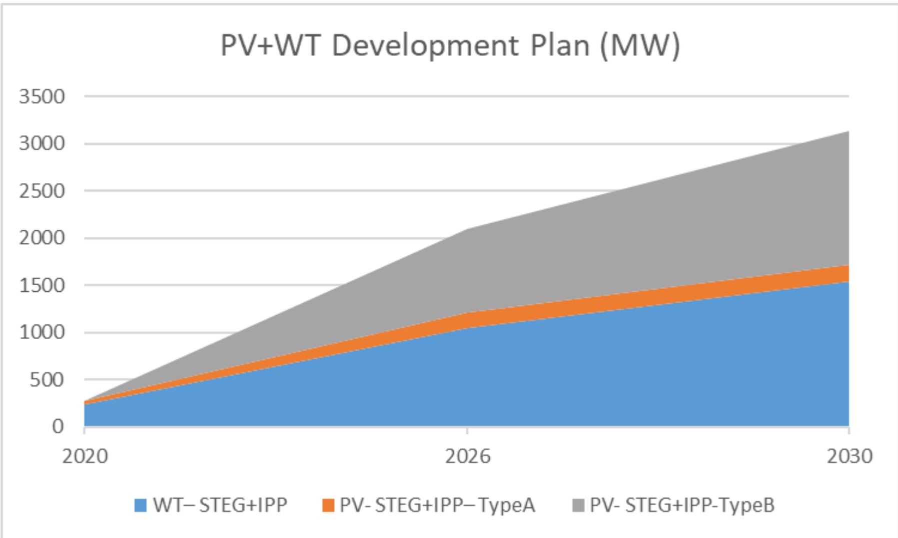
Type A is categorized for an existing PV facility. Type B is a planned PV facility.

Table 5-8 Additional development plan of WT and PV

Additional Development (MW)	2020	2026	2030
WT– STEG+IPP	242	800	500
PV- STEG+IPP– TypeA	31	144	0
PV- STEG+IPP-TypeB	0	881	540
	273	1825	1040

(Source: STEG)

The total installed capacity of WT and PV will be 2098 MW in 2026 and 3138 MW in 2030.



(Source: STEG)

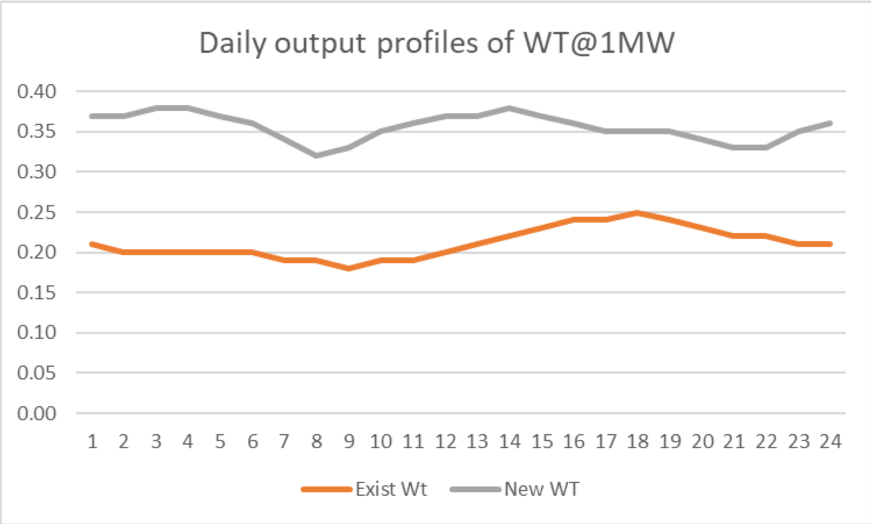
Figure 5-39 Installed capacity of WT and PV

1) Wind power plant condition

The study was conducted using the output forecast of wind power generation provided by STEG. The outline of the wind output data of STEG forecast is shown below.

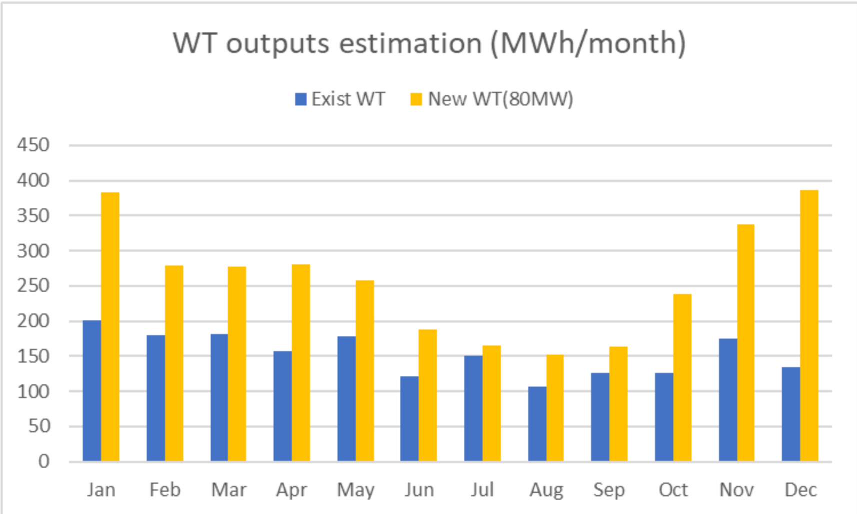
The newly constructed wind farm is expected to have 70% more output than the conventional one.

The output in July, August, and September is small, and it is assumed that the output will be about half of the maximum output.



(Source: STEG)

Figure 5-40 Daily output profile of WT

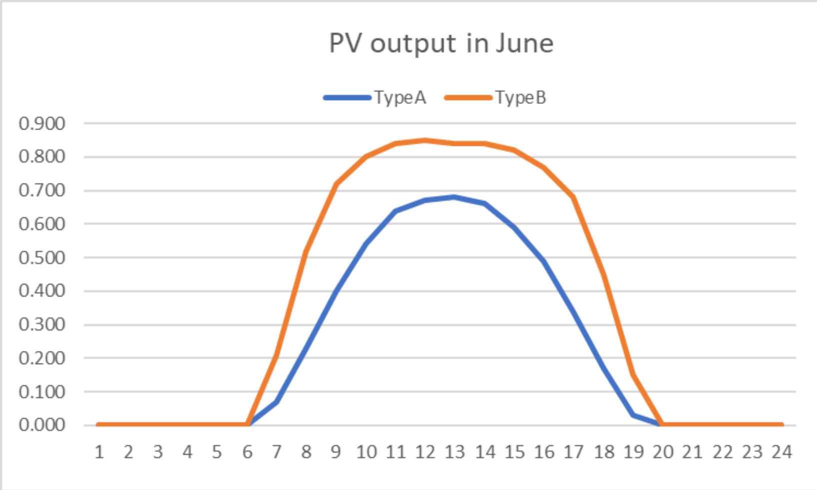


(Source: STEG)

Figure 5-41 Monthly outputs of WT

2) Solar power condition

The study was conducted using the PV output prediction data provided by STEG. The output of Type B, which will be used for PV to be constructed in the future, is 50% higher than the generating energy (GWh) of Type A of the existing PV.



(Source: STEG)

Figure 5-42 Daily output profile of PV

(6) Power transaction constraints in the system

If there are transmission restrictions between the northern regional system and the southern regional system, the supply and demand balance will be examined by dividing the system into two systems.

In this report, the simulation was considered as a single system.

5.4.3 Setting a development scenario for supply and demand simulation

The supply-demand balance 2026 and 2030 was examined in accordance with the conditions in the previous section. The balance between supply and demand was examined using the development plan in the previous section as the basic scenario.

Assuming that there are no system restrictions, we examined the supply and demand balance in a single system. Furthermore, as a sensitivity analysis, we examined the balance between supply and demand depending on the presence or absence of pumping, the case where batteries are introduced, and whether VRE development after 2027 is centered on PV or WT.

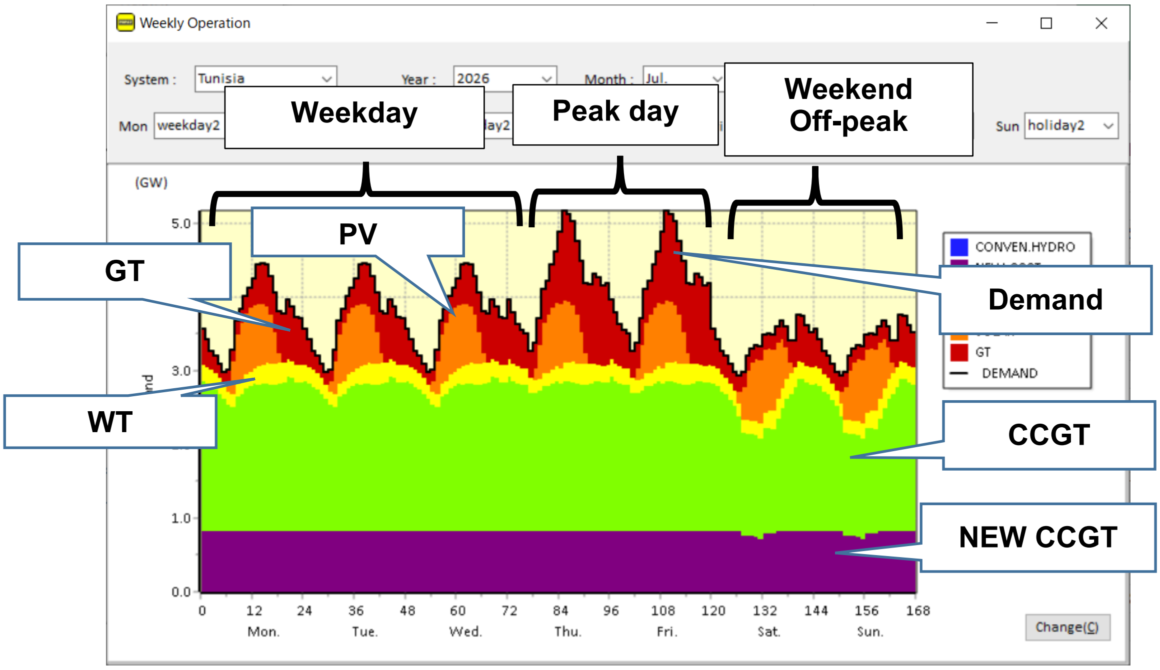
5.4.4 Implementation of supply/demand balancing simulation

(1) Base scinario

1) Supply/demand balance in 2026 (Base scenario)

According to the demand forecast for 2026, the maximum power will be 5180 MW in July, and the minimum power will be 1790 MW in the morning of January.

The balance between supply and demand was confirmed by simulation in consideration of the decrease in output of GT and CCGT in the summer (July, August, and September). It shows the supply and demand situation in July when the maximum electricity is generated. The black line in the figure is demand, yellow is WT, orange is PV, green is CCGT, purple is new CCGTs such as the Skhira CCGT, and red is GT. WT output is low in July due to poor wind conditions.

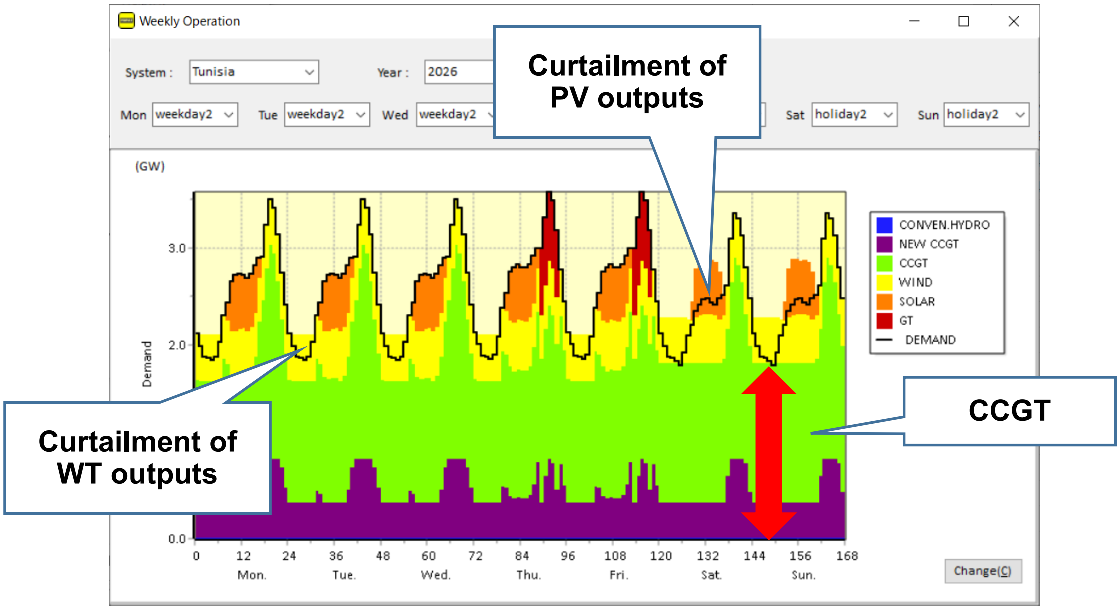


(Source: JICA study team)

Figure 5-43 Supply/demand balance in Jul. 2026 (Base scenario)

Shows the supply and demand in January at the time of minimum load. Even at the lowest load, there is room for operation of 1.2 GW or more for five synchronous generators.

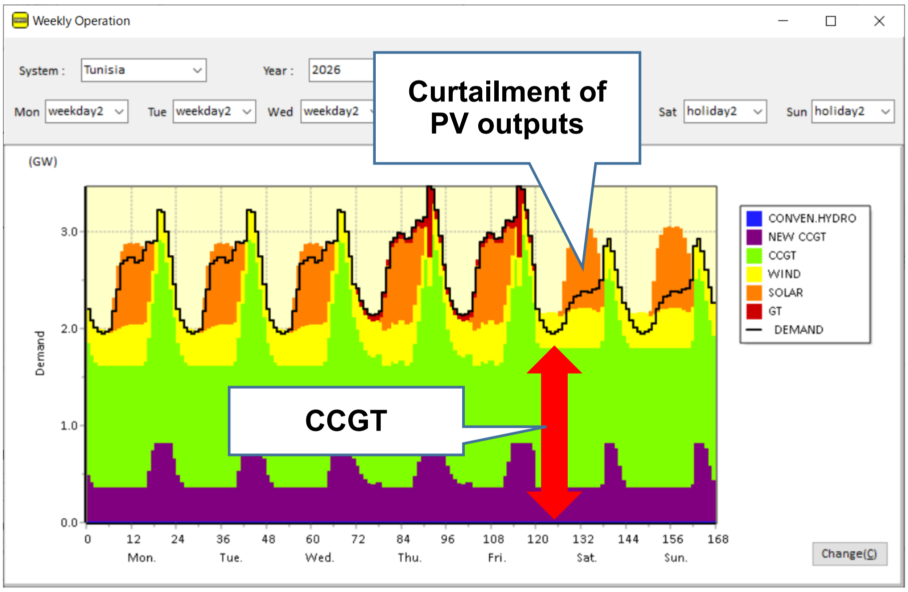
In the early morning when demand is low, the output of the synchronous generator cannot be fully throttled. There is a surplus of wind power.



(Source: JICA study team)

Figure 5-44 Supply/demand balance in Jan. 2026 (Base scenario)

It was confirmed that the supply and demand situation in April when the VRE output was large. During off-peak days, the output of thermal power equipment may not be reduced any further, and there may be situations where the output from VRE cannot be utilized.

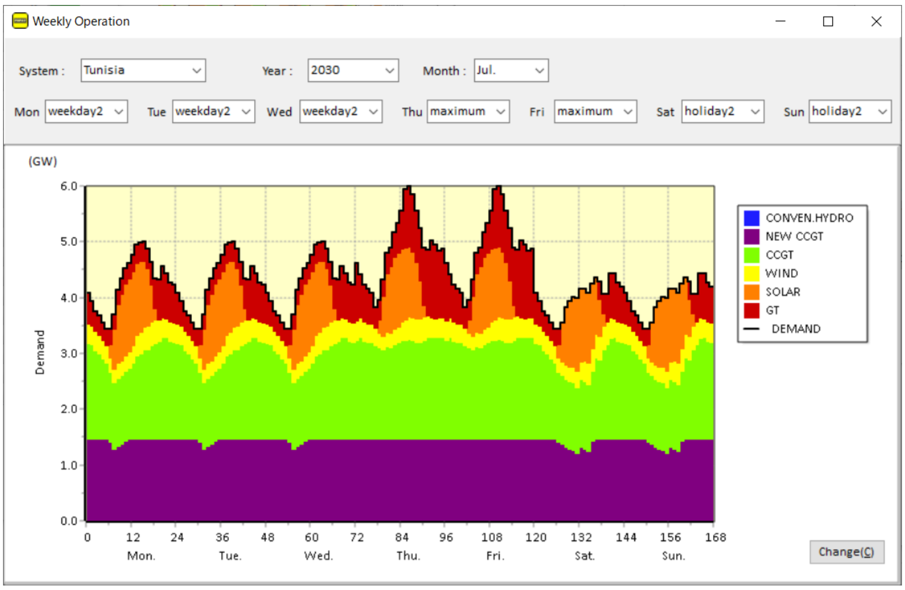


(Source: JICA study team)

Figure 5-45 Supply/demand balance in Apr. 2026 (Base scenario)

2) Supply/demand balance in 2030 (Base scenario)

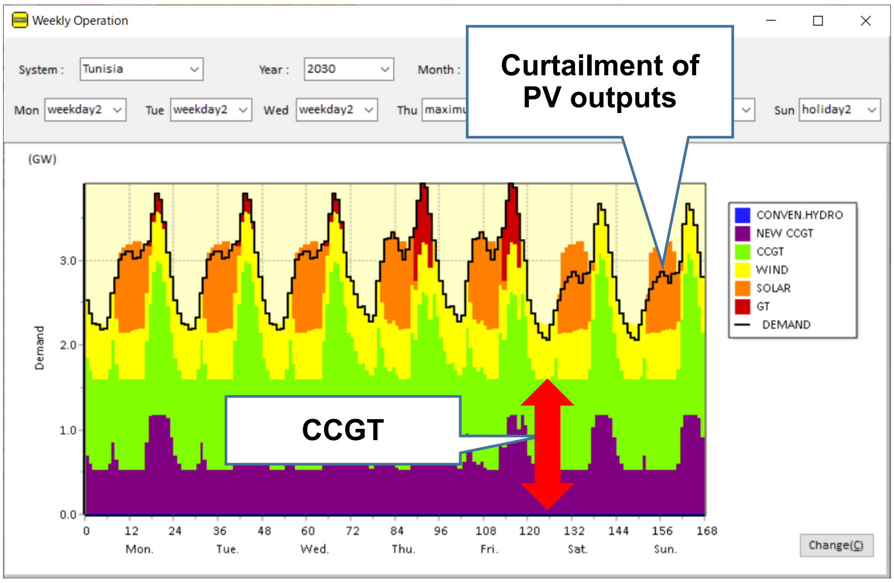
According to the demand forecast for 2030, the maximum power will be generated in July and 6000 MW, and the minimum power will be generated in the morning of February and will be 2064 MW. The base scenario does not include adjustable speed pumped storage hydropower plant (ASPSPP).



(Source: JICA study team)

Figure 5-46 Supply/demand balance at peak in Jul 2030 (Base scenario)

Shows the supply and demand in February at the time of minimum load. Even at the lowest load, there is a room over 1.2 GW or more for operation of a synchronous generator.

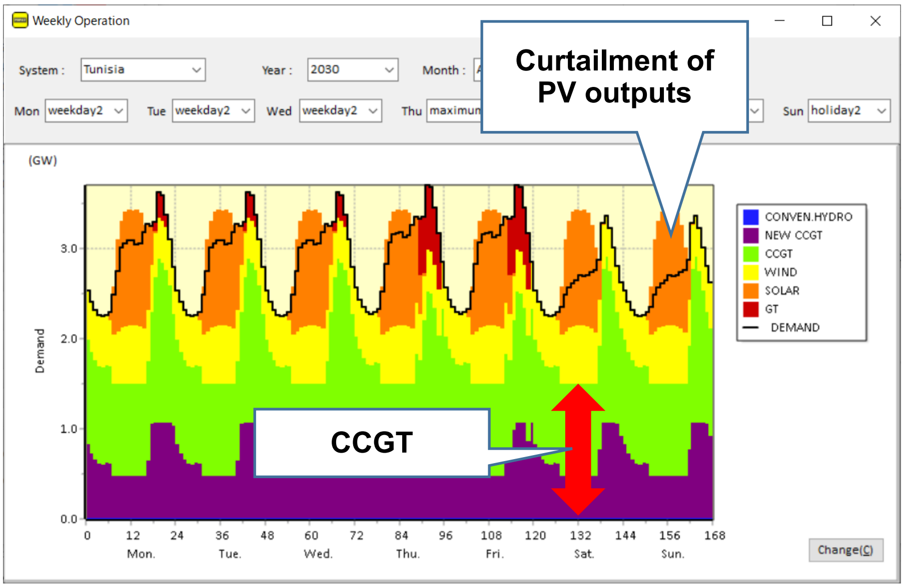


(Source: JICA study team)

Figure 5-47 Supply/demand balance at minimum in Feb. 2030 (Base scenario)

Since the PV output is large in April, in order to make the best use of the VRE output, it is necessary to reduce the output of the synchronous generator during the PV generating and off-peak hours. According to the current STEG development plan, even if six synchronous generators that cannot be shut down are operated at the lowest output, it is difficult to utilize all VRE outputs.

In order to utilize all VRE output, it is necessary to increase the annual maximum number of times the newly established CCGT is started from 26 to 200 or more so that Daily Start and Stop (DSS) can be performed. Alternatively, it is necessary to install an energy storage device such as ASPSPP or BESS.



(Source: JICA study team)

Figure 5-48 Supply/demand balance in Apr. 2030 (Base scenario)

(2) BESS installation scenario

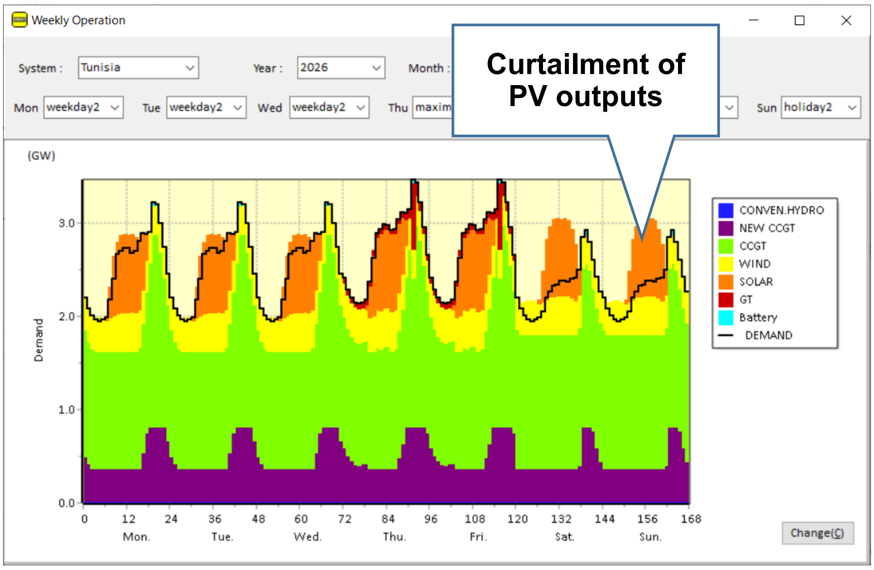
According to the analysis results of short-period fluctuations, it was necessary to introduce BESS with an output of 50 MW and a capacity of 25 MWh or more for VRE as of 2026. Comparing the C rate and cost of the storage battery, the 1C (50MWh) storage battery has an advantage over the 2C (25Mwh), so BESS (50MW / 50MWh) was the subject of this study.

BESS 50MW / 50MWh will be introduced in 2026 and 100MW / 100MWh in 2030, which is expected that the supply disruption during peak hours will be resolved as shown in the short-cycle fluctuation analysis results.

Economic comparison between BESS introduction and VRE fluctuation reduction is going to be finalized based on the results of demand/supply simulation.

1) BESS 50MW/50MWh(2026)

Introducing the BESS 50MW/50MWh in 2026 will reduce VRE loss by 14GWh / year. The thermal power output reduction is 11GWh/year. The fuel cost of thermal power plant is 6.1 c / kWh according to the supply and demand simulation using the fuel cost forecast data of STEG. Along with this, the fossil fuel burning reduction effect is 0.671MUSD / year.



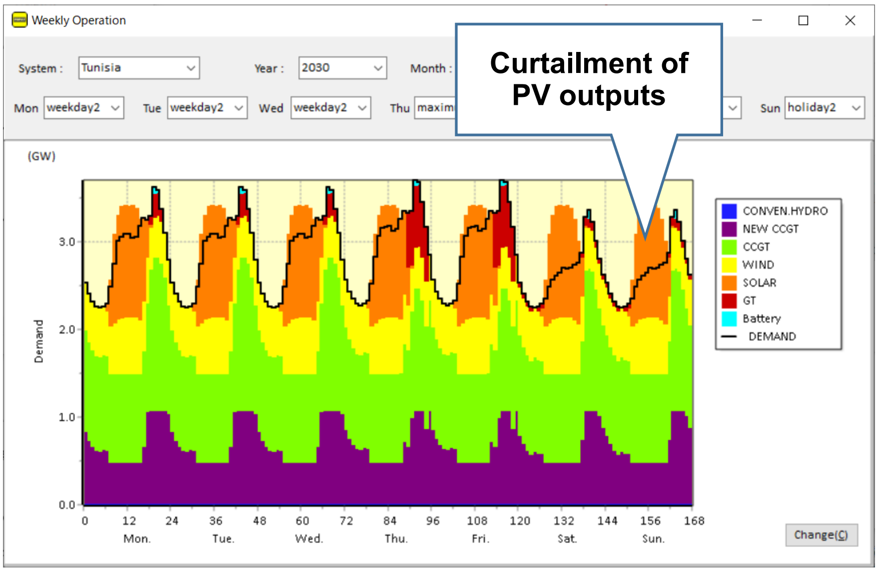
(Source: JICA study team)

Figure 5-49 Supply/demand balance in Apr 2026 (BESS 50MW/50MWh)

2) BESS 100MW/100MWh (2030)

BESS 100MW / 100MWh will be introduced in 2030, and it is expected that the supply disruption during peak hours will be resolved as shown from short period fluctuation analysis results. This case is expected that the supply disruption during peak hours will be resolved.

Introducing the BESS 100MW/100MWh in 2030 will reduce VRE curtailment by 27 GWh / year. The thermal power output reduction is 22GWh/year. The fuel cost of thermal power is 7.0 C / kWh according to the supply and demand simulation using the fuel cost forecast data of STEG. Along with this, the fossil fuel burning reduction effect is 1.54 MUSD / year.



(Source: JICA study team)

Figure 5-50 Supply/demand balance in Apr. 2030 (BESS100MW/100MWh)

(3) Calculation of power supply reliability of Base scenario

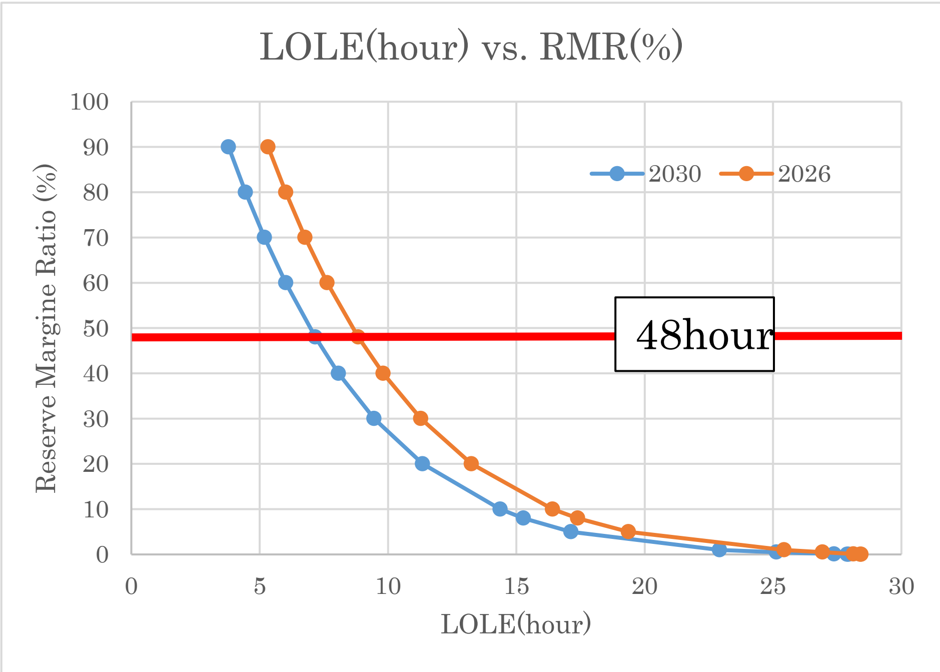
The power supply reliabilities in 2026 and 2030 in the Base scenario are calculated. LOLE was calculated with 50% of the PV output of VRE as the supply capacity.

The power supply reliability in 2026 is LOLE = 2.4 hour, operating reserve 22.2%,

The power supply reliability in 2030 is LOLE = 2.3 hour, supply reserve 20.6%,

The relationship between LOLE and operating reserve in the Base scenario is shown in the figure below based on the status of demand, VRE, and supply capacity. It was calculated that the reserve margin rate required to achieve the power supply reliability target of LOLE = 48hour is 8.8% in 2026 and 7.6% in 2030.

If PV and WT are also discretely arranged, some supply capacity can be expected. According to STEG standards, WT is not expected to be in supply capacity, but PV is expected to be 50% in supply capacity.



(Source: JICA study team)

Figure 5-51 Relation between LOLE and RMR in 2026 and 2030 (Base scenario)

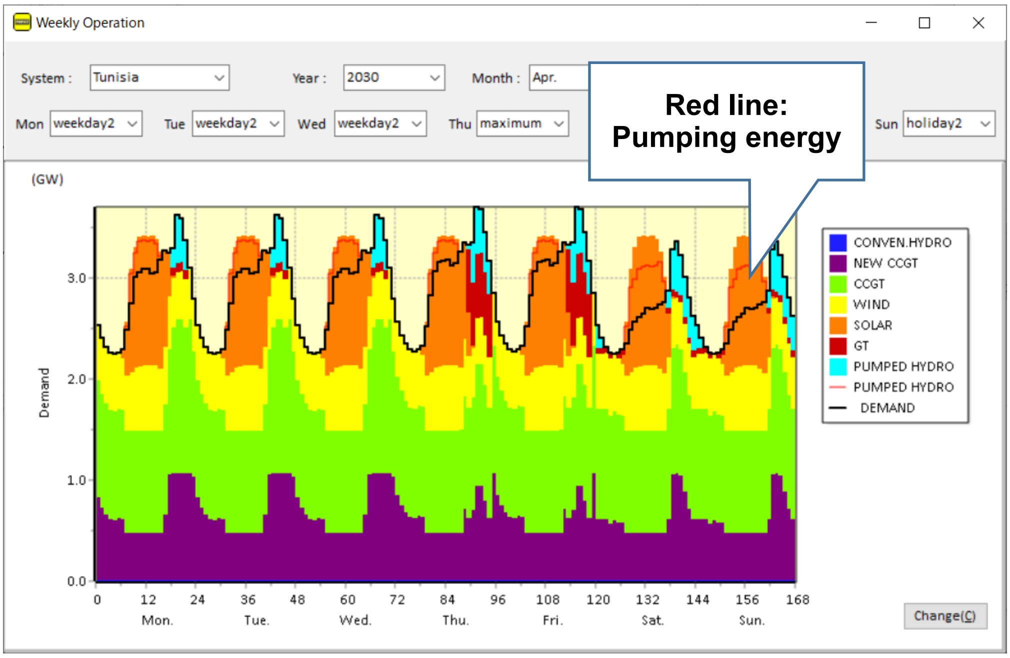
5.4.5 Sensitive Analysis Supply/Demand Balance in 2030

In 2030, 100 MW / 100 MWh of BESS will be required with or without ASPSPP to suppress short-cycle fluctuations in VRE. There is a plan to develop ASPSPPs, 400 MW (200 MW 2 units), by 2030. Examine the impact on the supply/demand balance when introducing ASPSPPs and BESS.

(1) BESS100MW/100MWh with ASPSPP 200MW 2units Case

In 2030, 2 units of BESS 50MW / 50MWh and 2 units of ASPSPP 200MW are introduced. The supply/demand balance was simulated in the case where the development of GT300MW was canceled in based on the STEG plan.

As a result, VRE output suppression is reduced by 528 GWh. 92GWh curtailment still remains. The thermal power output reduction is 399GWh/year. The fuel cost of thermal power plant is 7.0c / kWh. Therefore, the fuel cost will be reduced by 27.93 MUSD / year.



(Source: JICA study team)

Figure 5-52 Supply/demand balance in Apr. 2030 (With BESS, ASPSPP)

5.4.6 Results of Supply/Demand Balance analysis

(1) Demand forecast

From risk analysis aspect for the investment plan, it is recommended to set high demand and low demand to deal with investment risk so that supply capacity shortage and overinvestment.

(2) System stabilization measures from the supply/ demand balance simulation

Considering the investment cost, BESS selected 1C performance and conducted a supply and demand simulation.

As a result of economic operation examination by supply and demand simulation, the capacity of BESS required for grid stabilization is as follows.

1) By 2026, BESS needs 50MW / 50MWh.

2) By 2030, BESS is required at 100MW / 100MWh.

In this case, the amount of VRE output suppression reduction and the effect of burning reduction are as follows.

1) Effect of introducing BESS 50MW / 50MWh by 2026

--Reduction of VRE output suppression: 14GWh / year

--Reduction of fuel cost by reducing heating: 0.671MUSD / year per year

2) Effect of introducing 100MW / 100MWh by BESS by 2030

--Reduction of VRE output suppression: 27GWh / year

--Reduction of fuel cost by reducing heating: 1.541MUSD / year per year

(3) Reduction of VRE curtailment

In the examination of the Base scenario, only ASPSPP400MW has not been able to effectively utilize the planned amount of VRE power generation. Therefore, it is necessary to further consider additional power storage devices.

In addition, it is necessary to review the operation of CCGT (adopt DSS).

5.5 Examination of BESS installation location

5.5.1 Purpose of study

No matter where the BESS is installed, the frequency improvement does not change. However, regarding the voltage, the impact on the power system differs depending on the installation location. Therefore, a study will be conducted to select a location that has the effect of suppressing voltage fluctuations due to Variable Renewable Energies (VREs). In addition, stabilization of the system voltage is also beneficial for stable operation of the surrounding VREs.

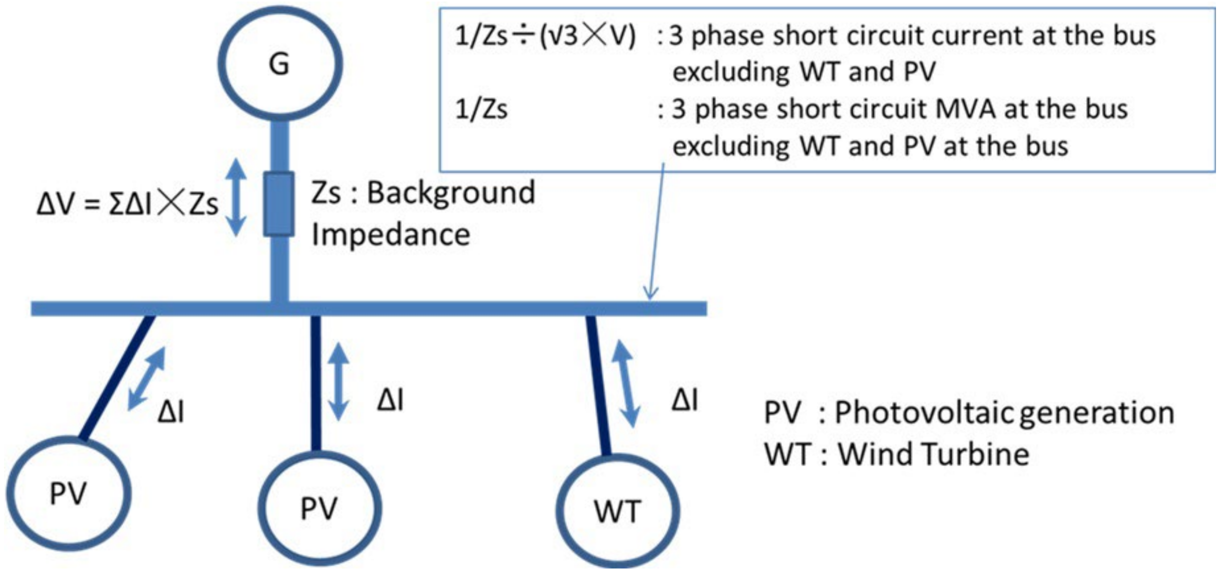
5.5.2 Examination method

If BESS is installed in a place where the system voltage fluctuates greatly, it can be expected to suppress the voltage fluctuation, so find that place.

The place where the fluctuation of the system voltage is large is the place where the three-phase short-circuit current is small compared to the VREs' installation amount. It can be used to improve the voltage fluctuation due to the output fluctuation of the renewables by using a battery.

In general as shown in Figure 5-53, the magnitude of the three-phase short-circuit current or MVA at that point is inversely proportional to the fluctuation of the system voltage if the same current fluctuation should occur. It can also be said that the **three- phase short-circuit current or MVA represents the strength of the AC system**. Therefore, to select a points with a small short circuit current or MVA could be the **screening method.**

By installing a battery, it might effectively suppress voltage fluctuation in normal operation, assuming the output fluctuation of VRE.

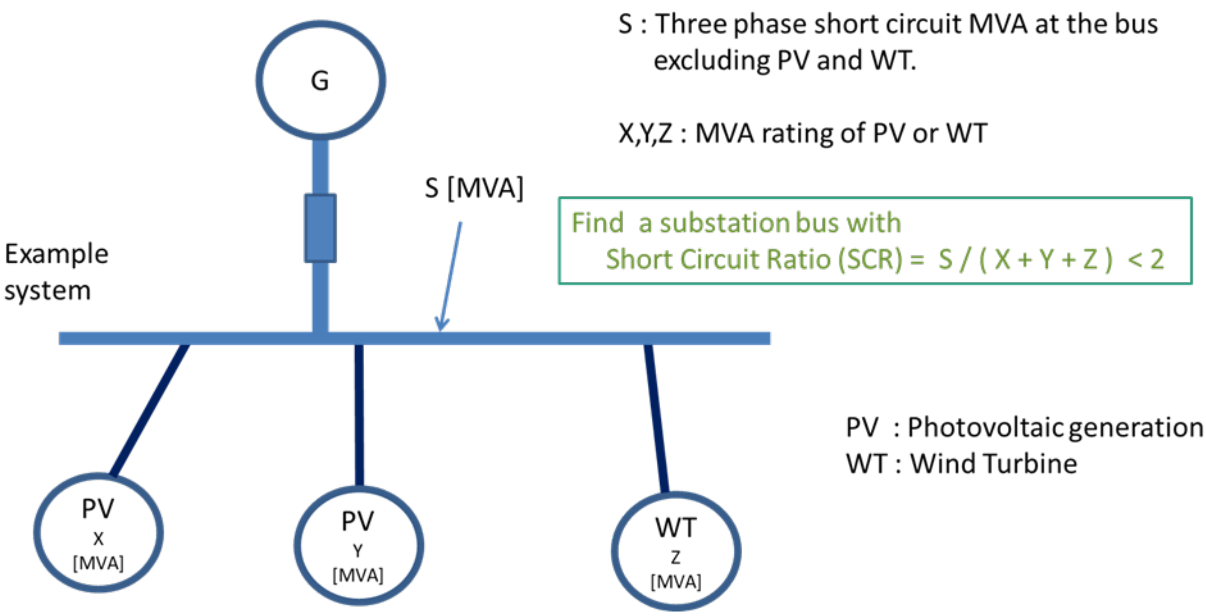


(Source: JICA study team)

Figure 5-53 Relationship between current fluctuation of VREs and voltage fluctuation

The following shown in Figure 5-54 are defined as screening criteria.

Screening Criteria SCR Three phase short circuit MVA is less than **twice** *of the MVA rating of the renewables in the area. *Generally, it is mentioned that less than 2 is a very weak AC system



(Source: JICA study team)

Figure 5-54 Description of screening criteria SCR

Instead of using the three-phase short-circuit MVA, SCR becomes the same result obtained by using the current value (Ampere) generally used as the result of the three-phase short-circuit calculation.

In addition, the BESS installation space, security, maintenance, and operational aspects will be examined.

5.5.3 Potential Candidate from SCR

Location sites were evaluated based on the Screening Criteria SCR described in Figure 5-54.

In calculating the SCR, we considered it severely assumed the following.

- ✓ The operating conditions of the thermal power generator were determined based on the merit order so that the total of minimum output of the thermal power generator would meet the OFFPEAK demand (around 2,000 MW).
- ✓ PSPP has stopped.
- ✓ Short-circuit current from VRE is not expected. (For comparison by SCR)

The calculation method of PSS/E is as follows.

- ✓ IEC 60909 SHORT CIRCUIT CURRENTS

  OPTIONS USED:

  - MAXIMUM FAULT CURRENT CALCULATIONS, IMPEDANCE CORRECTION FACTORS CALCULATED AND APPLIED
  - VOLTAGE FACTOR C=1.05 WHEN BUS BASE kV<=1.0 kV and C=1.1 WHEN BUS BASE kV>1.0 kV
  - SET SYNCHRONOUS/ASYNCHRONOUS MACHINE POWER OUTPUTS TO P=0.0, Q=0.0
  - SET GENERATOR POSITIVE SEQUENCE REACTANCES TO TRANSIENT
  - SET TRANSFORMER TAP RATIOS=1.0 PU AND PHASE SHIFT ANGLES=0.0
  - SET LINE CHARGING=0.0 IN +/- SEQUENCES
  - SET LINE/FIXED/SWITCHED SHUNTS=0.0 AND TRANSFORMER MAGNETIZING ADMITTANCE=0.0 IN +/- SEQUENCES
  - SET LOAD=0.0 IN +/- SEQUENCES

In the 2019 METI report, it lists the MEDHILLA substation in southern Tunisia as a potential candidate site.

Table 5-9 shows the results of recalculation of SCR based on the network data received from STEG in August 2021. The current value (Ampere) was used for the SCR calculation.

The MEDHILLA substation with an SCR of less than 2 is a strong potential candidate for the installation of BESS, which is no different from the 2019 METI report.

The SCR of the MEDNINE substation and the TATAOIN substation each exceeds 2, but it is about 3, which can be said to be a weak system.

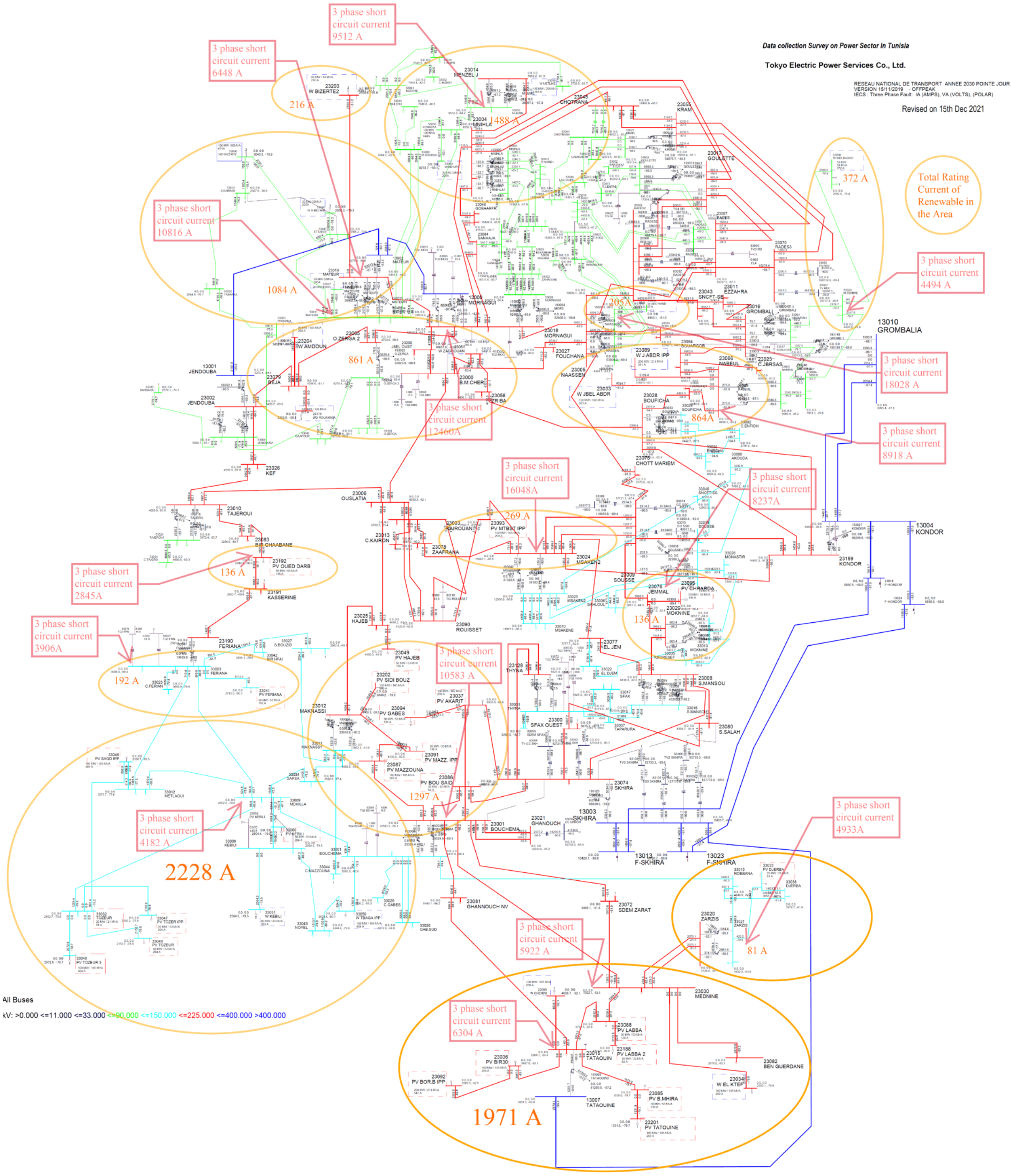
Since the SCR of other substations is 5 or more, it can be said that it is a strong system.

A map of the three-phase short-circuit current and the VREs' rated current are also shown in Figure 5-56. (See ANNEX 5-3 for details)

Table 5-9 SCR Calculation Results

Node Num	Substation Name	Bus Voltage [kV]	Short circuit current [Ampere] (a)	Total of VREs' rated current [Ampere] (b)	SCR (a / b)
33009	MEDHILLA	150	4182	2228	**1.9**
23030	MEDNINE	225	5922	1971	**3.0**
23015	TATAOUIN	225	6304	1971	**3.2**
53010	M.JEMIL (MENZEL J)	90	9512	1488	6.4
23001	BOUCHEMA	225	10583	1297	8.2
53011	MATEUR	90	10816	1084	10.0
23066	NABEUL	225	8918	864	10.3
53028	M.TEMIME	90	4494	372	12.1
23018	MORNAGUI	225	12460	861	14.5
33003	FERIANA	150	3906	192	20.3
23192	PV OUED DARB	225	2845	136	20.9
23019	MATEUR	225	6448	216	29.9
23024	MASAKEN2	225	16048	269	59.7
23076	JEMMAL	225	8237	136	60.6
33021	ZARZIS	150	4933	81	60.9
53012	NAASSEN	90	18028	205	87.9

(Source: JICA study team)



(Source: JICA study team)

Detailed map: ANNEX 5-3

Figure 5-55 Short circuit current and VRE's rated current

5.5.4 Required reactive power for BESS

The maximal reactive power output of BESS is considered to be sufficient as the active power at a rated power factor of around 90% (44% of the maximal active power).

5.5.5 Recommendation of BESS location from a system voltage aspect

Install BESS in a place where the system voltage aspect is weak and has a relatively low ratio of the three-phase short-circuit current and the VREs' rated current.

As a result of the examination, it is recommended to install BESS at the MEDHILLA substation first. It is also recommended to install BESS in such as MEDNINE and TATAOIN, of which SCRs are still low, in consideration of changes in the VRE development plan and security for BESS due to its break-down.

After the BESS candidates are confirmed, a field survey is required to comprehensively examine the installation space, security, maintenance, and operation.

5.5.6 Regarding system transient stability (reference)

As mentioned in 5.2.2, there are no issues with the system transient stability. Therefore, it is not necessary to consider the BESS candidate points from this point of view.

5.6 Economic Analysis of BESS installation

In this study, an economic analysis was conducted assuming a project to construct a 50 MW / 50 MWh BESS in 2026. The economic benefits of BESS were assumed to reduce output suppression of variable VRE by load shifting, to adjust demand-supply in the short-term fluctuation of VRE output, and GHG emission reduction effect. As a result of investigating the C rate and cost of the storage battery, the 1C storage battery has a cost advantage over the 2C; thus, the economic benefit was calculated assuming a 1C lithium-ion storage battery.

5.6.1 Caluculation Condition

Table 5-10 shows the prerequisites for evaluation.

The project period was set to 15 years according to the expected life of BESS. Since the construction period of BESS is short, the benefits have been counted since the construction year.

For the unit power generation cost of thermal power generation, the result (6.21 cent / kWh) of the supply and demand simulation of the 2026 section by PDPAT3 was used. For the CO2 emission factor in the power system in Tunisia, the value provided by STEG (2.8Mt-CO2 / Mtoe) was adopted. For the conversion of the GHG emission reduction effect into monetary value, the assumed value of STEG's GHG emission trading price shown in Table 5-11 was used.

Table 5-10 Calculation Prerequisites

No.	Symbol	Item	Value	Remark
1		Project Period	15 years	BESS life time
2	C_{BESS}	Capacity of BESS	50MWh	According to the study
5	$CAPEX_{BESS}$	Unit CAPEX of BESS	700 USD/kWh	C rate = 1C Assumption by the Consultant
6	$CAPEX_{GT}$	Unit CAPEX of GT	600 USD/kW	Assumption by STEG
8	$OPEX_{BESS}$	OPEX of BESS	1% of CAPEX	Assumption by the Consultant
9	$OPEX_{GT}$	OPEX of GT	1% of CAPEX	Assumption by the Consultant
13	UGC	TPP Unit Generation Cost	6.21 Cent/kWh =0.0621 USD/kWh	Average Thermal Power Plant kWh unit cost as of 2026 calculated by PDPAT3
14	EF_{CO2}	CO2 emission factor	2.8 t-CO2/toe =0.24kg/kWh	Assumption by STEG Converted with 1toe=11.63MWh

(Source: JICA study team)

The assumed value of STEG's GHG emission credit transaction price shown in Table 5-11 was used to convert the GHG emission reduction effect into monetary value. STEG assumes two scenarios: scenario 1 of No. 1 and No. 2 in Table 5-11 and scenario 2 of No. 3, 4, and 5 in the same table.

Table 5-11 GHG Emission Trading Price Assumption

No.	Symbol	Item	Value	Remark
1	$CF_{CO}(S1_1)$	Scenario 1 (2021-2022)	2.8 DT/t-CO2 =0.979 USD/t-CO2	Assumption by STEG Converted with 1USD=2.86DT as of 07-02-2022
2	$CF_{CO}(S1_2)$	Scenario 1 (2023-2030)	3.66 DT/t-CO2 =1.280 USD/t-CO2	ditto
3	$CF_{CO}(S2_1)$	Scenario 2 (2021-2022)	1.25 DT/t-CO2 =0.437 USD/t-CO2	ditto
4	$CF_{CO}(S2_2)$	Scenario 2 (2023-2025)	2.25 DT/t-CO2 =0.787 USD/t-CO2	ditto
5	$CF_{CO}(S2_3)$	Scenario 2 (2026-2030)	3.29 DT/t-CO2 =1.150 USD/t-CO2	ditto

(Source: JICA study team)

5.6.2 Economic Cost

BESS construction cost / OM cost

35 MUSD (700 USD x 50 MWh) was estimated as the construction cost of BESS in 2026, and the annual OM cost was assumed to be 1% of the construction cost.

5.6.3 Economic Benefit

(1) Fuel Reduction Effect by load-shifting

The fuel cost reduction due to the amount of reduction in thermal power generation with the load shift of BESS is a benefit of that. In Section 5.5, the fuel reduction due to the peak shift in 2026 was calculated to be 11 GWh / year per year. The cost of power generation from thermal power generation was calculated to be 6.1 cent / kWh. In this analysis, the fuel cost reduction effect of the annual load shift was assumed as 671,000 USD / year.

(2) Reduction of the CAPEX and OPEX of Gas Turbine

BESS installation will avoid CAPEX and OPEX of gas turbines as a regulating force to cope with short cycle fluctuations. The study team supposed the avoidable CAPEX is 30 MUSD in 2026 and the OPEX is avoidable 0.3 MUSD each year thereafter in the analysis. In this analysis, the unit construction cost of gas turbine thermal power was assumed 600 USD/kW, and the OM cost was assumed 1% of the construction cost.

(3) GHG emission reduction effect

The amount of GHG emission reduction was calculated by multiplying the amount of reduction in thermal power generation by the emission factor of Tunisia. The conversion from the amount of GHG emission reduction to the monetary value used the assumed GHG emissions trading price presented by STEG. For the GHG emissions trading price after 2030, the value of 2030 was used.

5.6.4 EIRR (Economic Internal Rate of Return)

The economic cash flow and EIRR for the project period of 15 years were calculated using the calculation conditions and calculation method described in the previous section. Tables Table 5-12 to Table 5-14 show the EIRR calculation results of the project.

The calculation results are 11.03% (Table 5-12) for EIRR, which does not expect GHG emission reduction effect, 11.14% (Table 5-13) for EIRR, which expects GHG emission reduction effect in STEG emission trading price scenario 1, and STEG emission trading price. The EIRR, which is expected to have a GHG emission reduction effect in Scenario 2, was 11.15% (Table 5-14). In each case, it was shown to be economical enough.

Table 5-12 Calculation Result of EIRR (without GHG emission reduction effect)

IRR= 11.03%

		Investment [kWh]	Cost [USD]	Benefit [USD]			
	Year	BESS	BESS	Reduced Fuel	Avoided CAPEX and OPEX of GT	Reduced GHG emission	CF
1	2,026	50,000	35,000,000	671,000	30,000,000	0	-4,329,000
2	2,027		350,000	671,000	300,000	0	621,000
3	2,028		350,000	671,000	300,000	0	621,000
4	2,029		350,000	671,000	300,000	0	621,000
5	2,030		350,000	671,000	300,000	0	621,000
6	2,031		350,000	671,000	300,000	0	621,000
7	2,032		350,000	671,000	300,000	0	621,000
8	2,033		350,000	671,000	300,000	0	621,000
9	2,034		350,000	671,000	300,000	0	621,000
10	2,035		350,000	671,000	300,000	0	621,000
11	2,036		350,000	671,000	300,000	0	621,000
12	2,037		350,000	671,000	300,000	0	621,000
13	2,038		350,000	671,000	300,000	0	621,000
14	2,039		350,000	671,000	300,000	0	621,000
15	2,040		350,000	671,000	300,000	0	621,000

(Source: JICA study team)

Table 5-13 Calculation Result of EIRR (with GHG emission reduction effect (STEG's scenario 1))

							IRR=	11.15%
		Investment [kWh]	Cost [USD]	Benefit [USD]			CF
	Year	BESS	BESS	Reduced Fuel	Avoided CAPEX and OPEX of GT	Reduced GHG emission	
1	2,026	50,000	35,000,000	671,000	30,000,000	3,389	-4,325,611
2	2,027		350,000	671,000	300,000	3,389	624,389
3	2,028		350,000	671,000	300,000	3,389	624,389
4	2,029		350,000	671,000	300,000	3,389	624,389
5	2,030		350,000	671,000	300,000	3,389	624,389
6	2,031		350,000	671,000	300,000	3,389	624,389
7	2,032		350,000	671,000	300,000	3,389	624,389
8	2,033		350,000	671,000	300,000	3,389	624,389
9	2,034		350,000	671,000	300,000	3,389	624,389
10	2,035		350,000	671,000	300,000	3,389	624,389
11	2,036		350,000	671,000	300,000	3,389	624,389
12	2,037		350,000	671,000	300,000	3,389	624,389
13	2,038		350,000	671,000	300,000	3,389	624,389
14	2,039		350,000	671,000	300,000	3,389	624,389
15	2,040		350,000	671,000	300,000	3,389	624,389

(Source: JICA study team)

Table 5-14 Calculation Result of EIRR (with GHG emission reduction effect (STEG's scenario 2))

						IRR=	11.14%
		Investment [kWh]	Cost [USD]	Benefit [USD]			CF
	Year	BESS	BESS	Reduced Fuel	Avoided CAPEX and OPEX of GT	Reduced GHG emission	
1	2,026	50,000	35,000,000	671,000	30,000,000	3,046	-4,325,954
2	2,027		350,000	671,000	300,000	3,046	624,046
3	2,028		350,000	671,000	300,000	3,046	624,046
4	2,029		350,000	671,000	300,000	3,046	624,046
5	2,030		350,000	671,000	300,000	3,046	624,046
6	2,031		350,000	671,000	300,000	3,046	624,046
7	2,032		350,000	671,000	300,000	3,046	624,046
8	2,033		350,000	671,000	300,000	3,046	624,046
9	2,034		350,000	671,000	300,000	3,046	624,046
10	2,035		350,000	671,000	300,000	3,046	624,046
11	2,036		350,000	671,000	300,000	3,046	624,046
12	2,037		350,000	671,000	300,000	3,046	624,046
13	2,038		350,000	671,000	300,000	3,046	624,046
14	2,039		350,000	671,000	300,000	3,046	624,046
15	2,040		350,000	671,000	300,000	3,046	624,046

(Source: JICA study team)

5.6.5 Sensitivity Analysis

Future equipment costs and power generation costs, and construction costs of gas turbine thermal power generation will fluctuate due to technological innovation and changes in the external environment.

Sensitivity analysis was performed with the base case as the condition in Table 5-15 (without GHG emission reduction effect) and with the variables as unit construction cost of BESS [USD/kWh], unit construction cost of gas turbine [USD / kW] and unit generation cost of gas turbine[USD/kWh].

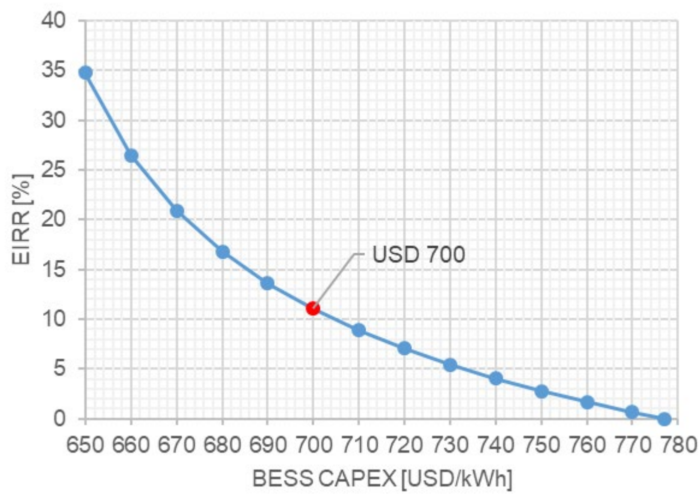
Table 5-15 Calculation Prerequisites (Base Case in Sensitivity Analysis)

No.	Symbol	Item	Value	Remark
1		Project Period	15 years	BESS life time
2	C_{BESS}	Capacity of BESS	50MWh	According to the study
3	$CAPEX_{BESS}$	Unit CAPEX of BESS	700 USD/kWh	C rate = 1C Assumption by the Consultant
4	$CAPEX_{GT}$	Unit CAPEX of GT	600 USD/kW	Assumption by STEG
5	$OPEX_{BESS}$	OPEX of BESS	1% of CAPEX	Assumption by the Consultant
6	$OPEX_{GT}$	OPEX of GT	1% of CAPEX	Assumption by the Consultant
7	UGC	TPP Unit Generation Cost	6.21 Cent/kWh =0.0621 USD/kWh	Average Thermal Power Plant kWh unit cost as of 2026 calculated by PDPATIII

(Source: JICA study team)

(1) Unit Construction Cost of BESS

Figure 5-56 shows the sensitivity analysis results of BESS construction costs. The construction cost of BESS was set to 700 [USD / kWh] in the base case based on the results of manufacturer hearings. (Red marker in the figure) When the construction cost of BESS is 777 [USD / kWh], the EIRR is 0%.

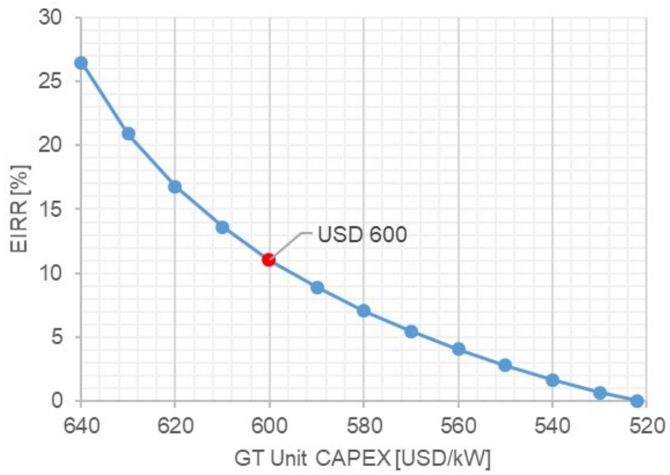


(Source: JICA study team)

Figure 5-56 Sensitivity Analysis in Unit Construction Cost of BESS

(2) Unit Construction Cost of Gas Turbine

Figure 5-57 shows the sensitivity analysis results of gas turbine-fired power generation construction costs. The construction cost of the gas turbine was set at 600 [USD / kWh] in the base case based on the data provided by STEG. (Red marker in the figure) When the construction cost of the gas turbine is 522 [USD / kWh], the EIRR is 0%.

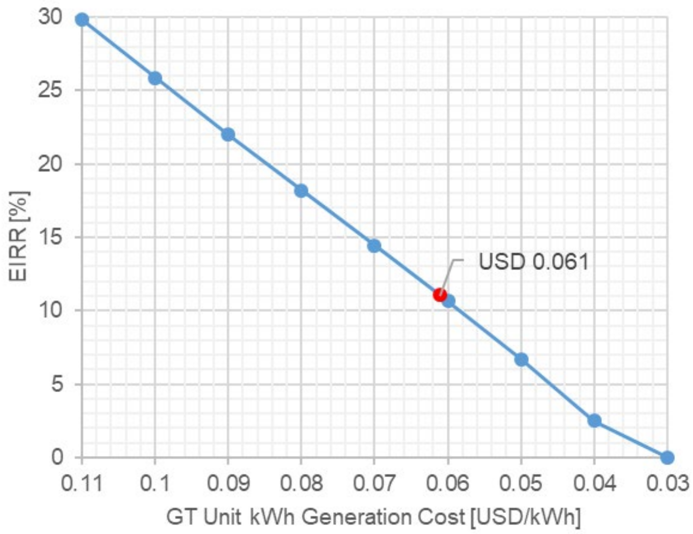


(Source: JICA study team)

Figure 5-57 Sensitivity Analysis in Unit Construction Cost of Gas Turbine

(3) Unit Generation Cost of Gas Turbine

Figure 5-58 shows the results of sensitivity analysis of gas turbine-fired power generation costs. The power generation cost of the gas turbine was 6.1 [USD / kWh] in the base case. When the power generation cost of the gas turbine is 3.4 [USD / kWh], the EIRR is 0%.



(Source: JICA study team)

Figure 5-58 Sensitivity Analysis in Unit kWh Generation Cost of Gas Turbine

5.6.6 The result of the Economic Analysis

The BESS project in an environment where the supply and demand adjustment market is not well developed is difficult to lead to the financial improvement of the business entity. However, the project contributes to the national economy by reducing imported fuel and also contributes to reduce GHG emission environment on a global scale.

In Tunisia, the supply-demand adjustment market has not been established, and it is difficult to predict the project's cash flow, as revealed in the sensitivity analysis. Thus, it is difficult to introduce the BESS project with private funds. However, BESS contributes to the national economy and global environment by reducing fuel consumption.

The government has decided to introduce 30% of VRE, and STEG is considering the introduction of ASPSPP and BESS as a system stabilization measure, but the financial burden is heavy, so the plan has not been formulated. The examination in Chapter 5 found that it is necessary to introduce BESS of 50MW / 50MWh by 2026 and 100MW / 100MWh by 2030 for system stabilization.

In addition, BESS can be introduced to distributed sites, and from the viewpoint of system voltage stability, one good point and two candidate points are listed. The introduction of BESS to these sites in stages according to the introduction status of VRE can reduce the financial burden of STEG.

According to STEG, as of 2022, the introduction of VRE is delayed by about two years from the plan due to COVID-19. Therefore, according to the progress of the introduction of VRE, it can be an option to develop BESS 20MW / 20MWh every year for five years from 2026 to 2030 and to develop a total of BESS 100MW / 100MWh by 2030. If BESS20MW / 20Mh is introduced in 2026, it can be expected to reduce fuel consumption by 268,400 USD / year. In considering the BESS project in the future, the gradual introduction of BESS is advantageous in terms of financing.

For example, the following supporting program is considered.

First, STEG will introduce a small-capacity BESS (for example, 20MW / 20MWh) with grant aid and acquire know-how (planning, specification, design, tender process, construction, and OM) about BESS. After that, depending on the progress of VRE introduction, large-scale BESS will be introduced with loan aid.

5.7 Results of examination of power system stabilization measures for mass introduction of VRE

5.7.1 Review of System plan

As a result of the calculation, there was no equipment that was overloaded (insufficient transmission capacity). From this, it is considered that a power transmission plan corresponding to the power supply enhancement has been made appropriately. In addition, as a result of calculating the transient (synchronous) stability due to the transmission line accident, it is considered that there is no problem.

5.7.2 Power supply and demand frequency simulation analysis results for short-period fluctuations

(1) Power supply and demand frequency simulation analysis of short-period frequency fluctuations

The results of frequency fluctuation analysis in the grid demand and short-period fluctuation model of the generator are shown below. The target range of frequency fluctuations in Tunisia is 50 ± 0.3Hz, and 50 MW of BESS will be required in 2026 to keep the frequency fluctuations within this range. In 2030, 100 MW of BESS will be required with or without ASPSPP.

Table 5-16 Frequency Fluctuation Calculation Result

CASE	0	1	2	3	4	5	6
Year	2030					2026	
ASPSPP (MW)	0	0	0	400	400	0	0
BESS(MW)	50	100	150	50	100	50	100
99.7 Percentile Value(Hz)	**0.3213**	**0.2778**	**0.2495**	**0.3343**	**0.2750**	**0.2976**	**0.2472**

(Source: JICA study team)

(2) BESS charge / discharge status calculation results

The charge / discharge status for suppressing short-period fluctuations in BESS was calculated, and the required capacity was obtained. The results are as follows.

- By 2026, BESS 50MW / 25MWh or higher is required.
- By 2030, BESS50MW / 25MWh 2 units or more are required.

5.7.3 Results of economic operation analysis by the supply/demand balancing simulation

(1) Results of supply/ demand balance simulation

As a result of economic operation examination by supply and demand simulation, the capacity of BESS required for grid stabilization is as follows.

1) By 2026, BESS needs 50MW / 50MWh.

2) By 2030, BESS needs 1000MW / 100MWh.

In this case, the amount of VRE output suppression reduction and the effect of burning reduction are as follows.

1) Effect of introducing BESS 50MW / 50MWh by 2026

--Reduction of VRE output suppression: 14GWh / year

--Reduction of fuel cost by reducing heating: 0.671MUSD / year per year

2) Effect of introducing 100MW / 100MWh by BESS by 2030

--Reduction of VRE output suppression: 27GWh / year

--Reduction of fuel cost by reducing heating: 1.541MUSD / year per year

(2) Reduction of VRE curtailment

In the examination of the Base scenario, only ASPSPP400MW has not been able to utilize the planned amount of VRE power generation effectively. Therefore, it is necessary to consider additional power storage devices further.

In addition, it is necessary to review the operation of CCGT (adopt DSS).

5.7.4 Necessity of grid voltage control

BESS is weak in terms of system voltage and should be installed in a location where the ratio of the three-phase short-circuit current to the rated current of VRE is relatively small. As a result of the study, it is recommended to install BESS at the MEDHILLA substation first. It is also recommended to install BESS in MEDNINE substations and TATAOIN substations with low SCR in consideration of changes in VRE development plans and outages due to BESS failures.

5.7.5 Economic efficiency of power system stabilization measures

An economic analysis was conducted assuming a project to construct a 50 MW / 50 MWh BESS in 2026. In the study, BESS's economic benefits were the reduction of VRE output suppression due to load shift, adjustment power (benefit of gas turbine replacement), and GHG emission reduction effect.

As a result of the analysis, the EIRR was 11.03% even in the pattern where the GHG emission reduction effect was not expected, indicating the economic validity of the project. However, a sensitivity analysis also found that the construction cost of BESS increased by 11% and the EIRR decreased to 0%.

In Tunisia, the supply-demand adjustment market has not been established, and it is difficult to predict the project's cash flow, as revealed in the sensitivity analysis. Thus, it is difficult to introduce the BESS project with private funds. However, BESS contributes to the national economy and global environment by reducing fuel consumption.

5.7.6 Impact of publicly announced grit code (GC)

In II.4) and III. Regarding the frequency control of the publicly announced GC for MV and HV, when connecting the power generation equipment using VRE to the grid, the frequency adjustment facilities should be installed in the same way as the existing power plant. According to III.1), WTs of more than and equal to 10 MW are required to be equipped with a device that can be activated by a command from the dispatching center that ΔP of 5% of the installed capacity can be increased or decreased as an inertial force for 10 seconds. In addition, according to III.2), when connecting renewable power generation equipment exceeding 10 MW to the grid, the control pattern of the frequency adjuster that can be used within 15 seconds from the command when the dispatching center is required is shown. According to III.2), it is required to suppress the output to 80% at 50Hz, increase it to 100% output by 49Hz, and reduce the output to 60% when the system frequency increases to 51.6Hz.

In the base scenario of 2030, PV is 1,596 MW and WT is 1,542 MW, so if all of these power generation facilities are 10 MW or more, the inertial force from WT will be 77 MW and the frequency adjustment force will be 627 MW. However, since the output from VRE changes suddenly depending on the weather, it is unclear whether the prescribed output for adjustment will be secured.

It is necessary to pay close attention to whether this GC is constructed and operated strictly.

Chapter 6 Priority Cooperation Framework

6.1 Challenges for mass introduction of VRE

Table 6-1 summarizes the issues related to the mass introduction of VRE. Regarding the Technical aspect, the issues are system constraints, mainly due to securing adjustment power to absorb frequency fluctuations due to VRE and insufficient transmission capacity to transmit power from the power source to the demand area. In recent years, regional distributed power systems using small-scale VRE distributed power sources have become widespread, and the technical and institutional handling of regional distributed power systems has become an issue.

Regarding institutional issues, introducing a market mechanism to promote the development and dissemination of grid codes is also an issue. It is also expected that an independent regulatory body will be needed to maintain a fair and transparent market environment.

On the other hand, to promote the introduction of VRE, it is necessary to improve the business environment as well as the introduction of the market mechanism. Currently, STEG's income-expense balance is in the red, and it depends heavily on subsidies, so it might be unable to invest in the system development of VRE introduction due to a lack of funds. Incentives to promote the entry of the private sector and improvement of the examination ability of VRE projects of financial institutions are also required.

In the interviews with related organizations in this survey, there were no requests for institutional design or improvement of the business environment, Tunisian side expressed interest in technical cooperation on short-period frequency fluctuation analysis, supply and demand simulation, and BESS technologies.

Table 6-1 Issues related to mass introduction of renewable energy

Issues	Countermeasures
<Technology>	
(1) System Stabilization measures Increased frequency fluctuations Insufficient inertial force	BESS installation
	ASPSS installation
	Demand Response
	Strengthening grid interconnection
	Improving grid operation technology
	Forecasting VRE output VRE
(2) Insufficient capacity of power transmission system	Strengthening transmission and distribution network
(3) Development of a regional distributed power system (Micro grid, mini grid, etc.)	Expanding regional distributed power systems
<Institutional>	
(1) No balancing market / capacity market	Establishing balancing and capacity markets
(2) No independent regulatory body	Establishing an independent regulatory body
(3) No grid code for VRE	Developing the grid code
(4) No laws/regulation/codes for minigrid/microgrid	Developing the law on mingrid/microgrid
<Business environment>	
(1) Electric power companies are in the red and highly dependent on subsidies	Management improvement, Subsidy reform
(2) Insufficient experience in VRE projects of financial institutions	Improving financial institutions' VRE project assessment capabilities
(3) Lack of incentives to encourage private entry	Establishing laws/schemes for the utilization of private funds

(Source: JICA study team)

6.2 Cooperation program (including support candidate project list (including implementation time information))

6.2.1 Request from Tunisian government

The Tunisian government has set a policy of introducing large amounts of Variable Renewable Energy (VRE) into the grid and reducing the consumption of imported fossil fuels. For this reason, Ministry of Industry, Energy and Mines (MIEM) has instructed STEG to consider grid stabilization measures for the introduction of large volumes of VRE.

According to the STEG plan reviewed earlier, the amount of VRE introduced in 2030 will be about 30% per amount of electricity. From the amount of VRE introduced, it is considered inevitable to suppress the output of VRE in order to maintain the frequency and voltage of the system.

In the JICA survey "Survey research on how to support developing countries in the era of mass introduction of renewable energy (project research)," in July 2019, the Tunisian side and the JICA study team organized the issues to introduce a large amount of variable renewable energy (VRE). (see ANNEX 6-1) Although they had a common understanding of the issues, solutions, and roadmap, there was no agreement, and MIEM submitted a Conceptual Note (ANNEX 6-2) that summarizes the requests for support later. STEG has expressed expectations for implementing technical assistance in Japan to consider and implement the grid stabilization measures described in the Conceptual note. This Conceptual note request item was narrowed down to the examination of system stabilization measures, and there were not a few items that were incompatible with the scope of this study. For the above reason, STEG and the JICA study team discussed requested items and organized them into three portions: the items to be implemented in this survey, those to be implemented in the technical assistance project, those to be implemented in the preparatory survey of the project.

On the other hand, in August 2021, a request for technical cooperation was issued. The contents of the technical cooperation project were discussed at the time of the field survey in November 2021, taking into consideration the contents of the Conceptual note based on this request.

6.2.2 Cooperation policy for policy formulating and implementing grid stabilization measures for the mass introduction of renewable energy

Based on the results of the studies in Chapter 5, we will review and organize support measures for system stabilization measures for mass introduction of VRE.

According to STEG's development plan, approximately 2GW of PV and WT VRE will be introduced into the grid by 2026. By 2030, about 3 GW of VRE is planned to be introduced into the grid.

On the other hand, we analyzed short-period fluctuations for frequency and voltage stability in a single system, examined economic operations including long-period fluctuations by supply and demand simulation, and examined the possibility of system voltage control.

As a result, it is recommended to introduce BESS 50MW / 50MWh by 2026, and to introduce BESS 100MW / 100MWh by 2030.

In addition, due to the need for system voltage control, we are proposing BESS distributed arrangements in two substations.

In order to realize these proposed system stabilization measures, we propose to provide support in the following steps.

(1) Short- and medium-term support (2023-2026)

It is planned that about 2GW of VRE will be introduced by 2026, and in order to realize this, the introduction of BESS 50MW / 50MWh will be realized. For this purpose, it is necessary to improve the capabilities of the following items. In particular, regarding BESS design capability, if the delivery date of BESS is one year from the order, it will not be in time for the start of BESS operation in 2026 unless the purchase specification (Bid Document) is completed in 2024.

1) Improvement of system / power supply planning capacity

Power equipment development plan Basic policy for setting scenarios

Planning method for equipment that can provide instantaneous reserve (ASPSPP, BESS)

Supply reliability (LOLE) calculation method

Supply and demand simulation method

System stability study (ROCOF, etc.)

2) Improvement of system operation capacity

Management and operation method of supply reserve (ASPSPP, BESS, VRE output suppression)

System voltage / power flow control analysis method

3) BESS design and operation capacity improvement

Formulation of BESS introduction method (distributed placement, stepwise introduction)

BESS basic specification settings (battery capacity, SOC, control method, etc.)

4) Support for BESS construction projects

BESS FS implementation

BESS detailed design, bid book creation

Funding support

Engineering support (bid, construction, testing, O & M)

(2) Medium- to long-term support (2026-2030)

It is planned that about 3GW of VRE will be introduced by 2030, and in order to realize this, the introduction of BESS100MW / 100MWh will be realized. For this purpose, it is considered necessary to continue to improve the capabilities of the following items.

1) Improvement of system / power supply planning capacity

Planning method for equipment that can provide instantaneous reserve (ASPSPP, BESS)

System stability study (ROCOF, etc.)

2) Improvement of system operation capacity

Management and operation method of supply reserve (ASPSPP, BESS, VRE output suppression)

System voltage / power flow control analysis method

3) Support for BESS construction projects

Funding support

(3) Long-term support (after 2030)

At present, the development plan has not been formulated after 2030, so the equipment requirements are not clear, but it is a medium- to long-term plan to further introduce VRE beyond 30% of the generated power. In addition to the operational support items, it seems necessary to consider the following items.

1) VRE and reserve reserves from the market

Establishing a flash reserve market

VRE market creation

6.2.3 Gradual introduction of BESS

The government has decided to introduce 30% of VRE, and STEG is considering the introduction of ASPSPP and BESS as a system stabilization measure, but the financial burden is heavy, so the plan has not been formulated. The examination in Chapter 5 found that it is necessary to introduce BESS of 50MW / 50MWh by 2026 and 100MW / 100MWh by 2030 for system stabilization.

In addition, BESS can be introduced to distributed sites, and from the viewpoint of system voltage stability, one good point and two candidate points are listed. The introduction of BESS to these sites in stages according to the introduction status of VRE can reduce the financial burden of STEG.

According to STEG, as of 2022, the introduction of VRE is delayed by about two years from the plan due to COVID-19. Therefore, according to the progress of the introduction of VRE, it can be an option to develop BESS 20MW / 20MWh every year for five years from 2026 to 2030 and to develop a total of BESS 100MW / 100MWh by 2030. If BESS20MW / 20Mh is introduced in 2026, it can be expected to reduce fuel consumption by 268,400 USD / year. In considering the BESS project in the future, the gradual introduction of BESS is advantageous in terms of financing.

For example, the following supporting program is considered.

First, STEG will introduce a small-capacity BESS (for example, 20MW / 20MWh) with grant aid and acquire know-how (planning, specification, design, tender process, construction, and OM) about BESS. After that, depending on the progress of VRE introduction, large-scale BESS will be introduced with loan aid.

6.3 Preparation for implementation of technical cooperation project (Request from Tunisian government)

The Tunisian government officially requested support for a technical cooperation project that contributes to system stabilization in August 2021. Based on this request and the necessary technical support items to STEG organized in 6.2 in the previous section, the content of technical cooperation was organized.

At the time of the field survey in December 2021, the current issue analysis and technical cooperation contents were organized as follows. (Refer to ANNEX6-3 Problem Analysis, ANNEX6-4 Draft PDM)

The implementing agency of the project is planned to be MIEM and STEG.

1. Overall Goal

   To promote sustainable development for low-carbon and decarbonized society in Tunisia.

2. Project Purpose

   To strengthen the capability of departments concerned for low carbon and stable supply of the power system in Tunisia.

3. Output

   1) To enhance the ability to operate the power utilities business and the monitoring ability of the independent regulatory body by sharing the knowledge and experience in Japan.
   2) To make estimation ability concerning the facilities providing various types of the margin supply facilities such as adjustable speed pump storage, storage batteries
   3) To make planning and operation capability to optimize various types of the margin supply facilities
   4) To improve sophisticated power balance analysis
   5) To establish ability of STEG of grid planning and operation with the sophisticated grid analysis in preparation for the situation where VRE ratio is more than 20%. (Capacity Building of Grid Operation and Management)
   6) To deepen understanding on measures for enhancing grid flexibility utilizing energy management system (EMS) and demand side management(DSM) and its enabling environment including policy, institutions (transaction market and regulations), and technologies.

4. Activity

   The activities related to outputs 2) to 5) are summarized below. Details will be decided through discussions again after the project is adopted. STEG requested the provision of a program necessary for short-period fluctuation analysis.

   1) The activities for ” Output 2: To make estimation ability concerning the facilities providing various types of the margin supply facilities such as adjustable speed pump storage, storage batteries” are described as followings.

   2-1 Overview/ Benchmark of the technologies / solutions to ensures power system flexibility taking into consideration costs and benefits in order to choose the most suitable solution for the Tunisian context.

   2-2 "Analysis of the dynamic frequency stability to identify the eventual constraints related to:

- the share of primary reserve that will be activated in minimum frequency.
- the value of Rate of Change of Frequency (ROCOF).
- Propose adaptive load shedding scheme based on the Rate of Change of Frequency (DF/DT) to enhance the stability of the power system.
-other constraints to be defined"

2-3 "To define an approach to identify the potential sites of BESS.
Selection of the potential candidate sites of BESS, considering the following items:
-The voltage stability criterion since BESS can improve the voltage fluctuation,
-The reduction of electrical losses in the transmission system,
-The reactive power capability amount of BESS. Using the BESS to control the flow of power in the interconnection lines to avoid their tripping."

2-4 "BESS function on the energy
Relation between BESS function and its specifications
Issues for determination of the specifications
Possible approach of BESS installation for Tunisian system
BESS Control system for realizing the coordination

2) The activities for “Output 3: To make planning and operation capability to optimize various types of the margin supply facilities” are described as followings.

3-1 Estimation of operational reserve (primary and secondary) for daily operation that takes into account the variability of RES

3-2 Training of the operational engineer in the national control center to supervise and control the electrical power system with high integration of ENRs and with new storage technologies such as BESS and others.

3-3 "Performing the flexibility study for a whole year instead of only one point in time “Day off peak” in order to estimate:
-The operation system cost
-The amount of renewable curtailment.

3) The activities for”Output 4: To improve sophisticated power balance analysis” is described as followings.

4 Knowledge sharing by the transfer of know-how to STEG engineers. (MATLAB simulation program, the methodology…)

4) The activities for”Output 5: To establish ability of STEG of grid planning and operation with the sophisticated grid analysis in preparation for the situation where VRE ratio is more than 20%. (Capacity Building of Grid Operation and Management)” are described as followings.

5-1 Estimation of operational reserve (primary and secondary) for 2022-2030 that takes into account the variability of RES

5-2 Analysis of the dynamic stability, in particular frequency and voltage stability, in order to identify the minimum number of must run unit (combined cycles) during the year of the study and to precise also their localization to ensure the stability of the electrical system (transient, frequency and voltage stability)

6.4 Feasible power sector cooperation projects and guidelines of medium- to long-term supports

STEG's current development plans were reviewed in 2026 and 2030. In the plan for 2030, the power storage equipment was not planned for the VRE introduction amount (3,138MW). When the supply and demand simulation in 2030 is carried out, the output of VRE is suppressed, and it is necessary to formulate a plan to develop the power storage facility in order to further introduce VRE in the future. In addition, in cases that a large amount of WT is introduced, it is considered for ASPSPP also necessary to adjust the power generation duration and the pumping timing , and further consideration is desired in operation conditions. Therefore, it is necessary to consider ASPSPP and BESS development.

If further development is difficult due to ASPSPP point of site restrictions, it is necessary to proceed with the study of BESS.

It is necessary to introduce ASPSPP and BESS in a middle and long term based on the examination of system stabilization measures for mass introduction of VRE. Of these, BESS can be distributed and arranged, so there is no need to collectively develop points as in ASPSPP. Therefore, it is possible to formulate a step-by-step introduction plan according to the amount of funds that can be procured.

The introduction of BESS is an indispensable measure for the introduction of VRE, but it is not economically viable and does not fit into private investment. Therefore, appropriate support is needed.

For this reason, the study team proposes to consider support in a middle and long term for the basic specifications and design of BESS, including financial aspects.

Furthermore, when considering participation in the European electricity market through RE supply, etc. in the future, it will be necessary to develop a market RE procurement and primary reserve procurement, and to establish standards for grid interconnection. In the long term, it is necessary to support the development of regulations, and organizational structures for marketization.

6.5 Training in this survey

In this survey, the study team conducted training on supply and demand/supply simulation when a large amount of VRE was introduced into the grid at the request of STEG (Fig. 6-1). The simulation software used was PDPAT3 developed by TEPCO PG. Table 6-1 shows the training content and schedule.

Table 6-2 Training Content and Schedule

Day	Training Contents

Day 1	Overview of PDPAT3
	Installing PDPAT3
	Data Input Method
	   Demand Data Input
	   Generator Parameter Input
	   Battery Storage Parameter Input
	
	Data Output Method
	   Output of Daily/Weekly Load Curve
	   Output of LOLE
	   How to Read the Output Data

Day 2	Simulation Exercise using 2026 data Simulation Exercise using 2030 data QA session

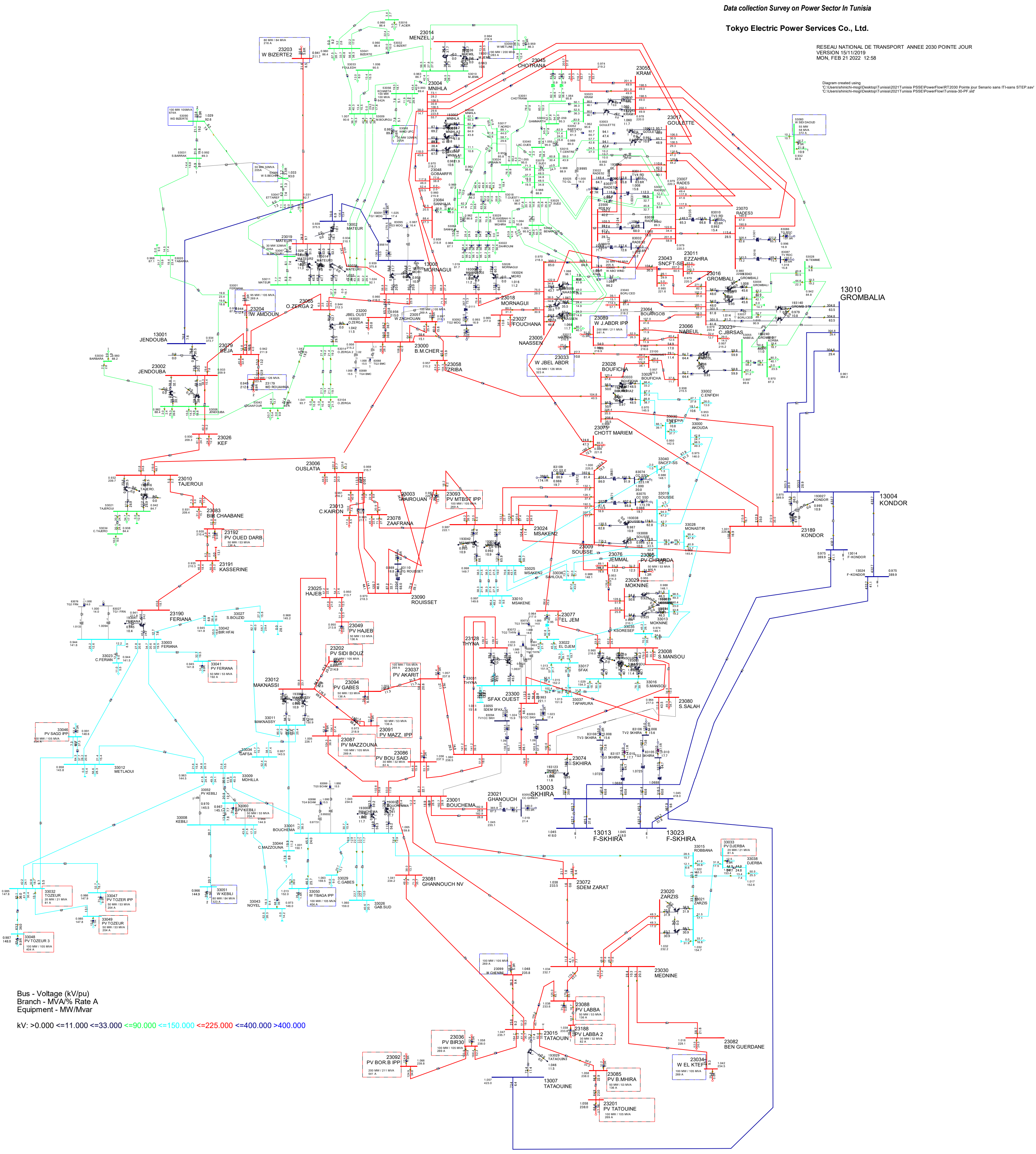
(Source: JICA study team)

Figure 6-1 Supply/Demand Simulation Training

ANNEX

Power flow diagram in 2030 without PSPP (STEP)

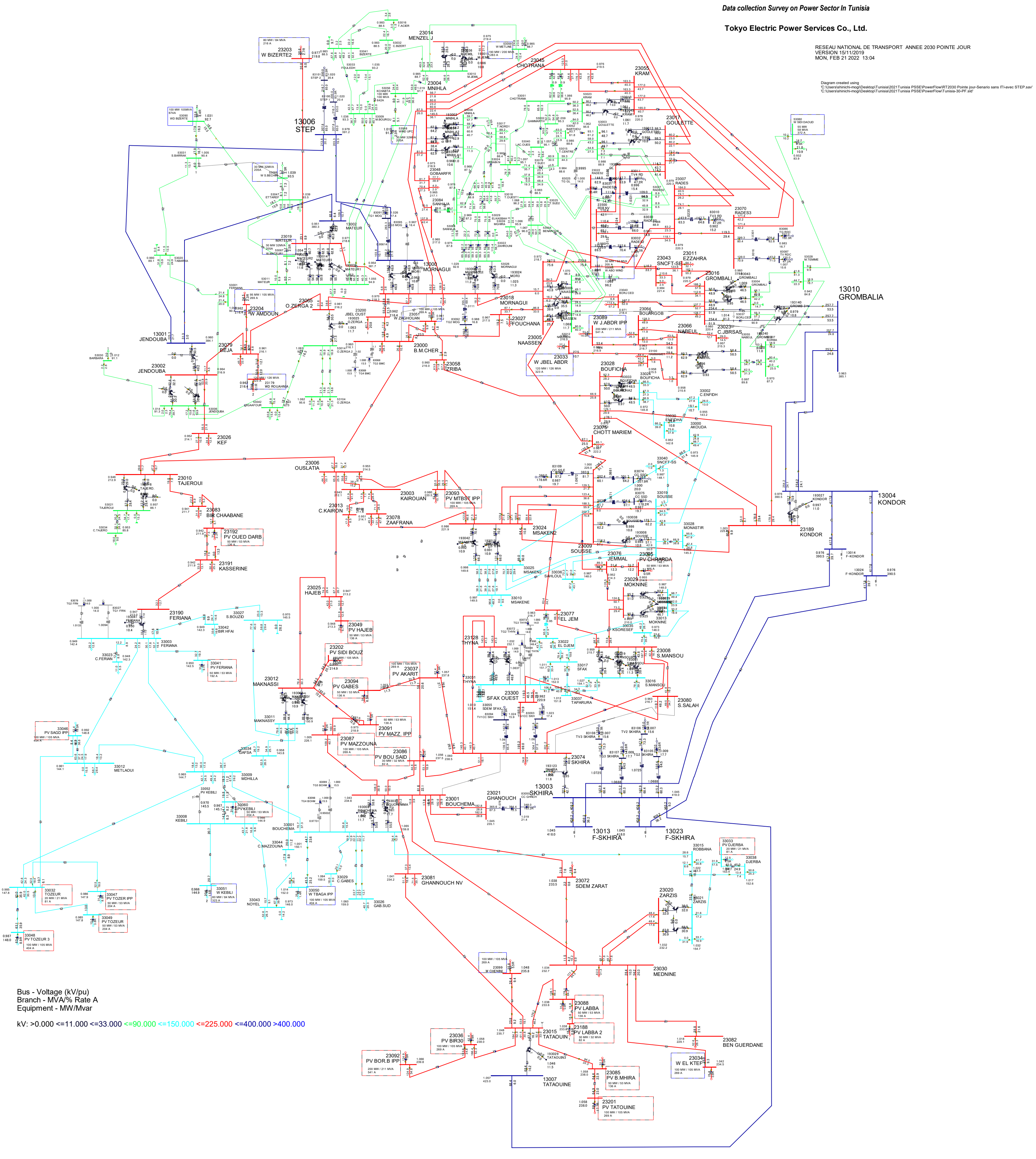
ANNEX 5-1



(Source : JICA survey team)

Power flow diagram in 2030 with PSPP (STEP)

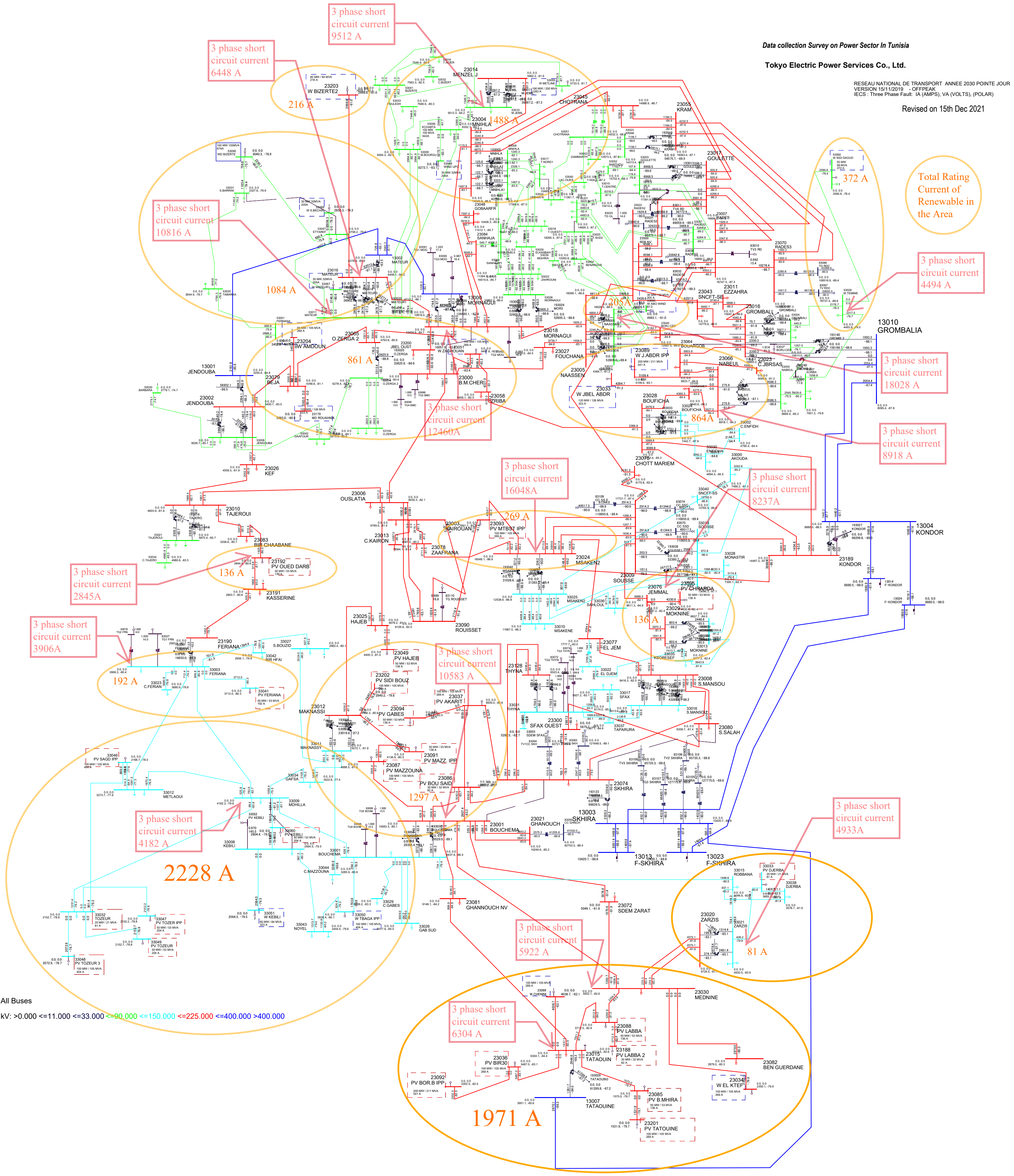
ANNEX 5-2



(Source : JICA survey team)

Short circuit current and VRE's rated current

ANNEX 5-3



(Source : JICA survey team)

Attachment I; Potential Issues and Solutions toward Renewable Energy 30% in 2030

Potential Challenges → ***Proposed Solutions***

<<Technical>>

・The significant duck curve will occur due to the massive PV introduction. (A)
→ Increase in primary and secondary control, peak cut/peak shift
・VREs will cause larger fluctuation of system frequency from around 2022. (B)
→ Reinforcement of frequency control capability (STEP, Battery Energy Storage System (BESS), small storage batteries and EVs)
・The capacity of transmission lines and substations will become insufficient to transfer electricity from the southern areas (more suitable for VRE) to the northern areas where the load center exists. (C) → Reinforcement of the transmission facilities
・The development of regional distributed power systems which ensure the diversity of energy resources and the independent operation of regional grids is still insufficient. (D)
→ Expansion of regional distributed power systems (Smart city development, etc.)
・Some system operation techniques such as weather and VRE output forecasting methodologies would be improved for optimal operation. (E)
→ Accumulation of data, refinement of forecasting methods and grid operating systems
・The existing interconnectors is inadequate. In addition, it is important to secure adequate primary frequency control capability (so called, inertia). (F)
→ Expansion of interconnectors, Optimal operational management of thermal power plants
・Rules and procedures for the dispatch of regulation reserves, the priority dispatch and the curtailment of VRE outputs are unclear. (G)
→ Clarification of dispatching code
・Any mechanism for secure necessary balancing capacity does not exist. (O) → Procurement of balancing capacity

<<Institutional>>

・Incentives to attract private participation in the self-production are insufficient. (H)
→ Improvement of incentive mechanisms
・Electricity tariffs and the associated cost burden of industries are being increased. (I)
→ Incentivize Energy efficiency actions for the Industries
・Electricity business management of STEG might not be self-reliant because of the financial deficit due to electricity pilferage, etc. (J)
→ Self-reliant management system, performance improvement, subsidy reform and installation of smart meter
・An independent regulator for the electricity industry with clear roles and functions does not exist. (L)
→ Formulation of an independent regulator
・Rules concerned with smart city operation has not yet been established. (M) → Pilot project of smart city
・Network access rules applicable to self-production has not yet been established (N) → Establishment of the rules

<<Business>> (except for those mentioned above)

・The price determination for PPA *of the Authorization regime* are not so clear. (K) → Clarification of the process
・Permission procedures are complicated and time-consuming. (Q) → Faster process
・Limited access to RE-related information makes it difficult to ensure the foreseeability of new VRE projects. (R)
→ Disclosure of weather data and curtailment plan
・Lack of experience of local financial institutions in VRE projects might delay VRE development (S) → Capacity building
・So far, local businesses are not so active in the electricity. (T) → Capacity building, *Expansion of Public-Private Finance*
・Some of the project risks including the off-taker risks and the foreign exchange risk cannot be mitigated easily. **(U)**
→ Development of proprietary insurance/guarantee products
・The number of electricity retailers *(self-production)* is quite limited. **(V)** → Business model development, Capacity building

Add 'of the Authorization regime'

Add 'Expansion of Public-Private Finance'

add '(self-production)'

MAIN TASKS RELATED TO THE FLEXIBILITY/STABILITY STUDY OF THE TUNISIAN POWER SYSTEM

We define by the following tasks, the different aspects that we want to deal with during this study, in order to meet our needs as well as our expectations.

1. Overview/ Benchmark of the technologies / solutions to ensures power system flexibility taking into consideration costs and benefits in order to choose the most suitable solution for the Tunisian context.
   For instance, a comparison between BESS and synchronous compensators in terms of voltage and frequency stability improvement and costs would be appreciated.
2. Estimation of operational reserve (primary and secondary) for 2022-2030 that takes into account the variability of RES.
3. Analysis of the dynamic frequency stability to identify the eventual constraints related to:
   - ✓ the share of primary reserve that will be activated in minimum frequency.
   - ✓ the value of Rate of Change of Frequency (ROCOF).
   - ✓ Propose adaptive load shedding scheme based on the Rate of Change of Frequency (DF/DT) to enhance the stability of the power system.
   - ✓ other constraints to be defined
4. Analysis of the dynamic stability, in particular frequency and voltage stability, in order to identify the minimum number of must run unit (combined cycles) during the year of the study and to precise also their localization to ensure the stability of the electrical system (transient, frequency and voltage stability)
5. Performing the flexibility study for a whole year instead of only one point in time “Day off peak”.
6. To establish the flexibility study, taking into account the constraints identified by the frequency and voltage stability, in order to estimate:
   - ✓ The operation system cost.
   - ✓ the amount of renewable curtailment

7. To define an approach to identify the potential sites of BESS.
8. To consider in the transmission analysis both scenarios: isolated case and interconnected case (with Algeria and future interconnection)
9. Selection of the potential candidate sites of BESS, considering the following items:
    - The voltage stability criterion since BESS can improve the voltage fluctuation,
    - The reduction of electrical losses in the transmission system,
    - The reactive power capability amount of BESS. Using the BESS to control the flow of power in the interconnection lines to avoid their tripping.
10. Knowledge sharing by the transfer of know-how to STEG engineers. (MATLAB simulation program, the methodology…).
11. Training of the operational engineer in the national control center to supervise and control the electrical power system with high integration of ENRs and with new storage technologies such as BESS and others.
12. A detailed report of the study would be appreciated.

Attachment

Project for Low carbon and stable supply at Power
- Issues composition analysis

Japan International Cooperation Agency (JICA)

December 2021

Background

- Tunisia relies heavily on oil and natural gas for its domestic primary energy. Imports have increased due to a decrease in domestic production of oil and natural gas and an increase in demand since 2000, and at present, the majority of all energy is dependent on imports.
- In the electric power sector as well, in addition to the conventional-issue of compensating for a loss margin of electricity prices, the burden will increase due to the increase in energy imports, and energy-related spending will be occupied more than half of the government's budget deficit. Reform and efficiency improvement of the electric power sector has become a major issue.
- To remedy this situation, the Tunisian government has decided to cover 30% of its electricity with renewable energy (RE) such as wind power (WT) and solar power (PV) in 2030 under its national energy strategy. This strategy has a policy of utilizing independent power generation companies (IPPs) for more than two-thirds of the introduction of renewable energy.

Requested Technical Cooperation Structure

Overall Goal
(Long-term objective)
To promote sustainable development for low-carbon and decarbonized society in Tunisia.

T/C Purpose
(Objective expected to be achieved by the end of the project period. Elaborate with quantitative indicators if possible)
•To strengthen the capability of Ministry of Energy, National Dispatching Center and related organizations for low carbon and stable supply at power system in Tunisia.

Outputs(1)
To enhance the ability to operate the power utilities business and the monitoring ability of the independent regulatory body by sharing the knowledge and experience in Japan.

Outputs(2),(3)
(2) To make grid operation sophisticated by sharing the knowledge of grid operation in preparation for the situation where VRE ratio is more than 20%. (Capacity Building of Grid Operation and Management)
(3) On the premise of introducing adjustable speed pumper storage and storage batteries, to optimize storage battery system and their characteristics by sharing Japan experience ad knowledge in this domain.

Output(4)(5)(6)
"To deepen understanding on measures for enhancing grid flexibility utilizing energy management system (EMS) and demand side management(DSM) and its enabling environment including policy, institutions (transaction market and regulations), and technologies."

Issue Analysis (Including Future Issues)

Emerging Problem

- less capability of STEG including National Dispatching Center for low carbon and stable supply at power system in Tunisia.
- Difficulty in the stable power system control under massive VRE installation
- Low capacity of primary and secondary reserve margin planning and operation with proper analysis tools
- Estimation on stable supply becomes more difficult

Multiple causal hierarchies

- Primary, Secondary Reserve margin not properly identified and planned
- Plans of Reserve power supply capacities such as PSPP and BESS under massive installation of VRE could not be decided, considering the proper optimization
- New concept of the margin such as instantaneous reserve could not be estimated
- Emerging of new load profile such as duck curve

Root Cause

- Lack of estimation ability concerning the facilities providing various types of the margin supply facilities such as adjustable speed pump storage, storage batteries
- Lack of planning and operation capability to optimize various types of the margin supply facilities
- Possible improvement on sophisticated power balance analysis
- Lack of ability of STEG of grid planning and operation with the sophisticated grid analysis in preparation for the situation where VRE ratio is more than 20%. (Capacity Building of Grid Operation and Management)

Issue Analysis (Framework)

(2) To make grid operation sophisticated by sharing the knowledge of grid operation in preparation for the situation where VRE ratio is more than 20%. (Capacity Building of Grid Operation and Management)
(3) On the premise of introducing adjustable speed pumper storage and storage batteries, to optimize storage battery system and their characteristics by sharing Japan experience ad knowledge in this domain.

Issues	Policies, Institutions and Organizations	Operation /Technology	Facilities /Financing
Primary, Secondary Reserve margin not properly identified and planned	○	○	○
Plans of Reserve power supply capacities such as PSPP and BESS under massive installation of VRE could not be decided, considering the proper optimization	○	○	○
New concept of the margin such as instantaneous reserve could not be estimated	○	○	
Emerging of new load profile such as duck curve	○		

Outputs and activities of full-scale cooperation are needed.

- Lack of estimation ability concerning the facilities providing various types of the margin supply facilities such as adjustable speed pump storage, storage batteries
- Lack of planning and operation capability to optimize various types of the margin supply facilities
- Possible improvement on sophisticated power balance analysis
- Lack of ability of STEG of grid planning and operation with the sophisticated grid analysis in preparation for the situation where VRE ratio is more than 20%. (Capacity Building of Grid Operation and Management)

Issue Analysis (Utility management and regulation)

Power utility's operation and business management ability, and government's monitoring and regulatory ability under de-regulated circumstances are not adequately developed

Power Utility

Strategy/Leadership
- Power utility 's overall strategy for competitive circumstances is not formulated / effectively implemented
- Power utility 's management's leadership / awareness may be insufficient
- Power utility 's organizational Management system may need to be adjusted to competitive environment

Finance
- Power utility 's financial status is not in favorable condition
- Power utility 's financial analyses and investment plan is not feasible taking into consideration drastic change caused by enormous RE integration and unbundling

HRD
- human resources are not adjusted to competitive environment
- HRD development plan and personnel policies are not adequately address the emerging needs
- HRD development system and resources are not in place for the emerging needs

Power Utility

Law/Institution
- Legal/regulatory regime is in place but not effectively enforced
- Detailed laws and by-laws, regulatory rules are not prepared
- Platforms for formulating those references and communication with stakeholders are not well functioning

Regulatory Practice
- New institutions for regulatory works are not established
- Detailed institutions, rules and guidelines for regulatory works are not prepared
- Officers do not have practical skills and experiences in regulatory administration works

Issue Analysis (Grid flexibility and Demand Side Management)

To deepen understanding on measures for enhancing grid flexibility utilizing energy management system (EMS) and demand side management(DSM) and its enabling environment including policy, institutions (transaction market and regulations), and technologies.

Policy	Institution/utility	Infrastructure/Technologies
Deregulation on power distribution /demand side is underway	Entities which can organize and carry out DSM business do not exist	Infrastructure available for DSM is not developed
Promotion / incentive policy frameworks and risk mitigation measures for DSM is not in place	Transaction mechanisms including direct trades and markets on supply demand transaction is not designed and enforced	Technologies used for DSM is not available for practical business
Benefit /cost sharing of investment for stabilizing power grid is not well coordinated	Grid codes for DSM including access, metering, arbitration are not well prepared	Investment and R&D on DSM is not made for business expansion
	Coordinating mechanism for stakeholders are not functioning well	Infrastructure for DSM is not systematically planned
	Incentive, benefit and necessity of DSM is not practically shared among policy makers and utilities	

Project Design Matrix（PDM）

Project Name	The Project for low carbon and stable supply at power system in Tunisia	Version: 0
Implementing Agen	Ministry of Energy, Mines and Energy Transition (MEMET) and Tunisian Company of Electricity and Gas (STEG)	Dated: December 2021
Target Group	MEMET staff on power management and planning and STEG staff on power system planning and operation	
Period of Project	April 2022 - March 2025 (3 years)	
Project Site	Tunis	

Those items need further technical discussion with concerned parties

Narrative Summary	Objectively Verifiable Indicators	Means of Verification	Important Assumptions
Overall Goal To promote sustainable development for low-carbon and decarbonized society in Tunisia.	Contribute to advancement of CO_2 reduction and RE integration into electric power system in Tunisia		
Project Purpose • To strengthen the capability of departments concerned for low carbon and stable supply of the power system in Tunisia.	Institutional actions taken to implement the procedures and plans, studies and action plans developed by each working group Share output achievements and proposals among department concerned and establish solid ground for decision makers		
Outputs *1) To enhance the ability to operate the power utilities business and the monitoring ability of the independent regulatory body by sharing the knowledge and experience in Japan.* *2) To make estimation ability concerning the facilities providing various types of the margin supply facilities such as adjustable speed pump storage, storage batteries* *3) To make planning and operation capability to optimize various types of the margin supply facilities* *4) To improve sophisticated power balance analysis* *5) To establish ability of STEG of grid planning and operation with the sophisticated grid analysis in preparation for the situation where VRE ratio is more than 20%. (Capacity Building of Grid Operation and Management)* *6) To deepen understanding on measures for enhancing grid flexibility utilizing energy management system (EMS) and demand side management(DSM) and its enabling environment including policy, institutions (transaction market and regulations), and technologies.*	Number of trainees participated in the training Action plans created and implemented Planning Manual for providing various types of the margin supply facilities Capable engineers for performing studies Daily VRE outputs estimation Yearly supply operation plan Capable engineers for performing analyses Guideline for long-term PDP and mid-term System Plan Capable engineers for performing development of those plans Number of trainees participated in the training Action plans created and implemented		

ANNEX 6-4

Activity	Inputs	
	Japanese side	**Tunisian side**
	"Expert members" Team leader	Counterpart personnels Office space with furniture Local expenses for project implementation
1 Participation to Knowledge Co-Creation Program "Management of Power Utilities."		
2-1 Overview/ Benchmark of the technologies / solutions to ensures power system flexibility taking into consideration costs and benefits in order to choose the most suitable solution for the Tunisian context.	System planning Short-priod flactuation analyis Supply /demand nanalysis VRE operation	
2-2 Analysis of the dynamic frequency stability to identify the eventual constraints related to: the share of primary reserve that will be activated in minimum frequency. the value of Rate of Change of Frequency (ROCOF).	Dispathing of Supply/demand balance Dynamic analysis BESS design BESS Controlle system	
2-3 To define an approach to identify the potential sites of BESS. Selection of the potential candidate sites of BESS, considering the following items: o The voltage stability criterion since BESS can improve the voltage fluctuation, o The reduction of electrical losses in the transmission system, o The reactive power capability amount of BESS. Using the BESS to control the flow of power in the interconnection lines to avoid their tripping.	Analysis Tools such as MATLAB, AGC30 and so on,	
2-4 BESS function on the energy Relation between BESS function and its specifications Issues for determination of the specifications Possible approach of BESS installation for Tunisian system BESS Control system for realizaing the coordination Approaches on the Phase 2 step	* Input s will be discussed later.	
3-1 Estimation of operational reserve (primary and secondary) for daily operation that takes into account the variability of RES		
3-2 Training of the operational engineer in the national control center to supervise and control the electrical power system with high integration of ENRs and with new storage technologies such as BESS and others.		
3-3 Performing the flexibility study for a whole year instead of only one point in time “Day off peak” in order to estimate: • The operation system cost		
4 Knowledge sharing by the transfer of know-how to STEG engineers. (MATLAB simulation program, the methodology…)		
5-1 Estimation of operational reserve (primary and secondary) for 2022-2030 that takes into account the variability of RES		
5-2 Analysis of the dynamic stability, in particular frequency and voltage stability, in order to identify the minimum number of must run unit (combined cycles) during the year of the study and to precise also their localization to ensure the stability of the electrical system (transient, frequency and voltage stability)		
6 Participation to Knowledge Co-Creation Program "Mass Integration of Variable Renewable Energy and Demand Side Energy Management."		