CO_2 Reduction Measures in the Electricity Supply Chain in Libya

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Abstract
The electricity supply chain consists of three components; electricity generation, transmission and distribution (T&D) system, and the end-user stage. CO_2 emissions from electricity generation are caused by the burning of fossil fuels. Unjustified end-users and electricity losses in the T&D system increase electricity production, which of course indirectly contributes to further emissions. Consequently, this study presents the state of the electricity supply chain in Libya and measures taken to reduce emissions. The analysis shows that efforts are currently being made to diversify the energy mix and to exploit the potential of solar and wind energy. Low carbon fuels and combined cycle technologies remain key sources of electricity generation. In the T&D system, Libya has built a strong transmission system and strict design criteria have been applied. Libya is working on the establishment of Energy Demand Management (EDM), where some power plants have installed EDM-related equipment. Further efforts are needed to reduce technical and non-technical losses. In the end-user stage, per capita electricity consumption corresponds to 3.73MWh, which is considered to be the largest energy consumer in Africa. There is no time-differentiated price that would encourage consumers to switch from peak hours. Libya is currently preparing a national energy efficiency action plan.

Keywords
Electricity Supply Chain, CO_2 emissions, Libyan Power Plants, T&D System, Energy Demand Management.

1. Introduction
The relationship between energy consumption and environmental pollution has become clear due to negative results such as high CO_2 and climate change. The unreasonable use of consumers and the loss of electricity in the transmission and distribution (T&D) system increase electricity production, which of course contributes indirectly to further CO_2 emissions. However, Libya's population growth requires new infrastructure, especially in power generation, which is dramatically increasing electricity demand. In fact, Libya has the highest per capita electricity consumption, 3.73 MWh, which corresponds to Africa's largest electricity consumption, in which electricity consumption increases by 8% per year, which in turn increases CO_2 emissions (energy-pedia and World Data). Also, of the 225 countries, Libya ranks 53rd in the list of countries in terms of CO_2 emissions, with a contribution of 0.22%, and 41st in the list of countries in terms of CO_2 emissions per capita (Nassar et al, 2017). Also, according to the IEA, in 2017, carbon emissions increased by 61.5% compared to 1990. Fig. 1a shows total CO_2 emissions between 1996 and 2017. This shows the emissions reached a maximum level of 48Mt in 2010 and 2013 then dropped to 42Mt in 2017 due to declining electricity production during armed conflict, and political instability. On the other hand, power plants account for approx. 35% of CO_2 emissions, followed by transport with 31% and then with the residential and commercial sector with 15% (Nassar et al., 2017) as shown in Fig. 1b.

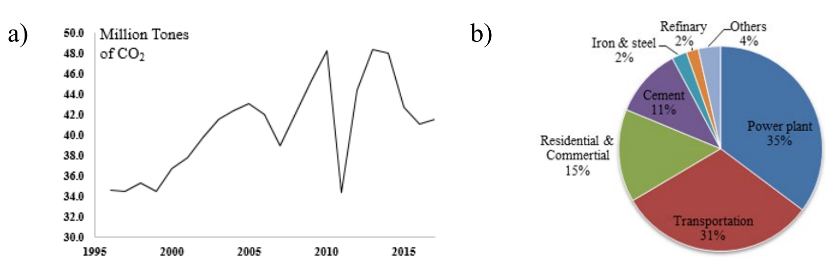


Fig. 1- CO_2 Emissions in Libya; a) Total Emissions from 1996 to 2017 b) Emissions by Sector.

Consequently, this study presents the situation of the Libyan electricity supply chain and the measures taken to reduce CO_2 emissions from Libyan power plants in the following three integrated components: (1) Electricity Generation Sector, (2) Electrical T&D System, and (3) End-Users Stage. Fig. 2 illustrates a typical diagram of an electricity supply chain. However, before discussing these measures, we would like to present the definition of the components of the electricity supply chain with an overview of the current situation of the electricity sector in Libya.

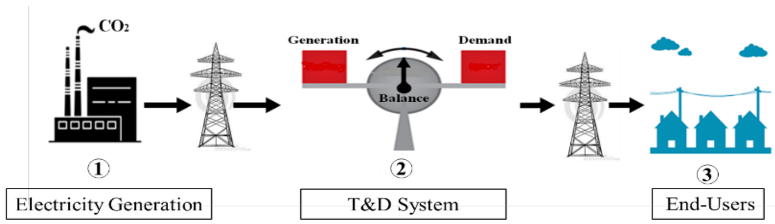


Fig. 2 - Typical Diagram of an Electricity Supply Chain

Electricity Generation:
The main purpose of electricity generation is to produce electricity by the conversion of other forms of energy into electrical energy; it is usually expressed in kWh or MWh. To generate electricity, fossil fuel power plants burn coal or oil to produce heat, which in turn is used to generate steam to power turbines that generate electricity. In gas-fired power plants, hot gases drive a turbine to generate electricity, while a combined-cycle gas turbine plant also uses a steam generator to increase the amount of electricity produced. Therefore, the burning of fossil fuels emits huge amounts of CO_2 into the atmosphere, causing pollution.

Electrical Transmission and Distribution (*T&D*) *System*:
The T&D system refers to the different stages of transmission of electricity from power generators through the grid to the end-users. More specifically, it is the mass transfer of electrical energy from an electricity generation plant to substations in populated areas, over long distances at overhead lines or underground cables. The power transmission system is called a grid. On the other hand, electricity distribution is the last phase of electricity supply; it provides electricity from the transmission system to individual consumers (Short, 2018). The distribution substations are connected to the transmission system and reduce the transmission voltage to medium voltage. The primary distribution lines transmit this medium voltage power to the distribution transformers near the receiver. Distribution transformers again reduce the voltage to the operating voltage used by lighting, industrial or household appliances (Sivanagaraju and Satyanarayana, 2008). Closer to the end-user customer, a distribution transformer steps the primary distribution power down to a low-voltage secondary circuit, usually 120/240V. The power comes to the customer via a service drop and an electricity meter (Short, 2018). However, this long-distance transmission causes a certain amount of electricity loss. Much of this loss comes from the Joule effect applied in transformers and electrical lines. Electricity is lost as heat loss in the conductors and in the main parts of the transmission and distribution system. According to the International Electrotechnical Commission (IEC, 2007) and Garg et al (2018), the total loss between the power plant and the end-user is between 8-15% of the electricity generation. 1-2% electrical loss through the gradual transformer from the generator to the transmission line, 2-4% electrical loss through the transmission line, 1-2% electrical loss through-transformer from the transmission line to the distribution network, and 4-6% losses by means of distribution network transformers, overhead lines and ground cables. Optimizing these losses therefore results in savings in electricity generation, which has reduced CO_2 emissions. Each unit saved along the T&D system represents one unit of electricity saved in the electricity generation phase.

Electricity End-Users Consumer:
Electricity end-use is for residential, commercial and industrial consumers. All types of end-users can reduce CO_2 emissions by reducing electricity consumption. This can be achieved by rationalizing electricity consumption and all end-users can be smart consumers. The amount of electricity consumed by the consumer, however, is measured in kWh through an electricity meter, which is usually placed near the input of housing for easy access to the meter reader.

2. Current Situation in the Electricity Sector

In many countries, electricity utilities own the entire infrastructure, from electricity generation to transmission and distribution infrastructure. However, the General Electricity Company of Libya (GECOL) is state-owned and responsible for the Libyan electricity system. GECOL has a total of fifteen thermal power plants and eleven small stations. All are completely dependent on heavy fuel oil (HFO), light fuel oil (LFO) and natural gas (NG). Most of these plants are located along the coastline where most of the population lives. As of 2010, Libya had a combined electricity capacity of 6.8 GW from oil and natural gas power plants. The World Bank estimates that 99.8% of Libyan people have access to electricity, which is the highest among African countries. Table 1 shows the electricity production between 2015 and 2018. Overall electricity generation has remained mostly stable since 2015, ranging between 36 and 37TWh. There are seven steam turbines (ST), three combined cycles (CC), six main gas turbines (GT) and eleven small GT. It is known that Libya has been politically and economically unstable since the 2011 civil war. Many infrastructure sectors have been damaged, including GECOL and most oil fields. As a result, some GECOL facilities were damaged and robbed. This has led to a severe shortage of generating capacity, which has caused power outages, especially at peak loads. The table shows that Tripoli West ST, Benghazi North ST and Abukamash Small GT were out of service between 2015 and 2018. Whilst, Derna ST became inoperable in 2017 and 2018. While, Zahra Small GT, Tripoli West Old GT, Zletan Small GT, Lamluda Small GT and Zawia GE Small GT were back to service in 2018. Also, in 2018, the Kufra Small GT and the Tripoli West GE Small GT were out of service. In 2018, however, power plants were generating 47% of the electricity from the combined cycle, 40% from the gas turbine and 13% from the steam turbine with total output 37,124,634 MWh.

In fact, as much electricity is generated, CO_2 is released into the atmosphere, which contributes to global warming, which today is a key issue for the future of power generation. Therefore, possible measures should be taken to reduce the CO_2 emissions in the electricity supply system. A number of mitigation measures have been applied to reduce CO_2 emissions in the electricity supply chain. The rest of the paper deals with current measures to reduce the carbon footprint of this chain in Libya.

3. CO_2 Reduction Measures of the Electricity Supply Chain in Libya

CO_2 emissions are concentrated in the electric power generation sector, where fossil fuels are burned. Therefore, unjustified use within the end-users, as well as losses in the T&D system, increase the electricity production in the power generation sector, which indirectly contributes to further CO_2 emissions.

The diagram shown in Fig. 3 illustrates the possible CO_2 reduction measures of the three main components in the electricity supply chain. Applicable measures in electricity generation may include: (a) the use of non-fossil fuels, (b) switching to low-carbon fuels, (c) improving the efficiency of power plants, and (d)) turn on carbon capture power plants. The measures can be applied to the electricity T&D system; (a) energy data management (EDM), (b) improving the efficiency of T&D, and (c) building a smart grid. While the actions taken in the end-user phase can be summarized between demand-side management (DSM) and smart consumers.

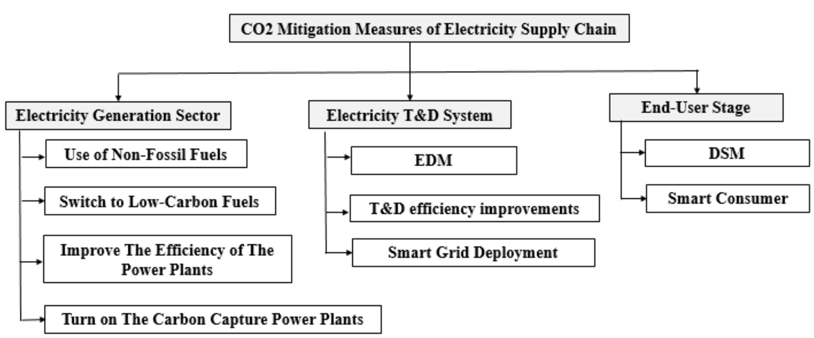


Fig. 3 - CO_2 Reduction Measures of the Three Components in the Electricity Supply Chain

3.1 Measures Taken in Electricity Generation Sector

The main purpose of the power generation sector is to generate and supply electricity to end-users. Table 2 shows the CO_2 reduction measures applied to the electricity generation sector. It shows that the electricity supply chain in Libyan is not pursuing nuclear power generation. Measures to reduce CO_2 emissions through turns on the carbon capture plants, and improves the efficiency of existing power plants by using supercritical and ultra-supercritical power plants have not yet been implemented in the Libyan electricity generation sector.

Table 1- Electricity Production between 2015 and 2018

Type	Power Plant		Electricity Production During Years																		
			2015					2016					2017					2018			
			MWh	Fuel				MWh	Fuel				MWh	Fuel				MWh	Fuel		
				HFO	LFO	NG	No Fuel		HFO	LFO	NG	No Fuel		HFO	LFO	NG	No Fuel		HFO	LFO	NG	No Fuel
ST	Khalij		942,132		√			568,518		√			167,904		√			1,095,412		√		
	Tripoli west		0					0					0					0				
	Khoms		3,044,061	√	√	√		2,763,291	√	√	√		2,982,314		√			2,994,690		√	√	
	Misurata Iron		632,910	√				630,852	√				322,160		√			567,149	√		√	
	Tubruk		84,560	√				216,455	√				234,470		√			125,630	√		√	
	Derna		116,405	√				2,471	√				0					0				
	Benghazi North		0					0					0					0				
Total ST			4,820,068					4,181,587					3,706,848					4,782,881				
CC	Zawia	Gas	6,043,120		√	√		5,733,996		√	√		5,751,829		√	√		5,596,733		√	√	
		Steam	2,485,867				√	2,051,668				√	1,761,822				√	1,900,893				√
	Benghazi North	Gas	4,910,868		√			4,778,825		√			5,701,180		√			5,783,078		√	√	
		Steam	359,415				√	492,966				√	515,700				√	28,813				√
	Misurata	Gas	3,400,963		√			3,353,208		√			3,073,512		√			3,383,642		√	√	
		Steam	1,343,047				√	1,268,075				√	694,188				√	801,847				√
Total CC			18,543,280					17,678,738					17,498,231					17,495,006				
Main GT	West Mounten		3,299,075			√		5,277,271			√		4,371,752			√		3,976,963		√	√	
	Khoms Gas I		2,960,597		√	√		3,652,575		√	√		3,018,995		√	√		2,738,879		√	√	
	Khoms Gas II		2906820					0					2,312,434		√	√		1,146,371			√	
	Tripoli South		1,805,132		√	√		2,772,941		√	√		2,897,900		√	√		2,726,314		√	√	
	Zwetina Gas		1,289,879		√	√		1,383,395		√	√		1,400,792		√	√		2,308,447		√	√	
	Alsrir		0		√			1,055,444		√			1,187,712		√			1,400,299		√		
Total Main GT			12,261,503					14,141,626					15,189,585					14,297,273				
Small GT	Aby Kmash		0					0					0					0				
	Zahra		0					0					0					146,253		√		
	Hy Jamei		44,419		√			36,414		√			15,650		√			8,478		√		
	Misurata Gas		77,354		√			96,337		√			34,049		√			39,015		√		
	Tripoli west old		4,144		√			8,683		√			0					11,842		√		
	Zleten		14,428		√			-					0					17,899		√		
	Kufra		20,030		√			25,604		√			12,584		√			0				
	Lamloda		0					0					0					19,866		√		
	Srir Rever		22,998					16,208		√			84,176		√			80,392			√	
	Zawia GE		118,975			√		0		√			0					225,730			√	
	Tripoli West GE		105,411		√			241,503		√			255,341		√			0				
Total Small GT			407,759					424,749					401,800					549,474				
Total Output			36,032,610					36,426,700					36,796,464					37,124,634				

Switch on carbon capture power plants means that CO_2 emissions must be captured at the power plant before release to the atmosphere. In fact, there are three technologies for carbon capture: post-combustion capture, pre-combustion capture and oxy-fuel capture. During post-combustion capture, CO_2 is separated from the flue gases before being released into the atmosphere. Pre-combustion capture means the removal of CO_2 from fossil fuels before the combustion is completed. While oxy-fuel combustion is the process of burning a fuel using pure oxygen instead of air as the primary oxidant.

3.1.1 Use of Non-Fossil Fuels

Coal, oil, and NG are commonly referred to as fossil fuels. Solar, wind, and hydro are non-fossil fuels and are referred to RE. In 2018, the Energy Information Administration (EIA) shows that the burning NG for electricity releases between 0.6 and 2 pounds of CO_2E/kWh (CO_2 equivalent per kilowatt-hour); coal emits between 1.4 and 3.6 pounds of CO_2E/kWh. Wind, on the other hand, is responsible for only 0.02 to 0.04 pounds of CO_2E/kWh on a life-cycle basis; solar 0.07 to 0.2; geothermal 0.1 to 0.2; and hydroelectric between 0.1 and 0.5.

Table 2 - CO_2 Reduction Measures Applied to the Electricity Generation Sector

Mitigation Actions		Case
Use of Non-Fossil Fuel	Renewable Energy Technologies	✓
	Nuclear Power Generation	✗
Switching to Low-Carbon Fuels		✓
Improve Power Plants Efficiency	Combined Cycle Technology	✓
	Subcritical, Supercritical and Ultra-Supercritical	✗
	Maintenance	✓
Turn on Carbon Capture Power Plants		✗

***Renewable Energy* (*RE*) Technologies**

Libya has huge sources of RE, mainly because parts of the country have the largest amount of solar radiation in the world. In 2013, the Libyan government launched the RE Strategic Plan for 2013-2025, which aims to achieve a 7% renewable energy contribution by 2020 and 10% by 2025 in the electricity mix. It comes from wind, concentrated solar energy, solar PV and solar heat. Unfortunately, this plan has been postponed as Libya's economy has been struggling since 2011 due to security and political instability, as well as Libyan oil production disruptions. Against all these barriers, in 2015, RE accounted for about 2.0% of total actual consumption in Libya.

Libya is located in the center of North Africa, 88% of its territory is desert. The Sahara Desert has great solar potential that can be used to generate electricity from solar cells, PV and thermal energy. According to NASA's Atmospheric Science Data Center, the average solar radiation in Libya is about 7.5 kWh/m^2/day, with about 3,000 to 3,500 hours of sunshine a year. In addition, according to Libyan climate archives, the average wind speed is roughly between 6 m/s and 7.5 m/s at a height of 40 m. This enormous amount of sunlight and wind, covering an area of 1,750,000 km^2, will provide Libya and its neighbors with future electricity needs and can also be transported to Europe through high-voltage DC connections. However, the use of RE reduces dependence on fossil fuels, which in turn reduces CO_2 emissions. With this expected growth in RE and the difficult current situation, Libya may face many challenges in planning for RE and decision-making. For example, lack of meteorological data throughout the country, there is no good survey or detailed study on the current energy situation, the evolution of electricity demand, and the impact of the penetration of RE into the grid. Asheibe and Khalil reported in 2013 that the development of RE technologies faces many barriers. All the planned RE projects, however, are financed by GECOL, which is a state company with no space for privatization or competition. Due to the inconvenient planning, some RE projects are delayed or suspended. Below, we present the current situation of wind farms, photovoltaics, concentrated solar projects, and nuclear power technology in Libya.

Wind Power: The use of wind power for electricity generation in Libya has not yet started, but there are currently twelve wind farms in various situations, details are given in Table 3. It shows that of the five wind farms in the eastern region, one project is under construction, two are still in progress, one is being awarded and one is under negotiation. There are four wind farms in the western region, three of which are under feasibility studies and one under construction. One wind farm in the south-east and one in the south-west, both under development. Currently, the two wind farms; The 60MW wind farm in Derna and the 50MW wind farm in Emselata have been shut down due to security and armed conflict situations.

Solar Energy: The main current uses of solar energy are solar water heating, solar heating of buildings, solar distillation, solar energy pumping, solar drying of agricultural and animal products, and solar energy furnaces. However, solar energy can be used to generate electricity in two ways: photovoltaic (PV) and concentrated solar energy (CSP). However, a solar power plant is any type of facility that directly converts sunlight, such as PV equipment, or indirectly, such as solar energy, into electricity. CSP systems concentrate the sun's radiation on heating a liquid substance, which is then used to drive a heat engine and electric generator. This is an indirect method that generates alternating current, which is then easily distributed over the power grid. PV panels, on the other hand, are completely different from CSP. PV systems convert sunlight directly to electricity by means of PV cells made of semiconductor materials (Joshi and Vyas, 2019).

Table 3 - Current Situation of Wind Farm Projects in Libya

Region	East					West				SE	SW
Projects	Derna Stage I	Derna Stage II	Al-Magrun Stage I	Al-Magrun Stage II	Tolmitha	Emselata	Misurata	Tarhuna	Assaba	Alkofra	Sabha
Project MW	60	60	80	110	50	50	50	50	50	120	120
Speed (m/s)	7	7	6.2	6.2	6.2	6.6	6.6	-	-	-	-
Area (ac)	1350	1200	-	-	-	-	-	-	-	-	-
Project Statues	Under Construction	Awarded	In Pipeline	In Pipeline	Under Negotiation	Under Construction	feasibility studies	feasibility studies	feasibility studies	Under Development	Under Development
Number of WT	37	37	80	80	25	16	-	-	50	-	-
Capacity/turbine (MW)	1650	1650	1500	1500	2000	2000	-	-	2000	-	-
High tower (m)	71	71	-	-	-	-	-	-		-	-
Blades Long (m)	42		-	-	40	-	-	-		-	-

The use of PV systems in Libya began in 1976. Since then, the role of PV application has increased in size and type of application. Table 4 summarizes the current situation of PV projects in Libya. However, Libya's climate is subtropical. So it's much drier and warmer than most parts of the United States or Central Europe. Only a few humid months a year, with a light rainfall. The average daytime temperature during the season is between 19 and 35°C. Temperatures in some parts of the country rise to 41°C. During colder months, depending on the region, the average temperature drops to 8°C. The Table shows six off-grid PV projects and two on-grid PV projects are in operation. Further details can be summarized as follows:

- The first PV project is a PV system that provides cathodic protection to protect the oil pipeline connecting the Dahra oil field and the Sedra port.
- Microwave communication networks contain more than 500 repeater stations. Until the end of 1997, only 9 remote stations operated with PV systems, with a total peak power of 10.5kWp
- The PV system used in communications projects started in 1980 to power a microwave transmitter near Zella village.
- The PV pumping system was used in 1983 to pump water for irrigation in El-Agailat city.
- Household heaters were started in 1980 with the installation of a 35 system pilot project, followed by some other projects. Water pumping projects were also built in early 1984.
- There are all together some 6,000 solar heaters
- PV systems were used in 2003 in rural electric and lighting fixtures as part of the national plan for the electrification of scattered houses, villages and water pumps in rural areas, PV systems in ten villages
- The peak PV achieved in full microwave communication networks installed by the end of 2005 is approximately 420KWp.
- The use of evacuated tubes for solar energy detectors has begun in some hotels and homes and is expected to grow soon. The energy consumption to heat the water is approximately 12% of the national electricity production.
- CSP concentrated solar energy is not yet used.

In addition, Misurata Free Zone (MFZ) signed a memorandum of understanding with iQ Power in 2018 to develop integrated CSP and PV projects with a total capacity of 300 MW. As a partner, iQ Power, an American company dedicated exclusively to the development of renewable energy in the Middle East and North Africa, is exploring how CSP, PV or Hybrid can best utilize and optimize the smartest and latest engineering designs for the solar energy industry to make the MFZ a state-of-the-art example of solar energy in North Africa. Moreover, MFZ is considering building a seawater desalination plant that will use all or part of its solar energy as an energy source to meet Misurata's energy needs.

Table 4 -Libya PV Projects

PV Projects		Capacity	In Pipeline	Under Construction	Operation
Off-Grid	Communication Repeater	950kWp			✓
	Mobile Phone	1859kWp			✓
	PV Water Pumping	120kWp			✓
	Street Lighting	1125kWp			✓
	Rural Electrification	725kWp			✓
	Roof Top Systems	3MW	✓		
	Wadi-Marsit Centralized	67.2kWp			✓
On-Grid	Grid Connected Small Scale	42kWp			
	Ghat Plant	15MW			✓
	Al-Jofra Plant	14MW		✓	
	Sabha Plant	40MW	✓		
	South Green Mountain	50MW	✓		
	Rural Electrification	275kWp			✓

However, Libya could become a supply and export platform for solar PV modules and inverters to countries in the Middle East and Africa with solid pipelines for upcoming PV and CSP projects. However, the civil war and the current unstable situation interrupted timid efforts to develop solar energy. Meanwhile, according to a recent study by the University of Zawia in Libya, the country currently has about 9 GW of power generation capacity, consisting of 16 gas and oil plants operated by GECOL.

Under Libya's new tax legislation, all RE equipment and parts are completely exempt from import duties, and a new electricity law is being prepared that will allow private sector companies to generate electricity. In addition, Libya has a Renewable Energy Authority (REAOL) established in 2007 and a Solar Energy Research Centre established in 1978. Meanwhile, Libya has been politically and economically unstable during the civil war since 2011, which has damaged many infrastructure sectors, including GECOL facilities, power plants and most oil and gas fields. Nonetheless, we are still suffering from a lack of capabilities to implement RE technologies. Here are some of the challenges and difficulties:

- The energy sector in Libya is closed to private investors. However, all planned RE projects are completely funded by GECOL and REAOL, which are state-owned bodies with no prospect of privatization or competition.
- No fund has yet been created to finance RE projects. However, all planned RE projects are completely funded by GECOL and REAOL, which are state-owned bodies with no prospect of privatization or competition. As a result, most renewable energy projects have been delayed or suspended due to planning and funding problems, mainly due to security and armed conflict situations since 2011.
- Wind and solar atlas have not yet been developed and the lack of field data is a burden on planning and decision-making.
- There are gaps and obstacles that need to be addressed quickly, such as the wind and solar atlas not yet developed, the lack of field data and the burden of planning and decision-making, the lack of appropriate surveys, detailed studies of the current energy situation and the lack of detailed network map for designated renewable energy sites.
- Besides small scale scattered PV projects, there are practically no PV manufacturers
- No grid code. Where, the grid code is a technical specification that defines the parameters that facilities connected to the public power grid to meet to ensure the safe, secure, and economically viable operation of the electrical system.

Nuclear Power

In 1963 Libya became a member of the International Atomic Energy Agency and has a Soviet-designed 10MWt research reactor, built-in 1981. In the late 1970s, Libya signed a contract with the Soviet Atomic Energy Company for two reactors, each supplying 440MW of electricity in the Gulf of Sirte. The reactors are designed for dual-use electricity generation and desalination of seawater. As Libya was dissatisfied with the technology the Soviet Union wanted to provide, Belgian nuclear company Belgonucleaire was asked to take over the contract. However, the United States rejected Belgonucleaire's protest over nuclear weapons concerns, and Libya once again appealed to the Soviet Union. Finally, the project was stopped during the 1986 design phase. Libya and France signed an agreement on the peaceful use of nuclear energy in 2006 and signed a memorandum of understanding in July 2007 on the construction of a medium-sized nuclear power plant with the Areva reactor for desalination of seawater. Germany opposed this agreement. This was followed by a memorandum sharing cooperation with Canada on nuclear medicine, desalination technology and nuclear research (Cigar, 2012).

3.1.2 Switching to Low-Carbon Fuels
Low-carbon power plants result from processes or technologies that produce significantly lower CO_2 emissions than conventional fossil fuel power generation. Switching from high-carbon to low-carbon fuels, such as HFO or LFO to NG, would greatly reduce CO_2 emissions. Commonly, the amount of CO_2 produced when fuel is burned is a function of carbon content of the fuel. NG has higher energy content relative to other fuels and produces relatively less CO_2. However, a gas-fired power plant is a thermal power station which burns NG to generate electricity. Thus, GECOL increased the dependence on the NG in order to reduce CO_2 emission. It depends entirely on the source of electricity in power plants HFO, LFO and NG to generate electricity demands. During 2018, 70% of the electricity generated by natural gas, 21% of LFO and 9% of HFO as displayed in Fig 4. Oil and NG are expected to remain the main source of energy in Libya, with mitigation measures for steam generators. It is worth noting that in 2016 electricity generated by NG was 80%, LFO 13% and HFO 7%. The consumption of HFO and LFO decreased from 80% in 2004 (36% HFO, 44% LFO) to 30% in 2018 (9% HFO, 21% LFO). NG consumption increases from 20% in 2004 to 80% in 2016 and 70% in 2018. The NG, as a low carbon fuel, will continue to be a key source of electricity generation.

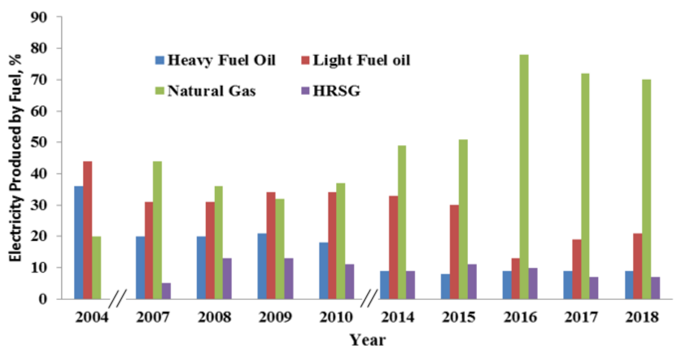


Fig. 4 - Electricity Production by Fuel

3.1.3 Improve Efficiency of the Electrical Power Plant
Improving the efficiency of a power plant can also reduce CO_2 emissions. One of the main efficiency goals of fossil fuel plants is to improve the amount of heat. In conventional fossil fuel power plants, the water is boiling and generating steam that activates the operation of the turbine (Rosen & Tang 2008). However, power plant efficiency can be improved by (1) regular maintenance, (2) a combination of gas and steam cycles. This type called combined cycle (CC) power plant or heat recovery steam generator (HRSG) power plant, (3) heating water to a critical point at high pressures and temperatures. in this case, water acts as a supercritical fluid, and power plants are called supercritical and ultra-supercritical power plants. However, supercritical and ultra-supercritical techniques have not yet been implemented in the Libyan electrical generation sector, while CC technology was introduced in 2007.

A CC or HRSG is an energy recovery heat exchanger that recovers the source from a hot gas stream, such as a combustion turbine or other waste gas stream. It produces steam that can be used to drive a steam turbine, in which case it is called a combined cycle (Rosen & Tang 2008). HRSG means that fuel does not burn to generate electricity, but that electricity is generated by a steam generator using the recovered heat from the CC (no fuel was burn). This technique is considered to be a method of improving the efficiency of an electric power plant. The CC plant has a thermodynamic cycle that operates between the high combustion temperature of the gas turbine and the waste temperature of the steam cycle capacitors (Langston, 2004). In a nutshell, as illustrated in Fig. 5, the hot exhaust gases from the initial GT are sent to the steam turbine, and its heat is used to generate steam. This steam is expanded through another turbine, generating even more electricity (no fuel used) to increase the overall efficiency of the power plant. GECOL started using CC technology in 2007 to improve the efficiency of the GT in Zawia and Benghazi North I, expanding the CC technology.

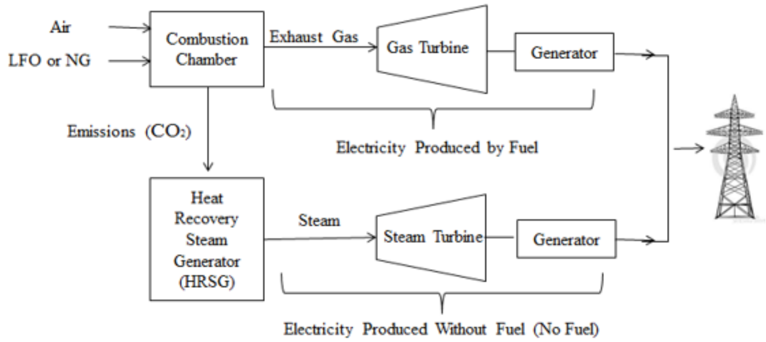


Fig .5 - CC Power Generation Technologies

Table 5 shows the efficiency of GECOL power plants between 2015 and 2018. During 2018, the average efficiency of ST power plants ranged from 23% to 32%, while the efficiency of GT power plants ranged from 26% to 35% and in CC from 32% to 42%. At the same time, there is a clear improvement in efficiency at some power plants between 2015 and 2018, especially in Zawia and Misurata, because these power plants have been modified to combined cycle in 2007 and 2013 respectively. The CC power plants shows more efficiency than ST and GT. On the other hand, efficiency improvements are not observed in GT power plants. Efficiency of ST power plants between 2015 and 2018 about 27%. While the GT shows better efficiency of 29% and a much better efficiency of about 41% in CC power plants. In short, there has been a slight improvement in the efficiency of power plants. Further efforts are needed with clear plans to improve performance, such as maintenance and good performance.

Table 5 - Efficiency of Power Plants between 2015 and 2018

Type	Power Plant	Average Efficiency, %				
		2015	2016	2017	2018	
ST	Khalij	33	30	34	32	27
	Khoms	29	29	30	30	
	Tobruk	13	25	25	23	
	Derna	21	19	-	-	
Average Efficiency		24	26	30	28	
GT	West Mountain	29	30	29	29	29
	Khoms	-	-	33	35	
	South Tripoli	27	27	26	26	
	Zwitina	30	28	27	30	
	Srrir	27	27	30	29	
Average Efficiency		28	28	29	30	
CC	Zawia	42	43	41	42	41
	Benghazi North	36	43	36	32	
	Misurata	47	36	42	42	
Average Efficiency		42	41	40	39	

Table 6 shows the existing HRSG power plants and their percentage of electricity generation between 2015 and 2018. Almost a quarter of total electricity is generated by HRSG at the Zawia and Misurata power plants, while HRSG in Benghazi North contributed only 7%. HRSG means that fuel is not burned to generate electricity. This is generated by a steam generator that uses the heat recovered from the CC.

3.2 Measures Taken in T&D System

After generating electricity, the electrical grid transmits electricity from the electric power plant to the end-users. This power grid is the overhead lines or ground cables that together form the so-called T&D system. Thus, the T&D system is not just a bridge that physically connects the generation sector to the end-user phase, but is an important tool to achieve the mitigating benefits of the two electrical supply chain components. There are a number of mitigation measures that can be used to reduce CO_2 emissions in the electrical T&D system. Table 7 shows the carbon mitigation measures that may be applied in the T&D system.

Table 6 - Combined Cycles Power Plants in Libya and their percentage of electricity generation between

Power Plant	No. of Units	Operation Date	Capacity (MW)	Fuel Type	2014	2015	2016	2017	2018
Zawia	4GT × 165	2000	660	LFO or NG	76%	71%	74%	77%	75%
	2 GT × 165	2005	330						
	3 ST × 150	2007	450	HRSG	27%	29%	26%	23%	25%
Benghazi North	3 GT × 150	1995	450	LFO or NG	90%	93%	91%	92%	100%
	1GT × 150	2002	165						
	2ST × 150	2007	300	HRSG	10%	7%	9%	8%	0%
Misurata	2GT × 285	2010	570	LFO or NG	75%	72%	93%	82%	81%
	1ST × 250	2013	250	HRSG	25%	28%	27%	18%	19%

Table 7 - Measures Applied in the Electric T&D System

Action Taken	Technology	Case
EDM	Balance between Power Generation & End-Users	✓
Smart Grid Technology	Use Fossil Fuel & Non Fossil Fuel on Grid	×
Improving Grid Efficiency	Reduce Technical Losses	✓
	Reduce Non-Technical Losses	×
	National Interconnection	✓

3.2.1 Energy Data Management (EDM)

Dukkipati et al. (2014), with regard to EDM, pointed out that the effective policy formulation in the energy sector relies on rigorous analysis of readily available, accurate, reliable and comprehensive data. The availability of such data requires institutional mechanisms and processes to collect, process and disseminate data in a timely manner. However, EDM Utilities cater to the needs of energy data management, dissemination and analytics. Data management applies the management of data collected from smart grids and smart meters, meter data analytics (Prasad & Avinash, 2014). The data collected in smart grids are heterogeneous and require data analytic techniques to extract meaningful information to make informed decisions (Potdar et al, 2018).

In early 2009, GECOL worked on the establishment of the EDM. This system consists of smart energy meters that are installed in all power transformers, unit and auxiliary transformers, and connecting lines. The smart meters are designed to be equipped with GSM communication to transmit data to telemetry stations. Some new power plants have included smart meters and EDM-related equipment in the technical specifications, as was the case with Fast Track units of Khoms.

The purpose of planning reserve margin is to measure the amount of generation capacity available over the planning horizon to meet expected demand. However, reserve margin is (capacity - demand)/demand. Where, capacity is the expected maximum available supply and demand is expected peak demand. For instance, a reserve margin of 15% means that an electric system has excess capacity in the amount of 15% of expected peak demand (EIA, 2012). However, peak demand on an electrical grid is simply the highest electrical power demand that has occurred over a specified time period (Gönen 2008). Peak demand is typically characterized as annual, daily or seasonal and has the unit of power. Peak demand, peak load or on-peak are terms used in energy demand management describing a period in which electrical power is expected to be provided for a sustained period at a significantly higher than average supply level. Peak demand fluctuations may occur on daily, monthly, seasonal and yearly cycles (Landsberg et al, 2008).

In 2017, the World Bank summarized the results of a rapid assessment of demand in Libya, noting that peak demand and past electricity consumption have been growing slowly since 2012. Fig. 6 shows the evolution of peak demand between 2000 and 2016. This shows demand peaked at 2.6GW in 2000 and continued to grow by 8%, reaching 5.8GW in 2010. Then, during the Civil War, in 2011, electricity production declined due to damage to the grid and some power plants. During this year, demand peaked at 6GW and started growing again, but this time it grew by 4% to reach 7GW in 2016.

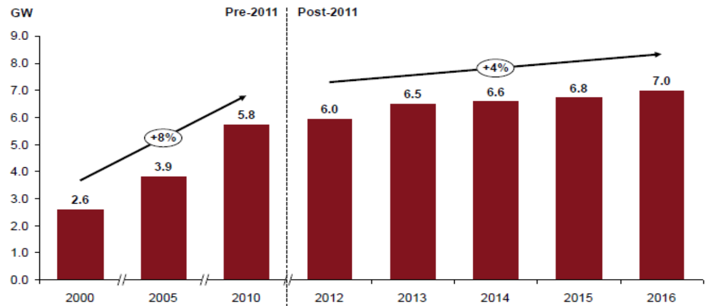


Fig 6 – GECOL Peak Demand (World Bank, 2017)

The World Bank (2017) also noted that Libya is increasingly unable to meet peak demand, mainly due to a large lack of capacity. Reserve margins are therefore very low, especially in the southern and western macro-regions. Likewise, the splay and demand balance between power generation and end-users presents in Fig. 7. It shows unavailable electricity capacity due to suspended units, installed electricity capacity at risk, and subject to availability. Obviously, the reserve margin increased 3.5-fold from -6% in 2013 to -21% in 2016. Thus, Libya is increasingly unable to meet its peak demand, mainly due to the high capacity unavailability. It is clear that GECOL has been suffering from a very low reserve margin since 2010.

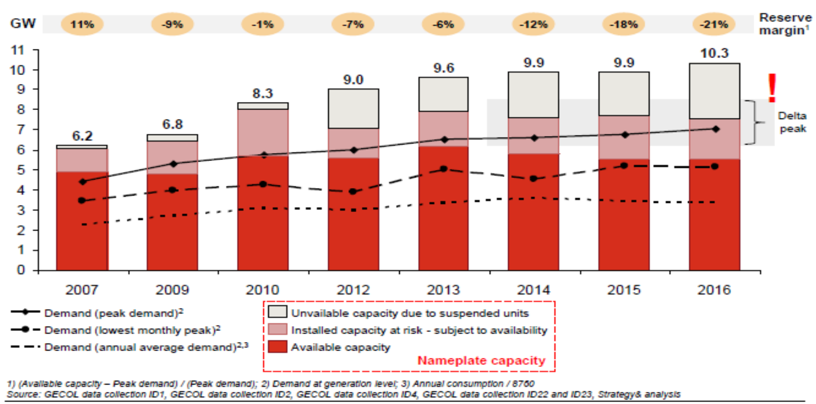


Fig. 7 - Balance Between Power Generation and End-Users (World Bank, 2017)

3.2.2 Smart Grid Technology

The term “smart grid” is used to represent a variety of interlinked social and technological changes to electricity systems, particularly modernizing networks that link electricity producers and consumers through advanced information and communication technologies (Morgan et al, 2009). Smart grid is considered to reduce energy consumption, improve the efficiency of the electricity grid and manage RE access to enter the grid. The smart grid is seen as a tool that increases the efficiency of the energy system in an environmentally friendly way and manage RE production. This can be achieved by upgrading the network deployment and generator efficiency, transmission and distribution, and power consumption (Abdalla et al, 2016). In a nutshell, smart grids are an important tool for achieving energy savings, reducing emissions and mitigating climate change.

GECOL has built a strong transmission system. Strict design criteria have been used to ensure an appropriate level of redundancy. GECOL has a solid vision for the creation and development of the power grid. The plan not only relies on meeting the necessary needs but also takes into account the possible future of advanced automated communication techniques and information technology, as well as other forms of techniques that manage RE access to the grid. There is no doubt, however, that the escalated civil war has caused serious disruption to the grid system, resulting in some deficiencies, delays, and poor coordination in the planning and expansion of the electrical T&D system. In the summer of 2017 and 2018, customers in Tripoli and its suburbs experienced one or two power outages that can last up to 13 hours in total.

However, Abdalla et al, in 2016 launched open research on the field of application of the smart grid in Libya. The study discussed the requirements that should be considered for the current grid to be a smart grid, and they recommended that GECOL begin upgrading its network equipment and installing new smart devices in each network section. Thus, the study, which is a noteworthy practical step in this area, and which should be considered as a road map for the implementation of the smart grid in Libya. With this and that, without a ceasefire, the transmission system will continue to operate with isolated systems and the Libyan population will continue to experience extended energy supply blackouts daily. National stability would enable foreign contractors to return and resume their work. However, GECOL Utility Maintenance teams have repeatedly entered conflict areas to repair repeated damaged power lines and restore electricity. Since the 400 kV transmission grid system is still relatively new in Libya, with recently installed overhead wires, GECOL has a relatively small supply of materials to repair damaged circuits. The situation is slightly better with the 220kV transmission system overhead lines and the 66 and 30kV distribution grid lines as GECOL has enough spare parts to repair the circuits. Where and whenever possible, GECOL started to repair damaged overhead lines as well as medium-voltage and low-voltage substations. Moreover, GECOL is taking advantage of this time to train its staff on smart devices, SCADA, and integrated energy. After national stability, GECOL will be ready to deploy a smart grid system.

3.2.3 Improve Grid Efficiency

Improving the grid means reducing electricity losses. In fact, there are two types of losses: technical losses and non-technical losses. Technical losses occur naturally and depend on the type of conductors used, the capacity of the transformer and other components used for the transmission and distribution of electricity. These losses are inherent to the distribution of electricity and cannot be eliminated, but can be reduced (Antmann, 2009). On the other hand, in the case of non-technical losses, the amount of energy consumed is uncertain. These can be considered as electricity consumed but not invoiced. These are losses due to unidentified, poorly distributed or inaccurate energy flows. Glauner et al (2018) stated that the three main types of non-technical losses are: energy theft, errors in unmetered supplies, and conveyance errors.

GECOL has upgraded its transmission line infrastructure to minimize network losses and improve efficiency and reliability. The total length of the 220kV and 400kV transmission systems is approximately 16,000km and the average voltage of the 33kV and 66kV systems is approximately 28,000km. GECOL, also, standardized the design of the overhead lines, so that they are all double circuit lines with towers capable of surviving some of the most severe environmental conditions and events. In addition to the growing reliance on natural gas, GECOL has, as a further step, build a 400kV transmission system that will increase the efficiency and reliability of the power transmission system. Lately, some transmission lines and substations are down, mainly due to security and conflict situations. Cut and broken OPGW lines and fiber optic connections, also, have led to widespread disruption of the telecommunications network. Fig. 8 shows the Libyan transmission system.

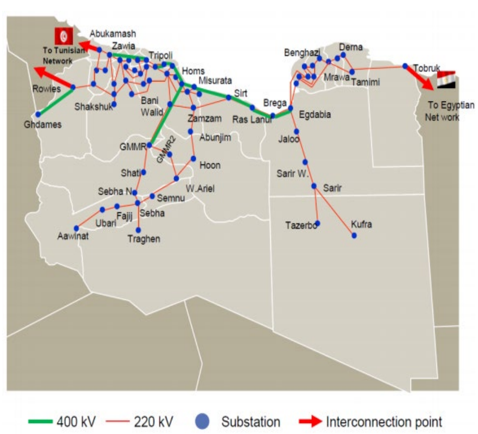


Fig. 8 – GECOL Transmission System and Interconnection Points

Reduce Technical and Non-Technical Losses

GECOL has established its own overhead line maintenance teams since the early 1990s. The overhead line maintenance teams acquired experience in all types of overhead maintenance and repair. on the other hand, GECOL has not been able to keep up with the cleanliness of the overhead required to keep its transmission overhead working well. The chains of contaminated insulators are subject to electric shocks during periods of high humidity, in addition to increasing system losses and electromagnetic noise that can cause interference in communications systems. Sources of pollution include saline deposits from the sea and dust from rock quarries, which are located near the transmission line in many parts of Libya. However, to minimize network losses and improve grid efficiency, overhead lines are usually cleaned with harsh force. The linemen would climb the towers to the insulating strings and clean the insulating discs by hand. The cleaning of individual dual circuits took many days to weeks. GECOL has been applying a less labor-intensive methodology in recent years.

Regular maintenance of the power grid is the main key to maintaining grid efficiency. However, GECOL maintenance activities are initiated by the maintenance programming department, which prepares the maintenance plan annually. Today, the maintenance department operates more than 30 km of high-voltage lines and nearly 300 substations. GECOL currently uses three different types of maintenance approaches to maintain the network; preventive maintenance, predictive condition-based maintenance, and corrective maintenance.

(1) *Preventive Maintenance*: maintenance approach that is regularly performed on equipment to check the likelihood of its failing. Preventative maintenance is performed while the equipment is still working, so that it does not break unexpectedly. This preventive maintenance for all substations equipment, high voltage lines, substations indoor feeders, line remote protection, and also, for load shedding schedule. So that they are scheduled (Periodically) Daily, weekly, monthly, semi-annually, annually, etc. Recently, the lines are mostly cleaned with water tankers fitted with pumps and water pipes. Tankers can be moved along the line, from tower to tower. The pumps are powerful enough to deliver a jet of water up to the height of the 220kV and 400kV insulating sleeves. The line guides partially work the hoses on the towers to better control the flow of water than the insulators.
(2) *Predictive Condition-Based Maintenance*: a maintenance approach used to predict the occurrence of equipment failure and in which monitors the actual condition of the device to determine if maintenance is required. This type of maintenance is for all substation equipment and high voltage lines depending on the situation of the triggered by asset and equipment condition.
(3) *Corrective Maintenance*: a maintenance approach that is performed when equipment failure occurs when triggered.

The basic analysis showed that the implementation of the GECOL maintenance plan is often interrupted by several unplanned maintenance work orders. In the recent period, the implementation of the maintenance plan has been negatively affected by the security situation, receiving emergency, unscheduled, and unplanned maintenance work orders. However, in 2012, GECOL contracted local contractors to assist in the maintenance of the 400KV and 230KV lines and achieved the highest performance rate the period 2012 to 2015. In 2015, the maintenance plan aimed to fulfill 12,576 maintenance work orders, but only 8,027 were fulfilled, representing a completion rate of 63.8%. In addition to the work orders included in the maintenance plan, GECOL had 8894 unplanned maintenance work orders, of which 8,113 executed work orders, representing a performance rate of 91.2%.

Current state of the transmission system; certain it has recently been severely damaged by civil war, vandalism and theft. It affected overall lines, substations and cables were affected. However, the most serious and lasting cases are the damages in the south and west of Benghazi between 2014 and 2015, which led to the unbundling of the network to the eastern and western sections, the reduction of load in Benghazi and the lack of production and the consequent load reduction in the western network. In almost cases GECOL has been able to repair, replace, or compensate for the damaged parts of the network. The World Bank (2017), indicating the current performance of technical losses, remained unchanged, losses were generally kept at pre-2011 levels and is aligned with regional peers. However, Fig. 9 shows transmission and distribution losses between 2010 and 2015. It is clear that T&D losses remain unchanged and generally show pre-2012 levels. In 2015, transmission losses were 1.8% and distribution losses were approximately 13.4%. Therefore, the total technical losses in 2015 was 15.2%.

Since technical losses are caused by technical reasons, non-technical losses (commercial losses) are caused by human factors. In 2009, GECOL performed an analysis of grid losses and the calculation of losses at each voltage level in the power grid. The results show that 15% of the losses were non-technical losses and 17% losses in technical lines losses. Fig. 10 shows the non-technical losses from 2010 to 2015 as well as the electricity generated versus the electricity invoiced in 2015. The value of non-technical losses jumped from 20% in 2010 to 65% in 2014, then it declining slightly to 60% in 2015. This is due to electricity theft, illegal connections, customer payment difficulties, and poor management of unpaid bills. However, there are currently no additional actions to reduce non-technical losses, but GECOL is following some measures to reduce technical losses through maintenance, 400 kV and 220 kV networks, substations and national interconnection. The analysis generally shows that the electric T&D system suffers significant and steadily increasing non-technical losses by 24%, which is considered very high. Thus, according to the World Bank (2017), the situation in Libya is critical towards regional partners such as Egypt, Algeria and Tunisia. However, the electricity generated, in 2015, was about 35.4TWh, while electricity invoiced only 8.9TWh, with total losses of about 75%.

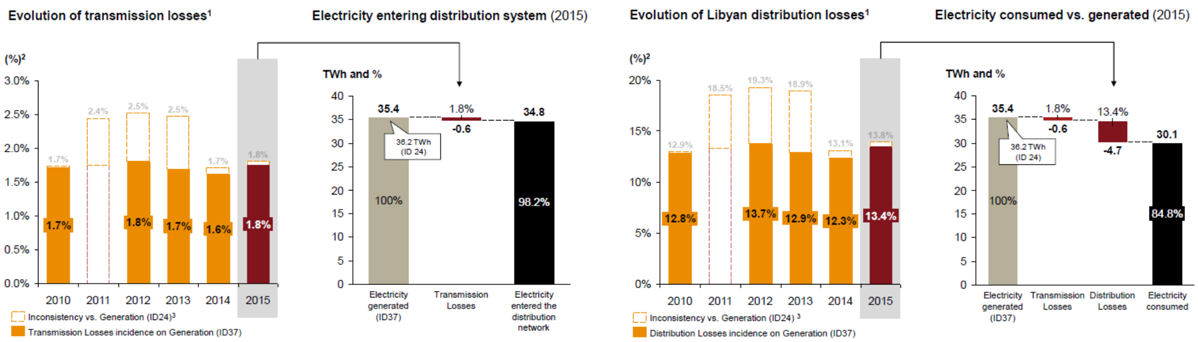


Fig. 9 - Technical Performance of the Transmission and Distribution Networks (World Bank, 2017)

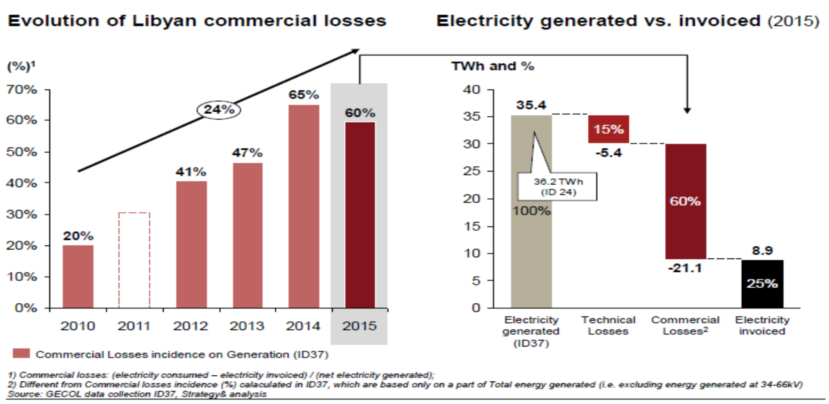


Fig. 10 - Non-Technical Losses from 2010 To 2015 (World Bank, 2017)

Interconnection National Grid

GECOL management also has a solid vision for the development and growth of the transmission system. The planning was not only based on the requirements to meet the load needs of the grid, but also considered the possible future energy transfer between Egypt and Tunisia via the Libyan grid network. However, the interconnection of electricity networks in several countries has many advantages. The main benefit is postponing or avoiding the construction of new power plants. it is sharing electricity between interconnected grids without affecting their security and reliability. Interconnection also reduces the need for standby capacity to meet fluctuations in demand, which in turn reduces operating costs. It allows the construction of new generation power plants in the most economically attractive areas, typically near inexpensive fuel sources. Accordingly, Libya's grid is currently connected to Egypt via a 220kV dual-circuit overhead line. The Egypt-Libya link, rated at 170MW, became operational on 220kV in 2008. The interconnection was supposed to be reinforced with a 500kV high-voltage line on the Egyptian side and a 400kV Libyan side, but the project seems to have stalled due to the political and economic instability that has existed since the 2011civil war. Also, there are two 220kV lines linking the Libyan grid to Tunisia, one double-circuit line along the coast and one single-circuit line through the desert. Fig. 8 shows the interconnection point between Libya and Egypt and between Libya and Tunisia.

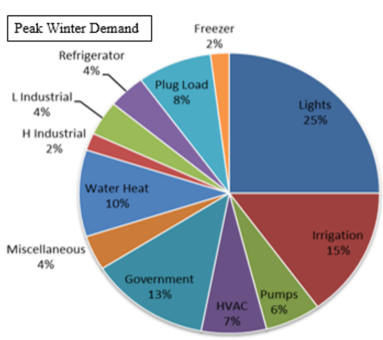
3.3 Measures Taken in End-Users Stage

Energy saving is the most effective measure to reduce CO_2 emissions at the end-user stage. It is a series of engagement activities aiming at energy conservation and environmental protection, by optimizing the terminal power consumption mode and improving utilization efficiency. Thus, the power demand and CO_2 emissions decrease indirectly. However, as end-users (consumers) are ever more dependent on electricity networks, they have certain expectations for electricity services. According to ISO 17743: 2016, energy efficiency aims to reduce the amount of energy required to provide products and services. Thus, the end-user wants electricity to be affordable, clean, reliable and capable of supporting both the developing economy and society. Therefore, managing energy demand and end-use efficiency can be a key contributor to reducing CO_2 emissions.

3.3.1 Demand Side Management (DSM)

DSM was coined following the time of the 1979 energy crisis (Torriti, 2015). DSM is the modification of consumer demand for energy through various methods such as financial incentives and behavioral change through education (Chiu, 2012). DSM was introduced publicly by Electric Power Research Institute (EPRI) in the 1980s. Nowadays, DSM technologies become increasingly feasible due to the integration of information and communications technology and the power system (Balijepalli et al 2011). Generally, the purpose of managing the demand side is to encourage the consumer to use less electricity during peak hours or to shift the time of electricity use to off-peak times such as night and weekends. Peak electricity demand, however, refers to the times when electricity consumption is highest.

The demand for energy in Libya is grown rapidly, against the backdrop of population growth and development projects. Generally, Libya's electricity consumption is high, while the country is considered to be Africa's largest energy consumer, as Libya is high in electricity consumption and Africa's per capita energy consumer (Energy Informations, 2013). On the other hand, 99.8% of Libyan people have access to electricity, which is the highest among African countries. According to GECOL, in 2011 Libya's electricity consumption totaled 32.960 TWh, which corresponds to 3.73MWh per capita. Commercial and public services accounted for 36%, while the retail sector accounted for 24% and the industry for 22%. Since DSM endeavors aim to control or limit the demand for electric energy, both are important to GECOL, the priority in the short to medium term should focus more on reducing peak power demand. GECOL implemented the first phases of a DSM study in 2010. Where, the study determined the average daily load curve during the summer and winter peak periods and the contribution of each consumer sector to the load curve, as well as a breakdown of the end-use contribution to this demand. Fig. 12 shows the peak demand for end-users in winter and summer system demand. It shows that residential lighting and heating, ventilation and air conditions (HVAC) together exceeded one-third of total demand. Demand for winter peak lighting and HVAC, which is about 32%, is slightly lower than the peak demand of 36% in summer. Lighting alone accounts for a quarter of total winter peak demand and exceeds this value in summer to become 29%. While at the summer peak, lighting and heavy industry sectors contribute to peak demand, which together account for 4%, while winter peak demand increases to 6% of total demand. However, a later review of the study questioned the amount of public lighting demand, and it estimated that it was overestimated by up to 10%. The study, also, shows that there is a potential to reduce peak loads by promoting high energy efficiency equipment such as air conditioners, water heaters and lighting. Currently, the government is encouraging a switch to solar irrigation systems, solar water heating and solar water pumping. Nevertheless, there is no time-differentiated price structure in the industrial sector that would encourage consumers to shift away from peak times. In addition, there is no special charge for households to encourage the rational use of energy.



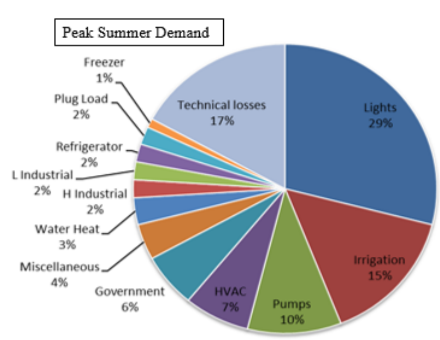


Fig. 12 - Peak Demand for End-Users in Winter and Summer

3.2.2 Smart End-Users

Currently, there is no designated energy efficiency agency. Where energy efficiency promotion activities are currently under the auspices of the Renewable Energy Authority of Libya (REAOL). While the number of electricity consumers in Libya and the amount of power consumed are constantly increasing, the Libyan electricity supply chain is struggling with the lack of energy and balancing opportunities within the system. However, Libya is currently preparing a National Energy Efficiency Action Plan (NEEAP). However, NEEAP is an initiative that started in 2010 to provide a strategic national plan framework that helps governments in Arab countries to apply their long-term energy efficiency goals. The initiative primarily aims to increase and promote energy efficiency practices and measures in Arab states by offering a standard action plan tailored to the region. The initiative was a result of the cooperation between the energy department at the League of Arab States, the Regional Center for Renewable Energy and Energy Efficiency, and the EU-funded regional projects (RCREEE website).

4. Summary

The electricity supply chain consists of three components, namely; electricity generation sector, electrical T&D system, and end-user stage. CO_2 emissions from the electricity generation sector are caused by the burning of fossil fuels. Unjustified end-user consumption and electricity losses in the T&D system increase electricity production, which of course contributes indirectly to further CO_2 emissions. Currently, however, the most important sources of CO_2 emissions in Libya are power plants, which account for about 35%, followed by transportation with 31% and then the residential and commercial sectors with 15%. As a result, this study presents the current situation and the measures already in place to reduce CO_2 emissions from the Libyan electricity supply chain. Thus, this section summarizes the measures the Libyan government has implemented to reduce CO_2 emissions from the electricity supply chain with a brief of the status quo of this chain.

4.1 Electricity Generation Section:

The analysis and the measures required in the field of electricity generation include the use of non-fossil fuels, shift to low-carbon fuels and the improvement of the efficiency of power plants, while the necessary actions to apply supercritical and ultra-supercritical techniques and switch on carbon capture power plants have not yet been implemented.

Use of a Non-Fossil Fuel: The use of RE reduces dependence on fossil fuels, which in turn reduces CO_2 emissions. As non-fossil fuel is referred to as RE. Libya has taken a number of measures to reduce CO_2 emissions through the use of RE. However, the Sahara Desert in Libya has great solar potential that can be used to generate electricity. The average daytime temperature during the season is between 19 and 35°C and in some parts of the Sahara rise to 41°C. The average solar radiation is about 7.5kWh/m^2/day, with about 3,000 to 3,500hrs of sunshine a year. In addition, the average wind speed is roughly between 6m/s and 7.5m/s at a height of 40m. This enormous amount of sunlight and wind, covering an area of 1,750,000km^2, will provide Libya and its neighbors with future electricity needs and can also be transported to Europe. With all these resources, the use of wind power for electricity generation has not yet started, but there are currently twelve wind farms in various situations. There are of the five wind farms in the eastern region, one project is under construction, two are still in progress, one is being awarded and one is under negotiation. There are four wind farms in the western region, three of which are under feasibility studies and one under construction. One wind farm in the south-east and one in the south-west, both under development. The two wind farms under construction are a 60 MW wind farm in Derna and a 50 MW wind farm in Emselata.

In terms of solar energy, the use of PV systems in Libya began in 1976. Since then, the role of PV application has increased in size and type of application. The first PV project is a PV system that provides cathodic protection to protect the oil pipeline connecting the Dahra oil field and the Sedra port. Currently, there are six small, off-grid PV projects and two on-grid PV projects. In addition, in 2018, the Misurata Free Zone signed a Memorandum of Understanding with iQ Power to develop integrated CSP and PV projects with a total capacity of 300MW and is considering building a seawater desalination plant that will use all or part of its solar energy.

Under Libya's new tax legislation, all RE equipment and parts are completely exempt from import duties, and a new electricity law is being prepared that will allow private sector companies to generate electricity. Libya is currently working to diversify its energy mix and exploit the potential of solar and wind energy. In 2015, RE accounted for about 2.0% of Libya’s total actual electricity consumption. However, in 2013, the Libyan government launched the RE Strategic Plan for 2013-2025, which aims to achieve a 7% renewable energy contribution by 2020 and 10% by 2025 in the electricity mix. It comes from wind, concentrated solar energy, solar PV and solar heat. As a result, most renewable energy projects have been delayed or suspended due to planning and funding problems, mainly due to oil production disruptions, security and the current armed conflict situations.

In the field of nuclear energy, Libya signed a contract with the Soviet Atomic Energy Company in the late 1970s for two reactors, each supplying 440 MW of electricity in the Gulf of Sirte. The reactors are designed for dual-use power generation and seawater desalination.

Switching to Low-Carbon Fuels and Improving the Efficiency: Libya has been switching to low-carbon fuels since 2007. The electricity generated by NG in 2016 reached 80% of the fuel used, LFO 13% and HFO 7%. The consumption of HFO and LFO decreased from 80% in 2004 (36% HFO, 44% LFO) to 30% in 2018 (9% HFO, 21% LFO). NG consumption increases from 20% in 2004 to 80% in 2016 and 70% in 2018. The NG, as a low carbon fuel, will continue to be a key source of electricity generation. Though, in order to reduce emissions by improving power plant efficiency, a CC technique was launched in 2007 for various power plants. The efficiency of CC power plants between 2015 and 2018 is about 41%. Almost a quarter of total electricity is generated by HRSG at the Zawia and Misurata power plants, while HRSG in Benghazi North contributed only 10%.

4.2 Electrical T&D Systems

The main measures carried out in the electrical T&D system are energy data management (EDM), smart grid and grid efficiency improvement.

***EDM*:** In early 2009, the country worked on the creation of EDM, where some new power plants integrated smart meters and EDM-related equipment. However, demand peaked at 2.6 GW in 2000 and continued to grow by 8%, reaching 5.8 GW in 2010. During the Civil War, in 2011and 2014, electricity production fell due to damage to the grid and some power plants in which demand peaked at 6 GW and started to grow again to reach 7 GW in 2016. Libya is increasingly unable to meet its peak demand, mainly due to the large capacity shortages resulting from the current critical situation.

***Smart Grid, and Improve Grid Efficiency*:** In 2013, the Libyan government launched the RE Strategic Plan for 2013-2025, which aims to achieve a 7% renewable energy contribution by 2020 and 10% by 2025 in the electricity mix. However, Libya has not yet begun building a smart grid system. Though, in the shadow of this harmful electricity grid, the implementation of a smart grid system is too difficult these days. Consequently, GECOL is taking advantage of this time to train its staff on smart devices, SCADA and integrated energy. After national stability, GECOL will become ready to launch a smart grid system. To minimize network losses and improve efficiency, overhead lines are usually cleaned with harsh force. However, the analysis shows that around 13% of losses are technical losses, while the value of non-technical losses increases by 24% since 2010. This is due to electricity theft, illegal connections, customer payment difficulties and poor handling of unpaid bills. However, there is currently no contribution action to reduce non-technical losses, but has some measures to follow to reduce technical losses through network maintenance. Generally, T&D losses remain unchanged and generally show pre-2012 levels of 15.2%. however, during, 2009, GECOL performed an analysis of grid losses and the calculation of losses at each voltage level in the power grid. The results show that 15% of the losses were non-technical losses and 17% losses in technical lines losses. Certainly, the transmission system has recently been severely damaged by civil war, vandalism and theft. It affected overall lines, substations and cables were affected. In almost case, GECOL has been able to repair, replace or compensate for the damaged parts of the network. GECOL management also has a solid vision for the development and growth of the transmission system. The planning was not only based on the requirements to meet the load needs of the grid, but also considered the possible future energy transfer between Egypt and Tunisia via the Libyan grid network.

4.2 End-User Stage

DSM and smart end-users are the measures used to limit electricity demand at the end-user stage. However, the demand for energy in Libya is grown rapidly, against the backdrop of population growth and development projects. Libya is considered the largest energy consumer in Africa, where, in 2011 Libya's electricity consumption totaled 32.960TWh, which corresponds to 3.73MWh per capita. Therefore, GECOL implemented the first phases of a DSM study in 2010. Where, the study determined the average daily load curve during the summer and winter peak periods and the contribution of each consumer sector to the load curve, as well as a breakdown of the end-use contribution to this demand. On the other hand, 99.8% of Libyan people have access to electricity, the highest among African countries. However, commercial and public services accounted for 36%, retail for 24% and industry for 22%. Also, residential lighting and HVAC together exceeded one-third of total demand. Demand for winter peak lighting and HVAC, which is about 32%, is slightly lower than the peak demand of 36% in summer. Lighting alone accounts for a quarter of total winter peak demand and exceeds this value in summer to become 29%. While at the summer peak, lighting and heavy industry sectors contribute to peak demand, which together account for 4%, while winter peak demand increases to 6% of total demand. Nonetheless, there is no time-differentiated price structure in the industrial sector that would encourage consumers to shift away from peak times. In addition, there is no special charge for households to encourage the rational use of energy. The government is encouraging a switch to solar irrigation systems, solar water heating and solar water pumping. Libya is currently preparing a national energy efficiency action plan.

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Husen Emhemed Bader holds a degree in Electrical and Electronic Engineering from the Bright Star University of Technology in Brega, Libya. He is currently a postgraduate student in engineering management at the Libyan Academy for graduate studies, School of Applied Science and Engineering. At the same time, he is a member of the Tripoli West Power Plant 4X 350 MW project at GECOL. Mr. Bader worked for GECOL in 2004 and 2005 as a device and control engineer. Then, he moved to ACESCo to work as a Design Review Engineer from 2006 to 2015, where he was responsible for some major works in power plants and desalination Projects.

Saber Khalid Elmabrouk has extensive experience in industry, teaching, and research in a variety of fields of petroleum engineering and engineering management. Based on his research and development experience, he has published several high-quality international scientific publications and supervised several MSc students in the area of; reservoir management, SCAl, PVT analysis, well testing, gas engineering, oil and gas production, CO2 capture, EOR projects, engineering economics, modeling, artificial intelligence, data mining, big data analysis, uncertainty analysis, and risk management. Dr. Saber graduated from University of Tripoli. He began his career at the Libyan Petroleum Institute, where he has participated in various researches in the field of PVT and SCAl. After obtained his MSc. from the University of Tripoli in Reservoir Modeling, he became a faculty at the same university, where he taught several petroleum courses. He continued his career in education and research after receiving a doctorate in Petroleum System Engineering from University of Regina. Currently, he is an Associate Professor and head of the Department of Chemical and Petroleum Engineering at the School of Applied Science and Engineering, Libyan Academy for Postgraduate Studies. Besides, he is an adjunct faculty, in the Department of Engineering Management at the University of Tripoli.