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I declare that this Master's thesis does not include any borrowings from the works of other authors without corresponding references.

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Kyiv, 2020

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Introduction

Energy demand is a vital issue which must be dealt with great significance. With the advent of innovative communication technologies and advancements in power systems, the trend of conventional grid is gradually shifting to the modern grid. Smart grids play an important role in various energy issues.

The Libyan electric power system is on the verge of significant changes that will change the industry model functioning in the future. The need for changes is caused by factors that, on the one hand, are associated with an increase in the requirements of stakeholders, and on the other, with the internal problems of the industry itself. The latter include high depreciation of equipment used, a shortage of qualified personnel, high cost of capital and construction, insufficient utilization of network and generating capacities, and low labor productivity.

Digitalization of the economy is one of the priority tasks set in the program documents that determine the long-term development strategy of Libya. The Libyan National Energy Efficiency Action Plans (NEEAP) [47] is the most important strategic government document that describe energy system development.

The digitalization of the electric power industry can, in particular, be understood as the introduction of various automation elements that create an integrated “smart” grid (Smart Grid). An active discussion in the scientific literature (in particular in Arab Future Energy Index Energy Efficiency report in 2019 [8]) on the development of renewable sources in Libya determines the relevance of the introduction of Smart Grid systems in the context of increasing energy demand in Libya, where the private sector is the main consumer with a share of 42.15% in 2017 [30], and the country's population is according to The

World Bank data is growing rapidly, the average annual growth for 2000-2018 was 1.25%, the total growth is 24% [76].

The smart energy systems of the future include smart power systems; integration of various types of energy resources and means of distributed energy generation is expected. The expected results of the implementation of such projects are a qualitative increase in the controllability, reliability and efficiency of the functioning of the main energy systems, including electric power ones.

Implementation Research Smart Grid systems in Libya reviewed in Agha, K. [4], Al-Hashmi, S. A., Sharif, M., Elhaj, M., Almrabet, M. [5], Ameri, M., Hejazi, S. [7], Bayindir, R, Colak, I. and G. Fulli. [9], Bharothu, J. N., Sridhar, M., Rao, R.S. [11], Bigerna, S., Bollino, C. A., Micheli, S. [12], Dezaki, H., Hariri, A., Hejazi, M. A. [17], Elghawi, U., El-Osta, W. [19], Ellery, M. L., Ndawula, M. B., Hernando, I. [20], Elsayh, K., Ochieng, E., Zuofa, T., Ruan, X. and Mpofu, B. [22], Elwerfelli, M. [23], Nanduri, M. [46], Nouri, A. [49], Rohouma, S., Zubi, H. [53], Saleh, I. M. [54], Shahzad, U. [56-58], Shlibek, M. [61], Shmeleva T. A. [62], Tuballa, M. L., Abundo, L. M. [68], Zikalala, D.P. and Chowdhury, P.S.P. [79].

The thesis aim is to develop proposal for commercial electricity metering for Libya based on Power system and electricity system analysis in Libya.

The main tasks according to aim is

- describe power system and electricity system in Libya;
- analyze Libya electricity balance and legal regulation of power system;
- develop structure, function for Libya smart meter system;
- provide cost-benefit analysis of smart meter system in Libya.

The object of thesis is smart metering system in Libya.

The thesis based on analysis methods that were used to characterize the Libyan energy system, energy control system and energy balance; a comparative analysis of the legislative framework and documents of strategic regulation of the development of a Libya energy system; cost-benefit analysis of the advantages of smart grid systems on the basis of developed industrial countries.

Chapter 1. Power system and electricity system in Libya

1.1 The General Estimate of Libya's Energy Potential

Over the past few years, there has been a positive trend in the growth of oil and gas production in Libya, which again turns this country into one of the most important players in the global electricity market. This African country is currently one of the suppliers of natural gas to Europe. According to the British Petroleum Statistical Review, proven reserves of oil in Libya are 48.6 billion barrels (2.9% of global reserves). In terms of oil reserves, it ranks first in the African continent [14]. In 2018, daily oil production in Libya amounted to 865 thousand barrels, while this state has doubled its oil production compared to 2017. This fact should not be surprising, since in 2011-2012 there was a sharp decline in oil production in connection with the civil war [14]. Moreover, the Libyans are still not reached pre-war levels of its production. 13.5% of oil is less than in the period 2006–2010. According to a number of experts, the level of oil production in Libya can be increased to 1.6 million barrels per day, and with foreign investment up to 2.1 million in 2018 Libya earned \$ 25 billion in oil revenues [73].

Explored natural gas reserves in Libya are 1.4 trillion cubic meters (0.7% of world reserves). In 2018, 11.5 billion cubic meters were produced here. Most of Libyan natural gas is exported. Its main consumer is Italy. Since 2004, Libyan gas has been supplied to this country via the Greenstream pipeline, whose initial throughput was 8 billion cubic meters per year, but then it increased to 11 billion [58].

After the end of World War II, Libya was one of the poorest countries in the world with an annual per capita income of about \$ 50. To correct the situation, in 1955 the law on oil concessions was passed in the kingdom, according to which the

profit between the state and oil companies was divided equally , and after a certain period Tripoli had the opportunity to increase its share. Despite the fact that at that time these conditions were not very liberal, more than twenty large Western companies, including Royal Dutch Shell and BP, immediately began exploration work in the Sub-Sahara region. For Europeans, Libya was extremely important because of its strategic position. While in connection with the Suez crisis of 1956, access to the Suez Canal was closed, and, unlike oil from the unstable and explosive Middle East, Libyan oil could become the guarantor of the energy security of European states [62].

Soon, the Americans were able to get ahead of the Europeans, and Standard Oil of New Jersey (now ExxonMobil) became the pioneer of Libyan oil production: in 1955, its foreign subsidiary Esso found a large Zelten oil field in northern Libya. Subsequently, the American companies Standard Oil, Marathon, Amerada and Continental Oil until the end of the 60s controlled 90% of the country's oil production and 80% of all investments in the industry. The Libyan business was very profitable for its proximity to the main sales market – Europe, in addition, local oil is characterized by extremely high quality (density – up to 44 ° API *), low sulfur content and low cost due to shallow bedding [70].

Because of the 1969 revolution, a group of “free officers” headed by Colonel M. Gaddafi came to power in the country. Since at that time foreign companies received the lion's share of profits from oil exports, a state priority was taken to nationalize the oil industry. To do this, it was first necessary to withdraw foreign military bases from the country, which was done during 1970. Having received freedom of maneuver and secured the support of Iraq and Algeria, where pan-Arab and socialist forces also came to power, Libya began to pursue a policy of increasing the role of the state in Fuel and energy complex [62].

In 1970, based on a new oil law, the Libya National Oil Company (NOC) was officially announced, and the next year, with the Libyan supply, OPEC raised the oil price quite substantially – to \$ 3.45 per barrel. Two years later, Gaddafi announced the transfer of a controlling stake in US oil companies operating in Libya to state ownership [62].

In 1974, M. Gaddafi completely nationalized the assets of Exxon, Shell and Texaco, and the American energy companies took the place of the Americans, who agreed to play according to the new rules [62].

The nationalization of the oil and gas complex has significantly increased Libyan budget revenues. This allowed Gaddafi and his supporters to carry out large-scale social reforms, significantly raising the standard of living of the population.

According to 2009 data [76], Libya was the leader among African states in terms of per capita income. In terms of the number of citizens living below the official poverty level (6%), Libya overtook even the Netherlands [71]. Among the undoubted achievements of the Jamahiriya, it is necessary to include free medical care and education (any Libyan citizen could receive secondary and higher education at public expense, the latter both in Libya and abroad). As a result, the literacy rate in Libya was significantly higher than in neighboring Tunisia and Egypt.

For the period of 2009-2018 Libyan energy system was not changed significant. As AFEX¹ data shows [2; 5], there was not changes in transmission and distribution processes, institutions and regulatory framework. The rating AFEX Energy efficiency score in 2013 was 18%, as in 2017 and 2019 (also 18%).

¹ AFEX is the first Arab index dedicated to monitoring and analyzing sustainable energy competitiveness and governance in the region (20 countries) and offers both quantitative and qualitative assessments on key RE/EE markets.



Figure 1.1 – AFEX Energy Efficiency Results, Libya, 2013 [2]

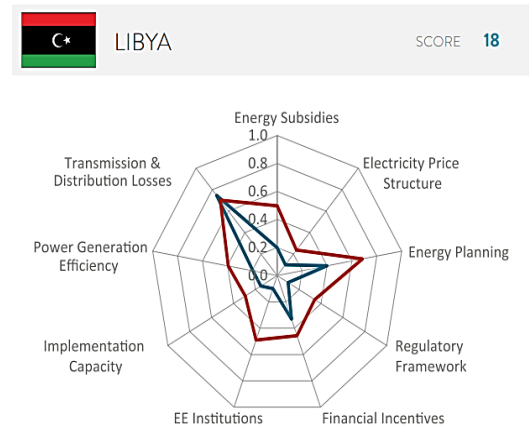


Figure 1.2 – AFEX Energy Efficiency Results, Libya, 2017 [5]

Libya has made little substantive progress since 2015 in energy efficiency (EE). With the lowest diesel and gasoline prices in the region and one of the lowest electricity prices, Libya needs to implement significant subsidy reform in its energy sector. Furthermore, in 2017 Libya still does not have a long-term EE strategy and its' NEEAP (2014-2016) and such documents was still under final stages of approval. Developing and implementing and effective NEEAP would be a vital move to create a sound and comprehensive EE policy and program framework to achieve said goals [5].

In 2018, the leadership of the Libyan NOC, headed by M. Sanalla, managed to achieve certain successes in the growth of oil production and attracting foreign partners to cooperate. In January 2018, NOC announced the resumption of production at the Sara field, which is being developed by the German company Wintershall, and it is planned to increase production there up to 57 thousand barrels per day [43]. The second important indicator of improving the situation in Libya was the decision of Royal Dutch Shell and BP to sign with NOC annual

contracts for the purchase of Libyan oil [13]. Soon after, other foreign companies began to show keen interest in the fuel and energy complex of Libya.

Despite political instability, the past two years have shown positive dynamics in the development of the Libyan oil and gas sector. The interest in working in it as buyers of Libyan hydrocarbons and investors is increasing. The level of oil production in the country doubled in 2018. The main reasons for this are the clear work of the Libyan National Oil Company, as well as the desire of the EU states to increase import of Libyan oil in connection with the next US sanctions against Iran, which do not allow the purchase of Iranian oil in full.

Over the past three years, the state has done a great job in order to consolidate in its own hands the country's oil industry, including the extraction, transportation and sale of oil.

Libya is one of the largest countries in North Africa. Its area is about 2 million square kilometer, with coastline stretched on the southern shore of the Mediterranean Sea for about 2000 km length [1].

Today, the electricity power system of Libya is a state owned vertically structured power utility company and is responsible for generation, transmission and distribution of electric energy.

There were a number of factors affecting electricity demand in Libya. These included the average real price of electricity, the real value of imported appliances, gross domestic product, population, temperature differences and lag in demand for electricity. Secondly, from the point of view of electricity power supply, there are a number of factors that affect electricity projects in Libya or even the development of existing projects. These factors include electricity demand, political implications, recession, oil prices, and improved development of other infrastructure [22].

The Libyan National Electricity Network consists of a high-voltage network of about 12,000 km, a medium-voltage network of about 12,500 km and 7,000 km of a low-voltage network. The transmission system consists of long transmission and sub-transmission lines operating at various voltage levels in the range of 400, 220, 132, 66, 30 and 11 kV. Some villages and remote areas located far from these networks cannot be connected to the network for economic reasons. In those settlements, with a small population and low energy consumption, diesel generators are used as a power source, requiring regular maintenance and fuel supply [54]. There is an existing network connection at a voltage level of 220 kV to Egypt with a capacity of 240 MW, a length of 180 km, and the connection between Libya and Tunisia was completed in 2009 at a level of 220 kV [51]. Figure 1.1 indicate a Libyan national grid at 220 kV and 400 kV levels.

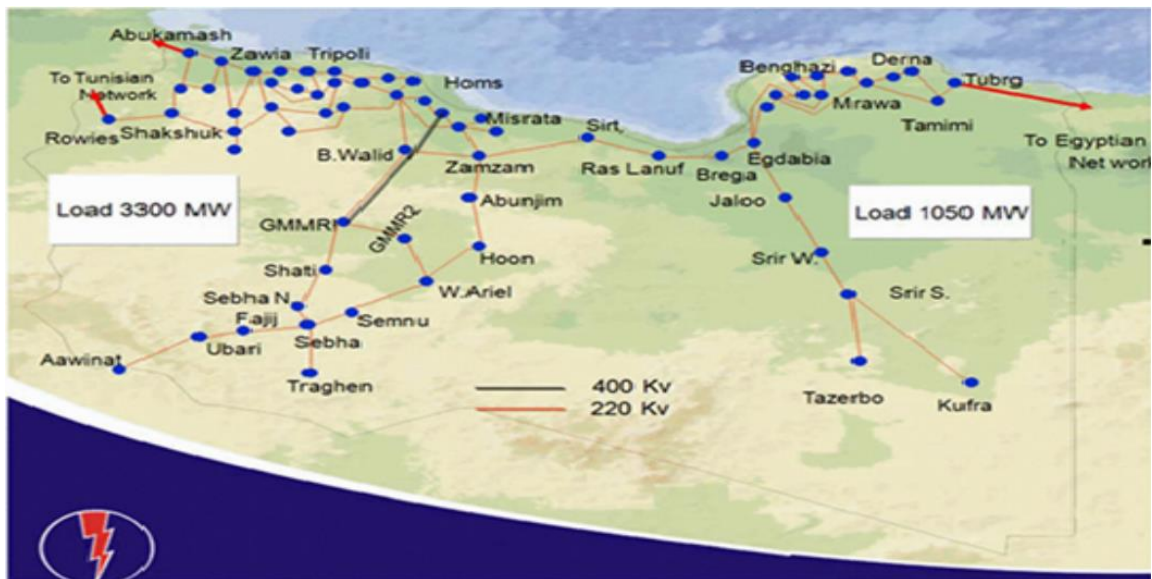


Figure 1.2 – Libyan national grid (220 and 400 kV) [16]

The Libyan economy is dominated by the oil sector, about 95% of export revenues are generated by the energy sector. From the point of view of solar energy, it can be argued that solar energy is the most important renewable energy

source, since Libya has a high level of insolation. Solar energy is considered one of the main resources due to the location of Libya on the line of the orbit of cancer, where the sun's rays are during the year and long hours in the afternoon.

There are several aspects of the Libyan energy sector that are considered quite problematic. Due to the abundance of fossil sources, renewable energy sources were transferred to the background. Despite early efforts to create and develop a renewable energy sector under a pre-revolutionary government, the pursuit of a diversified and sustainable energy sector was limited. Instead of being aggressive in developing alternative energy sources, the old regime heavily subsidized energy derived from domestic fossil sources. He developed and supported a rather one-sided economy that relied heavily and still depended on the availability of fossil fuels. This will not only exacerbate future efforts to reform the Libyan energy sector, but also weaken the potential benefits of using renewable energy sources and the related economic and environmental benefits. From a more general point of view, there was no economic incentive to move towards a more sustainable combination of energy.

All energy companies in Libya remain state owned. The electricity generation market is still closed to private investors. A new law on electricity is being prepared, which will allow private companies to generate electricity. The Libyan legal framework does not allow the private sector to independently generate renewable energy sources (car manufacturers) with the possibility of supplying excess electricity to the network. Besides small scattered photovoltaic projects, in practice there are no RE carmakers [52].

The advantage of using both renewable and traditional energy sources is that the deficiency in one source can be compensated for by another in a normal or controlled manner. Renewable energy cannot be universally reliable due to its stochastic nature. The integration of renewable energy will reduce the overall

reliability of the hybrid system. The integration of traditional sources with renewable sources will effectively compensate for the shortcomings of renewable sources. To reduce its dependence on fossil fuels and promote renewable energy, the Libyan Renewable Energy Authority has set targets by 2030. Long-term plans are to ensure by 2525 25% of energy supplies to Libya using renewable energy sources and increase to 30% by 2030 [54]. The intermediate targets of renewable energy share are 6% by 2015 and 10% by 2020 as Table 1.1. indicate.

Table 1.1 – Renewable energy share [37]

2015	2020	2025
6% RE Share	RE Share 10%	RE Share 25%
750 MW Wind	1500 MW Wind	2000 MW Wind
100 MW CSP	800 MW CSP	1200 MW CSP
50 MW PV	150 MW PV	500 MW PV
150 MW SWH	300 MW SWH	600 MW SWH

Since the costs of developing renewable energy sources are largely supported in all sectors of the economy in Libya, it is difficult to stimulate the use of renewable energy sources and improve energy efficiency on a cost-effective basis. Renewable energy sources are not used in significant quantities, and only 5 MW of solar energy, in the form of several small photovoltaic projects that were installed in 2012.

Solar power. The sun's rays radiating the earth's surface are ultimately the main renewable energy source. Recently, figures confirming an increase in the use of solar energy for various applications have risen sharply. Libya has significant potential for the use of solar energy. In coastal areas, the average daily value of solar radiation on the horizontal plane is 7.1 kWh / m² / day, and in the southern region it is 8.1 kWh / m² / day [54] .According to the Libyan Renewable Energy Authority, the average duration of sunlight is more than 3,000 hours per year. This

is equivalent to a layer of 25 cm of crude oil per year on the surface of the earth [54].

Biomass. Libyan biomass potential is limited. Biomass energy sources are small and can only be used on an individual level as an energy source. It is not suitable for energy production on a large scale.

Wind power. Wind energy in Libya was used to pump water in the mid-20th century. Recent interests in the use of wind energy have arisen recently [51]. Since windmills need to be regularly maintained, this method of energy production is not widespread. Libyan authorities recognized the importance of finding alternative energy sources, as well as integrating wind energy into electric networks. The wind potential is good, and the average wind speed at an altitude of 40 meters is 6-7.5 m / s. [51]. One of several attractive places along the Libyan coast is located in Dernah, where the average wind speed is about 7.5-8 meters per second.

1.2 Analyze legislative and regulatory documents for ensuring the functioning of the power system and power supply systems in Libya

Over the past decades, Libya has funded its electricity infrastructure. The investment was directly funded by the Libyan government through a development budget. However, GECOL, General Electric, the only Libyan national energy company, was a key institution for planning and organizing investments. The combination of oil in the country and the policy of universal electrification, energy supply with strict criteria for planning the expansion of the Libyan system led to the creation of a reliable power transmission network and ambitious projects for the construction of generating stations [49].

Libya's electricity market is still a complete monopoly. The price of electricity in Libya is very low. There must be an honest and practical FiT. There is

no energy regulator in Libya. Energy investment laws do not exist. The energy market in Libya is very fragmented, and it is not easy to come up with a risk assessment [49].

Since Libya is one of the oil and gas producing countries, almost all of its electrical loads come from power plants that are fully powered by heavy, light oil or gas fuels, especially steam and gas turbine power plants. In fact, this strategy leads to increased operating costs, increased maintenance costs, and is detrimental to the environment. Although there is currently no existing renewable energy station, apart from solar energy sources that are built to power the communications network, the master plan for future energy in Libya includes many projects [5].

Table 1.2 – Libya’s institutional and legal framework [69]

Basic Elements	Response
Presence of an Enabling Institutional Framework for sustainable energy development and services (Max 5 institutions) most critical ones	Ministry of Electricity and Renewable Energy Energy Council Atomic Authority Solar Energy Research Centre management, Renewable Energy Authority of Libya (REAOL) 2007 Centre for Solar Energy Studies (CSES)
Presence of a Functional Energy Regulator	None
Ownership of sectoral resources and markets (Electricity/power market; liquid fuels and gas market)	State-owned General Electricity Company of Libya (GECOL)
Level of participation in regional energy infrastructure (Power Pools) and institutional arrangements	Comite Maghrebin De L’electricite (COMELEC) Power Poo
Environment for Private Sector Participation	-

Whether the Power Utility(ies) is/are vertically integrated or there is unbundling (list the Companies)	-
Where oil and gas production exists, whether upstream services and operations are privatized or state-owned, or a mixture (extent) e.g., licensed private exploration and development companies)	National Oil Corporation (NOC)
Extent to which Downstream services and operations are privatized or state-owned, or a mixture (extent)	-
Presence of Functional (Feed in Tariff s) FIT systems	-
Presence Functional IPPs and their contribution	-
Legal, Policy and Strategy Frameworks	-
Current enabling policies (including: RE; EE; private sector participation; & PPPs facilitation)	Renewable energy roadmap to 2030 National Energy Efficiency Action Plan (NEEAP) Libya Renewable Energy Strategic Plan 2013-2025
Current enabling laws/pieces of legislation (including: RE; EE; private sector participation; & PPPs facilitation) – including electricity/grid codes & oil codes	Prime Ministerial Decision of 8 September 2009 establishing Energy Council Draft Electricity Bill

The Energy Council is responsible for the energy sector; and there is also the Ministry of Electricity and Renewable Energy, which regulates and controls the electricity sector. The vertically structured General Electric Company in Libya (GECOL) is responsible for the production, transmission and distribution of electricity; and it works closely with the Libyan Renewable Energy Authority (REAOL). However, coordination between them is weak (MOF, 2014). At the regional level, the country is a member of the Comité Maghrébin De L'électricité Energy Fund (COMELEC). The draft law on electricity provides for the legal framework.

The Libyan General Electric Company was established in accordance with Law No. 17 in 1984, which is responsible for the implementation of projects for the operation and maintenance of electric networks, power generation stations and their distribution and conversion stations. In addition, the company is responsible for energy transformation lines and their distribution, electrical control centers and operation and maintenance of desalination plants throughout the country. He is also responsible for the creation and implementation of any projects in the above areas. Moreover, the company is responsible for the production of equipment and materials that the company uses in cooperation with specialized companies in this field. The company also offers general services and services for customers in the field of electricity for a fee [26].

State owned company GECOL controlled the actual electricity system of Libya. This company operates 30 electricity generation plants, mainly steam and simple-cycle gas-turbine units and diesel generators in rural areas. The company is also the sixth largest operator of water desalination plants in the world. More than \$1,000 million will be spent on new desalination units over the next ten years consist mainly from based mainly on oil.

Libya Renewable Energy Strategic Plan 2013-2025 developed by Ministry of Electricity and Renewable Energy aims to achieve 7% renewable energy contribution to the electric energy mix by 2020 and 10% by 2025. This will come from Wind, Concentrated Solar Power, photovoltaic and solar water heating [37].

The technology breakdown will look like this [37]:

- By 2020 the 600 MW capacity is wind, the 150 MW capacity is CSP, the 300 MW capacity is solar PV, the 250 MW capacity is solar water heating;
- By 2025: the 1000 MW capacity is wind, the 400 MW capacity is CSP, the 800 MW capacity is solar PV, and the 450 MW capacity is solar water heating.

The Government of Libya established the Libyan Renewable Energy Authority (REAOL) in 2007. The main goal of REAOL is to implement appropriate policies in order to achieve the government goal of 10% of the total energy from renewable energy sources by 2020.

REAOL Implements projects using renewable energy sources, encourages and supports related industries, offers support for laws and regulations and evaluates the potential of renewable energy sources in Libya to identify priority areas.

REAOL implement a long term Plan for Renewable Energy Development for 2008-2030 that was divided into targets [37]:

- Reach 6% of renewable energies by 2015, with 750 MW wind capacity, 100 MW concentrating solar power (CSP) capacity, 50 MW solar photovoltaic (PV) capacity, 150 MW of solar water heating (SWH) capacity;
- Reach 10% of renewable energies by 2020, with 1500 MW wind capacity, 800 MW CSP capacity, 150 MW PV capacity, 300 MW of SWH capacity;
- Reach 25% of renewable energies by 2025, with 2000 MW wind capacity, 1200 MW CSP capacity, 500 MW PV capacity, 600 MW of SWH capacity, and eventually;
- Reach 30% of renewable energies by 2030.

After the events of February 17, 2011, the state of GECOL changed, which began to affect the work of the main divisions of the company and the energy infrastructure of Libya. Insecurity and political instability led to a halt in most projects, consistent attacks on GECOL assets and personnel, a significant increase in thefts, especially conductors and electrical appliances, and a significant decrease in GECOL's ability to carry out maintenance work. As a result, some infrastructure assets, a drop in power grid capacity and a serious shortage of generating

capacities were lost, which led to a prolonged blackout in many parts of the country, especially during peak periods in summer and winter [9].

1.3 Distribution Control Centers (DCC)

Since the 1970s, GECOL has introduced monitoring centers to monitor generating plants and supply systems. The energy infrastructure control system includes the following institutions: National Control Center (NCC), two Regional Control Centers in Tripoli and Benghazi (TRCC and BRCC respectively), and Distribution Control Centers (DCC's) around the country.

Until 2011, NCC and TRCC worked at full capacity and functionality. BRCC was in the process of changing the system to integrate the software and hardware base with NCC and TRCC. A project was launched to create ten new DCCs, the purpose of which was to introduce mid-level voltage and distribution network management tools. Since that time, Distribution Control Centers focused on five of ten control centers that were highly advanced and could be commissioned. Distribution Control Centers in Tripoli were put into operation, but work ceased in 2014. Software and hardware systems are over 10 years old and require urgent updates. In control centers, network data is only 20%. In the communication network, decisions and concerted actions must be taken to eliminate problems in the communication network and substations. The problems today are causing deterioration in the availability of data about the entire system for management engineers. Without data, it is not entirely possible to control the power system and are limitations for personnel with control. Of particular importance is the adoption of decisions and measures for the repair of fiber optic cables. Damage to the cables that transmit data in the network and between stations aggravates the system. The network is operating in a stressed state. To ensure its

safety and stability, it is advisable to ensure the operation of reserves. GECOL should create a new backup control center outside the Tripoli region.

Currently, we consider the main points of concern in the Control area to include [66]:

1. NCC and TRCC: The hardware and software systems are now over 10 years old and need to urgently be upgraded. Network data at the control centers is very poor at only 20%. A concerted effort must be made resolve the problems in the substations and the communications network causing the deterioration in available data to the control engineers, without which they are very constrained in their ability to manage the power system. Particular effort must be made to repair the many fiber optics that are damaged and that carry the data between the control centers and the substations. The network is currently operating in a very stressed condition, and it is important to provide some spinning reserve to add to system security and stability. Also AGC functionality must be put back into operation. Finally, GECOL should proceed with establishing a new backup control center for the NCC outside Tripoli.

2. BRCC: Control engineers at the BRCC must contend with two separate control systems, an old one and a new one, neither of which is fully functional. It is therefore important to complete and commission the new control system and shift all control functions to it. Benghazi also suffers to similar data problems as the TRCC, with only a third of substation visible to the SCADA system and much data missing, and a similar plan of action is required to resolve the poor data situation. BRCC operators must also regain their control functionality over network switchgear and not be dependent on operators at each substation.

3. DCC's: Project works have stopped since 2014. Contractual problems may require renegotiations or new contracts to be put in place, and GECOL should refocus on at least completing the initial 5 distribution control centers.

4. Staff and control functionality development: It is critical for GECOL to resume a project similar to that underway before 2011 with the French utility and consultant RTE, to both develop its control staff capabilities and skills and to develop the procedures, codes and regulations key in maintain a large and growing system such as GECOL's under control and coordinated.

5. Load growth: Despite Libya's instability and financial difficulties, consumer load has continued almost unrestrained at some 4% per year since 2011. GECOL should begin instituting demand side management programs to limit the future growth, especially when political and financial stability return and the economy begins to recover and grow, otherwise GECOL will be hard pressed to construct new generation capacity to keep up with the load demands.

From a power network viewpoint, the NCC is responsible for dispatching all generation plants and units in the Libyan network. It also responsible for control and operations at all 400kV substations and main 220kV transmission lines that directly impact and control the power flow through the transmission grid. The lines and substations in this latter category are not fixed and change according to network configuration. For example, outage of a 400kV transmission line could make the parallel 220kV transmission lines critical to the network power flow and put them under the control of the NCC, while putting the 400kV line back in service will return the 220kV lines to the control of the TRCC or BRCC. Where in doubt, the TRCC and BRCC control engineers will consult with the NCC before taking action on 220kV elements that might have network-wide implications [66].

In time of power shortage, it is the NCC that determines the amount of power that needs to be shed, and the RCC's (and sometimes the DCC's as well) that carry out the actual disconnection of loads. As part of GECOL's public relations, transparency, and communications efforts, GECOL updates its official Facebook page with daily estimates of the hours of power outage expected. This

information is provided to GECOL's PR department by the NCC manager. GECOL now has a project to maintain and upgrade the NCC SCADA system. The contract is in progress, although the work is on hold because of the security situation and payment difficulties. At a later stage GECOL will also erect a new back up NCC in another city outside Tripoli, and consider the Tripoli NCC the main [66].

The Tripoli center was responsible for city's sprawling 30kV network, the Benghazi center for that city's 11kV network, and Tobruk center for the local 30kV and 11kV networks. The original control center equipment has long been out of service, and GECOL has more recently contracted to install 10 new control centers in the cities of Tripoli, Benghazi, Zawia, Sebha, Misurata, Beida, Gharyan, Sirt, Tobruk, and Sarir.

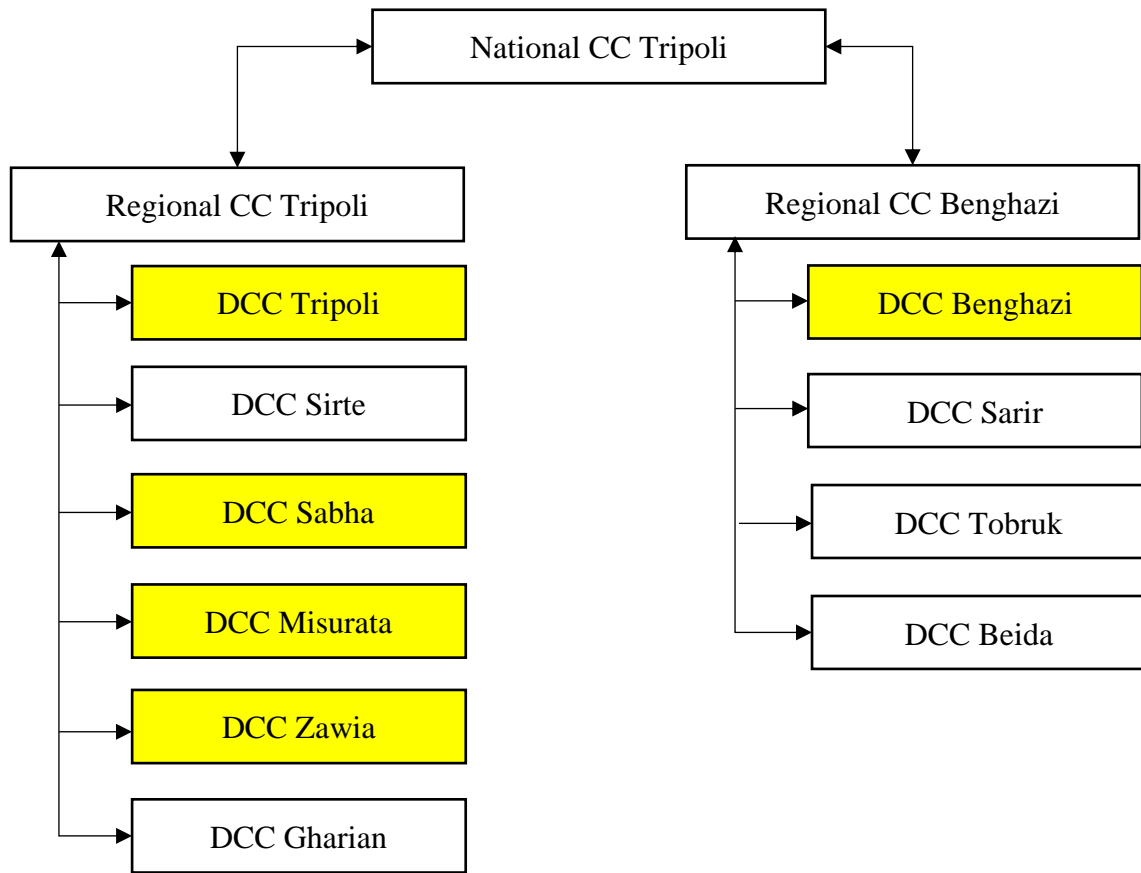


Figure 1.3 – Distribution Control Centers hierarchy. Priority DCC's in yellow [66].

The project is not turnkey. While the supplier, Siemens, is responsible for the control center SCADA and DMS systems, GECOL has agreed with ABB on the telecommunications infrastructure, which is mostly fiber optic cables paralleling the routes of the 30kV cable networks between substations, and GECOL is directly responsible for the adaptation and modification works at the substations to prepare them for connection to the new DCS's. This combination of responsibilities and division of roles has led to complex project management demands on coordination between the parties, and GECOL has generally been behind schedule in delivering the parts of the works under its responsibility.

Of course, the events post 2011 have further complicated matters, and even several of the control centers that had advanced in the erection works were damaged by the conflict or subject to vandalism. As a result, GECOL decided to focus on the 5 distribution control centers with the greatest possibility of completion within a reasonable timeframe, namely Tripoli, Benghazi, Zawia, Sebha and Misurata, being the control centres most advanced in their installation works and/or least damaged by the fighting and hostilities. Of these, the SCADA systems were put in operation in Tripoli, Benghazi and Zawia.

By 2014, when works by the contractor came to a renewed halt, Site Acceptance Tests were almost complete in Tripoli, well underway in Zawia, and were planned to begin in Benghazi. Tripoli is in the most advanced state, having been mostly commissioned, but not contractually handed over, in early 2014, but even here only 60 out of some 104 substations in the Central Tripoli area that have been commissioned and connected are currently actually working and accessible to the Tripoli DCC. This also compares with the total of some 245 substations that are

supposed to be connected to the DCC SCADA system covering Greater Tripoli and outlying regions.

Most of the problems are due to RTUs, others to failure of communication links. A major constraint on expanding the number of substations working with the SCADA system is staff capabilities. Most of the persons trained by the contractor on modelling the substations in the control center and entering the data into the system have transferred out of the DCC, and no one currently working there has the knowledge to complete the data entry work. Additionally, the system is Unix-based and DCC staff are not experienced with the operating system. Since the contractor pulled out of Libya in 2014, GECOL has only now been able to arrange training for one software engineer, to be held in Tunis.

Despite this, control and monitoring of the Greater Tripoli Medium Voltage network is dependent on the substations that are accessible and visible to the control room engineers and the telemetry data received from those substations. Key parts of the central Tripoli network are visible to the engineers, from which they can derive a general understanding of the remaining network. Current power outages in Tripoli that can last six hours or more have acted as an additional constraint. Batteries at the substations are generally old and provide power to the substation equipment for only some 3 to 4 hours. In some substations batteries have been replaced and the new battery sets can provide some 6 to 7 hours. Of course, with power cuts that last 8 or 9 hours, this is still not sufficient.

Other problems faced have been theft of batteries and damage to switchgear by attempts to steal copper, even from the contact fingers of circuit breaker trucks. As with the transmission system, actual switchgear operations are manual and carried out by GECOL operators in the field. Tripoli is divided into 20 operations points, located in one of the key substations in the city and manned 24/7, with each responsible for around 10 substations. Operators move from the operation points to

the substations where switching or other operations are required. In 2007 to 2009, GECOL contracted with the Korea power utility KEPCO to develop a set of distribution standards covering the 66kV, 30kV and 11kV systems and equipment. This included operations and safety rules. Discussion with the control engineers indicated that they had no knowledge of these rules and standards. They operated the system based on their experience and in line with the documents and forms they had in hand, such as the Permit to Work forms that specified directly some of the safety precautions that needed to be in place to allow persons to work on the system. As with the other planned DCC's, the Tripoli DCC has a second control room for the 11kV network. This is currently not in use. 11kV control engineers occupy a small office and monitor and supervise 11kV network operations using pen and paper. This is the situation at all other 11kV control points in the Libyan network.

It is worth noting that management responsibility for the two control rooms at the DCC is split, with the Medium Voltage General Department responsible for the 30kV control room and the Distribution General Department responsible for the 11kV control room. With respect to the remaining priority distribution control centers, Benghazi system installation has been completed and some 80% of the substation and communications systems have been put in place. Some of the fiber optic cables have since been damaged and need repair, and the SCADA/DMS system is also in need of an upgrade. At Zawia, over 85% of the communications and substation works have been completed and the central SCADA/EMS equipment has been installed. Commissioning was begun but not completed in 2014. Also some of the fiber optic cable links have been damaged and require repair. In Sebha almost all the substation and communication system works have been completed, but the central SCADA/DMS system was vandalized after installation. In Misurata over 80% of communication and substation works are

completed and the central SCADA/AMS system installed but not commissioned, and has not been put in service yet.

No system control and monitoring system is fully operational. And engineers are forced to solve performance problems in both systems.

Therefore, it is important to develop a new management system. Benghazi is facing the same difficulties. Only one third of the stations are visible in the control system, most of the data is missing. BRCC operators depend on the operators at each substation, so you need to ensure the restoration of the management functions of network distribution devices.

1.4 Main Consumers and Electricity Balance

In 2015, energy intensity² for Libya was 4 MJ per dollar of GDP. Though Libya energy intensity fluctuated substantially in recent years, it tended to decrease through 1996 - 2015 period ending at 4 MJ per dollar of GDP in 2015 [76].

In 2014, energy imports³ for Libya was -103 %. Though Libya energy imports fluctuated substantially in recent years, it tended to increase through 1995 - 2014 period ending at -103 % in 2014 [76].

Table 1.3 indicate the indicators of energy balance in Libya. The production from natural gas increase in 2015-2017 on 12.69% to 22834 GWh, while production from oil decrease on 19.06% to 13955 GWh. Total production decrease on 1.90%.

Table 1.3 – Libya Electricity data in 2015-2017 [30]

	Electricity	Electricity	Growth, %	Electricity share in
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² Energy intensity level of primary energy is the ratio between energy supply and gross domestic product measured at purchasing power parity at constant prices of 2011. Energy intensity is an indication of how much energy is used to produce one unit of economic output. Lower ratio indicates that less energy is used to produce one unit of output.

³ Net energy imports are estimated as energy use less production, both measured in oil equivalents. A negative value indicates that the country is a net exporter. Energy use refers to use of primary energy before transformation to other end-use fuels, which is equal to indigenous production plus imports and stock changes, minus exports and fuels supplied to ships and aircraft engaged in international transport.

	2015	2017		World
Production from:		GWh		
Coal**				
Oil	17241	13955	-19,06%	1,66%
Natural gas	20262	22834	12,69%	0,39%
Solar PV	8	8	0,00%	0,00%
Total production	37511	36797	-1,90%	0,14%
Imports	-	302	100,00%	0,04%
Exports	-	-	-	-
Domestic supply	37511	37099	-1,10%	0,14%
Statistical differences	-14376	-14875	3,47%	39,27%
Energy industry own use	731	717	-1,92%	0,03%
Losses	7127	7383	3,59%	0,37%
Final consumption	15277	14124	-7,55%	0,07%
Industry	1892	1225	-35,25%	0,01%
Transport	-	-	-	-
Residential	5488	5953	8,47%	0,10%
Commercial and public services	1757	1521	-13,43%	0,03%
Agriculture / forestry	1211	1238	2,23%	0,19%
Fishing				
Other non-specified	4929	4187	-15,05%	0,42%

Total Primary Energy Supply (TPES) is the total amount of primary energy that a country has at its disposal. This includes imported energy, exported energy (subtracted), and energy extracted from natural resources (energy production) [67]. Total losses were -635 or 7383 GWh in Libya in 2017. The main source of losses in Libya is electricity, which is 100% of the total TPES.

Domestic supply decrease on 1.10% in 2015-2017. The losses increase on 3.59% and the share of losses is 19.7% in 2017. Energy industry own use share was 2.0% in 2015-2017. Final consumption decrease on 7.55% due to low consumption in industry (-35.25%), commercial and public services (-13.43%),

other non-specified sectors (-15.05%). While the residential and agriculture / forestry consumption increase on 8.47% and 2.23% accordingly.

The main energy consumption sector is residential (figure 1.4 and figure 1.5), which share increase in 2015-2017. The other non-specified sector is the next in energy consumption structure. Industry, commercial, and public services also have great share in energy consumption structure.

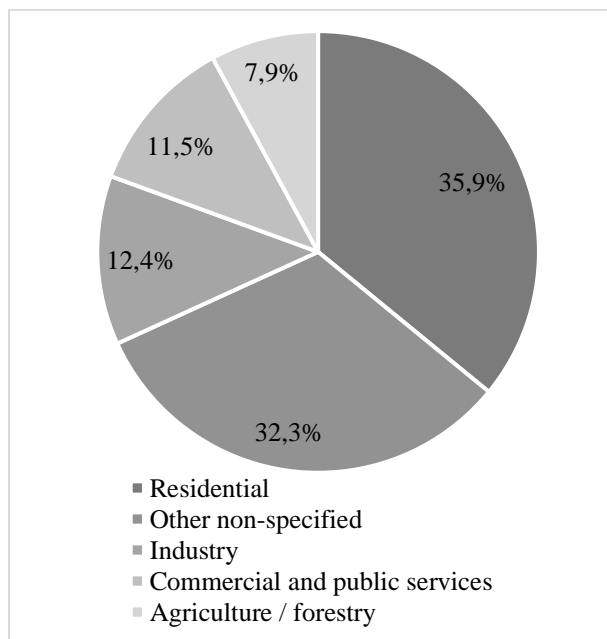


Figure 1.4 – Structure of energy consumption in Libya by sector, 2015, % [30].

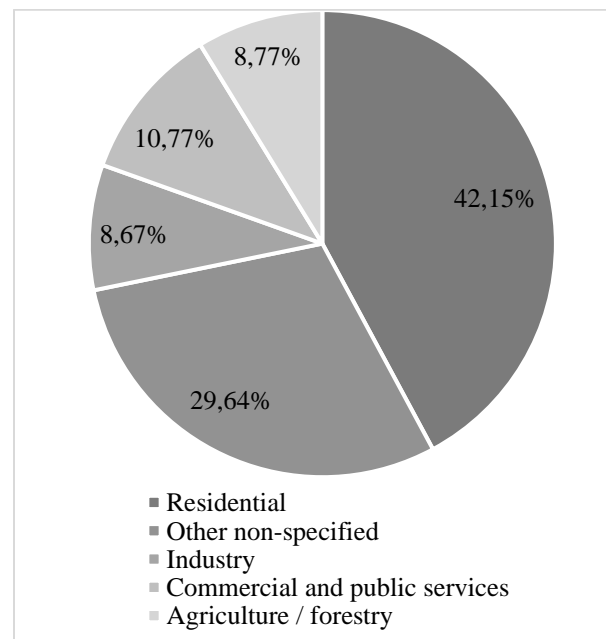


Figure 1.5 – Structure of energy consumption in Libya by sector, 2017, % [30].

In 2017, primary energy production for Libya was 2.28 quadrillion btu. Though Libya primary energy production fluctuated substantially in recent years, it tended to decrease through 1998 – 2017 period ending at 2.28 quadrillion btu in 2017 [33].

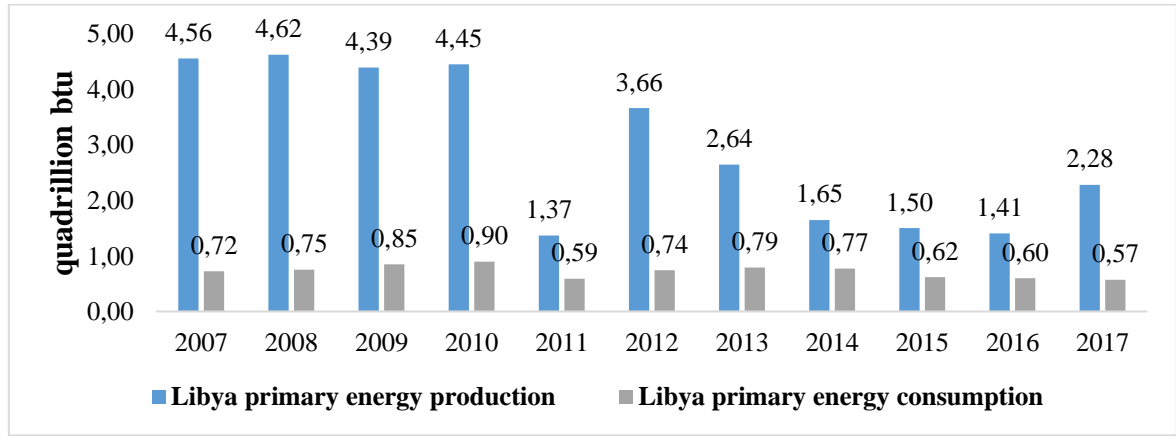


Figure 1.6 – Libya Total primary energy production and energy consumption in 2007-2017 [32-33].

In 2017, primary energy consumption for Libya was 0.57 quadrillion btu. Though Libya primary energy consumption fluctuated substantially in recent years, it tended to decrease through 1998 – 2017 period ending at 0.57 quadrillion btu in 2017 [32].

1.5 The technical equipment for commercial electricity metering in Libya

GECOL manages about 26 power plants, which contain 85 power units of various sizes, ages and technologies distributed throughout Libya. Most of the power plants are located on the Libyan coast of the Mediterranean Sea. GECOL's official installed capacity as of 2017 is 10.238 GW. Despite the fact that the power available for powering the mains is constantly changing in accordance with external and internal restrictions, as well as maintenance and other work, at the time of this study, the available power of GECOL was up to 5.35 GW, which amounted to 52% of the installed power.

Libyan electricity is based on gas turbine generators. In accordance with the volumes of electricity consumption and production, the nationwide network of power plants (PS) with a total capacity of 5,000 MW is divided into 6 regional: Tripoli (32% of the total capacity of all PS), Benghazi (15%), the western region (20%; Zavia,

Nelut, Zentan), central (18%; Hon, Sirte, Misrat), eastern (6%; Shahat, Tubrak, Salun), Southern (9%; Jalu, Saba, Kofra, Morsek) [21]. The entire nationwide network of power plants (ES) is divided into 6 regions in accordance with the volumes of electricity consumption and production.

GECOL's EDM system physically consists of smart energy meters installed on all power transformers, single and auxiliary transformers, and on communication lines. Intelligent meters are designed to provide GSM communications for transmitting data to telemetry stations. The project included the following main stages:

- a. Counter installation: more than 80% of existing stations are already equipped with smart meters. In addition, work continues on the installation of meters at new plants and installations.

- b. Establishment of a central telemetry station: this work has also been suspended. The counters were also not yet equipped with GSM Sims.

Some new plants have included smart meters and equipment related to the EDM system in their specifications, as was the case with the Khoms fast track and some other new generations. However, the constant growth of the grid, where such specifications were not included in the supply and installation contracts, made it difficult to install meters in order to keep up. Therefore, there is a significant time gap between the supply of power to new transformers, other equipment, and their inclusion in the energy balance circuit, so any measurements are currently approximate, incomplete and inaccurate. The GECOL EDM team is doing everything possible to monitor and equip new transformer plants. A lot of effort is also devoted to replacing faulty meters.

1.6 Summary chapter 1

Despite political instability, the past two years have shown positive dynamics in the development of the Libyan oil and gas sector. The interest in working in it as buyers of Libyan hydrocarbons and investors is increasing. The level of oil production

in the country doubled in 2018. Today, the electricity system of Libya is a state owned vertically structured power utility company and is responsible for generation, transmission and distribution of electric energy. The Libyan National Electricity Network consists of a high-voltage network of about 12,000 km, a medium-voltage network of about 12,500 km and 7,000 km of a low-voltage network.

All energy companies in Libya remain state owned. The electricity generation market is still closed to private investors. A new law on electricity is being prepared, which will allow private companies to generate electricity. The Libyan legal framework does not allow the private sector to independently generate renewable energy sources (solar manufacturers) with the possibility of supplying excess electricity to the network.

The Energy Council is responsible for the energy sector; and there is also the Ministry of Electricity and Renewable Energy, which regulates and controls the electricity sector. The vertically structured General Electric Company in Libya (GECOL) is responsible for the production, transmission and distribution of electricity; and it works closely with the Libyan Renewable Energy Authority (REAOL).

Since the 1970s, GECOL has introduced monitoring centers to monitor generating plants and supply systems. The energy infrastructure control system includes the following institutions: National Control Center (NCC), two Regional Control Centers in Tripoli and Benghazi (TRCC and BRCC respectively), and Distribution Control Centers (DCC's) around the country. GECOL manages about 26 power plants, which contain 85 power units of various sizes, ages and technologies distributed throughout Libya. Most of the power plants are located on the Libyan coast of the Mediterranean Sea. GECOL's official installed capacity as of 2017 is 10.238 GW.

The instability and low security level in Libya negatively affect the implementation of projects on network management systems in the country's energy sector. After 2011 in Libya, there are practically no changes in the operation of

control and monitoring systems, the old and new systems do not fulfill all functions. The control system does not prevent fuel control and control of the operation of all units, substations. Government agencies should implement smart metering systems that provide benefits in energy consumption. The experience of European countries shows positive results after the introduction of smart metering systems: benefit per metering point is 80%, energy saving is 55%.

Chapter 2. Libya electricity balance analysis

2.1 Detailed analysis of situation of balance

Libya has the largest oil reserves in Africa, estimated at 48 billion barrels of oil. However, a seven-year conflict between various military groups has led to a reduction in hydrocarbon production and export. Back in the 1970s, more than 3 million barrels of oil were produced in the country per day, but by the time of the overthrow of Muammar Gaddafi, about 1.6 million barrels of oil were extracted here per day. After a series of military conflicts over export ports and mining assets during 2017, oil production in Libya grew by 1 million barrels of oil equivalent per day, reaching by February 2018 the level of 1.28 million barrels of oil equivalent per day. The official Libyan NOC recently announced plans to increase production to 2.2 million barrels of oil by 2023 per day, investing 18 billion dollars for these purposes.

Energy demand is a vital issue which must be dealt with great significance. With the advent of innovative communication technologies and advancements in power systems, the trend of conventional grid is gradually shifting to the modern grid. Smart grids play an important role in various energy issues [58].

With growing concerns about the global environment, energy security and other related issues, energy efficiency is attracting many nations and became their best choice. That is why it is so important to balance what the World Energy Council (WEC) defines as the energy trilemma. WEC in its report 2015 Trilemma Index quantifies the energy trilemma and relatively ranks world countries in terms of their ability to provide a secure, affordable, and environmentally sustainable energy system. Energy performance indicators consider supply, demand, affordability of and access to energy, and the environmental impact of a country's energy use. The related indicators consider the energy performance of these countries including political, social and economic strength and stability. The overall Index performance of 130 countries was assessed in 2015. Libya was ranked 120 in year (2015) with an overall

score of (CCD) according to this report (World Energy Council report, 2015). Improvement of this score necessitate the improvement of the energy system and its performance in the first place. Also, as Arab Future Energy Index (AFEX) Energy Efficiency, 2017 (AFEX, 2017) results indicate, the Libya is at the end of Arab countries list with its 18% score. AFEX EE 2017 provide assessment of countries progress in the energy efficiency according to such evaluation categories: policy framework, energy pricing, institutional capacity and energy utility. Under these categories, countries are assessed according to 9 different factors and 30 quantitative and qualitative indicators (AFEX, 2017). These indications calls for quick action to promote energy efficiency measures and programs in Libya [21].

Libya is one of the leading oil producing countries in the world. The leading industries are oil production, oil refining, petrochemical, metallurgical, transportation, cement, textile and food. The country accounts for 35% of all oil reserves in African countries. By this indicator, it ranks first on the continent and fifth among OPEC member countries (after Saudi Arabia, Kuwait, the United Arab Emirates and Iraq). The capacity generated by Libyan power plants is 86% of installed capacity and 94% of available capacity. Generating power is carried out by simple cycle and combined cycle units. GECOL has not supported the construction of a new steam power station since 1985. In fact, it was not until 2014 that the first unit of a new power station in the Gulf of the country was commissioned.

Table 2.1 – Electricity balance in Libya, 2016 [3]

	Thousand Tonnes of Oil Equivalent (ktoe)	Electricity
Primary supply	Production	-
	Imports	32,33
	Exports (-)	-
	International Marine Bunkers (-)	-
	International Aviation Bunkers (-)	-
	Stock Changes (+ draw, - build)	-
	TPES	32,33
	Transferts	-
	Statistical Difference	1280,49
ma tio n	Transformation	3132,42

	Electricity Producers	3132,42
	Petroleum Refineries	-
	Charcoal Plants	-
	Gas-To-Liquids	-
	Coal-To-Liquids	-
	Blast Furnaces	-
	Other Transformation	-
	Energy Industry Own Use	-52,45
	Losses	-629,75
	Total Final Consumption	1202,06
Final consumption	Industry	104,3
	Transport	-
	Households	506,79
	Com. & Public	129,49
	Agriculture/Forestry	105,07
	Others (Non Specified)	356,41
	Non-Energy Use	-

In our research, we need to investigate the demand for energy in Libya. Libya is in transition phase of development for its infrastructure growth, including development of the energy sector. The total final energy demand in Libya had grew from 4.2 tons of oil equivalent (Mtoe) in 1980 to 10.6 Mtoe in 2006. The electric energy demand had more than doubled in ten years; from 0.3 Mtoe in 1980 to 0.6 Mtoe in 1990 and has been four folds from 1980 to 2000 (1.1 Mtoe) and six folds from 1980 to 2006 and it is expected to grow to 5.59 Mtoe by 2030. This demand could be met either by increase of supply or improving the efficiency of energy supply and end use. Energy-efficient technologies could offer solutions and could reduce environmental impacts associated with recent energy systems use [21].

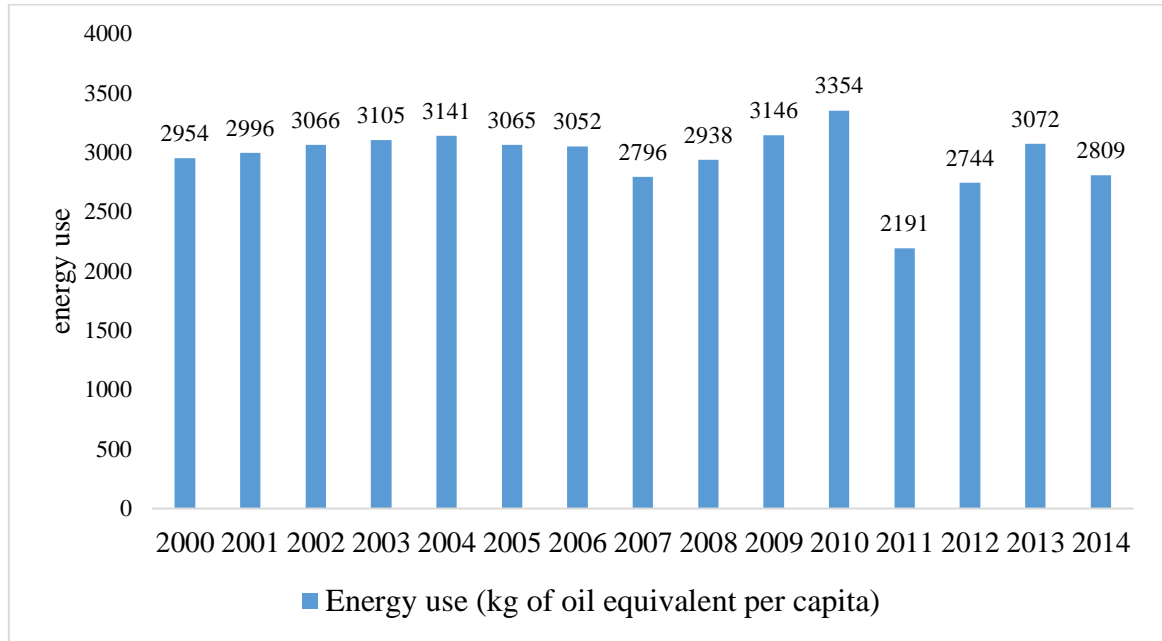


Figure 2.1 – Energy use (kg of oil equivalent per capita) in Libya in 2000-2014 [76].

Energy use per capita decrease rapidly in Libya in 2011 and since 2012 increase slowly. As the electricity demand in Libya is continuously increasing and aged national power grid operating at its critical capability and their stability limits, innovative techniques for more effective electrical energy generation and management is a vital desire for the Libyan electricity sector.

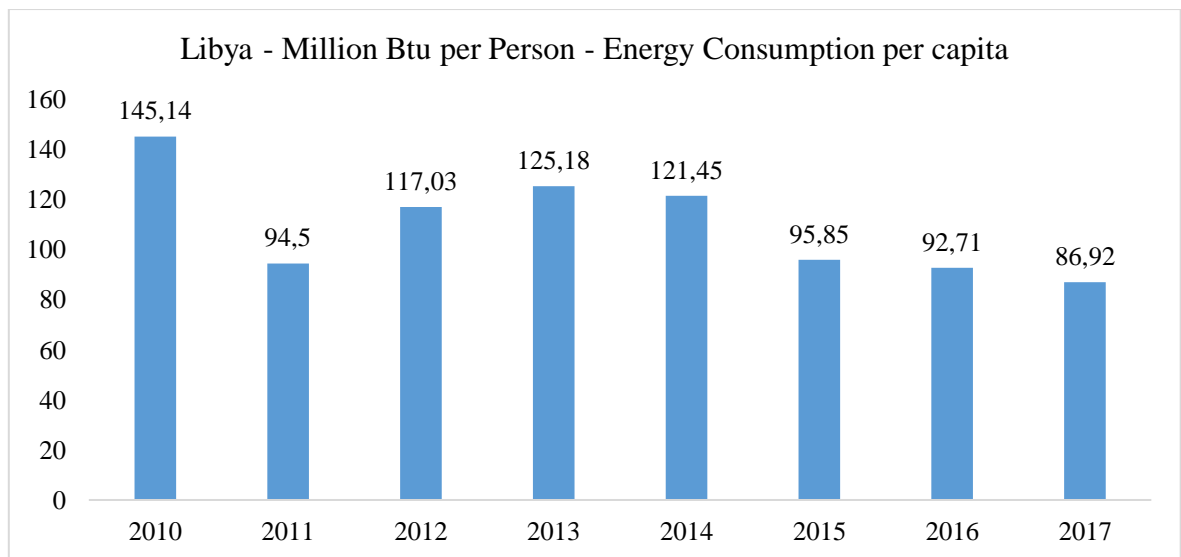


Figure 2.2 – Libya, World Energy Consumption per capita, Million Btu per Person [30]

This implies different challenges and vital opportunities that can be utilized to propose a smarter ways to provide and manage electricity to the consumers [53].

Electricity production from oil sources in Libya decrees from 2005. Production of coal in 2017 was 3 773 421 ktoe, of crude oil was 4 477 212 ktoe. The import of crude oil was 2 453 086 ktoe, while export was – 2 381 804 ktoe. The import of oil products was 1 364 755 ktoe, while export was – -1 477 490 ktoe.

In 2010-2016, Libya availability of weighted average generating unit fall to 66% from 78,3% and the capacity available fall to 53,7% from 64,6% of installed capacity. In the other hand, demand growth near 4% per year [29].

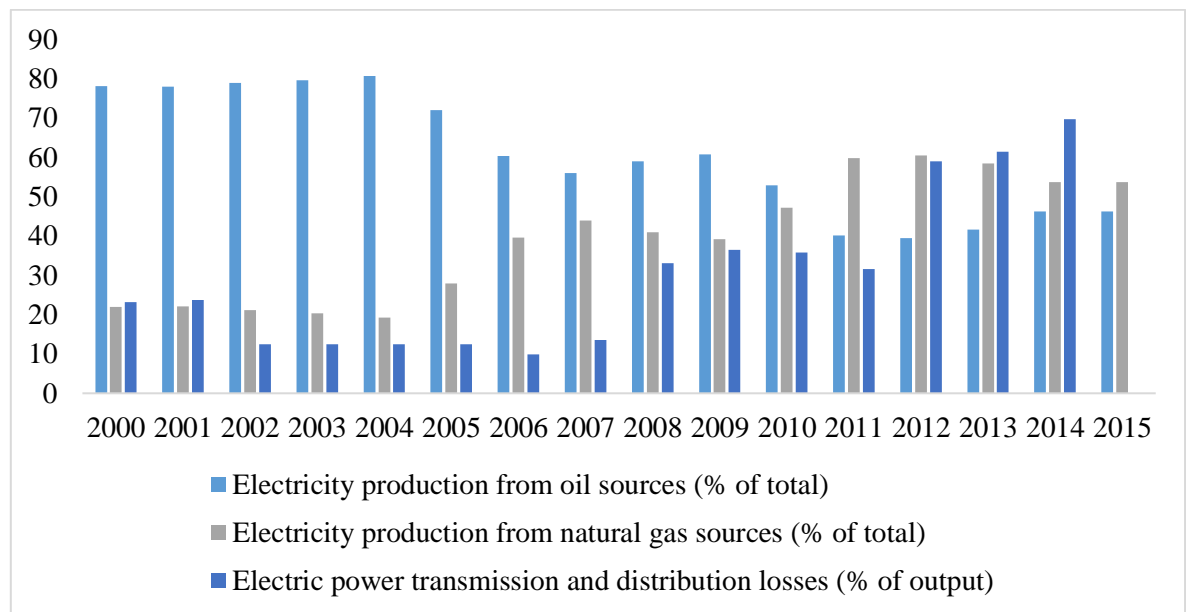


Figure 2.3 – Electricity production from different sources in Libya in 2000-2015 [76]

In 2010-2016 GECOL's generation power thermal efficiency increased by 7,3% due to the steam units, that was introduces. It is associated with the gas turbine units combined cycle at Misurata and North Berghazi. It help to increase generation operation of natural gas instead of liquid fuel. In 2016 energy production grew due to gas production from 40% in 2010 to 80% [76].

Despite the difficult political situation of Libya, the country is targeting opening its renewable energy market to IPPs, where recently the Renewable Energy Authority of Libya (REAOL) has established a new affiliated company that will use public private-partnerships to allow for more reliance on private investments. An updated RE strategy was lately developed, outlining its main objectives as well as the institutional framework required under the currently difficult circumstances for future stability. Libya Institutional stability will be the first necessary step in supporting Libya's long-term renewable energy goals [51].

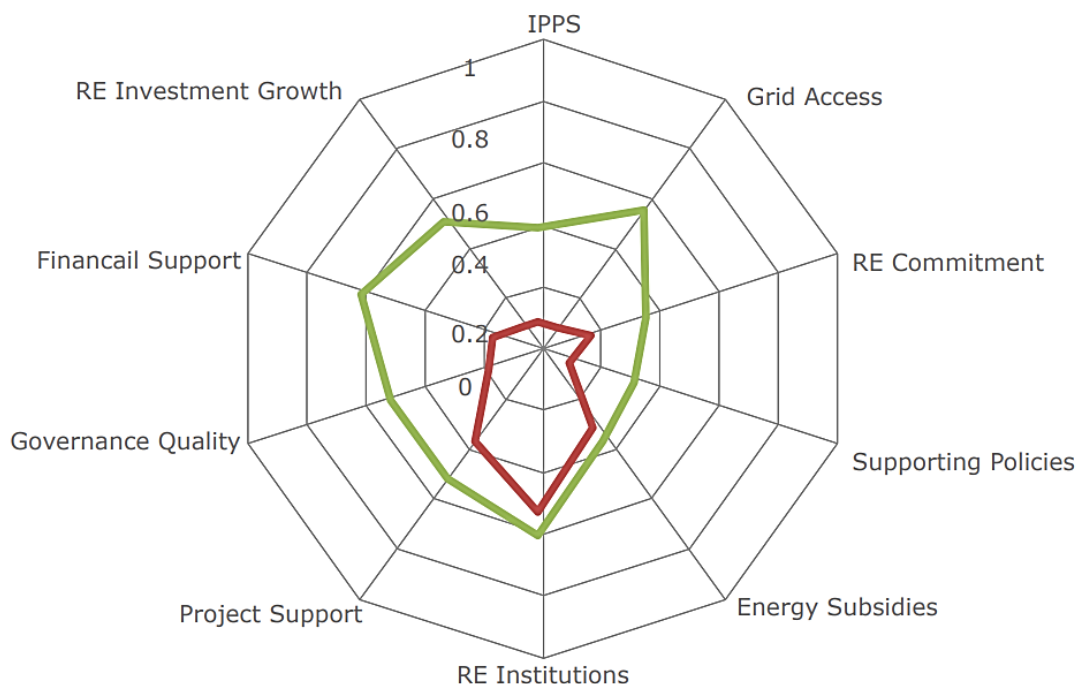


Figure 2.4 – Libya Future Energy Index (AFEX) [8], 2019

Fuel oil electricity generation in Libya in 2000-2016 decrease in 2006-2007, 2011 and 2016.

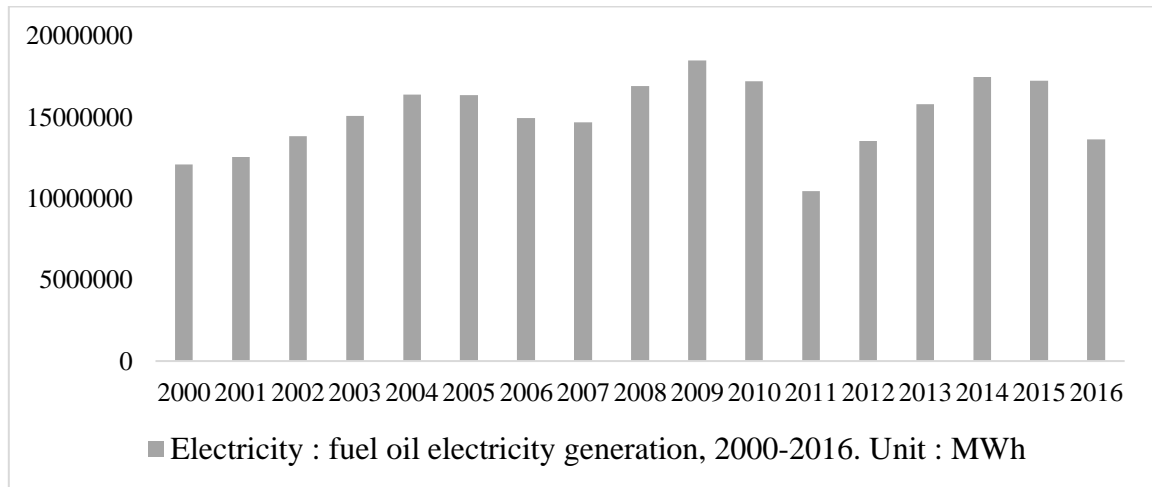


Figure 2.5 – Electricity : fuel oil electricity generation in Libya, 2000-2016, MWh [3]

Despite all the difficulties of Libya's project environment since 2011, GECOL has commissioned 14 new generating units between 2012 and August 2017, total an addition of 2.295GW to the installed capacity.

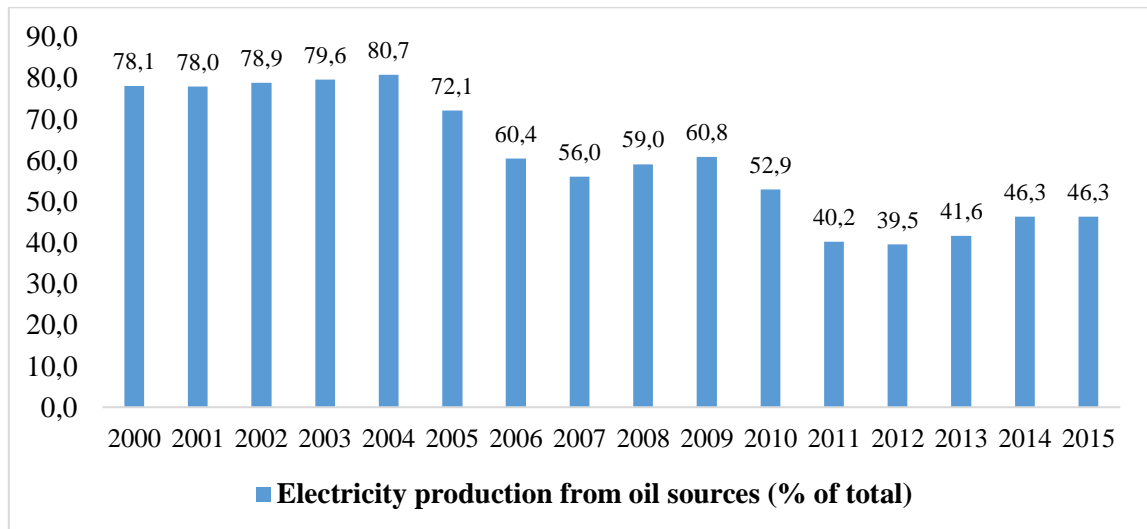


Figure 2.6 – Electricity production from oil sources in Libya, % of total [76]

The loss of installed capacity of more than 600 MW in Libya is due to several reasons. One of them is restrictions in the supply of fuel. Another problem is the loss or decommissioning of facilities due to maintenance problems. Lack of fuel and fuel reserves exacerbates the situation, because it limits the operation of capacities.

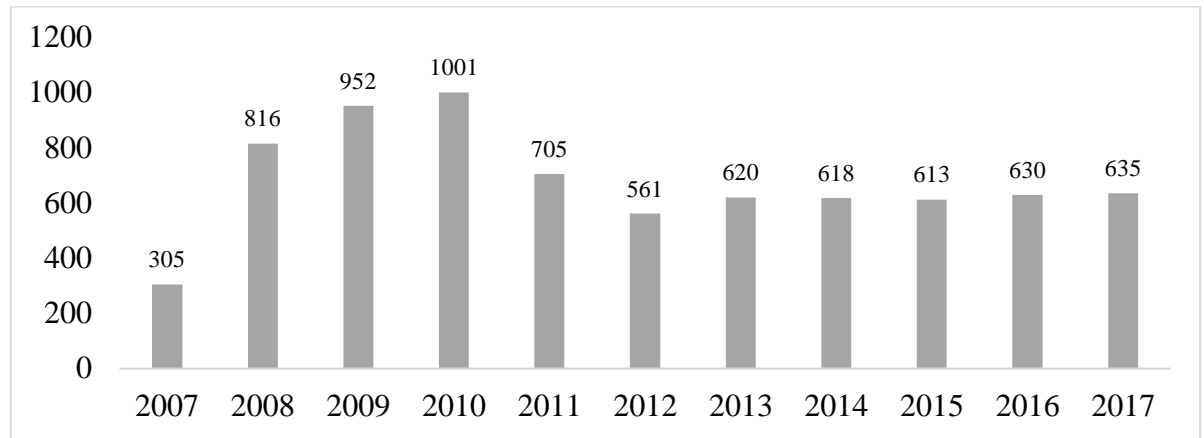


Figure 2.7 – Libya electricity losses in 2007-2017, ktoe [23]

Libya's energy production depends on fuel. Instability and insecurity in Libya lead to a permanent shutdown of power plants that supply fuel. Another problem is the dependence of the country's power plants on the main working fuel – gas. Gas production and infrastructure in the country are constraints to meet fuel needs. Disconnecting units from the network is also a problem in Libya due to the need for larger units in the country. The direct and indirect costs of using the LFO are also high. Thus, all these problems in the aggregate significantly affect losses. [9].

The average electricity consumption of households per capita (kWh/cap) for Libya compared to the average world and Africa for the period of 2000- 2014. As it could be noticed that the consumption in Libya is higher than the world average and much higher than the average African countries. This could be explained mainly by the rapid growth in electricity demand in the residential sector, in line with the increase in the appliance ownership such as air condition AC, information technology devices and other home appliances as well as the big urbanization that happened during last few years. After the onset of hostilities in 2011, the consumption started to decrease due to electricity network as well as power generation problems. The average decrease rate of electricity consumption of households per capita is in Libya is (- 2%) per year during the period 2000-2014 as shown in Figure 2.7, while the world average increase is 1.6% per year and in Africa at 3% per year. Energy efficiency and energy conservation should be the primary solution to solve these

problems as well as using distributed generation by renewable energy sources (PV and WECS's) instead of using fossil fuel small generators that are available right now at the market and are used by publics which contributed to noise and environment pollution [21].

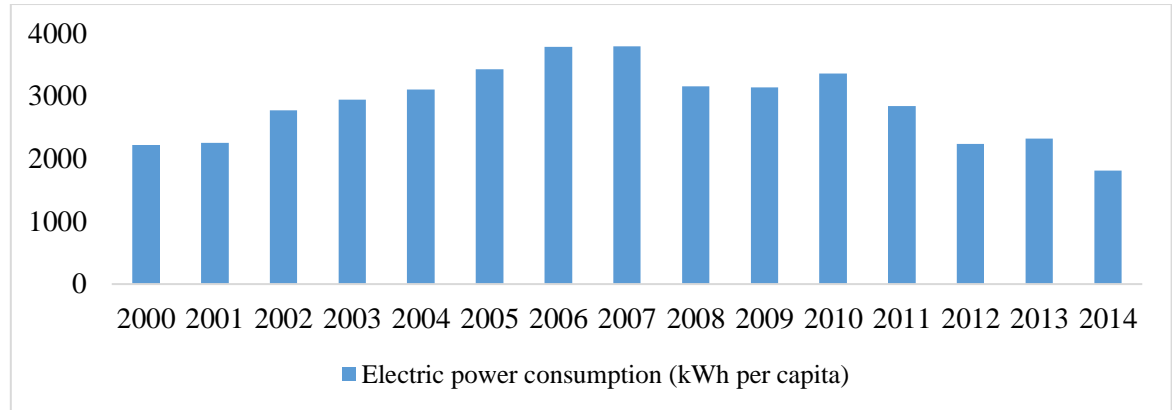


Figure 2.8 – Electric power consumption* in Libya in 2000-2014 (kWh per capita) [76].

* Electric power consumption measures the production of power plants and combined heat and power plants less transmission, distribution, and transformation losses and own use by heat and power plants.

Because of unforeseen national events, GECOL faced a shortage in the energy production process, which led to 1200 MW load shedding (20% of total peak load). Energy demand has risen rapidly in Libya over the last decade and high peak demand has led to many blackouts. Currently, peak load is growing at an average annual rate of about 10%, which constitutes a great challenge for Libya's power sector. Since gas turbines are quickly installed and the prime cost of such plants is much lower than that of other types of plants for generating peak-load electricity, gas-turbine power stations are popular. They are particularly suitable for this duty as they can be brought up to full power in only a few minutes. In oil and gas producing countries, as in Libya where fuel costs are still well below the world market level, gas turbines are also employed in shift-operated and base-load stations [21].

2.2 Detailed analysis of situation in smart meter systems

Since 2009, GECOL has been working on the creation of an energy data management system (EDM). It was supposed to support GECOL in:

1) Analysis of technical losses, calculation of losses at each voltage level of the electric network and providing a clear and accurate comparison of the generated and consumed power and energy.

2) Compare the calculated losses with historical data and determine the energy losses both by voltage level and by geographical area.

3) Develop a consumer demand profile based on 15-minute breakdowns of power and voltage profiles.

4) Calculation of system reserves according to supply and consumption data.

5) Real-time balance monitoring to detect deviations or unforeseen events.

6) Continuous power monitoring by integrating and extrapolating the power flow in the trunk.

In addition to analyzing the load profile and peak demand, the system will allow for comparative comparisons of current indicators with historical data, extracting an average daily profile for aggregate analysis, and correlation with temperature and weather conditions.

GECOL's EDM system physically consists of smart energy meters installed on all power transformers, single and auxiliary transformers, and on communication lines. Intelligent meters are designed to provide GSM communications for transmitting data to telemetry stations. The project included the following main stages:

a. Counter installation: more than 80% of existing stations are already equipped with smart meters. In addition, work continues on the installation of meters at new plants and installations.

b. Establishment of a central telemetry station: this work has also been suspended. The counters were also not yet equipped with GSM Sims.

Some new plants have included smart meters and equipment related to the EDM system in their specifications, as was the case with the Khoms fast track and some other new generations. However, the constant growth of the grid, where such specifications were not included in the supply and installation contracts, made it difficult to install meters in order to keep up. Therefore, there is a significant time gap between the supply of power to new transformers, other equipment, and their inclusion in the energy balance circuit, so any measurements are currently approximate, incomplete and inaccurate. The GECOL EDM team is doing everything possible to monitor and equip new transformer plants. A lot of effort is also devoted to replacing faulty meters.

Current energy measurements are largely unreliable for the following reasons:

1. Meter readings are collected manually, and not all substations are accessible to GECOL employees due to security problems. Missing measurements are estimated based on historical readings /

2. In many places, there are installation errors, such as disparate measuring transformers, incorrect wiring, etc. Intelligent meters are able to carry out installation checks and notify about installation problems. However, the solution to these problems was slowed down due to the complexity of the lines of responsibility between the EDM teams and the departments responsible for the locations where the meters were installed.

3. Many substations are not yet equipped with meters.

At present, the EDM Meter is responsible for servicing the meters, but the meters are installed on funds owned by the General Departments of Medium Voltage, Transmission and Generation. We recommend that the relevant meters be the direct responsibility of the Department in which they are located. Boundary meters between departments should be installed on both sides of the partition. Therefore, for example, the transmission department will measure the energy exported to the medium voltage department, while at the same time the average voltage will also measure the energy it

receives. Thus, accuracy and accountability will be greatly improved, and all departments will be motivated to reduce their systemic losses.

In order to meet the energy demand in Libya, the local electric grid must be upgraded into a Smart Grid (SG). However, the obstacle is that the structure of today's power grids is not designed to adapt the daily increase of the power demand. Libyan electric utility company still has to send its employees out to gather the data needed for providing and operating the electricity system manually. The employee reads meters, look for broken equipment's and measure voltages at different nodes and places, since most of the devices used to deliver electricity have not yet be automated and computerized. All the gathered data are currently stored in the SCADA database. This data is utilized by the company to analyze the customers' combustion, produce estimated bills and periodic reports, generate and upgrade tariff plans of the consumers, etc. SCADA in fact is used by GECOL for other purposes like the supervision and monitoring of the whole network [4]. Generally, GECOL has been using fixed format files such as Excel and Access to store data related to the customers and the company itself, along with some software applications to perform multiple tasks on these data [61].

The use of an intelligent meter poses many problems in a distribution electric network, such as the collection, storage and management of data [5], and how to maintain consistency of transactions between the consumer and company personnel, how to manage backup, recovery, performance and scalability [61]. In addition, another major goal of GECOL is to maintain the physical infrastructure of their networks; because it has been changed over time and structured to "work in one way: from manufacturer to customer" [61].

Key benefits of using Smart Metering in Libya:

1. Save 2.9 million barrels of oil per year
2. Avoid around a million tons of carbon dioxide per year.
3. The financial profit from the sale of carbon emission reduction certificates is estimated at approximately (6 - 8 million US dollars per year)

4. To help cover part of the demand for electricity
5. Gaining experience and transfer of knowledge and technologies of localization.
6. Sustainable spatial development and job creation
7. Will pave the way for Libya to become an exporter of clean energy.

2.3 Isolation in electricity metering area in Libya

Demand side management endeavours aim to control or limit the demand for electric energy. They can be designed to reduce or redistribute the peak demand for power, i.e. reduce the value of peak load, or to reduce the overall demand for electricity, thereby reducing the annual energy consumption. While both are important and relevant 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 Demand Side Management study in 2010. 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.

The Arab region and Libya as a part, largely, relies on the single-buyer model. A state-owned entity is the wholesale purchaser from power generating companies and is responsible for selling the electricity to distribution companies that deal with the final consumers. All Arab countries have adopted legislation or institutional settings allowing Independent Power Producers (IPPs) to operate in power generation activities. Private participation in RE power generation is becoming a trend in the Arab region.

IPPs are those typically building, owning, and operating power generation facilities to sell electricity either to the utility or directly to a third party through a PPA. IPPs can also have forms of direct export or partial self-consumption. Exclusive self-consumption is not typically defined through IPPs, although some of the

literature includes this form among the IPP schemes. IPPs selling directly to the utility are the common practice in the Arab region, while third-party sales can be considered as an emerging supply option particularly appealing for larger industrial and commercial actors with high electricity needs and who are reluctant to become auto-producers of electricity.

Libya is the most recent Arab country that open its renewable energy market to IPPs, where recently the Renewable Energy Authority of Libya (REAOL) has established a new affiliated company that will use public-private-partnerships to allow for more reliance on private investments (REAOL Decree on Establishing RE Private Investment Promotion Co. (2018).

2.4 Regulatory base

Energy efficiency in addition to renewable energy can enhance an energy system. Using renewable energy sources in the national energy mix will improve primary energy intensity. Recent economic and political crisis had affected the country at different levels. Energy efficiency is a prerequisite to achieve different energy system goals such as reducing environmental pollution, which will improve health and wellbeing, providing energy access and security, reduce or lower investment in building new power plants and related infrastructure, reduce energy bills as well as create jobs. However, implementation of energy efficiency might face different barriers, which are mostly related to regulatory, legal and institutional issues, as well as economic and financial barriers. The main obstacles that could face energy efficiency programs are low prices of fossil fuel since it is subsidized by the government. The highly subsidized electricity prices could delay renewable energy and energy efficiency programs and will discourage national and international investors to invest in these programs. The other barrier is the high initial costs of these appliances (renewable and efficient appliances). National policies should be devised to reduce or remove all barriers that could face these policies and ensures

the regulation of energy efficiency programs. Development of policies and measures needs tremendous efforts and work that should be assigned to specialists in committees and working groups.

Renewable Energy Authority of Libya (REAoL) is a national authority that was dispersed the task of providing and employment of energy efficiency in the country. They had prepared a National Energy Efficiency Action Plan (NEEAP). In doing so, they reviewed the world practices of energy efficiency trying to come up with best of these practices in order to implement it in Libya in a proper way. They determined and defined all barriers that are facing energy efficiency. They were also assigned to propose the required laws, regulations and incentives to be approved by the Libyan government as well as perform tasks of raising public awareness and acceptance of energy efficiency programs that would be implemented (K. Agha, 2012) [21].

The National Energy Efficiency Action Plan (NEEAP) [47] is the strategic structure of the national plan that helps Arab countries implement energy efficiency goals. Since the launch of the initiative in 2010, RCREEE has been a key tool in helping countries apply this vision. The purpose of this guide is to promote and improve energy efficiency and rationalize consumption for end users in the Arab States. The guide can be applied to energy suppliers, distributors, end users of energy. The Council of Arab Ministers of Electricity instructed RCREEE to monitor the implementation of NEEAP and publish annual reports.

The guide provides indicative goals, mechanisms, incentives, institutional frameworks and the financial and legal measures necessary to remove barriers and weaknesses in national markets. He also recommends appropriate conditions for the development of the energy services market and its promotion for end-users of electricity. The guidelines help governments define six-year strategic plans for the two three-year phases of energy efficiency and establish guidelines for monitoring progress. RCREEE holds various regional and national seminars and trainings to educate Member States on the use and application of guidelines, as well as to share success stories and best practices of countries [47].

To encourage investment in electricity generation in Libya, it is important that all producers are treated equally. A common approach is to identify the technical details of grid access in national regulations and grid codes specified in the PPA, which helps to avoid negotiations in each case. In addition, regulated tariffs for the transportation of energy systems combined with a divided energy sector can help ensure non-discriminatory access.

2.5 Developing proposal for a code of commercial electricity metering for Libya

Grid Code is a technical guidelines to connect distributed smaller PV systems to low-voltage grid adopted, to connect utility-scale PV systems to medium- and high-voltage grids adopted, to connect wind parks to medium and- high-voltage grids adopted.

Grid codes, or network codes are technical specifications regulating the general conditions pertaining to how, different power generation installations connect to the grid, as well as the management and functioning of the electricity grid and system services. The grid codes in some cases include cost sharing specifications and priority conditions as mentioned in the previous section. The specifications in the grid code apply to all generation facilities feeding the grid, whether large utility scale power plants of several hundred megawatts or a decentralized solar rooftop system of few kilowatts. Since the technical capacity of the grid can be particularly problematic for energy developers, grid codes must clarify which technical rules govern access to the grid for all types of energy projects. Furthermore, the grid code defines specific conditions for plants to receive pre-qualification and participate under different supporting schemes such as net metering or bids/auctions. As shown in the following table, for the Arab region, technology-specific energy grid codes and network connection guidelines have been introduced progressively, especially in countries introducing regular support schemes for energy system of Libya.

Legal Actions for a code of commercial electricity metering for Libya:

1. Develop official and appropriate regulatory framework for electricity tariff in order to integrate renewable energy into national energy supply system and attract public and investors
2. Develop legislative and regulatory framework to invest in energy efficiency and renewable energy through national and international investors.
3. Develop legislative and regulatory framework to produce fuels from renewable energy sources and related infrastructure.
4. Develop legislative and regulatory framework to improve energy consumption and intensity of transportation sector.

Development of Technology for a code of commercial electricity metering for Libya:

1. Development of appropriate standards and codes for energy efficiency technologies.
2. Promote of energy efficiency research and development and set appropriate steps and programs for its implementation [21].

2.6 Proposals for the smart meter system deployment in Libya

GECOL is the only producer and supplier of electricity in Libya. Currently, GECOL has traditionally used one-way communication with customers to provide and manage power supply services. This method has proven to be inefficient and needs to be developed in the Smart Grid. The company continues to rely on manual meter readings to collect data and generate settlement accounts to manage customer spending. However, it is recognized that the AMI system is an important component for implementing intelligent network solutions. AMI provides secure and efficient two-way communication between utilities, smart meters, and customers. This solution, applied to GECOL, will reduce the cost and time of operations, provide automatic data collection in real time, produce timely and accurate accounts instead of

inaccurate settlement accounts and support the transfer of instructions, remote reports and tariff plans periodically between GECOL and customers [61].

Smart Grid (SG) can be considered as a superposition of communication networks on electric networks [64]. Consequently, it can increase the efficiency, reliability, safety and reliability of power supply to consumers through the seamless integration of renewable and alternative energy sources such as photovoltaic systems, wind power, biomass power generation, tidal power, small hydropower plants, and plug-in hybrid electric vehicles using automated control and modern communication technologies [64]. For the implementation of SG, the most important key is an advanced measurement infrastructure (AMI) based on smart meters [27].

Advanced Meter Infrastructure (AMI) is a system that collects and analyzes smart meter data using two-way communication and provides intelligent management of various power-related applications and services based on this data. AMI is a measurement solution with two-way communication with the meter. The introduction of AMI is widely regarded as the first step in the digitalization of power management systems. Recently, AMI has become very attractive both in industry and in the field of trade due to the precise improvement of online meter reading and control [46]. In order to meet the demand for energy in Libya, the local power grid must be upgraded to Smart Grid (SG). However, the obstacle is that the structure of modern electric networks is not designed to adapt to the daily increase in demand for electricity. The Libyan electricity grid company is still forced to send its employees to collect the data necessary to ensure and operate the power supply system manually. The employee reads the meters, looks for faulty equipment and measures the voltage in different nodes and places, since most of the devices used to supply electricity are not yet automated and not computerized. All collected data is currently stored in the SCADA database. These data are used by the company to analyze customer combustion, compile settlement accounts and periodic reports, create and update consumer tariff plans, etc. SCADA is actually used by GECOL for other purposes, such as overseeing and monitoring the entire system. the network [46]. As a rule, GECOL uses fixed-

format files, such as Excel and Access, to store data related to customers and the company itself, as well as some software applications to perform many tasks with this data.

The use of an intelligent meter poses many problems in a distribution electric network, such as the collection, storage and management of data [40], and how to maintain consistency of transactions between the consumer and company personnel, how to manage backup, recovery, performance and scalability [42]. In addition, another major goal of GECOL is to maintain the physical infrastructure of their networks; because it has been changed over time and structured to “work in one way: from manufacturer to customer”.

2.7 Summary chapter 2

The built environment accounts for over 40% of delivered energy consumption. The majority of energy consumed is for space and water heating, not electricity in most buildings. The domestic sector in the Libya accounts for almost 39% of final energy consumption. The energy efficiency of the bulk of the housing stock is poor. There is significant scope for energy efficiency improvements with savings in space heating of up to 90% achievable. The capacity generated by Libyan power plants is 86% of installed capacity and 94% of available capacity. Electricity production from oil sources in Libya decreases from 2005. Production of coal in 2017 was 3 773 421 ktoe, of crude oil was 4 477 212 ktoe. The import of crude oil was 2 453 086 ktoe, while export was – 2 381 804 ktoe. The import of oil products was 1 364 755 ktoe, while export was – 1 477 490 ktoe.

This demand could be met either by increase of supply or improving the efficiency of energy supply and end use. Energy-efficient technologies could offer solutions and could reduce environmental impacts associated with recent energy systems use. As the electricity demand in Libya is continuously increasing and aged national power grid operating at its critical capability and their stability limits,

innovative techniques for more effective electrical energy generation and management is a vital desire for the Libyan electricity sector.

Since 2009, GECOL has been working on the creation of an energy data management system (EDM): 1) Analysis of technical losses, calculation of losses at each voltage level of the; 2) Compare the calculated losses with historical data and determine the energy losses both by voltage level and by geographical area; 3) Develop a consumer demand profile based on 15-minute breakdowns of power and voltage profiles; 4) Calculation of system reserves according to supply and consumption data; 5) Real-time balance monitoring to detect deviations or unforeseen events; 6) Continuous power monitoring by integrating and extrapolating the power flow in the trunk. GECOL's EDM system physically consists of smart energy meters installed on all power transformers, single and auxiliary transformers, and on communication lines. Intelligent meters are designed to provide GSM communications for transmitting data to telemetry stations.

Key benefits of using Smart Metering in Libya:

1. Save 2.9 million barrels of oil per year
2. Avoid around a million tons of carbon dioxide per year.
3. The financial profit from the sale of carbon emission reduction certificates is estimated at approximately (6 - 8 million US dollars per year)
4. To help cover part of the demand for electricity
5. Gaining experience and transfer of knowledge and technologies of localization.
6. Sustainable spatial development and job creation
7. Will pave the way for Libya to become an exporter of clean energy.

The National Energy Efficiency Action Plan (NEEAP) is the strategic structure of the national plan that helps Arab countries implement energy efficiency goals. Development of Technology for a code of commercial electricity metering for Libya should consist of development of appropriate standards and codes for energy

efficiency technologies and promote of energy efficiency research and development and set appropriate steps and programs for its implementation.

Chapter 3. Structure and functions of smart meter systems in Libya

3.1 General structure for smart meter system

The smart meter is an advanced energy meter. Compared to a conventional energy meter it supports two-way communication. Therefore, it measure data on energy consumption by the consumers, and transmit information to utility companies in order to support generation sources based on decentralized approach and storage devices of energy and bill the consumers. The smart meters system includes different devices and sensors to monitor and determine parameters, situations in the smart grid, and transmits to the control center the collected data or transmits command signals to customer's house devices [3].

In this way, smart meters are used to record usage in real time. On the client side, smart meters located in the client's homes read data such as peak and off peak consumption, power consumption ratio, consumption time period, display and recording of energy consumption at time intervals. This data is then collected online from GECOL smart meters and often sent to the customer service system (CSS) database for further processing after temporary storage in the local database of the online system. It is like a website to be developed along with a local database to act as an intermediary between a service provider, smart meters and customers. This system architecture is explained in Fig 3.1. The data is also made available online to the customers through the website's database in order to view their consumption usage periodically as required, pay the bills and print out a receipt of payment if needed and other services.

On the GECOL side, the company is able through the gathered real time data to produce computerized accurate bills, remote reports, and analyze the collected data either automatically 'where the system itself automatically determines the tariff plans or recommend a better tariff-plan', or in a manual mode 'where GECOL staff adjusts

the tariff rates manually based on the customers usage behavior and generate a suitable tariff for each customer individually.

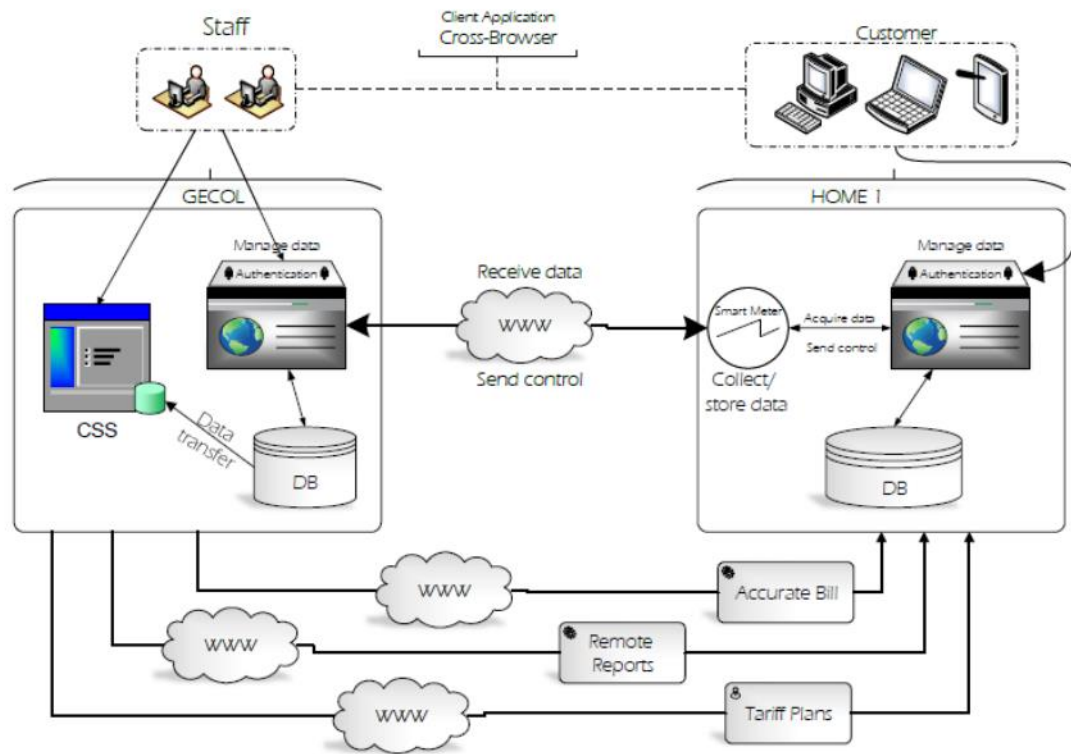


Figure 3.1 – Proposed smart meters system architecture

However, the exact operations that both the customers and GECOL can undertake are explained in details in the analysis phase below. The resulted information is sent back remotely to the consumers via their accounts which can create awareness of energy usage, encourage customers to adapt their consumption and modify their usage behavior accordingly.

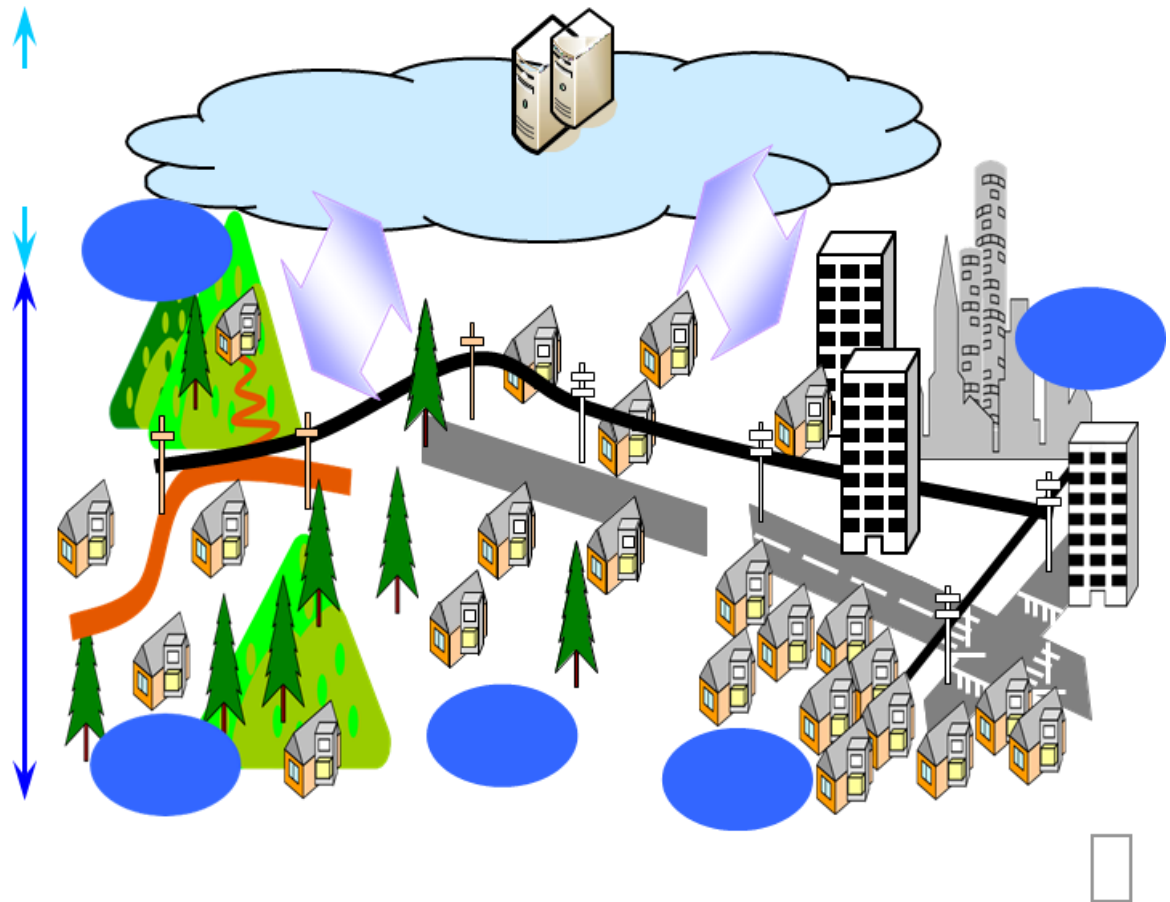


Figure 3.2 – Features of Smart Meter Communication Network

Features of Smart Meter Communication Networks include:

1. Smart meter communication network realizes the transmission from smart meters installed at customer houses to Meter Data Management System (MDMS), and remote switch control from MDMS.
2. There is a need to take into account various regional conditions such as high- density residential areas, underground malls, high-rise apartment buildings, suburban areas, and mountainous areas.

Requirements for Smart Meter Communication Networks are the next:

1. Transmit and collect data reliably from each meter. Despite its small size per customer, the data collected from a vast number of meters must be transmitted to MDMS.

2. Ensure the data security. Robust security must be ensured against the threats of illegal access or information leakage because this communication network handles the data related to customers' privacy including the electricity use.

3. Maintain and manage the communication network effectively and properly. Install management function and rapid recovery function from failure to maintain healthy communication.

4. Continue running for a long time. Selecting a communication system to be used for a long time is essential by considering penetration prospects and continuous usage since smart meter will be used for 10 years after installation.

5. Construct and maintain at low cost. As for a vast number of smart meters, it is important to suppress not only the initial cost but also the TCO (Total Cost of Ownership), including the maintenance cost of the communication network.

Pre conditions for Smart Meter Communication Network. Candidates for the Communication System. It is necessary to adopt a communication system suitable for local characteristics, including high-density residential areas, underground malls, high-rise apartment buildings, suburbs and mountainous areas in order to construct a communication network (FAN) that serves all customers. Using overseas introduction situation as a reference, the following three types of communication systems are potentially applicable for the smart meter communication network (FAN).

1. RF mesh network

Low-Power RF Networking Technology. Low-power RF networking refers to the use of 315-MHz/433-MHz/780-MHz/2.4-GHz frequencies with transmit power equal to or less than 50 mW. Low-power RF modules may be embedded within electrical meters, to enable the use of wireless data communications in automatic meter reading (AMR) for power-consumption monitoring and data collection. Such modules can be embedded directly into the meter during production and installed on-site without laying cables when deploying.

Matured, wireless mesh networking technology allows the concentrator to communicate with all of the meters within its network control. This kind of low-

power RF network is best suited for deployment within a restricted range that has a concentration of a large number of low-power communications modules (e.g., within a single floor of a building or a room of networked electrical meters).

Low-power RF networking also features low power consumption, auto-routing networks, two-way real-time communications, and mobility. RF modules can easily embed into electrical meters, data concentrator units (DCUs), and electrical appliances. Because low-power RF communications use publicly available radio frequencies, other devices that utilize the same frequencies will inevitably cause signal interference. In addition, RF signals are vulnerable to obstructions, such as walls, which cause signal instability and result in shorter effective communication distances. Frequency hopping can alleviate that signal interference. However, when other devices also use frequency hopping to counter interference, this in itself introduces more interference. Hence, it's difficult to resolve the problem of mutual interference. The fact that RF signals are vulnerable to obstructions limits their use in smart-grid applications, too. For example, thick walls often impede wireless communications between different floors (i.e., between the basement and the ground floor), resulting in unstable or no communications at all. PLC networks can easily resolve such problems.

Wireless star network means that transmits data between a base station and wireless terminal directly using a relatively high-power radio

PLC (Power Line Communications) offers a unique means of communication for a power-supply system, which takes full advantage of the wide coverage of power-line installations without having to lay dedicated cables. The technology has attracted the attention of power producers as well as users. Like RF wireless modules, it's easy to embed PLC modules into electrical meters. DCUs can exchange data with all of the electrical meters within its network of control. Power lines go through floors and walls in the building. Therefore, theoretically, as long as there are power lines, it's possible to achieve communications over them. However, power lines are constructed with the primary objective of delivering electricity. Electricity's complex

distribution network and noisy environments may cause various forms of interference to PLC, resulting in unstable communications. Interference-inducing factors include:

1. Huge load-impedance variations: Load-impedance changes will affect PLC signal voltages coupled onto the power lines, which directly affects the transmission distance. Changes in power factor and location of power loads will change load impedances dynamically over time.

2. Attenuation on selective PLC carrier frequencies: The random switching of electrical devices on a power distribution network may lead to changes in power parameters, resulting in attenuation on PLC signals on selective frequencies. At the same location and instance, this impact may vary across different PLC carrier frequencies. When certain frequencies are unsuitable for PLC, changing to different frequencies for communication might yield better results.

3. Strong noise interference: Electrical equipment on the power grid, such as switched-mode power supplies and inverters, can produce significant amounts of interference on multiple frequencies that vary randomly.

PLC devices, like RF devices, can be networked, which boosts effective communication distances between the DCU and its meters. However, the realization of reliable long-distance communications between two points should be the basis of any PLC network. Unlike low-power RF, PLC may often enjoy exclusive use of the entire power-line-communication frequency spectrum from 50 to 500 kHz, thus triggering the above three issues and subsequently affecting the ability to address the reliability of PLC effectively.

There are two ways to tackle the above issues. First, depending on different load-impedance situations, transmitter output power must be automatically adjusted. This would boost the signals coupled onto the power line when required and maximize the transmit distance as much as possible.

The second method involves the use of single-frequency hopping. PLC orthogonal frequency-division multiplexing (OFDM) technology, which employs multiple carrier frequencies, effectively counters selective carrier frequency

attenuation. However, its inherent peak-to-average power ratio issue presents another set of problems, resulting in signal power being averaged down as compared to using a single carrier frequency.

3.2 Smart meter and smart meter technologies

Continuous power supply is one of the key tasks of Smart Grid. This is the need for an hour with an ever-growing need for a power system and increased reliability. Due to the characteristically interconnected and interdependent nature of the power system, to achieve this goal it is necessary to strengthen monitoring of a vast territory and situational awareness. Failure in a certain place in the power system can quickly turn into a huge problem with disastrous results. Global Situational Awareness (WASA) is the development of technology to strengthen monitoring of power grids over large areas. This successfully enables power system operators with an extensive and consistent scenario of the entire functioning network.

An important step taken by utilities to create a smarter energy system has been the increasing use of demand response (DR). The demand response is the deduction of energy consumed by consumers in response to an increase in the cost of electricity during peak periods. Demand response can significantly reduce peak load by exploiting the relationship between energy price and energy demand to benefit consumers and producers.

Advanced Metering Infrastructure (AMI) allows utilities to collect, track, and verify energy consumption data for network management, failure notification of lines or generators, and billing using bidirectional communication lines. Although automatic meter reading (AMR) already exists, only unidirectional communication is used to achieve meter reading, mainly for billing functions. AMI can be improved to provide consumers with historical data on energy consumption, contrasts in energy use during the day, real-time cost information and increased energy consumption

during peak loads. AMI networks, a valuable consumer asset, require significant investment and are not yet implemented in most consumer applications.

The Cybersecurity Intelligent Network is a digital system that depends on the use of information technology and must securely transmit data throughout the network. Despite the fact that energy companies have been using cybersecurity devices for the past twenty years, recent cyber attacks and terrorist attacks around the world have made digital devices pay more attention to cybersecurity. Cybersecurity is an important part of an intelligent network, because it includes the protection of information that may be confidential, as well as the protection of the integrity of the digital part of intelligent systems. Intelligent network constantly monitors itself to detect unsafe circumstances that could affect its high reliability and smooth operation. Cybersecurity will be included in all systems, including physical ones, to protect confidential and confidential data from all users and clients.

Communication technology The continuous development of communication technology has improved electrical networks, leading to the creation of an intelligent network. Improved communications and monitoring devices allow electric networks to be more advanced and better responsive than ever before. The main attention in this subsection will be given to the main types of communication devices that can be found in a typical intelligent network system.

The Global System for Mobile Communications (GSM) is the standard that most cell phones use in Europe. This technology is gradually developing in other parts of the world, and currently more than 2 billion people use this form of system. Most GSM networks use 900 MHz and 1800 MHz, but in the United States, the frequency ranges of 850 MHz and 1900 MHz are common. This technology can be used on mobile monitoring devices for communication via the Internet, for example, on a mobile phone.

General Packet Radio Service (GPRS) is a system used to transmit data at speeds up to 60 kbps. GPRS is a well-applied system that is reliable enough for standard mobile data exchange and is suitable for the most moderate data needs. After

establishing connections and settings, the network can be used without additional system settings or communication devices.

The data transfer rate exchange for GSM Evolution (EDGE) is a new step forward based on the GPRS system, which was classified as the “3G” standard, because it can operate at speeds up to 473.6 Kbps. If the smart grid system is compatible with EDGE, it can be used to transfer large amounts of data, for example, to receive a large number of energy flows. To use EDGE, source and boot sites must be adapted to receive this type of equipment. High Speed Downlink Packet Access (HSDPA) is a 3G-based technology that can support speeds of up to 7.2 megabits per second.

Another technology that plays an important role in smart networks is ZigBee. ZigBee is a specification based on IEEE 802.15.4 for combining high-level communication protocols used to create personal networks with small low-power digital radio stations, for example, for automation functions. The technology is designed to be cheap compared to other wireless personal area networks (WPANs) such as Bluetooth or Wi-Fi. Applications include wireless light switches, electric smart meters with home displays and motion control systems.

The technological advances of the smart energy system, mainly due to the development of embedded systems and microprocessors, have allowed the use of smaller and more accurate devices to monitor the use and flow of electricity in the network. These newly developed devices allow manufacturers and consumers to provide and use energy in a more efficient and reliable way.

Flexible AC Transmission Systems (FACTS) are used to overcome the boundaries present in the static and dynamic bandwidth of electrical networks. IEEE defines FACTS as "AC transmission systems that include power electronic devices and other static controllers to improve control and power transmission capabilities." The main objective of the FACTS system is to provide the network with inductive or capacitive reactive power adapted to its specific requirements as soon as possible, as well as to increase the reliability and safety of the power system. The facts give the

network the opportunity to increase the transmission of electricity through long power lines and reduce fluctuations in active power. This gives energy companies the opportunity to effectively use their existing transmission networks, significantly increase the availability and reliability of their networks and, therefore, increase stability during the transition phase. Some common examples of FACTS are a static compensator (STATCOM), a static VAR compensator (SVC), and a series reactance with silicon rectifier (SCR).

Phasor Measurement Units (PMUs) are devices that measure electrical waves in an electrical network using a common time source for synchronization. Time synchronization allows you to synchronize real-time measurements of many remote measurement points in the system. The resulting measurement is called synchrophasor. PMUs are usually included in protective relays. The basic block diagram of the PMU is shown in Figure 2 [6]. Analog AC signals are digitized by an analog-to-digital converter for each phase. The phase-locked oscillator, together with the GPS reference source, provides the necessary high-speed synchronized sampling. The result is a time-stamped vector that can be transmitted at up to 60 samples per second. PMUs can measure voltages and currents at critical points in the power supply network and can generate accurate voltage and current vectors. This information can be used to assess the state of the system, for example, changes in frequency, active and reactive power, voltage in the network, unforeseen circumstances in the network and other useful information necessary for the operator. PMU technology can increase energy savings by increasing the flow of electricity through existing lines instead of creating new, more efficient lines. Consequently, the bottleneck in the power line will be improved throughout the electrical network.

3.3 Minimum function for smart meter system

Requirements analysis is the process of determining customer expectations for the system and then document, action, measure and test these requirements in order to

create the system with the required restrictions [8]. Although requirements analysis are categorized in several ways, but this paper focuses only on two kinds of these requirement which are: the functional and non-functional requirements.

Functional Requirements. The functional requirements are the main tasks that the customer expects from the software, this paper focuses on the system main operations such as remote meter readings, consumption cost calculations, generation of bills and periodic reports. The system is dealing with two kinds of users: admin user (GECOL employee) and ordinary user (customer) as described below:

Administrator (Employee): The administrator will have full access to the system, manage customer's personal files such as: add new file, edit, delete and view customer file, manage customers' accounts: create customer account, edit, delete and view customers' accounts, View customer's consumption, manage received data from the smart meters, analyze customers usage, generate tariff plans, produce reports, and follow up the website alerts.

Customer: The customer will access the system via login details provided by the system administrator, the customer can perform tasks like: apply for power connection, manage account information such as editing personal data, view own consumption, check on company newsletters, view the consumption fees, pay the fees, ask for device or network maintenance and (but not necessarily) ask for service unsubscribing.

Non Functional Requirements. Security requirements are important factors in this system as all remotely collected data will be stored in the database and customers are intended to pay for their consumption fees either in cash, with credit card, with a pre-paid cards or through their bank accounts. Customer validation will be done during login to insure that the customer is valid and that the customer only has access to his or her permitted data/account. Nonsubscriber customers can explore the website and apply for electricity connection, while subscribed customers will be authenticated at login process and be redirected to the appropriate page based on his/her account type to perform all the permitted activities. The system will have consistent interface

formats and button sets for all forms in the application, the system will also have a form-based interface for all viewing activities, and will generate reports that are formatted in a way that will look the same as the existing manual report formats for the customers.

There are the next functions of Smart Meter:

1. 30-minute meter reading. Smart meters measure 30-minute meter readings, and transmit them to MDMS. When a 30-minute meter reading is lost, MDMS checks that the communication with the meter is recovered. The meter retransmits the data in response to a recollection request from MDMS.

2. Smart meter setting and control. The smart meter that received the setting and control request data for switch control and others from MDMS executes the requested process, and transmits the results to MDMS.

3. Hand-held terminal communication. When communication via the communication network between MDMS and smart meter is not available, meter reading, setting and control can be performed directly by using hand-held terminal on site.

4. Home Area network. In regard to the interface specifications for smart meter and HEMS (Home Energy Management System), compliance with the standardization established by the Smart House Standardization Study Group will be achieved.

5. Network Security. Smart meters deal with private customer information, which require assured security measures against the threats of illegal access, leaks or alteration of information and so on.

6. Operation and Maintenance. To manage the large-scale network efficiently and accurately, smart meter automatically transmits facility management information to MDMS. To effectively improve the communication software of smart meter, the communication software is remotely updated using communication network.

3.4 Demand side management technologies based on smart meter system

The Use Case Diagrams (UCD) was used in order to present the smart system functional requirements and defines the interaction with the system. It shows the relationship between the users and the different tasks in which the users are involved [9].

1) Use Case Overview of the System.

Figure 3.3 Explains the abstract level of the system that shows only the main system requirements due to the size and complexity of the diagram. It starts with the customer checking in the website and applying for a power connection. The employee tasks include: handling customer's request for a new power connection, create and manage customer personal file, creating and managing customer account, inquire customer consumption, generate bills, generate reports, and tariff plans, follow up consumer's complains and questions, manage received data from the smart meters and follow up website alerts about user subscription details.

The customer tasks include: apply for a power connection, manage customer personal file, view his/her consumption details, view and pay the bills, View system notifications and alerts, ask for unsubscribing from the system, ask for power maintenance.

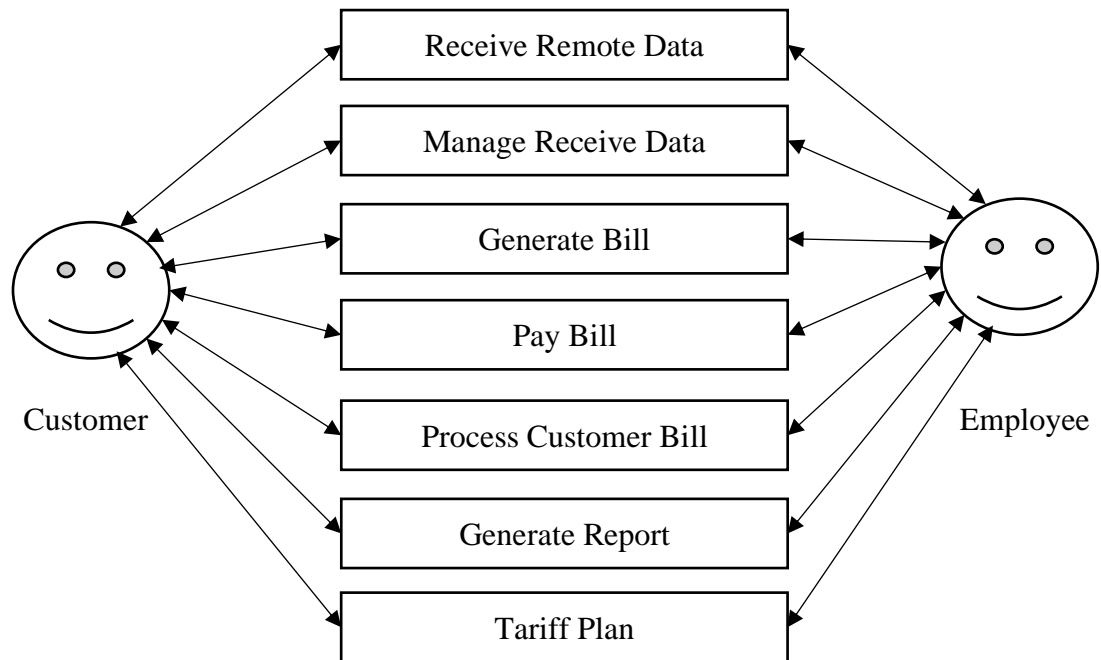


Figure 3.3 – Main System Requirements

2) Manage consumers personal file Registration to The system has two phases and both are performed by the employee, these phases are performed after receiving a request and the required documents from the consumer. The first one is accomplished by entering personal customer information such as his full name, national ID number, address, email address, phone number and any other data the company thinks is important to be available in the customer personal file. The system permits the employee to add, edit and delete customer personal file. The employee can also change any information or even delete the whole account upon request (see Fig. 3.4)

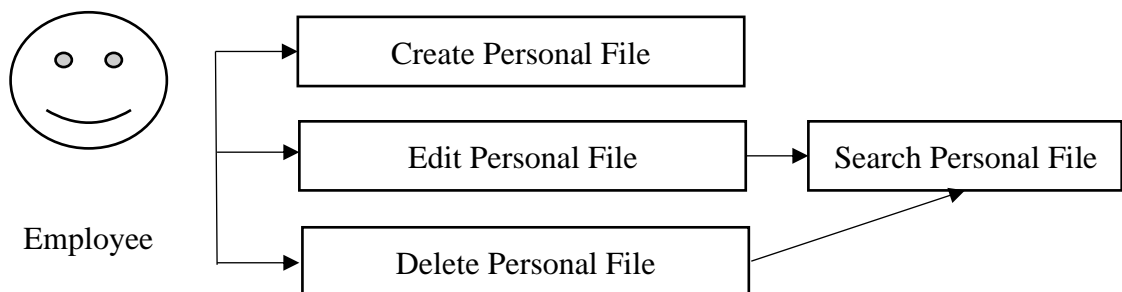


Figure 3.4 – Manage Customers personal files

3) Manage Consumers accounts The second phase of user registration is creating customer account, and then at a later stage amending and deleting accounts as

required. The last two activates requires searching for the file before performing the updating task. Fig. 3.5 shows how these activities can be performed.

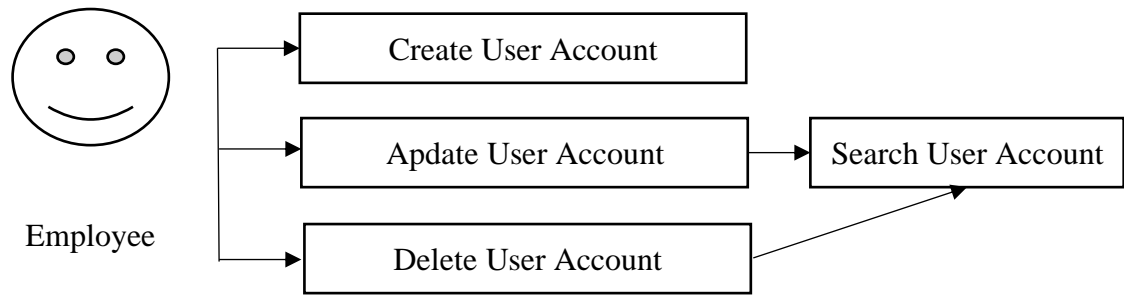


Figure 3.5 – Manage Consumers accounts

4) Manage Received Data

The employee manages data that was received from the smart meters to the CSS Database which is located at GECOL. The data includes the following: customer account number, daily amount of consumption, total consumption amount from the beginning of the subscription, voltage and current value at certain times, the customer usage limit which is determined by the type of his subscription (home, shop, farm, factory, etc.). This data is received remotely in a standard format and stored permanently in the CSS database (Fig. 3.6).

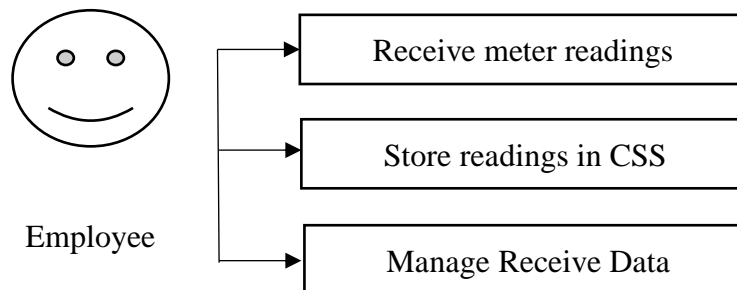


Figure 3.6 – Manage Received Data

5) Generate The Bills

In order for the employee to automatically generate a bill, he/she is required to obtain the customer consumption for a certain period of time from the database. Fig. 6. Explains the way how the system will automatically calculate the cost of consumption and send the bill to the customer for payment purposes. The system will

archive the bill for future activities such as checking the payment when needed, the analysis of usage and recommendation of tariff plans.

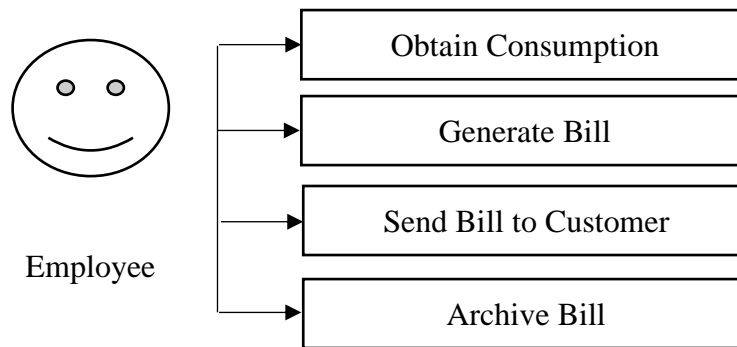


Figure 3.7 – Generate the Bill

6) Generate Tariff Plans

The GECOL as the service producer and provider is responsible for providing the best electricity services to its customers. The company is required to utilize advanced analysis techniques to analyze and better understand the behavior and consumption of the customers. Based on the results, GECOL can contact the customer and recommend a better tariff plan that better suits his/her spending. The consumer has the choice to accept or reject the offer. This helps the company to aim high and reach the level of satisfaction of the consumers (Fig. 3.8).

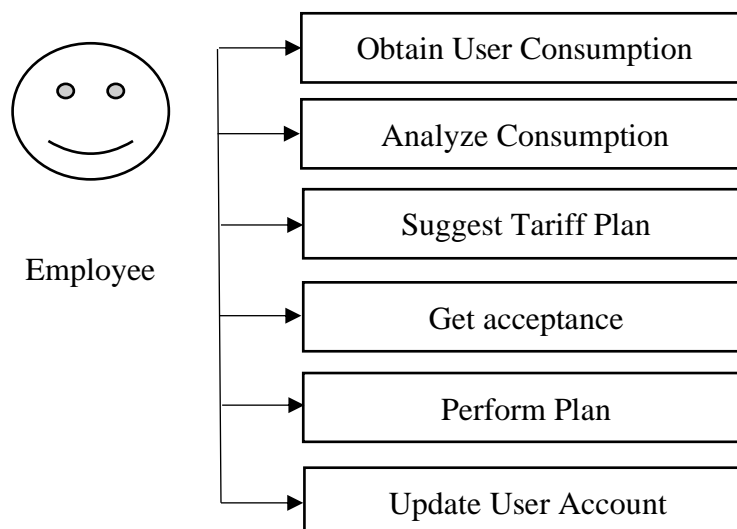


Figure 3.8 – Generate the Tariff Plan

7) Pay Bills Fees

The customer has many methods of payment, either in cash, with credit card, with a pre-paid cards or through his bank account. In case one of the last three methods is used, the customer will have to access the system, view the bill and choose the preferable method of payment. The system allows the customer to automatically generate a receipt and print it out if needed (Figure 3.9).

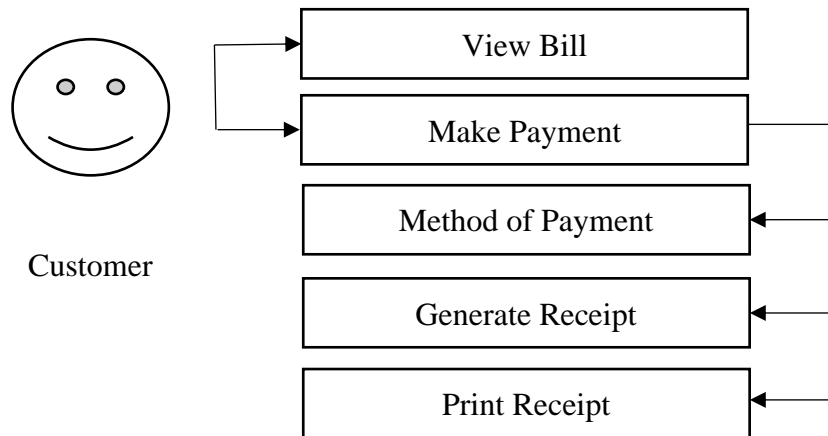


Figure 3.9 – Pay Bills Fees

8) Follow Up System Alerts

The system is intended to generate many alerts and notifications to both employees and customers such as: the customer has exceeded his subscription type limit; notification of unpaid bills, alerts on a timed black out. It will generate alerts for any engineering work that is scheduled to take place for a period of time and any other events that may come up will also be made available online for all consumers.

3.5 Summary chapter 3

This chapter has presented an approach that automates the billing system in GECOL company based on the Smart Metering Services. The analysis phase presented clearly and graphically the interaction and type of services provided between the utility, consumers, and the smart meter devices, while the design phase presented the database design of the system. The outcome of this chapter is an attempt to develop an online billing system that GECOL can use to produce timely accurate

bills instead of inaccurate estimated bills, reduce the cost and time of operations, provide automatic real time data collection, and support the transmission of instructions, remote reports and tariff plans periodically between GECOL and its customers. This will in turn allow GECOL to operate more effectively and improve its service delivery and performance.

Chapter 4. Cost-benefit analysis of smart meter system in Libya

4.1 Social, economic and environmental impact of smart metering

The implementation of smart grid comes with a wide range of advantages and challenges that vary depending upon social, political, and environmental views of the consumers and shareholders of companies trying to implement the smart grid. This section will elaborate the impact and challenges faced by smart grids in the following crucial areas: social, economic, environmental, and technical [7-11].

Social Impact. Consumer electrical usage is changing as society is becoming digital due to an increase in energy consumption by consumer electronics. Residential sectors are expected to see the largest amount of load growth. This trend is influencing electric service providers to move towards smart grids that will provide uninterrupted and highly reliable power. In the U.S., present day electric service outages range from 90 to 214 minutes, on average, per year. Smart grid technology, reduces these outages, using self-healing grids which are important due to the growth of modern economies that are largely reliant upon computers and information technologies. The impact of the smart grid that will first be noticed by consumers and society is the ability to participate in smart grid programs that in the long-term benefit all of society and the overall creation of the smart grid. Smart grid gives more control to the consumer. The consumer can choose where, when, and how they get their electrical energy. This motivates consumers to incorporate renewable energies, which in turn greatly alleviates the energy burden of non-renewable sources (coal, oil, gas etc.) Society will greatly benefit from an increase in choices allowing for more consumer input and control in the advancement of the energy sector.

Economic Impact. The World Economic Forum ranked the U.S. Infrastructure below 20th among the world's nations in nine categories and below 30th for the quality of electric power sectors. The electrical power grid is one of the last sectors in the United States to modernize and is lacking behind many of its counterparts in the

modernize world. Although, an expensive investment, the payback of smart grid technologies, in the United States, is projected to be three to six times greater than the money invested. As of March 2012, the total amount of money invested into the electrical grid was valued to be \$2.96 billion, and is projected to generate at least \$6.8 billion in total economic output. The projected total cost to completely overhaul the current power grid in favor of the smart grid is estimated to be approximately \$165 billion dollars, but is expected to lead to a 4:1 benefit to cost ratio. The investment in the electrical power system infrastructure also benefits the United States working force as a projected 47,000 new full-time jobs will be created in direct support of the new smart grid systems. Another 250,000 jobs are projected to be created in relation to the application of the smart grid. Through the investment in a smart grid, high paying jobs in the industrial sector will directly benefit technical people, with a gross domestic product multiplier of 2.6, that is, for every million dollars, invested into the smart grid systems, 2.6 million dollars will be earned. One of the main concerns, along with the high cost, required in the implementation of the smart grid, is that over one-half of the 500,000 utility workers in the United States will be eligible to retire in the next five years. This will create a vacuum of talent and experience, creating a need to replace a highly trained and motivated work force. This poses to create problems in the application of smart grid technology as having work forces that lack experience can cause major delays and increased costs associated with improving the power grid. Although, smart grid systems will incur an expensive initial investment that many investors must pay for, the impact of a smart grid system economy will far outweigh the initial costs. The key concern in the economic impact of a smart grid system will be whether the investors and market will allow companies to move towards a smarter electrical system.

Environmental Impact. The smart grid helps to facilitate an improved environment by reducing greenhouse gases and other pollutants. Reduced amount of greenhouse gas means less global warming and acid rain. Smart grids reduce emissions by reducing the use of inefficient generating sources, such as certain forms

of fossil-fuel-powered plants. The smart grid provisions the use of renewable energy, including consumers owning their own generating devices, and creates an opportunity to store and sell excess energy back to the grid. The smart grid will also allow the eventual replacement of fossil fuel powered vehicles with electric vehicles, further reducing emissions. According to EPRI, the smart grid combined with a portfolio of generation and end-user options, could decrease overall CO₂ emissions by 58%, relative to 2005 emissions, by 2030. Emission reductions from the smart grid are predicted to be 60 to 211 million metric tons of CO₂ per year in 2030 [12].

The ability of smart grids to deliver energy in a more efficient manner, by reducing energy losses, and its ability to motivate users, to use less energy, makes it an ideal platform, to be used with green energy. Through the improvement of transmission and energy storage devices, the future electric grid will be able to store energy from devices such as solar panels and wind turbines and evenly distribute the power when needed. Improved efficiencies in the electric grid will also lower the environmental impact of producing electricity by lowering the losses in an electric system. Although, the price of green energy has been declining in recent years, as improvements in technology and regulations on fossil fuels have been enacted, the current price of green energy is still more expensive than traditional fossil fuel generated power. The cost of green energy and the overall lack of knowledge from the public have slowed the advancement of green energy and smart grid systems. The implementation of a smart grid system will positively impact the environment and will encourage the use of green energy sources. The environmental impacts of smart grid systems go far beyond money value as there cannot be a price tag put on the value of cleaner air and a healthy planet.

Technical Impact. The smart grid improves the reliability and efficiency of the electrical system. It keeps the user informed, who can modify the way, they consume and purchase electricity. Through this ability to choose, the consumer can help to drive new technologies and markets by making sure their money is used on innovative technologies and in ways that benefit themselves. The smart grid creates the ability to

accommodate all generation and storage options. It gives the consumer the ability to get their energy from large centralized power plants, like the ones that are currently used in power grid, or produce and store their own power from things such as home solar panels or wind farms.

4.2. Challenges Faced by Smart Grids

The smart grid system is a complex system that faces a wide array of challenges. Smart equipment such as Intelligent Electronic Devices (IEDs) will require robust amounts of embedded computing equipment that must be replaced every 5–10 years. Along with the vigorous computing systems, the communications technologies being implemented in smart grid systems are at different levels of development and implementation. This further produces issues as to what devices will be best suited for the long-term future of the smart grid system. Management of all the data that will be communicated is another challenging aspect of future smart grid systems. The management of data is an extremely time-consuming process that is made further complicated through the immense scale of a smart grid system. Another issue with adoption of smart grid technology seems to be an absence of awareness by people involved in designing smart grid systems at a high level and an absence of consistent regulatory guidelines. The present electrical network consists of numerous distributed nodes which are strongly coupled. Since all network components have organically grown over years, finding out where intelligence needs to be placed is quite complicated. Another main issue is to integrate substitutable components from various distinct providers. There is a dire requirement for interoperability standards that will permit utilities to purchase components from any retailer knowing that they will work with each other and with present equipment at all possible levels.

4.3 Cost-benefit analysis of smart meter systems deployment

In most industrialized countries, a fundamental solution to energy controls problems is the transition to the path of innovative development of the electric power industry, which consists in a radical change in the system of views on its role and place in modern and future society based on the Smart Grid concept.

The emergence of a new concept and the large-scale work on its implementation in industrialized countries, which have taken it as the basis of their national policy of energy and innovative development, should undoubtedly be taken into account in the development of domestic energy.

The choice in favor of the innovative direction of the electric power industry development is determined by the global political and economic situation: developed countries have embarked on innovative development and ensuring their energy independence and security. In addition, the influence of factors such as technological progress, increased demands from consumers, reliable electricity supply, market changes, increased requirements in the field of energy efficiency and environmental safety make it necessary.

The practice and analysis of the activities of Western electric grid companies have shown that the optimal development of electric networks with their simultaneous modernization is possible only in combination with the optimization of the network management system based on an intelligent electric network, which allows for a minimum level of electricity loss, minimum maintenance costs and makes it possible consumers to optimize the cost of using electric energy.

The Smart Grid concept assumes an active role of the energy consumer when he becomes, on the one hand, an active subject of development and decision-making on the development and functioning of the energy system, and on the other hand, an object of control that ensures the implementation of key requirements. There is even a new concept of “Prosumer”.

Moreover, an intelligent network should be the result of active interaction between the state, the energy company and the consumer, when it is equally

unprofitable for all three parties to violate the general rules of work within the network and at the same time, each participant gets its own economic benefit.

Smart Grid technologies balance energy generation and power consumption by optimizing power system management, including in cases of emergency outages. This innovative approach in the EU and North America, despite the high cost of solutions, is today much more preferable compared to the extensive expansion of generating capacities.

An analysis of world practice in the creation and use of smart metering systems shows that from 1999 to 2002, 3.5 million smart metering devices were installed as part of the reform in India, which made it possible to detect more than 150 thousand cases of theft of consumed electricity and improve billing and collection of payments.

From 2002 to 2017, smart metering systems were created in 28 European countries, including Switzerland and Norway; for 2017, there are 950 projects with an average investment of one project from 3.3 to 9 million euros, depending on the type of project and a total volume of 5.5 billion euros. There are serious differences between the EU countries in the number of projects and the general level and rate of investment. Only 15% of the projects were funded exclusively by private investment, which is especially large in the UK and Luxembourg, as well as in Belgium and Denmark. The share of private investment in other projects ranges from 40 to 60%, the rest is national funding (within one country) and European Union funding, which have a significant impact on the project.

16 Member States (Austria, Denmark, Estonia, Finland, France, Greece, Ireland, Italy, Luxemburg, Malta, Netherlands, Poland, Romania, Spain, Sweden and the UK[5]) will proceed with large-scale roll-out of smart meters by 2020 or earlier, or have already done so. In seven Member States (Belgium, the Czech Republic, Germany, Latvia, Lithuania, Portugal, and Slovakia), the CBAs for large-scale roll-out by 2020 were negative or inconclusive, but in Germany, Latvia and Slovakia smart metering was found to be economically justified for particular groups of customers. In 15 out of the 16 Member States that have decided to proceed with a

large-scale roll-out, the distribution system operators (DSOs) are responsible for implementation and own the meters, so the operation is to be financed through network tariffs.

While divergence in key roll-out parameters calls for caution (Table 1 and Table 2), available data indicate that a smart metering system could cost on average €200 to €250 per customer. Cost per metering point ranges from under €100 (€77 in Malta, €94 in Italy) to €766 in the Czech Republic.

Table 4.1 – Summary statistics — key smart metering roll-out parameters for electricity (based on Member States’ long-term economic assessments) [5]

Indicator	Range of values	Average based on data from positively assessed cases
Discount rate	3.1 to 10%	5.7% + 1.8% (70%[10])
Lifetime	8 to 20 years	15 + 4 years (56%)
Energy saving	0 to 5%	3% + 1.3% (67%)
Peak load shifting	0.8 to 9.9%	-
Cost per metering point	€77 to €766	€223 + €143 (80%)
Benefit per metering point	€18 to €654	€309 + €170 (75%)
Consumer benefits (as % of total benefits)	0.6% to 81%	-

Table 4.2 – Summary statistics – key smart metering roll-out parameters for gas (based on Member States’ long-term economic assessments) [5]

Indicator	Range of values	Average based on data from positively assessed cases
Discount rate	3.1 to 10%	-
Lifetime	10 to 20 years	15 - 20 years (75 %)
Energy saving	0 to 7%	1.7% + 1% (55%)
Cost per metering point	€100 to €268	€200 + €55 (65%)
Benefit per metering point	€140 to €1000	€160 + €30 (80%)

Smart metering systems are expected to deliver an overall benefit per customer of €160 for gas and €309 for electricity along with assumed energy savings of 3%. The latter range from 0% in the Czech Republic to 5% in Greece and Malta. Of the countries that have completed roll-outs, Finland and Sweden have indicated energy savings of the order of 1-3%, but no data were available for Italy.

4.4 Summary chapter 4

The implementation of smart grid comes with a wide range of advantages and challenges that vary depending upon social, political, and environmental views of the consumers and shareholders of companies trying to implement the smart grid.

The impact of the smart grid that will first be noticed by consumers and society is the ability to participate in smart grid programs that in the long-term benefit all of society and the overall creation of the smart grid. Smart grid gives more control to the consumer. Through the investment in a smart grid, high paying jobs in the industrial sector will directly benefit technical people, with a gross domestic product multiplier of 2.6, that is, for every million dollars, invested into the smart grid systems, 2.6 million dollars will be earned. The smart grid helps to facilitate an improved environment by reducing greenhouse gases and other pollutants. Reduced amount of greenhouse gas means less global warming and acid rain. The smart grid improves the reliability and efficiency of the electrical system. It keeps the user informed, who can modify the way, they consume and purchase electricity.

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Conclusion

Despite political instability, the past two years have shown positive dynamics in the development of the Libyan oil and gas sector. The interest in working in it as buyers of Libyan hydrocarbons and investors is increasing. The level of oil production in the country doubled in 2018. Today, the electricity system of Libya is a state owned vertically structured power utility company and is responsible for generation, transmission and distribution of electric energy. The Libyan National Electricity Network consists of a high-voltage network of about 12,000 km, a medium-voltage network of about 12,500 km and 7,000 km of a low-voltage network.

All energy companies in Libya remain state owned. The electricity generation market is still closed to private investors. A new law on electricity is being prepared, which will allow private companies to generate electricity. The Libyan legal framework does not allow the private sector to independently generate renewable energy sources (solar manufacturers) with the possibility of supplying excess electricity to the network.

The Energy Council is responsible for the energy sector; and there is also the Ministry of Electricity and Renewable Energy, which regulates and controls the electricity sector. The vertically structured General Electric Company in Libya (GECOL) is responsible for the production, transmission and distribution of electricity; and it works closely with the Libyan Renewable Energy Authority (REAOL).

Since the 1970s, GECOL has introduced monitoring centers to monitor generating plants and supply systems. The energy infrastructure control system includes the following institutions: National Control Center (NCC), two Regional Control Centers in Tripoli and Benghazi (TRCC and BRCC respectively), and Distribution Control Centers (DCC's) around the country. GECOL manages about 26 power plants, which contain 85 power units of various sizes, ages and technologies distributed throughout Libya. Most of the power plants are located on the Libyan

coast of the Mediterranean Sea. GECOL's official installed capacity as of 2017 is 10.238 GW.

The instability and low security level in Libya negatively affect the implementation of projects on network management systems in the country's energy sector. After 2011 in Libya, there are practically no changes in the operation of control and monitoring systems, the old and new systems do not fulfill all functions. The control system does not prevent fuel control and control of the operation of all units, substations. Government agencies should implement smart metering systems that provide benefits in energy consumption. The experience of European countries shows positive results after the introduction of smart metering systems: benefit per metering point is 80%, energy saving is 55%.

The built environment accounts for over 40% of delivered energy consumption. The majority of energy consumed is for space and water heating, not electricity in most buildings. The domestic sector in the Libya accounts for almost 39% of final energy consumption. The energy efficiency of the bulk of the housing stock is poor. There is significant scope for energy efficiency improvements with savings in space heating of up to 90% achievable. The capacity generated by Libyan power plants is 86% of installed capacity and 94% of available capacity. Electricity production from oil sources in Libya decreases from 2005. Production of coal in 2017 was 3 773 421 ktoe, of crude oil was 4 477 212 ktoe. The import of crude oil was 2 453 086 ktoe, while export was – 2 381 804 ktoe. The import of oil products was 1 364 755 ktoe, while export was – 1 477 490 ktoe.

This demand could be met either by increase of supply or improving the efficiency of energy supply and end use. Energy-efficient technologies could offer solutions and could reduce environmental impacts associated with recent energy systems use. As the electricity demand in Libya is continuously increasing and aged national power grid operating at its critical capability and their stability limits, innovative techniques for more effective electrical energy generation and management is a vital desire for the Libyan electricity sector.

Since 2009, GECOL has been working on the creation of an energy data management system (EDM): 1) Analysis of technical losses, calculation of losses at each voltage level of the; 2) Compare the calculated losses with historical data and determine the energy losses both by voltage level and by geographical area; 3) Develop a consumer demand profile based on 15-minute breakdowns of power and voltage profiles; 4) Calculation of system reserves according to supply and consumption data; 5) Real-time balance monitoring to detect deviations or unforeseen events; 6) Continuous power monitoring by integrating and extrapolating the power flow in the trunk. GECOL's EDM system physically consists of smart energy meters installed on all power transformers, single and auxiliary transformers, and on communication lines. Intelligent meters are designed to provide GSM communications for transmitting data to telemetry stations.

Key benefits of using Smart Metering in Libya:

1. Save 2.9 million barrels of oil per year
2. Avoid around a million tons of carbon dioxide per year.
3. The financial profit from the sale of carbon emission reduction certificates is estimated at approximately (6 - 8 million US dollars per year)
4. To help cover part of the demand for electricity
5. Gaining experience and transfer of knowledge and technologies of localization.
6. Sustainable spatial development and job creation
7. Will pave the way for Libya to become an exporter of clean energy.

The National Energy Efficiency Action Plan (NEEAP) is the strategic structure of the national plan that helps Arab countries implement energy efficiency goals. Development of Technology for a code of commercial electricity metering for Libya should consist of development of appropriate standards and codes for energy efficiency technologies and promote of energy efficiency research and development and set appropriate steps and programs for its implementation.

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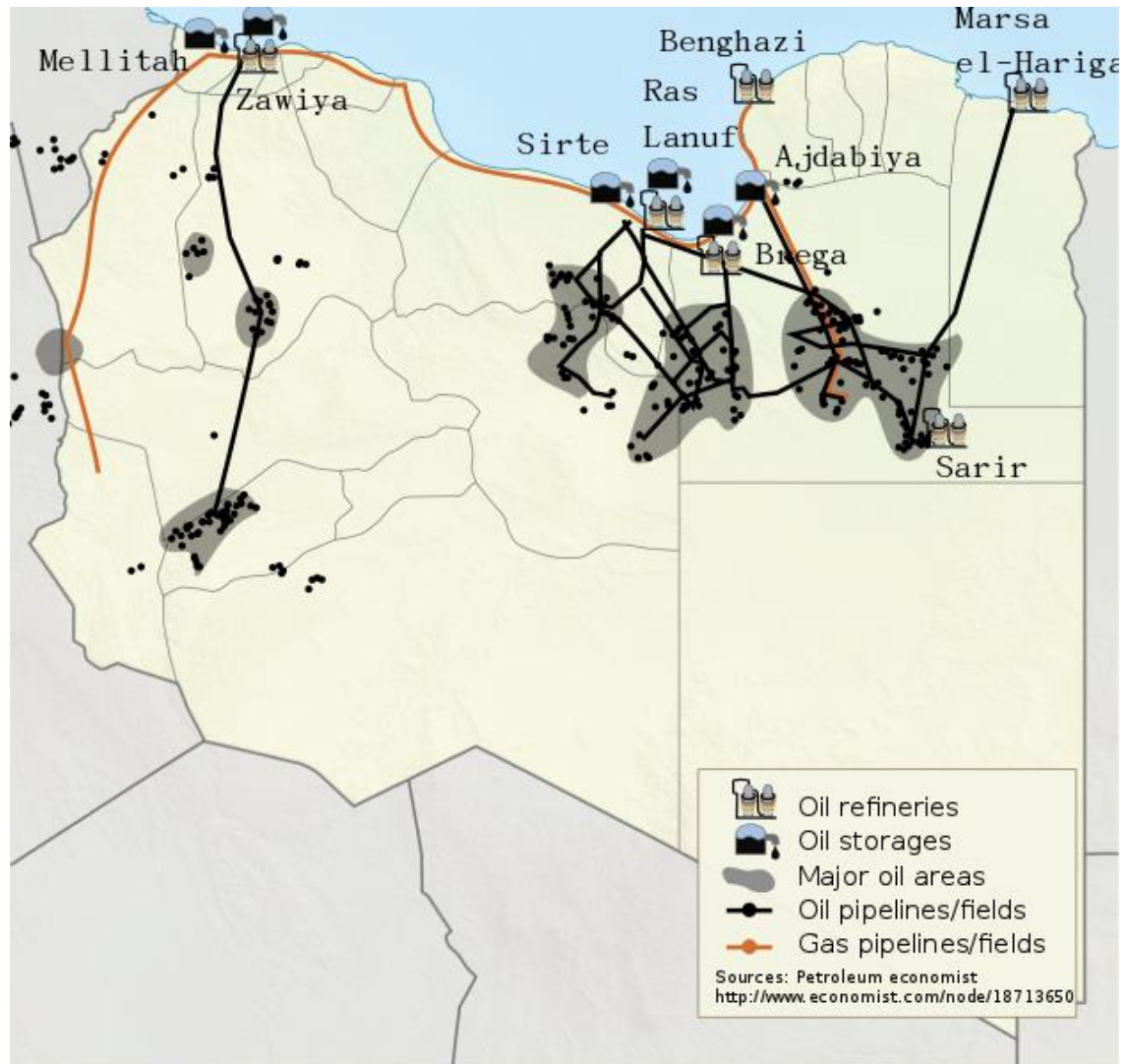
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Appendices

Annex 1

Libya location map-oil & gas 2011



Annex 2

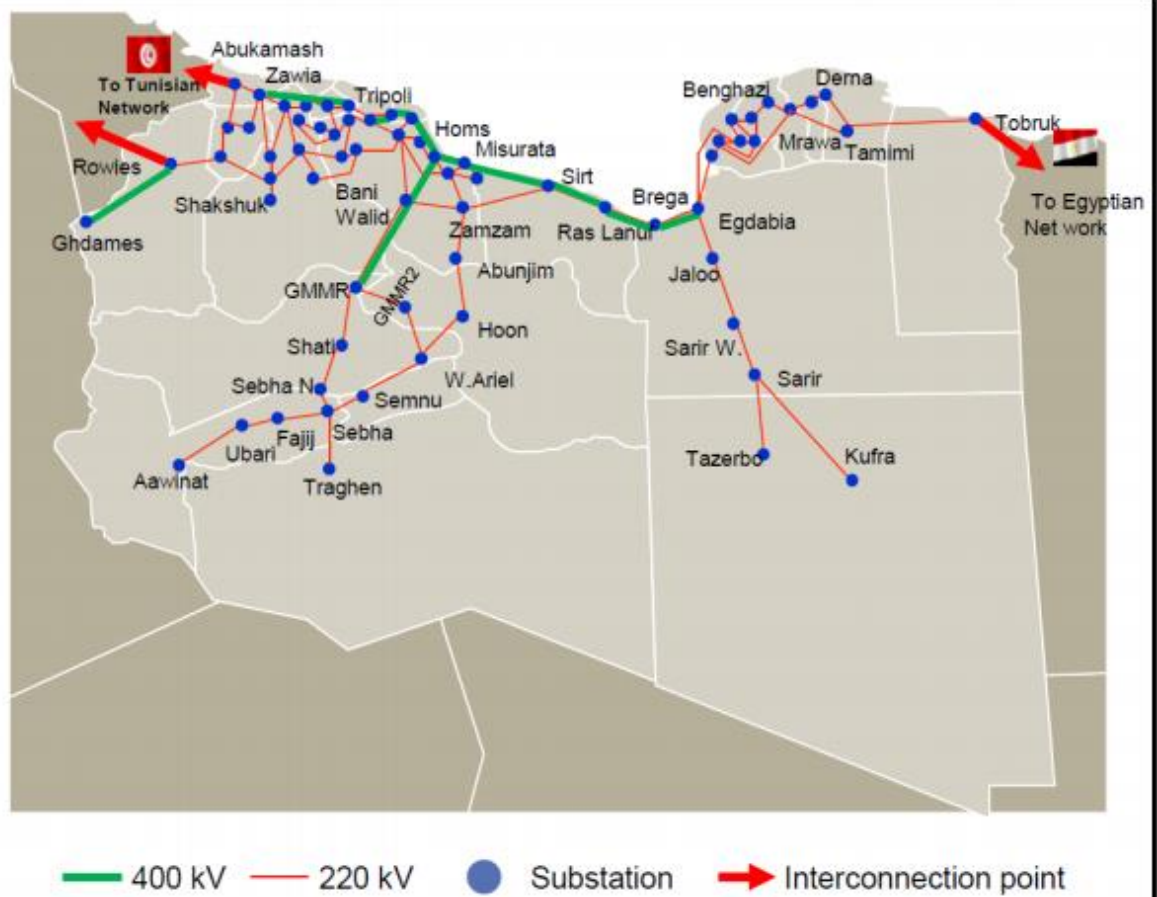
Location of GECOL generation plants



Source: GECOL data collection, Strategy& analysis.

Annex 3

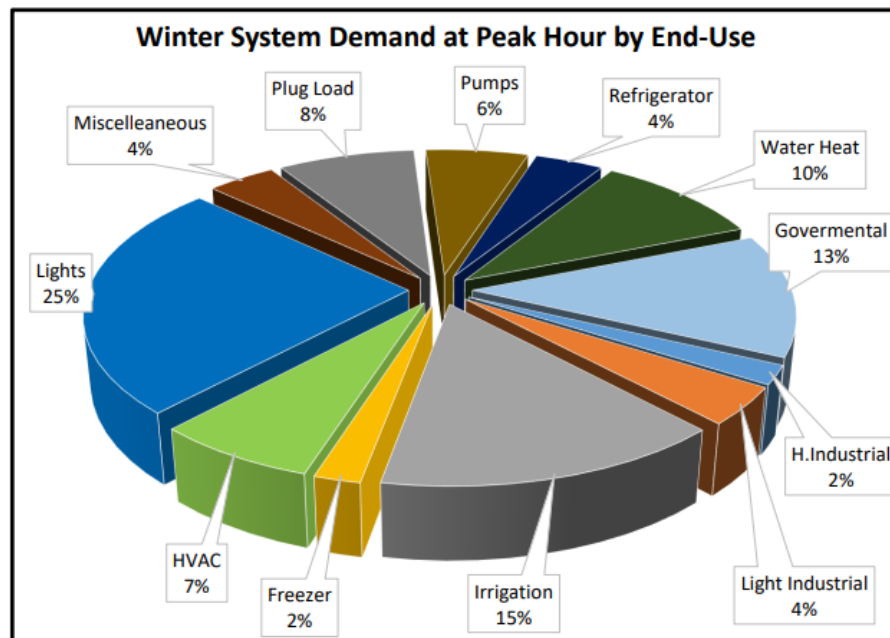
Libyan transmission system overview



Source: GECOL data collection, Strategy& analysis

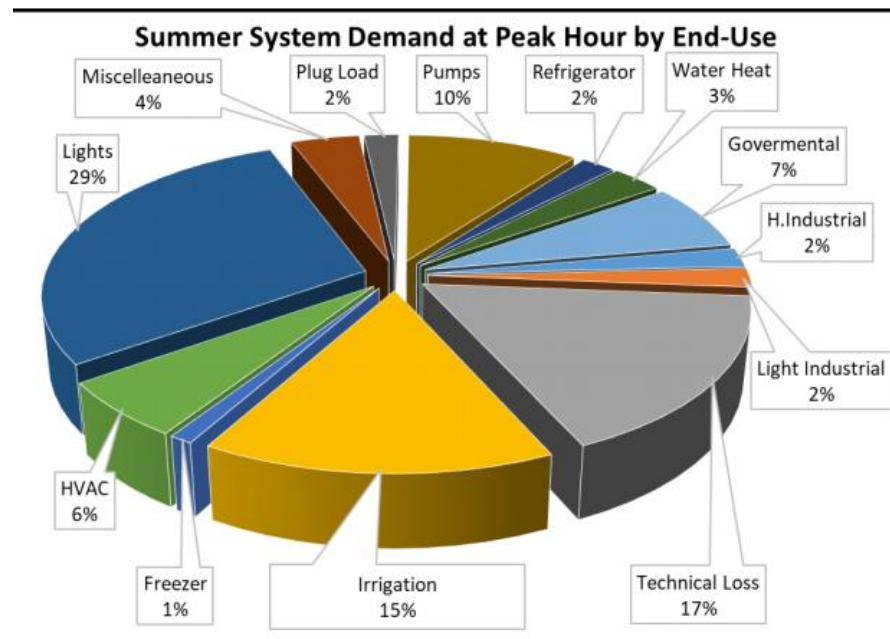
Annex 4

Winter peak demand by end use (Demand side management (DSM))



Source: GECOL data collection, Strategy& analysis

Summer peak demand by end use (Demand side management (DSM))



Source: GECOL data collection, Strategy& analysis

Annex 5

An overview of the National Energy Efficiency Action Plan, 2014-2016

Item	Cost	Date	Cumulative saving upto 2016
Replacement of Electric Heaters with Solar Water Heaters	225,000,000	2016	490.56 GWh
CFL	5,000,000	2016	438 GWh
Energy Management in Government Buildings	5,000 L.D. for training of Energy Managers	2016	Supportive
construction of 3 energy efficient building (Government)	2,000 L.D. / m2	2016	60% reduction in energy consumption
executing 60 energy auditing studies	5,000 L.D (training of energy auditing specialist)	2016	supportive
reduction of commercial losses	125 L.D. per meter	2016	Card meters, public awareness, incentives
EE labels	to be set	2016	supportive
Building Energy Code	300,000	2016	supportive
Award of Arab EE day	40,000	2016	supportive

Annex 6

Total energy statistics (ktoe) in Libya

Category	2000	2005	2010	2015 P
Production of coking coal	-	-	-	-
Production of charcoal	0	0	77	79
Production of crude oil, NLG and additives	63,884	77,528	73,240	44,036
Production of natural gas	5,337	10,619	14,340	11,450
Production of electricity from biofuels and waste	0	0	0	0
Production of electricity from fossil fuels	1,316	1,935	2,816	3,103
Production of nuclear electricity	-	-	-	-
Production of hydro electricity	-	-	-	-
Production of geothermal electricity	-	-	-	-
Production of electricity from solar, wind, Etc.	0	0	0	2
Total production of electricity	1,316	1,935	2,816	3,105
Refinery output of oil products	15,128	15,877	19,478	8,053
Final Consumption of coking coal	0	0	0	0
Final consumption of oil	6,137	6,394	8,759	7,599
Final consumption of natural gas	2,388	3,228	1,971	1,015
Final consumption of electricity	1,051	1,679	2,442	2,690
Consumption of oil in industry	1,467	1,494	2,296	1,896
Consumption of natural gas in industry	1,027	984	421	204
Consumption of electricity in industry	263	273	179	124
Consumption of coking coal in industry	0	0	0	0
Consumption of oil in transport	3,845	3,974	5,770	5,204
Consumption of electricity in transport	0	0	0	0
Net imports of coking coal	0	0	0	0
Net imports of crude oil, NGL, Etc.	-46,518	-60,360	-48,307	-66,325
Net imports of oil product	-4,636	-4,889	-1,455	3,208
Net imports of natural gas	-726	-4,901	-9,328	-6,067
Net imports of electricity	0	0	-7	4