

Cost-Effectiveness Analysis of Power Generation in Turkish Republic of Northern Cyprus

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ABSTRACT

Electrical energy has reached an indispensable position in production, transportation, distribution, and communication activities in the general economy. It is essential to human life with its prevalent use from lighting to heating, televisions to computers. With this feature, electrical energy rapidly replaces other forms of energy in proportion to the development level of countries.

The situation is not different in the Turkish Republic of Northern Cyprus. With the increasing population and developing technology, the demand for electrical energy is increasing day by day. With the increase in demand, the installed power of the power plant is becoming more and more insufficient.

This study analyzes the electrical energy supply sources "Fuel Oil, Natural Gas, and Interconnector," which can be used in the TRNC to meet the increasing energy demand. Cost-Effectiveness Analysis (CEA) and Levelized Cost Of Electricity (LCOE) production compare the most appropriate electricity supply to the country's conditions. It aims to identify the source of production.

Keywords: TRNC, Electricity generation, CEA, LCOE, HFO, CCGT, LNG.

ÖZ

Elektrik enerjisi aydınlatmadan ısıtmaya, televizyonlardan bilgisayarlara kadar son derece yaygın kullanım alanı ile insan hayatının vazgeçilmezi olduğu kadar genel ekonomi içinde üretim, ulaşım, dağıtım, iletişim faaliyetleri açısından da vazgeçilmez bir konuma ulaşmıştır. Bu özelliği ile elektrik enerjisi, ülkelerin gelişmişlik düzeyleri ile orantılı olarak hızla diğer enerji biçimlerinin yerini almaktadır.

Kuzey Kıbrıs Türk Cumhuriyeti'nde de durum farklı değildir. Artan nüfus ve gelişen teknoloji ile birlikte elektrik enerjisine olan talep her geçen gün artmakta, talep artışı ile birlikte de kurulu santral gücü git gide yetersiz kalmaktadır.

Bu çalışma, artan enerji talebini karşılamak amacıyla KKTC'de kullanılabilecek elektrik enerjisi tedarik kaynakları olan “Fuel Oil, Doğalgaz ve Enterkonnekte” ile elektrik üretiminin Maliyet Etkililik Analizini (CEA) ve Seviyelendirilmiş Elektrik Maliyetini (LCOE) karşılaştırmalı olarak analiz ederek, ülke şartlarına en uygun üretim kaynağını belirlemeyi amaçlamaktadır.

Anahtar Kelimeler: KKTC, Elektrik üretimi, CEA, LCOE, HFO, CCGT, LNG.

To My Family

ACKNOWLEDGEMENT

I want to thank Prof. Dr. Glenn Jenkins for his continuous support and guidance in preparing this study. Without his invaluable supervision, all my efforts could have been short-signed.

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LIST OF ABBREVIATIONS

BOTAŞ	Turkey's State-Owned Gas Enterprise
CAPEX	Capital Expenditure
CBA	Cost-Benefit Analysis
CCGT	Combined Cycle Gas Turbine
CE	Cost-Effectiveness
CEA	Cost-Effectiveness Analysis
CER	Cost-Effectiveness Ratio
CSP	Concentrated Solar Power
EIA	The US Energy Information Administration
EMR	Eastern Mediterranean Region
EOCK	Economic Opportunity Cost of Capital
FSU	Floating Storage Unit
FSRU	Floating Storage & Regasification Unit
FSRP	Floating Storage, Regasification & Power Generation Unit
FPP	Floating Power Plant
GWh	Gigawatt Hour
HFO	Heavy Fuel Oil
HVAC	High Voltage Alternating Current
HVDC	High Voltage Direct Current
IEA	The International Energy Agency
IRENA	International Renewable Energy Agency
Kg	Kilogram
Kıb-Tek	Cyprus Turkish Electricity Authority

KW	Kilowatt
KWh	Kilowatt Hour
LCOE	Levelized Cost of Energy
LNG	Liquified Natural Gas
LNGC	Liquified Natural Gas Carrier
MJ	Megajoule
MMBTU	Million British Thermal Units
MW	Megawatt
MWh	Megawatt Hour
OPEX	Operational Expenditure
PM	Particulate Matter
PPA	Power Purchase Agreement
PV	Photovoltaic
TEİAŞ	Turkish Electricity Transmission Corporation
TL	Turkish Lira
TON	Tonne
TRNC	Turkish Republic of North Cyprus
USD	United States Dollar
USD'M	Million United States Dollar

Chapter 1

INTRODUCTION

1.1 Background Information

Electrical energy has reached an indispensable position in production, transportation, distribution, and communication activities in the general economy. It is essential to human life with its prevalent use from lighting to heating, televisions to computers. With this feature, electrical energy rapidly replaces other forms of energy in proportion to the development level of countries. Today, electricity shortages mean poor quality of life for developed countries and poverty for developing countries. Although research and studies on renewable sources are underway, it is clear that fossil resources continue to weigh on them today. [1] [2] [3]

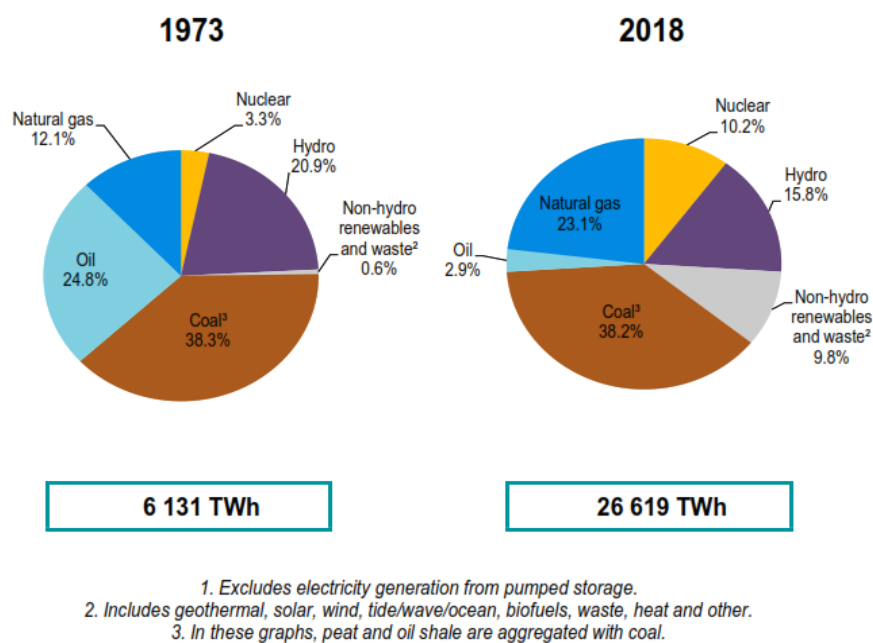


Figure 1.1: Source Shares of Electricity Generation 1973-2018 [9]

The situation is not different in the Turkish Republic of Northern Cyprus. With the increasing population and developing technology, the demand for electrical energy is increasing day by day. With the increase in demand, the installed power plant capacity becomes more and more insufficient.

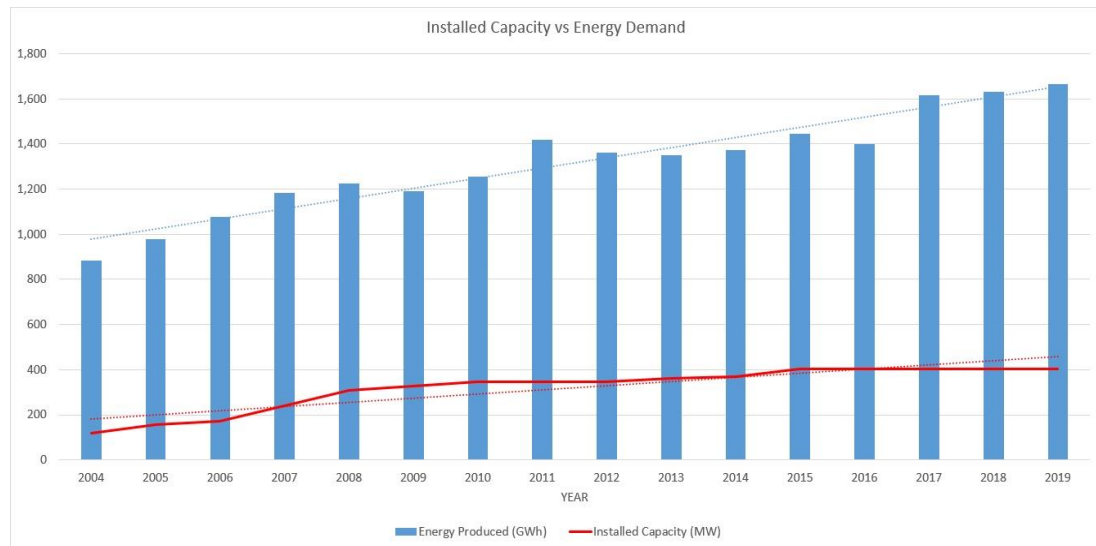


Figure 1.2: Installed Capacity vs. Energy Demand of TRNC between 2004-2019 [29]

The total installed capacity of the Turkish Republic of Northern Cyprus (TRNC) is 404 MW. Our operational installed capacity is 336 MW, consisting of two units of 60 MW steam turbines and eight units of 17 MW diesel engines that KIBTEK owns. Eight units of 17.5 MW diesel engines and 1 unit of 8 MWs of the waste heat steam boiler owned by AKSA. Solar Energy Systems were established by private and legal persons in a total capacity of 80 MW as of August 2021. According to the data of the past 15 years, the electricity demand of TRNC has increased an average of 5% annually.

All installed capacity of 404 MW is based on heavy fuel oil (HFO) and causes significant environmental problems. While the solid wastes released from Fuel Oil threaten both land and sea life, electricity production by burning Fuel Oil causes

emissions, especially SO_x, NO_x, CO, PM₁₀, and PM_{2.5} (Particulate Matter), pose a significant threat to public health and the environment. Filter investments must be made in the existing system to provide the necessary conditions for health and the environment, but these investments have very high initial investment and operating costs.

Also, EU Environmental Laws and targets; as of the end of 2020, 0.5 percent sulfurous fuel oil has been used instead of 1 percent sulfur fuel oil, and by 2030, it is aimed to ban the use of Fuel Oil completely. But the emissions and the environmental effects of electricity production are not the subjects of this study.

1.2 Objectives and Methodology

According to the data of the past 15 years, there is an increasing electricity demand of TRNC with 5% annually. Existing power plants become insufficient day by day to meet the demand, and these plants have low efficiencies, causing significant environmental problems. So, new investments need to be made to meet the increasing electricity demand.

This study analyzes the relevant sources of electrical energy supply in TRNC, which are "Fuel Oil, Natural Gas, and Interconnector," to meet the increasing energy demand. Cost-Effectiveness Analysis (CEA) and Levelized Cost of Electricity (LCOE) were used to compare these sources to find the most appropriate electricity supply to the country's conditions.

1.3 Study Framework

- i. Chapter 2: Overview of the existing electricity generation system
- ii. Chapter 3: Overview of the available sources
- iii. Chapter 4: Overview of the proposed scenarios
- iv. Chapter 5: Cost-Effectiveness Analysis
- v. Chapter 6: Levelized Cost of Electricity
- vi. Chapter 7: Sensitivity Analysis
- vii. Chapter 8: Conclusion and Recommendation

Chapter 2

CURRENT SITUATION & FUTURE PROJECTIONS

2.1 Cyprus Island

2.1.1 General Information

Cyprus island is in the middle of the Eastern Mediterranean is led by two administrations. The island's south is led by the Greek Cypriots, whereas the Turkish Cypriots lead the island's northern part with a United Nations-administered buffer zone in the middle.



Figure 2.1: Map of Cyprus [14]

The national power company known as Kıbrıs Türk Elektrik Kurumu (Kıb-Tek) is the authority in North Cyprus handling the production, generation, and distribution of electricity.

2.2 Current Situation

2.2.1 Generation

The "Electricity Department," which served as a State Agency until March 1975, was converted into the Cyprus Turkish Electricity Authority (Kıb-Tek) as of March 1, 1975, by the decision of the Council of Ministers. Kıb-Tek is the largest institution of the TRNC, which has the largest budget after the Ministry of Finance with 640 employees, 193,000 subscribers, and a budget that is approximately 1/3 of the TRNC budget.

Until 1994, some of the electricity needs were produced with three primitive and motorized Gas Turbine Plants from the 1970s which two of which were 20 MW and one 15 MW, and most of the electricity needs met from Southern Cyprus.

In 1990, with the support of Turkey, serious steps were taken for electricity generation, and with an investment of 125 million USD were covered by Turkey, the contemporary Steam Turbine Power Plant started to be installed in the Teknecik Power Plant according to the conditions of that day. The first unit was completed in 1995 and the other in 1996. The plant consists of two units, and each unit is 60 Megawatts (MW) and has a total power of 120 Megawatts. Heavy Fuel Oil is used as fuel in power plants. With the introduction of the Steam Turbine Plant, Cyprus completely cut off its electricity to the TRNC in March 1996. Since then, this plant alone met a large part

of the country's energy needs until 2003. For this purpose, it worked with a very high order of over 95 percent in terms of time and production.

By the early 2000s, the increasing energy demand became unaffordable by the two units in Teknecik alone. A new power plant was introduced by the State with the Leasing and Receiving Services model. There was an explosion in the construction sector within the framework of mobility in the Cyprus negotiations and, simultaneously, as demand increased. With the mobility in the construction sector, energy demand increased dramatically (10-12% per year), and a Guaranteed Purchase Agreement was signed between the TRNC Government and AKSA in line with the increasing energy demand. Within the framework of the signed contract, Kalecik Power Plant Investments, which started with two 17.5 MW Diesel Machines in 2003, reached eight 17.5 MW Diesel Machines and one 8 MW Waste-Heat Steam Boiler in 2014.

A total of eight 17 MW Diesel Machinery investments were made by K1b-Tek, including four units in 2007, 2 in 2008, and 2 more in 2015. With all these investments, TRNC's Installed Power Plant Power reaches 405 MW, while Operational Available Power Capacity totals 336 MW.

2.2.2 Transmission

With the start of the Teknecik Power Plant Installation, investments for 66kV High Voltage Power Transmission Line and Transformer Center started in the 1990s, and these investments were completed in 2005. As of 2007, investments to transform 66 kV transmission lines and substations to 132 kV have been formed to reduce transmission losses and increase network stability. These investments have been completed at a rate of 90 percent across the island as of 2019. With the 132 kV High

Voltage Power Transmission Line and The Substation, the Fiber Optic Communication Network was established along the High Voltage Lines, and the High Voltage SCADA System "Central Supervision Control and Data Collection" was also implemented.

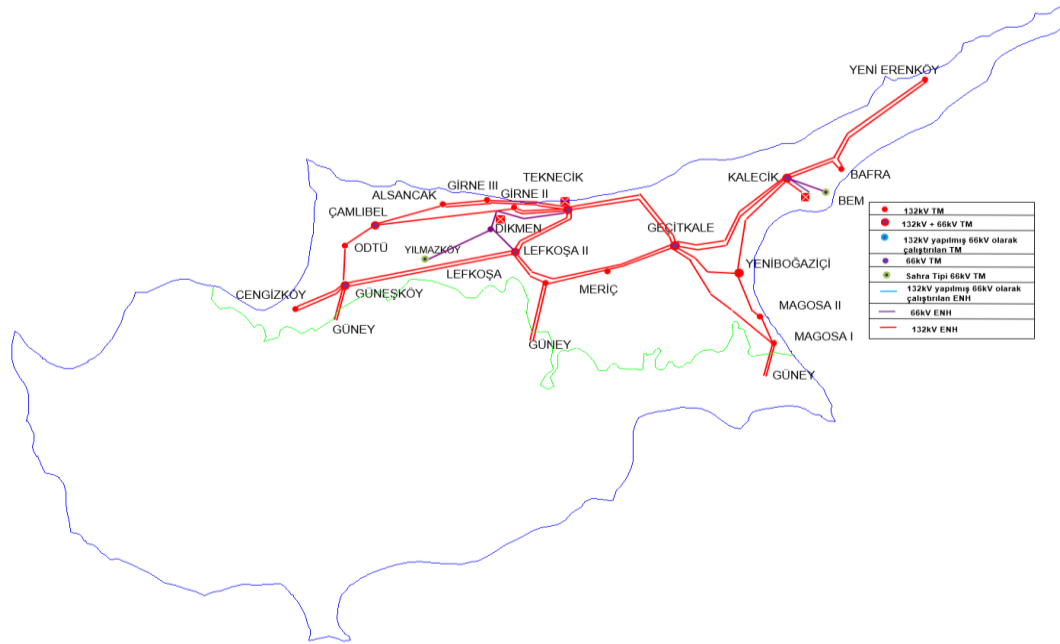


Figure 2.2: TRNC's Electricity Network, (K1b-Tek) [29]

Simultaneously with the investments in 132 kV High Voltage Power Transmission Lines, MV investments were also made to increase the network, which was designed as 11 kV at Medium Voltage Level, to 22 kV. With all these investments made in the main backbone of the Transmission Line, significant reductions in transmission line losses, fault detection, and troubleshooting times have been achieved.

2.2.3 Distribution

Smart Meter investments started in 2014. All existing Mechanical Meters in the K1b-Tek network were replaced with Electronic Meters, and AMM (Automatic Meter Management) System was established with the transition to Electronic Meters. With the installation of the AMM System, by providing remote access to each meter from a

single center, the loss and theft rate was significantly minimized; it offered a decrease in the detection times of the failures in the Distribution Network. It played a significant role in achieving a collection rate of over 96 percent.

2.2.4 Consumption

According to the consumptions by tariff type for the ten years between 2009 and 2019; Commercial Tariff consumes the most significant amount of energy with 36.27%, followed by Housing Tariff with the consumption of 32.55%, Industrial Tariff with 16.00%, State Tariff with 10.97%, Lightning Tariff with 2.97% and Transient Current Tariff with the consumption of 1.25%.

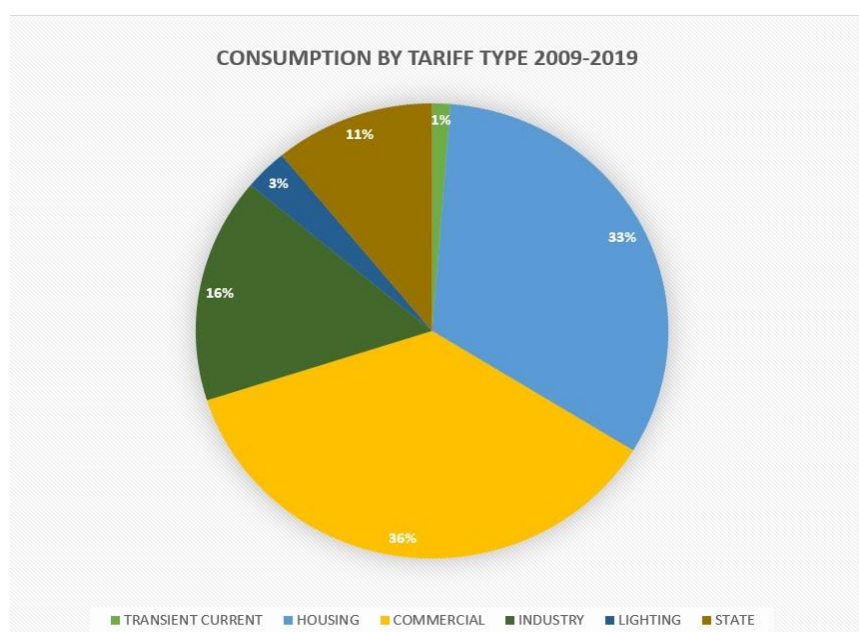


Figure 2.3: TRNC's Electricity Consumption by Tariff Type 2009-2019 [29]

2.2.5 Pricing Policy

It is denoted by the letter Average Cost Price (M), and the formula for calculating the average cost price per kWh is "Fuel Cost (Variable Cost) + Fixed Cost."

Variable Costs = Fuel Price + Freight + Bank Charges.

Fixed Costs = Personnel Expense Cost + Pension Fund Cost + Depreciation Cost + Financing Cost + General Expense Cost + Kalecik Power Plant Rental Cost + Additional Investment Share Cost.

Variable cost is recalculated for periods not exceeding 3 (three) months depending on the change in one ton of fuel price. The Fixed Cost is recalculated twice a year in February and August by reviewing production, consumption amounts, economic changes, and other cost elements; in the light of changes, if any, the new situation is reflected in the costs.

2.3 Future Projections

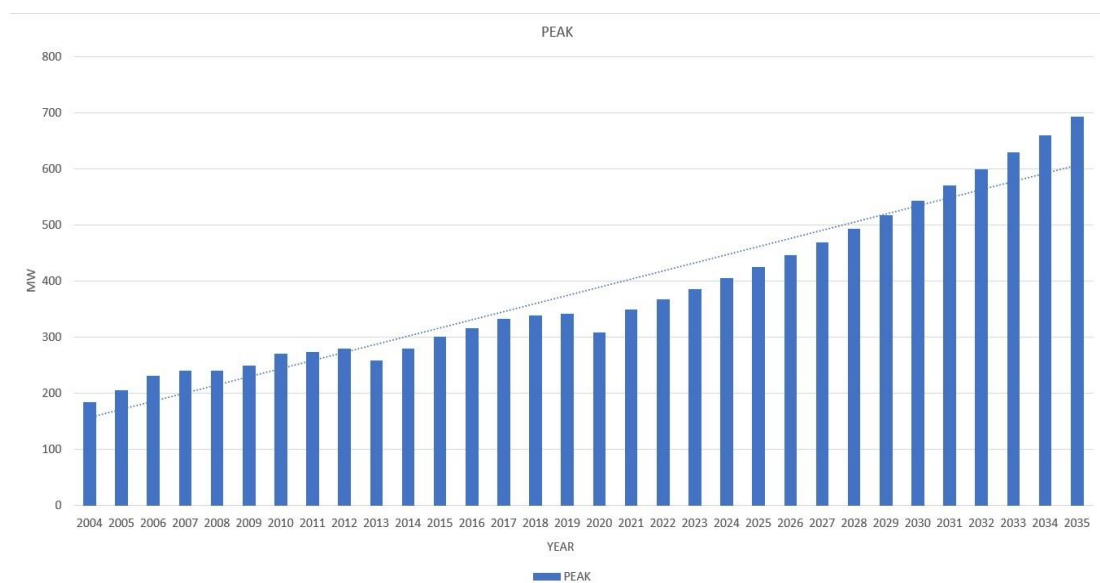


Figure 2.4: TRNC's Peak Power Projection 2004-2035

The peak consumption values of the last 15 years show an average increase of 5% annually. The highest peak value experienced has already reached the maximum available capacity of the existing installed power plant in 2019 with 339 MW.

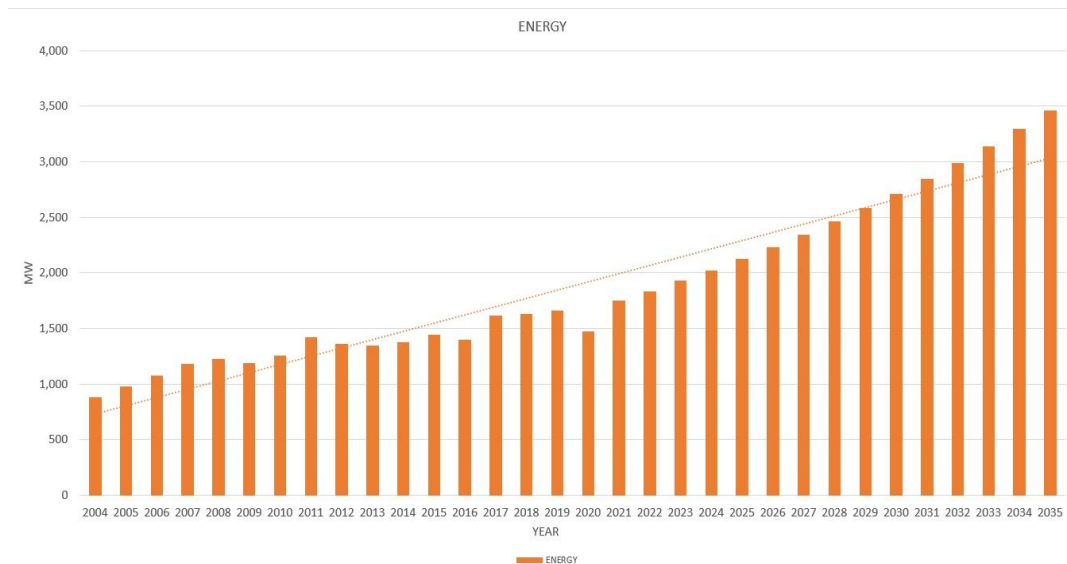


Figure 2.5: TRNC's Average Annual Electricity Generation Projection 2004-2035

Total consumption values of the last 15 years show an average increase of 5% annually too. In 2020, due to the Covid-19 pandemic, energy consumption naturally decreased due to travel restrictions and closures. In this study, an average increase of last 15 years taken as reference and the future years projection has done according to 5% increase annually.

Chapter 3

LITERATURE REVIEW

3.1 Sources of Energy

We can group energy sources into three main types: Non-Renewable Sources & Renewable Sources and Submarine Cable Interconnector.

Table 3.1: Sources of Energy

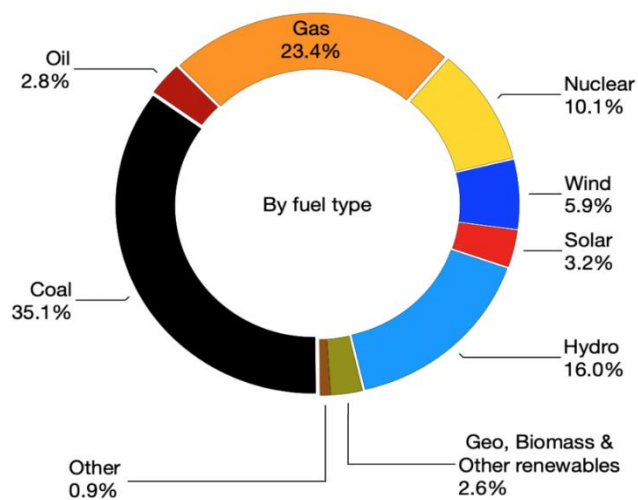
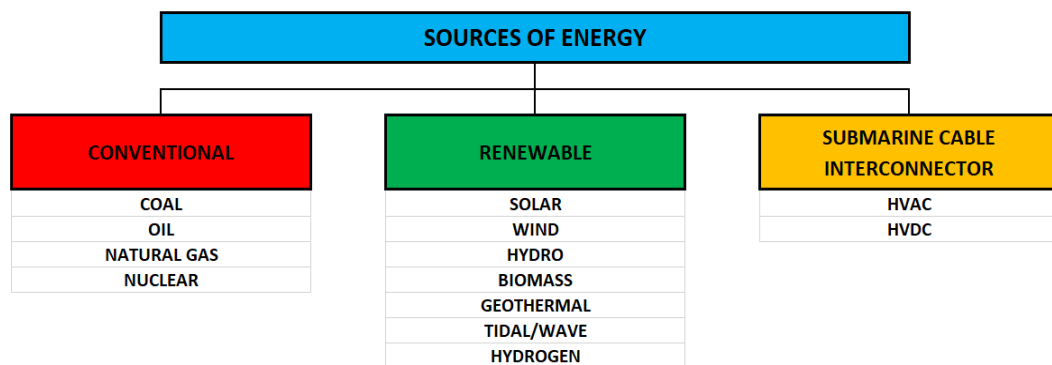


Figure 3.1: World Electricity Generation, 2020 [5]

3.1.1 Non-Renewable (Conventional) Energy Sources

The most striking feature of this group of energy resources is that they are non-renewable; they can be used once and are exhausted. Although they can be reproduced by discovering new reserves, one day, they will indeed become extinct. These are; Coal, Oil (TRNC's Existing Power Plants), Natural Gas, and Nuclear resources.

3.1.2 Renewable Energy Sources

Renewable energy sources are defined as the ability to renew themselves at an equal rate to the energy taken from the energy source or faster than the depletion rate of the resource. These are; Solar, Wind, Hydro, Geothermal, Biomass, Tidal, and Hydrogen.

3.1.3 Submarine Cable Interconnector

An electricity interconnector runs under the sea, underground or via overhead cabling, to connect the electricity systems of two countries. It allows the trading and sharing of surplus electricity. Inter-connector cables are being laid to move energy freely throughout countries, thereby ensuring the security of supply. Sharing energy between countries reduces the frequency and severity of high price spikes and smoothes the supply/demand timelines.

3.2 Available Sources in TRNC

Available sources in TRNC can be grouped in three. These are; Existing Power Plants with Fuel Oil, Natural Gas, and Submarine Interconnector Cable.

3.2.1 Existing Power Plants

Heavy fuel oils are mainly used as a marine fuel, and HFO is the most widely used marine fuel, and older steam locomotives and oil-fired power plants also generate energy from heavy fuel oils. They are black.

HFO can be divided into three groups according to their sulfur content; Which are "High sulfur fuel oil (HSFO) 3.5%, Low sulfur fuel oil (LSFO) 1.0%, Ultra low sulfur fuel oil (ULSFO) 0.1%". Both of the existing power plants in TRNC are working with Low sulfur fuel oil (1.0%)

Table 3.2: TRNC's Existing Power Plants [29]

Plant Specification				
Owner	Generation Technology	Number of Units	Total Installed Capacity (MW)	Total Operational Capacity (MW)
Teknecik (Kıb-Tek)	Steam Turbine	2	120	110
	Intenal Combustion	8	140	120
Kalecik (AKSA)	Intenal Combustion	8	136	98
	Heat-Waste	1	8	8

3.2.1.1 Teknecik Power Plant

Teknecik is a government-owned (Kıb-Tek) Power Plant with 8 x 17 MW Diesel Engines and 2 x 60 MW Steam Turbines, with a total of 256 MW Installed Capacity, located in Kyrenia.



Figure 3.2: Teknecik Power Plant

Jenkins G.P., Özbafı A. (2015). The willingness to pay by households for improved reliability of electricity service in North Cyprus. *The existing plants should have been replaced by new, more efficient plants much earlier. The return on such investment both in terms of consumer satisfaction and in terms of the overall economy is extremely high.* (P9) [43]

3.2.1.2 Kalecik Power Plant

Kalecik is a Private Company Owned Power Plant with 8 x 17.5 MW Diesel Engines and one 8 MW Waste-Heat Steam Boiler, with a total of 148 MW Installed Capacity, located in İskele. AKSA has a Power Purchase Agreement (PPA) in the Take-and-Pay Contract, including a 700 GWh annual purchase guarantee, with the rental price of 0.038 USD/KWh (incremented annually by CPI). However, the contract is expected to expire in 2024 March. Because of the contract termination after the first quarter of 2024, Kalecik is not considered an installed capacity in this study.



Figure 3.3: Kalecik Power Plant

3.2.2 Natural Gas

Natural gas is a naturally occurring hydrocarbon gas mixture consisting of methane and commonly including varying amounts of other higher alkanes, and sometimes a small percentage of carbon dioxide, nitrogen, hydrogen sulfide, or helium. Natural gas

is colorless, odorless, and explosive, so a sulfur smell is added for early detection of leaks.

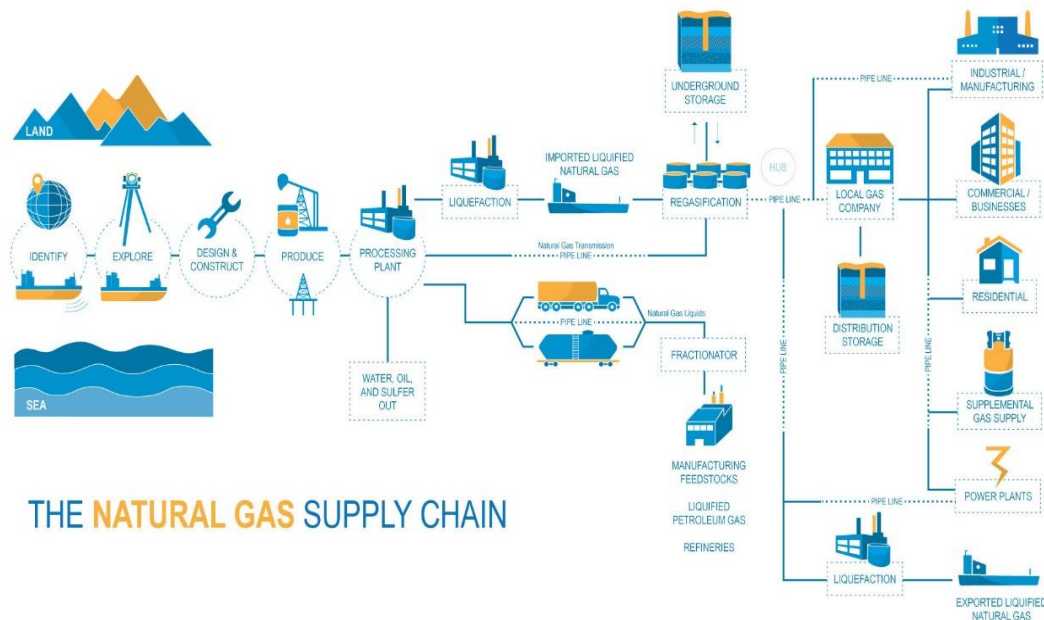


Figure 3.4: Natural Gas Supply Chain [13]

Natural gas is a non-renewable hydrocarbon used as energy for heating, cooking, and electricity generation. Natural gas produces negligible amounts of sulfur oxides (SO_x), mercury (Hg), and particulate matter (PM₁₀) when burned.

3.2.2.1 Pipeline Gas

There are three major types of pipelines: the gathering system, the interstate pipeline system, and the intrastate pipeline system. The gathering system consists of low-pressure, small diameter pipelines transporting raw natural gas from the wellhead to the processing plant. Interstate pipelines carry natural gas across state boundaries, in some cases clear across the country. Intrastate pipelines, on the other hand, transport natural gas within a particular state. But, the construction of a natural gas pipeline on earth is a costly and challenging business. According to BOTAŞ, a Gas Pipeline from

Turkey to TRNC costs 1 Billion USD, approximately three times more than LNG Project. Because of this, the pipeline project is not taken as an option in this study. [33]



Figure 3.5: Natural Gas Pipeline

3.2.2.2 LNG (Liquified Natural Gas)

When natural gas is cooled down to -162°C at atmospheric pressure, it condenses into the liquid phase called "Liquefied Natural Gas." LNG is an odorless, colorless, and non-toxic liquid phase fuel. It is transported and stored in the liquid phase, and it is offered for consumption in the gas phase. With LNG, much natural gas can be stored in liquid form by reducing its volume approximately 625 times under low pressures. This feature makes it convenient to transport natural gas by ship, truck, and tanker to places where it is not technically and economically possible to transport it through pipelines. [26]

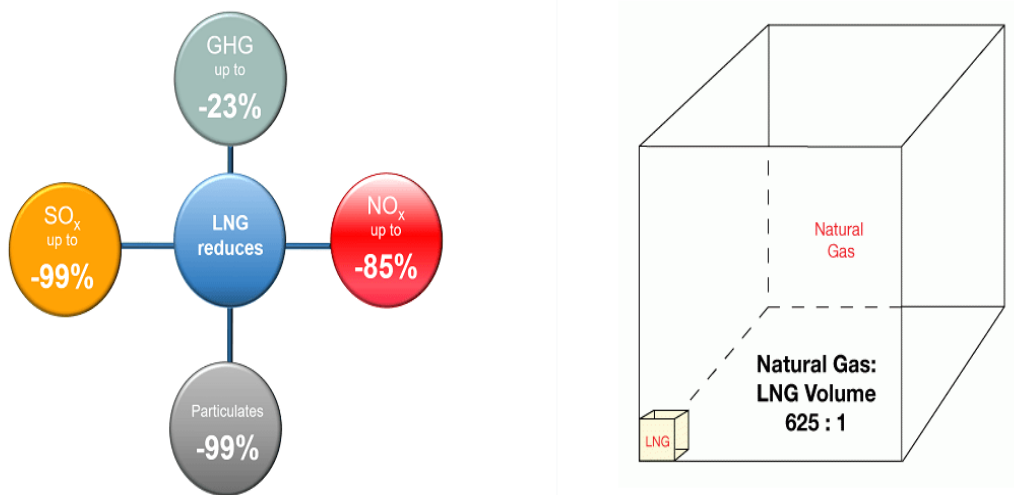


Figure 3.6: LNG Emissions & Volume [12]

The LNG industry, which has grown significantly in recent years, has begun to play an increasingly important role in the international gas trade. With the increase in the number of producer and consumer countries globally, the global trade network in the LNG value chain has matured. LNG tankers/cargo traffic has also become widespread in maritime trade, parallel with liquefaction and regasification capacities. [40]

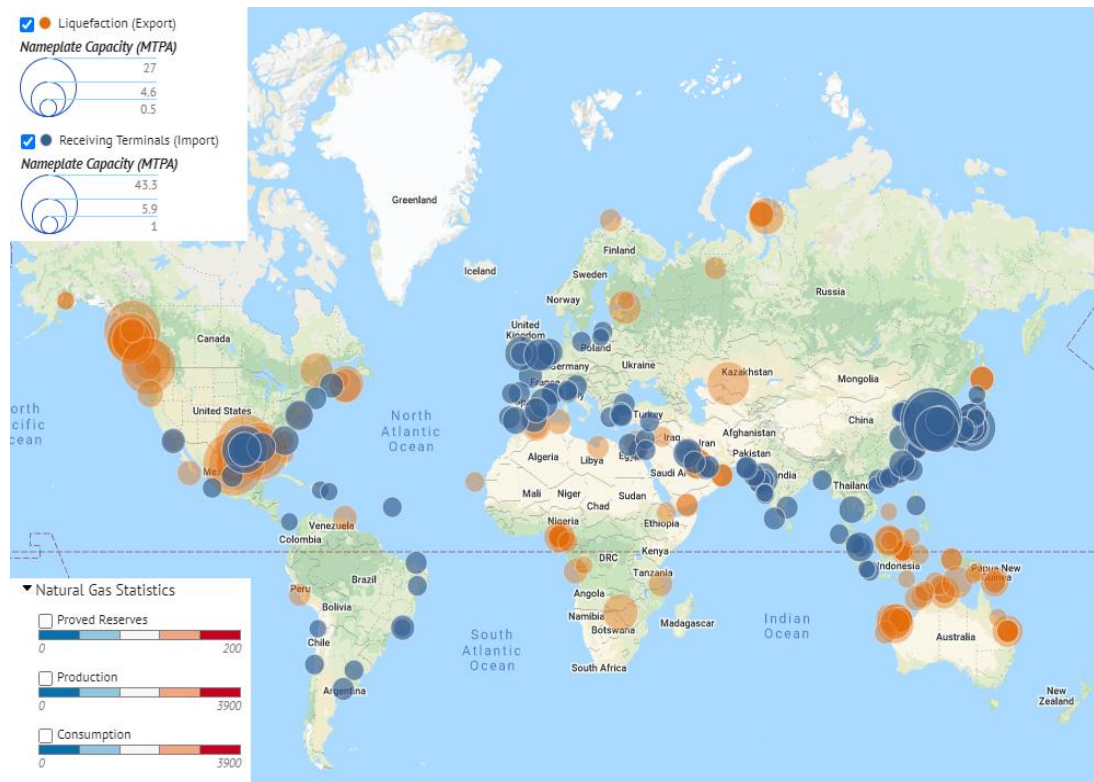


Figure 3.7: Global LNG Liquefaction Plants and Receiving Terminals [38]

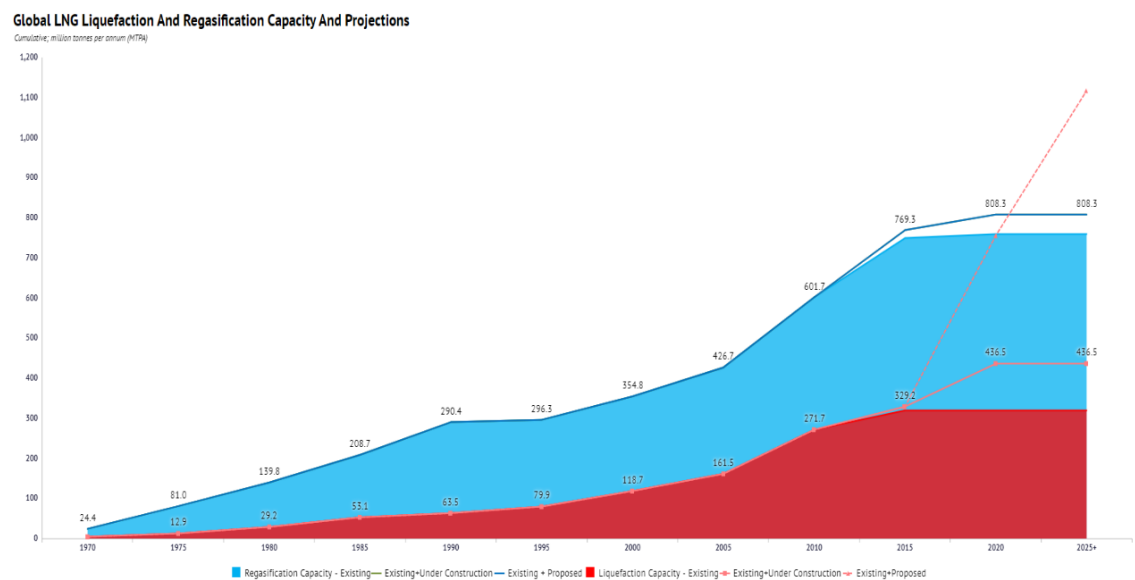


Figure 3.8: Global LNG Liquefaction & Regasification Capacity and Projections [39]

It is only possible for natural gas to reach many points where pipeline construction is difficult and costly, with LNG contributing to the supply security of the producing countries. For the same reason, LNG is an indispensable dimension of supply security as it provides a significant source diversification opportunity compared to pipe gas for consumer countries. Thanks to the flexibility offered by sea routes compared to terrestrial transport, LNG is considered the primary catalyst of the 'World natural gas market.' LNG is still in its nascent stage, as it connects regional gas markets that have developed separately and are in isolation. [10]



Figure 3.9: LNG FSRU & LNG Carrier

Existing/Under Construction/Planned Large Scale LNG Regasification Terminals at Eastern Mediterranean Region is below,

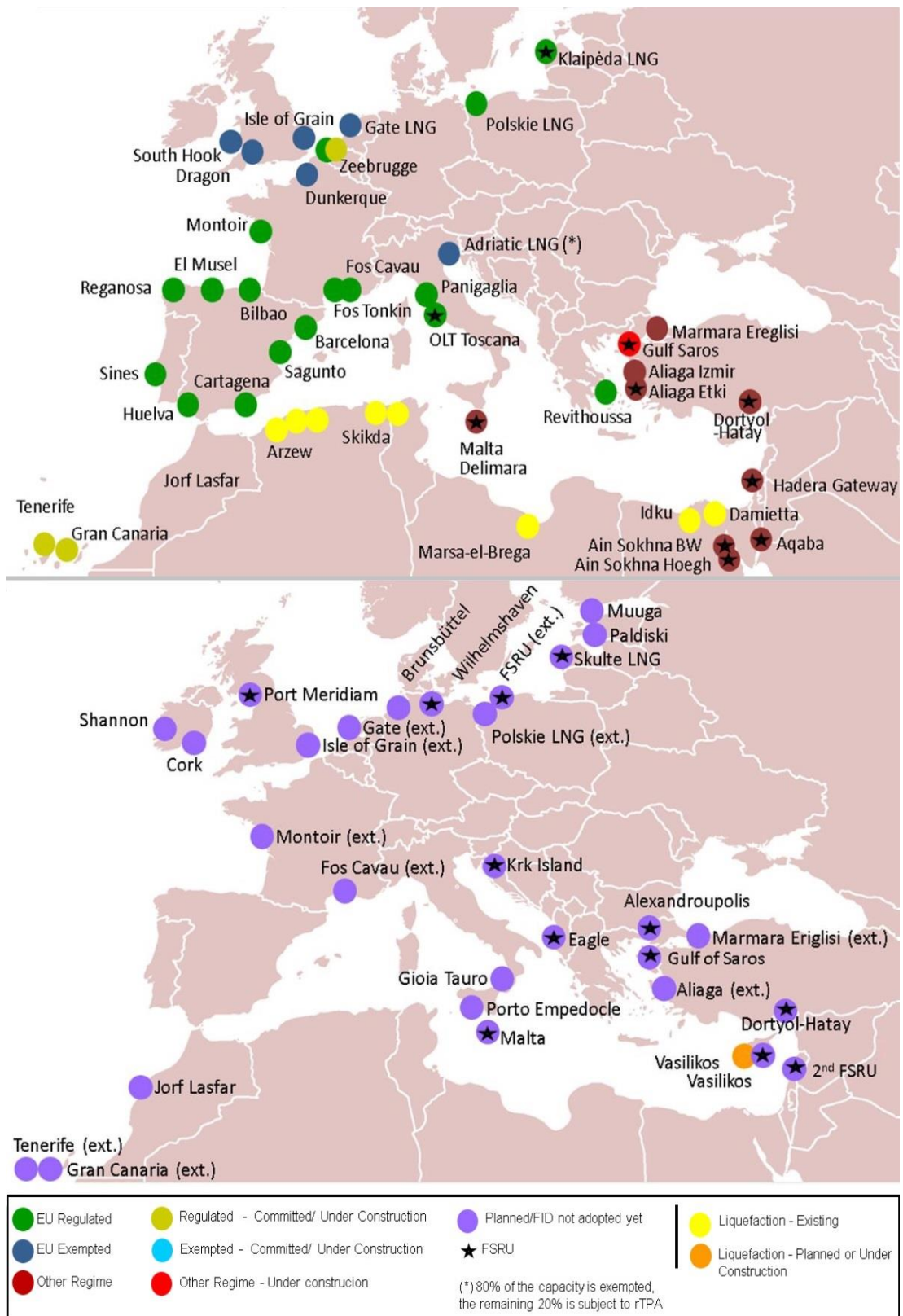


Figure 3.10: Existing/Planned Large Scale LNG Regasification Terminals at EMR[20]

LNG to power production methods are listed below,

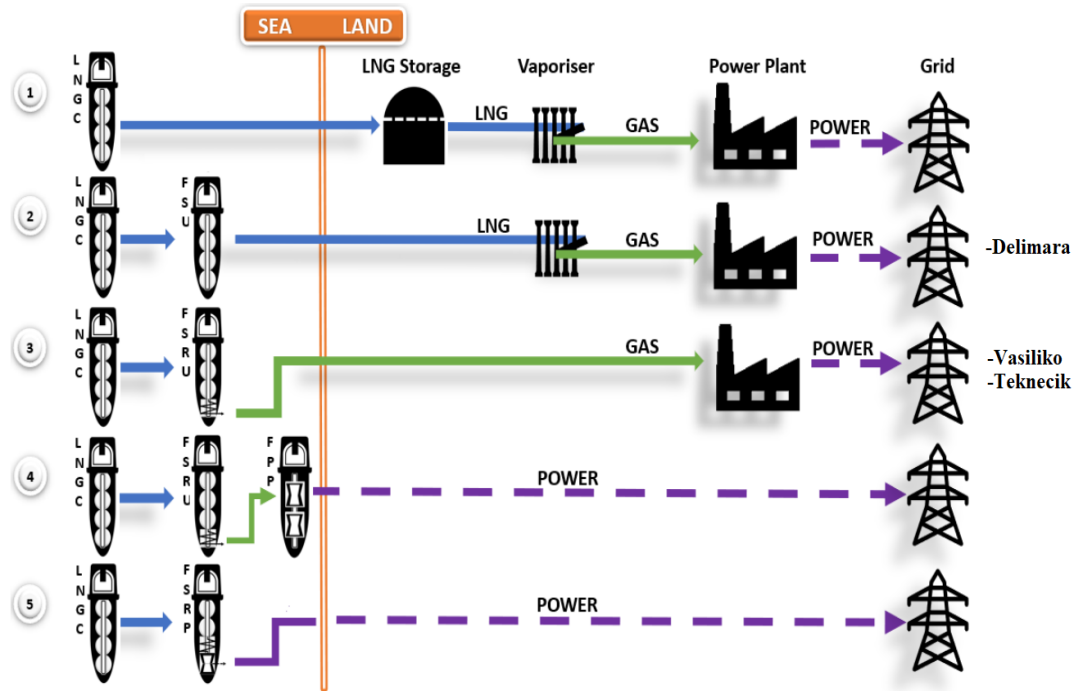


Figure 3.11: Global LNG Liquefaction & Regasification Capacity and Projections.[15]

Teknecik Power Plant LNG Project (TRNC), Vasiliko Power Plant (South Cyprus) both use the same (third) method, while Delimara Power Plant (Malta) uses the second method.

3.2.3 Submarine Cable Interconnector

Inter-connector cables are being laid to move energy freely throughout countries, thereby ensuring the security of supply. Sharing power between countries reduces the frequency and severity of high price spikes and smoothes the supply/demand timelines.[22]

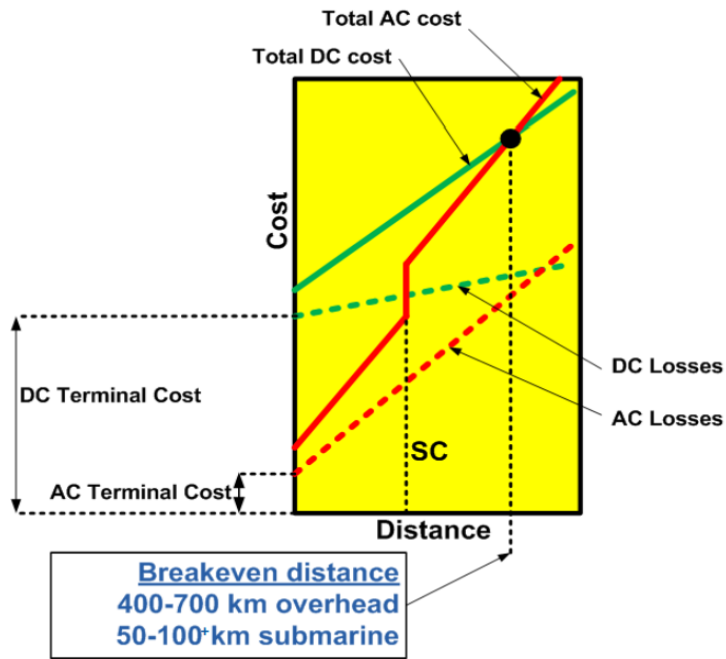


Figure 3.12: Break-Even Distance for Interconnector Power Cables [46]

Typically for a route length less than 80km, AC would be the most economical system as it is cheaper, but the distance limits it can go. Longer distances have to be undertaken using DC technology.

A comparison between DC and AC Interconnectors is presented in the table below,

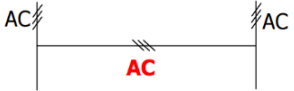
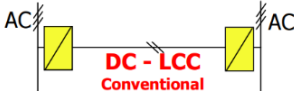
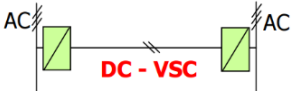
Transmission solution	Advantages	Drawbacks/Limitations
	- simple (no conversion) - no maintenance - high availability	- heavy cable - limited to 50-150 km - rigid power control - require reactive compensation
	- less no. of cables, lighter - no limits in length - low losses - good power control - very high transmission power	- needs strong AC networks - cannot feed isolated loads - polarity reversal for reverse flow - large space occupied - special equipment (trafo, filters)
	- can feed isolated loads (oil platforms, wind parks, small islands, etc.) of medium power - modularity, short delivery time - small space and environmental impact - no polarity reversal for reverse flow - standard equipment	- higher conversion losses - limited experience - limited power

Figure 3.13: Comparison Between AC, DC - Line Commutated Converter, DC - Voltage Source Converter Interconnectors [16]

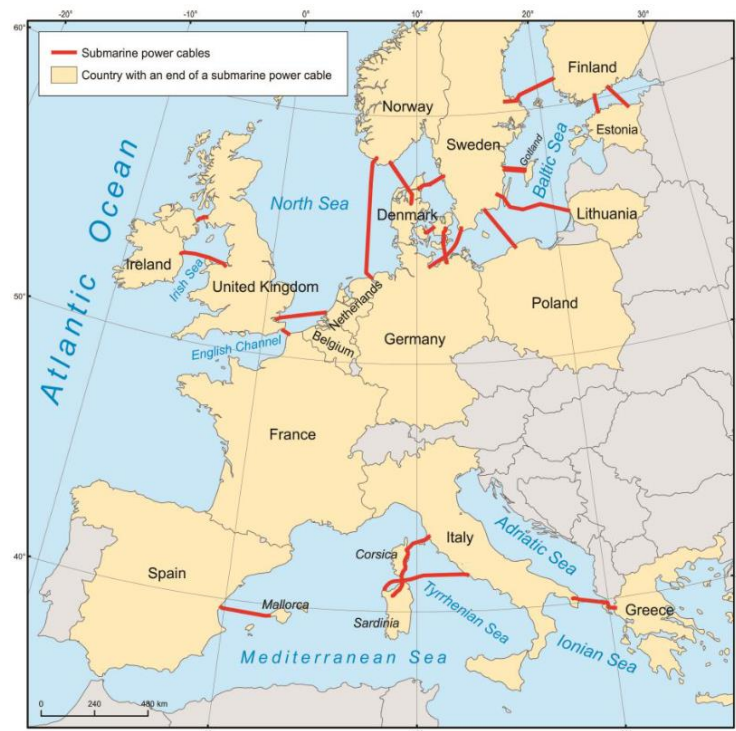
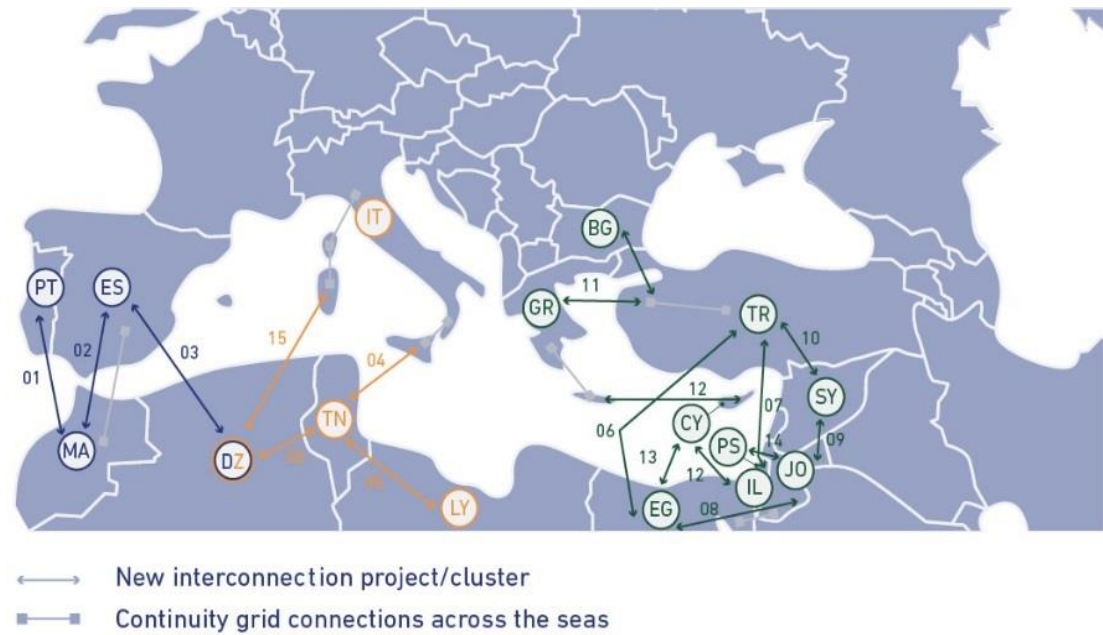


Figure 3.14: Existing Submarine Interconnectors at Europe [16]



NO.	Interconnection project/cluster	Capacity (MW)	NO.	Interconnection project/cluster	Capacity (MW)
1	MA-PT (Morocco-Portugal)	1000 MW	9	JO-SY (Jordan-Syria)	800 MW
2	MA-ES (Morocco-Spain)	900 MW	10	SY-TR (Syria-Turkey)	600 MW
3	DZ-ES (Algeria-Spain)	1000 MW	11	GR-TR-BG (Greece-Turkey-Bulgaria)	500/500 MW
4	TN-IT (Tunisia-Italy)	600 MW	12	IL-CY-GR (Israel-Cyprus-Greece)	1000/1000 MW
5	DZ-TN-LY (Algeria-Tunisia-Libya)	1000/2000 MW	13	EG-CY (Egypt-Cyprus), joint with project 12	1000 MW
6	TR-EG (Turkey-Egypt)	3000 MW	14	JO-PS (Jordan-Palestine)	100 MW
7	TR-IL (Turkey-Israel)	2000 MW	15	DZ-IT (Algeria-Italy)	1000 MW
8	EG-JO (Egpy-Jordan)	550 MW			

Figure 3.15: Existing/Planned Submarine Interconnectors at EMR Region [17]

3.2.3.1 HVAC Interconnector (High Voltage Alternating Current)

AC is the cheaper interconnector technology, but the range limits it typically for a route less than 80km. AC interconnectors are "three-phase" cables laid either as bundles in a three-core formation or three separate cables. The HVAC interconnector doesn't meet the TRNC's requirements because they have a limited range and capacity. And costs two times more than an HVDC Interconnector, according to TEİAŞ, and is not taken as an option in this study. [23][24][25]

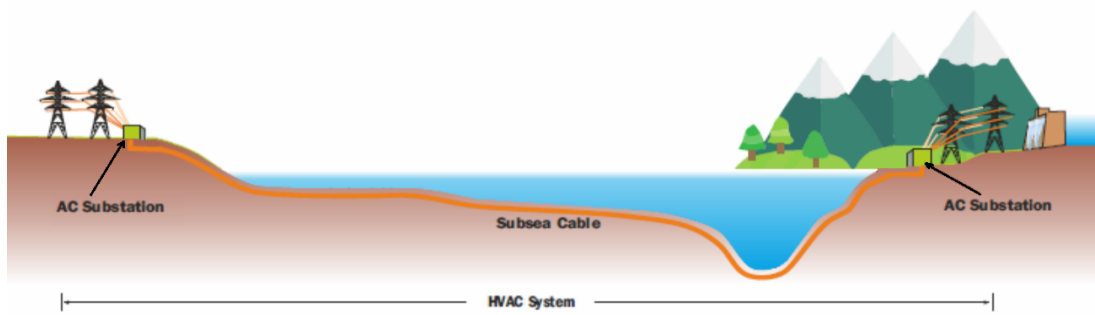


Figure 3.16: Submarine High Voltage Alternating Current Interconnector

3.2.3.2 HVDC Interconnector (High Voltage Direct Current)

High-voltage direct current transmission requires a converter at each end of a direct current line to interface to an existing alternating grid. There are two main types: Mono-polar and Bi-polar. Generally, they consist of two conductors, either laid separately, bundled together, or in a co-axial arrangement. HVDC interconnectors can carry a higher amount of energy to longer distances. [21][25]

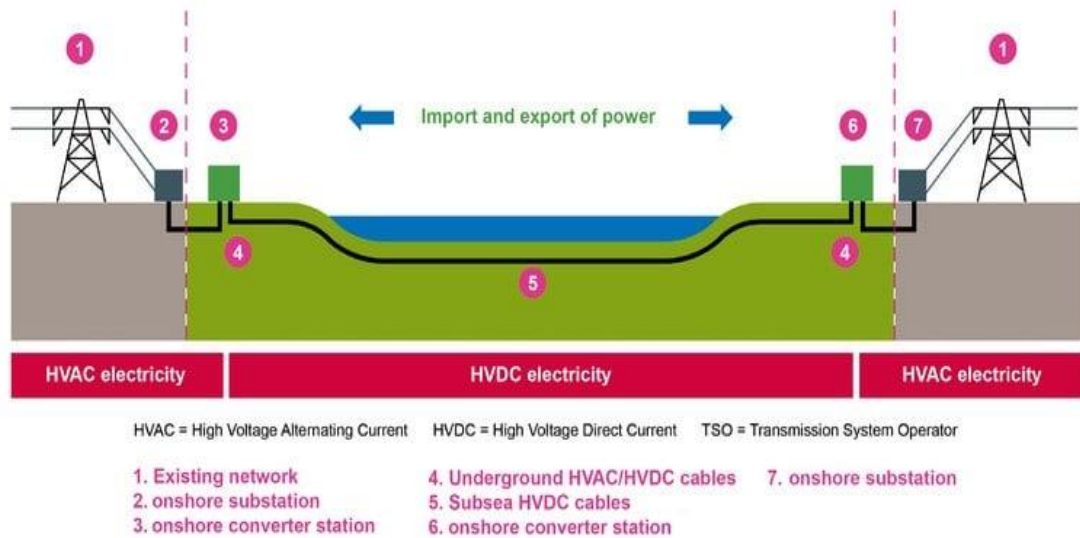


Figure 3.17: Submarine High Voltage Direct Current Interconnector

On the other hand, the interconnector system is the electricity transportation system used to transmit energy from the production points to the end-users in a quality, reliable and uninterrupted manner.

Rasheed A., (August 2019). Feasibility Analysis of Turkey - North Cyprus Submarine Electric Interconnector Cable Including Externalities. *The submarine electric interconnector cable tends to be the cheapest source if Turkey agrees to invest the capital cost, shared investment of Turkey and North Cyprus is the second cheapest, while the option of North Cyprus sole investment on project stands third in the cheaper source of energy order. All three of aforementioned options are still cheaper than the isolated generation option for North Cyprus.* (P57-58) [44]

Unfortunately, according to the Ministry of Energy of Turkey, such a Submarine Cable Interconnector will be TRNC's sole investment. And this is not the only difficulty in front of this investment, and there are also political difficulties.

With the observer membership agreement signed on January 14, 2016, TEİAŞ became the first observer member of ENTSO-E (European Transmission System Operators Network for Electricity), connections made through Bulgaria and Greece, TEİAŞ has been interconnected with the ENTSO-E network. The net transfer capacity in import and export is allocated as annual, monthly, and daily auctions.

ENTSO-E has 42 transmission system operator members from 35 countries and aims to create a standard internal electricity market model with greater grid integration of the European Union countries. Thereby increasing the security of supply in energy, maximizing the efficiency of generation, transmission, distribution, and use of energy, minimizing environmental problems, and improving the energy diversity of the grids.

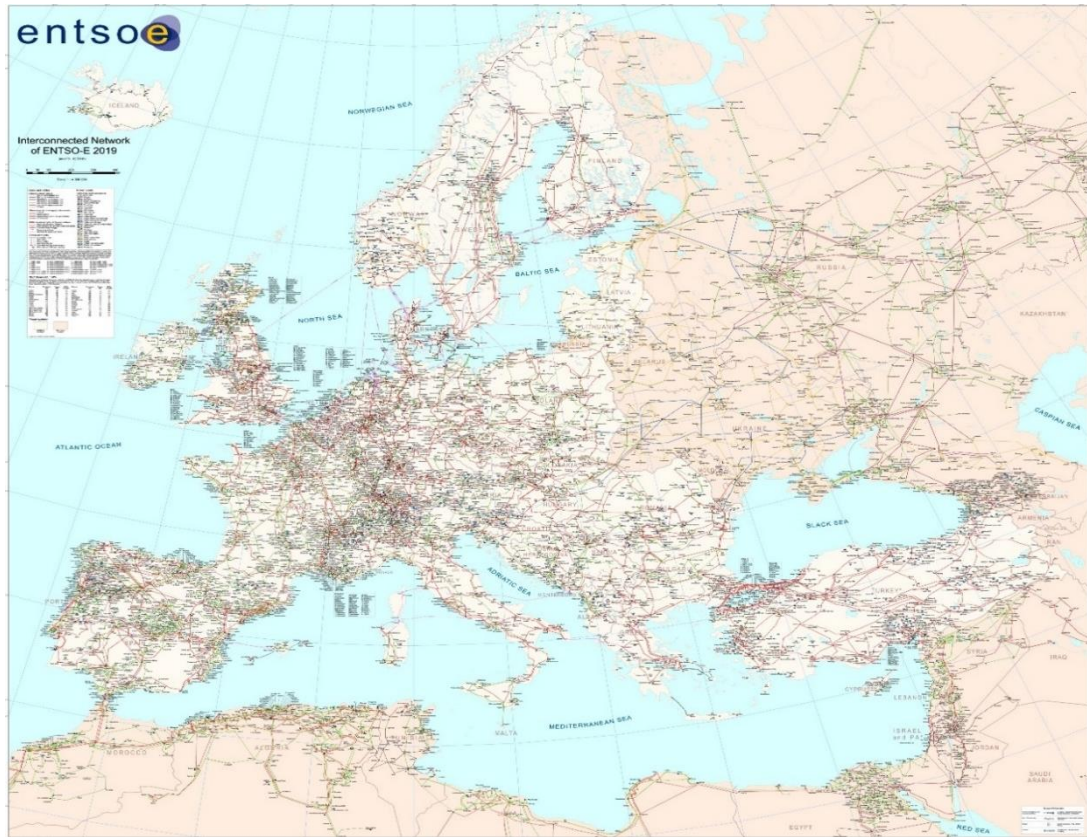


Figure 3.18: ENTSO-E Interconnections Grid Map [19]

With the integration of the Turkish Electricity System into the ENTSO-E system, synchronous parallel operation with countries other than its western neighbors is only possible if these countries also fulfill specific standards and procedures and "within the framework of ENTSO-E's approval."

Back-to-Back, DC connection, unit routing, and isolated zone feeding methods are used in energy exchanges with third countries of a country that started to work in parallel with the ENTSO-E system. Energy exchanges to be made with these methods are subject to the permission of ENTSO-E.



Figure 3.19: ENTSO-E Interconnections Grid Map for EMR [19]

Interconnector offers tremendous advantages to increase energy supply security and network stability to minimize environmental problems by maximizing the use of renewable energy by using the energy diversity of the networks and with the possibility of connecting to the energy market pool when instant capacity is needed or when energy prices are below production costs. In this respect, the technical advantages of interconnection are not open to discussion, but the financial and the economic sides need to be examined well. This project is reviewed in this study.

There are two things to note at this point. First of all, a possible interconnected connection model/agreement should be designed to allow "double-sided energy transfer" under all circumstances to get the maximum benefit from solar energy, especially during daylight hours. Secondly, an agreement should be made in a format that will allow electricity prices to be lowered by supplying the needed power over interconnection when generation costs are more expensive than the wholesale energy prices in the shared energy pool.

Chapter 4

SCENARIOS

4.1 Introduction

The average of the TRNC's last 15-year monthly electricity production data is projected in Figure 4.1 below to show how the load curve differs according to the seasons.

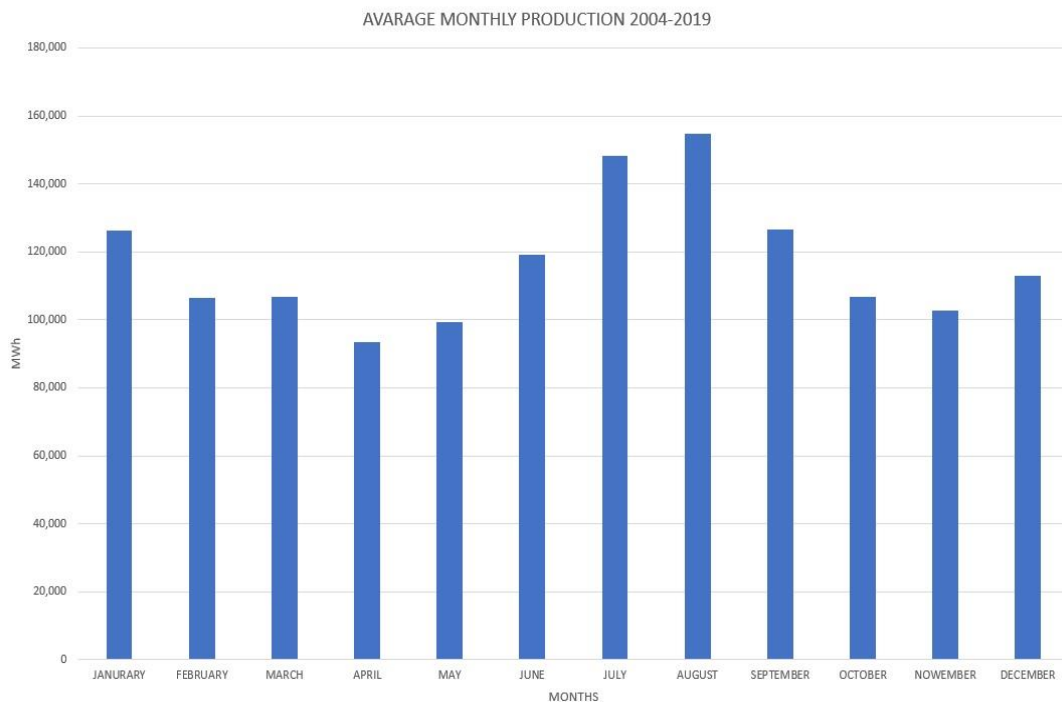


Figure 4.1: TRNC's Average Monthly Electricity Production between 2004-2019 [29]

TRNC's Annual Energy Consumption between 2004-2019 is illustrated in figure 4.2 below. As can see from the figure, there is an increasing trend in consumption which has an average of 5% annually.

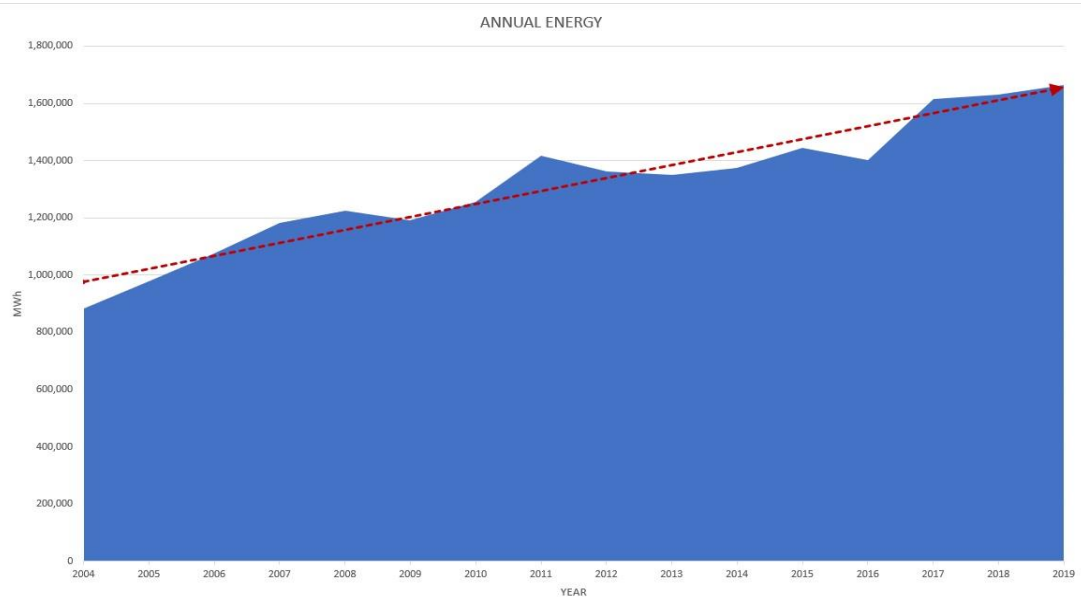


Figure 4.2: TRNC's Annual Energy Consumption 2004-2019 [29]

TRNC's Annual Peak Power between 2004-2019 is illustrated in figure 4.3 below. As can be seen from the figure, same as the Annual Energy Consumption, there is an increasing trend on the peaks with an average of 5% annually.

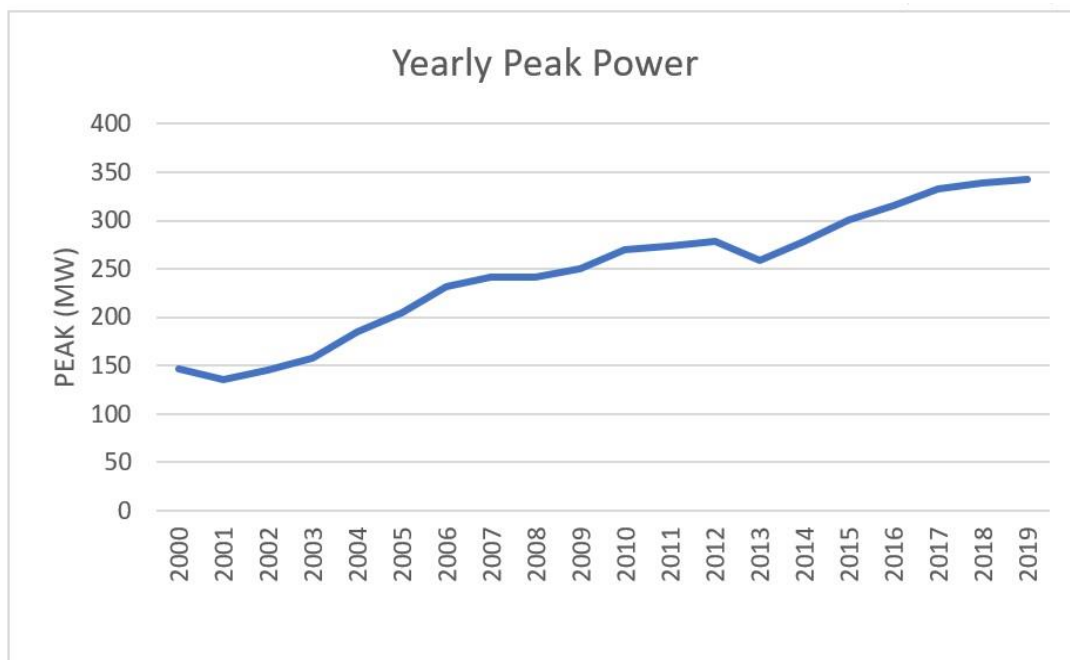


Figure 4.3: TRNC's Annual Peak Power 2004-2019 [29]

4.2 Interconnector Scenario

Interconnector scenario consists of a 2-stage Submarine HVDC Interconnector investment, in which the first stage is 400MW and the second stage of 400MW in total 800MW capacity. In this scenario, to keep the balance between the two networks and to ensure supply security. Diesel Engine capacity needs to be increased simultaneously with the interconnector investment to prevent power outages in the event of a malfunction like the one experienced in the water pipeline project in 2020. Figure 4.4 illustrates the projection of annual electricity production by generation types for the years 2021 to 2035 below;

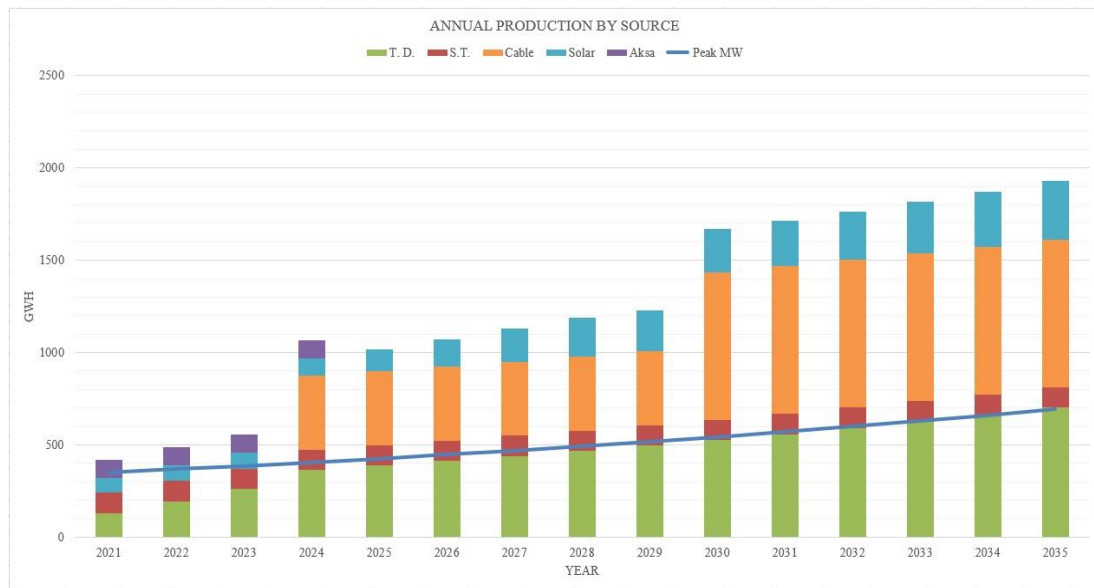


Figure 4.4: Annual Production by Source 2021-2035

Figure 4.5 illustrates the projection of annual power production represented in percentages according to the generation types for years 2021 to 2035 below;

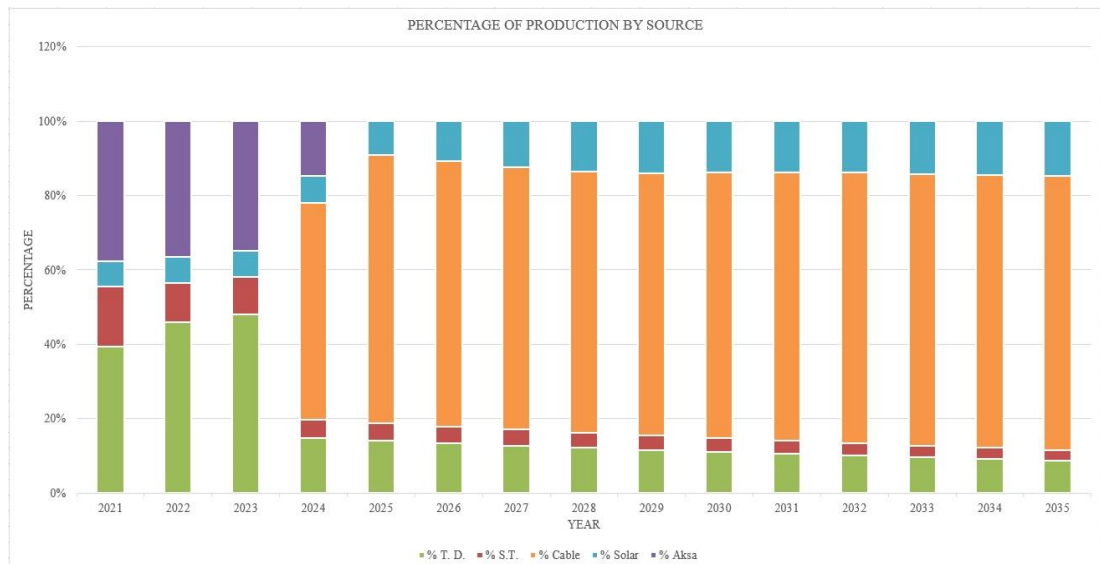


Figure 4.5: Percentage Distribution of the Annual Production by Sources 2021-2035

4.3 LNG Scenario

LNG scenario consists of a 138,000m3 FSRU Ship, Mooring System, Gas Pipeline between the Teknecik and Kalecik Power Plants, conversion of the existing Single-Fuel (HFO) Diesel Engines to Double-Fuel (HFO and LNG), and new CCGT investments of 150 MW each. Figure 4.6 illustrates the projection of annual electricity production by generation types for the years 2021 to 2035 below;

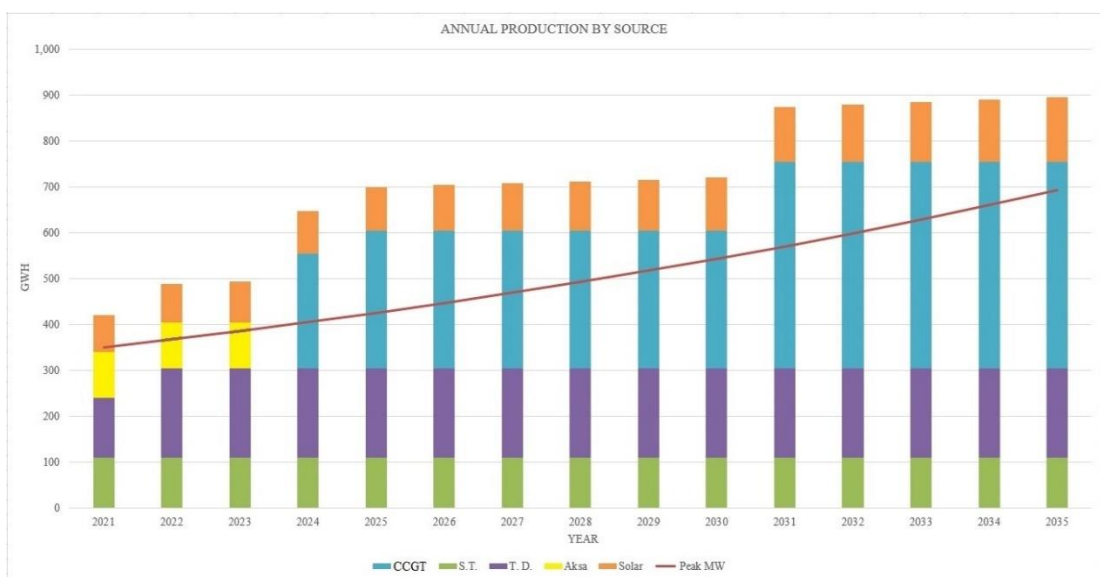


Figure 4.6: Annual Production by Source 2021-2035

Figure 4.7 illustrates the projection of annual power production represented in percentages according to the generation types for years 2021 to 2035 below;

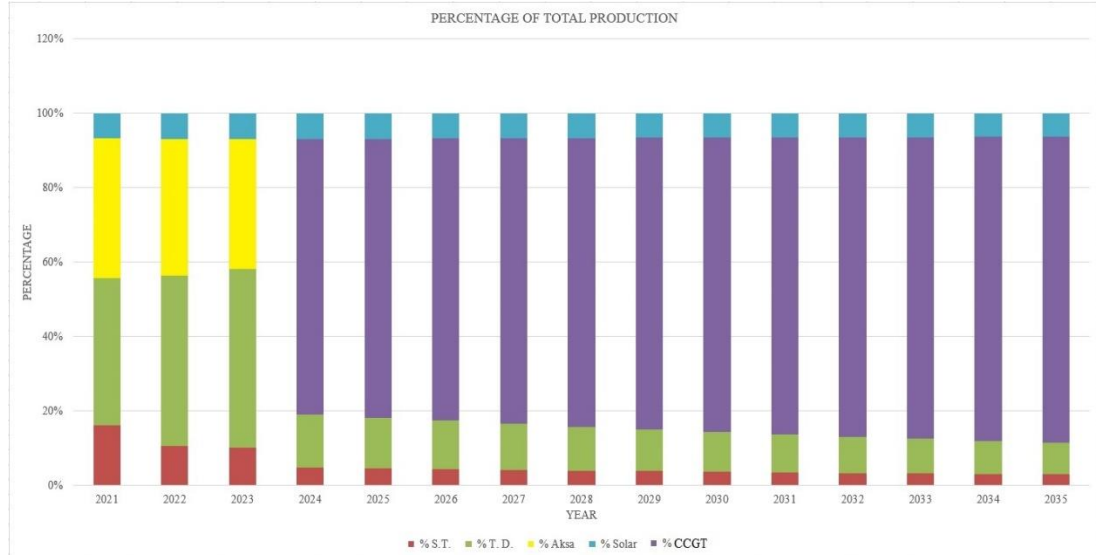


Figure 4.7: Percentage Distribution of the Annual Production by Sources 2021-2035

4.4 Diesel Scenario

Diesel scenario consists of new Diesel Generator investments only, according to the demand on energy. Figure 4.8 illustrates the projection of annual electricity production by generation types for the years 2021 to 2035 below;

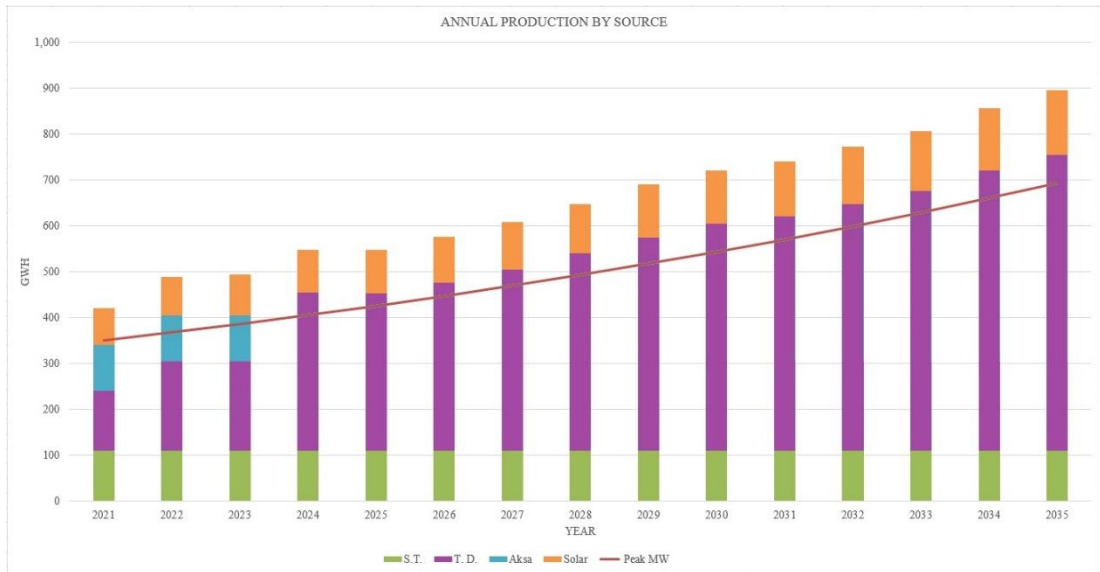


Figure 4.8: Annual Production by Source 2021-2035

Figure 4.9 illustrates the projection of annual power production represented in percentages according to the generation types for years 2021 to 2035 below;

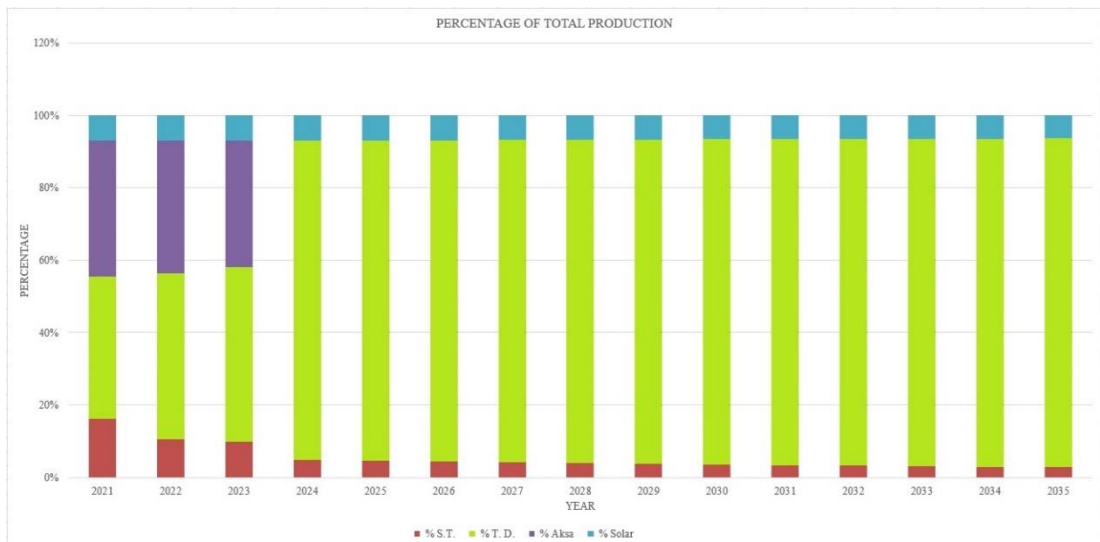


Figure 4.9: Percentage Distribution of the Annual Production by Sources 2021-2035

Chapter 5

COST-EFFECTIVENESS ANALYSIS

5.1 Introduction

Cost-effectiveness analysis refers to a systematic process that helps in comparing two or more courses of action by considering their relative costs and outcomes or effects. This concept is applied in many aspects of life, such as electricity generation systems, healthcare systems, and national defense policy when the priority is to keep costs low, systems efficient, and maximize benefits. Cost-effectiveness analysis (CEA) tends to estimate costs and benefits through methods other than dollar amounts. Effectiveness is measured in a unit applicable to the situation, whereas CBA is measured purely in dollars. One of the fields where cost-effectiveness analysis is mostly used is the electricity generation systems.

5.2 Inputs and Presumptions

This study was modeled dynamically based on data provided by K1b-Tek, TEİAŞ, BOTAŞ, EÜAŞ, and the NBT LNG Price database for the Mediterranean region specific for the TRNC.

5.2.1 Time Scope

The proposed project is assumed to start in 2021 with a 15-year concession but excludes any extension limitations.

5.2.2 Demand for Electricity

The demand for electricity in TRNC is assumed to increase by 5% per year, according to the last 15 years' data. The peak hour demand for electricity generation capacity in 2019 is 342 MW, and the total electricity demand is about 1,664 GWh. Therefore, the minimum installed operational capacity should be more than the peak demand for a reliable electricity generation system without interruptions and blackouts.

On the other hand, estimations are not 100% certain, and always there is a possibility of malfunction. So, the operational installed capacity should be more than the maximum peak hour demand. The reserve installed capacity should be equal to or more than the capacity of the largest generator unit, at least in case of emergencies and unexpected events.

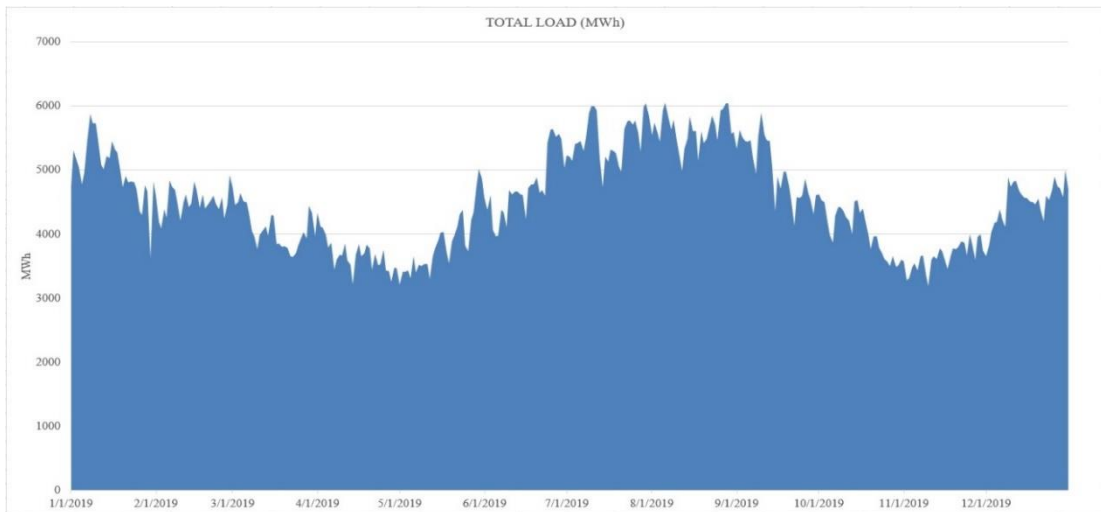


Figure 5.1: TRNC's Annual Total Load Curve 2019

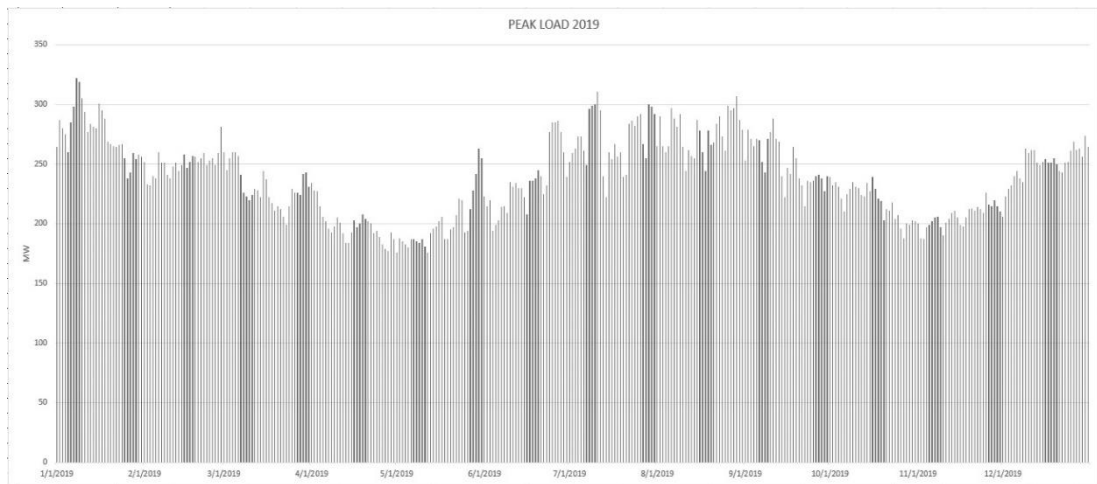


Figure 5.2: TRNC's Annual Peak Load Curve 2019

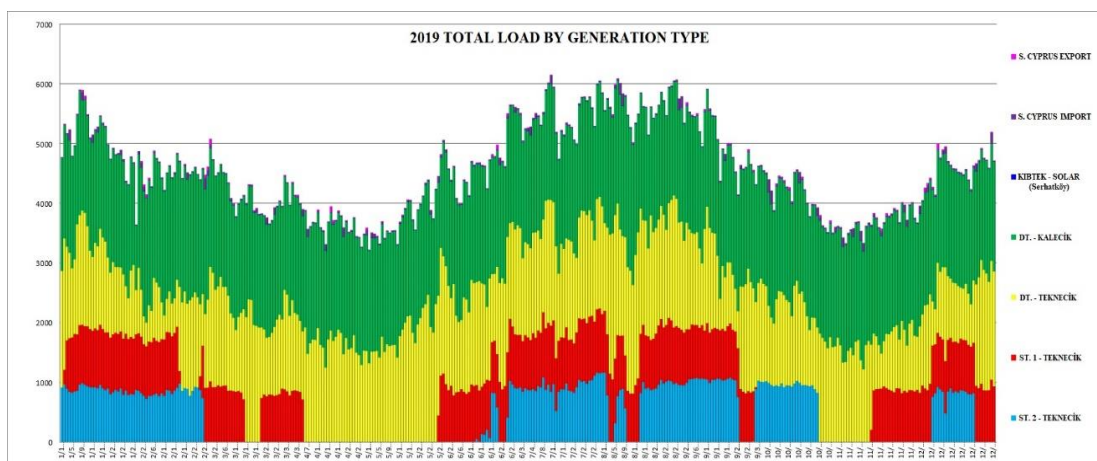


Figure 5.3: TRNC's Annual Total Load by Generation Type 2019

It's seen from Figure 5.4 that the Diesel Engines are used as a baseload generator because of their higher efficiency and lower fuel consumption, and the Steam Turbines are used to meet the peak loads.

Zubair O.U., (July 2021). Modeling Renewable Electricity Generation for Northern Cyprus (TRNC), *It can be concluded that in order for TRNC to be able to make optimal use of their renewable energy resources, which can be a better solution to their current energy challenges, they must abandon baseload generation.* (P18) [45]

Unfortunately, Cyprus is an electrically isolated island from the mainland and faces many grid problems due to renewables. Especially solar energy systems cause voltage,

frequency, and harmonics. Due to this problem, without being interconnected to the mainland, without battery storage systems and smart grid infrastructures, it's impossible to do the baseload generation from renewables.

The peak hour demand for the base period of the project is 350 MW, and the total electricity demand is 1,749 GWh. Therefore, annual electricity demand and the peak hour forecast for the project's lifespan are estimated according to the 5% increase in demand and shown in Figure 5.5 below.

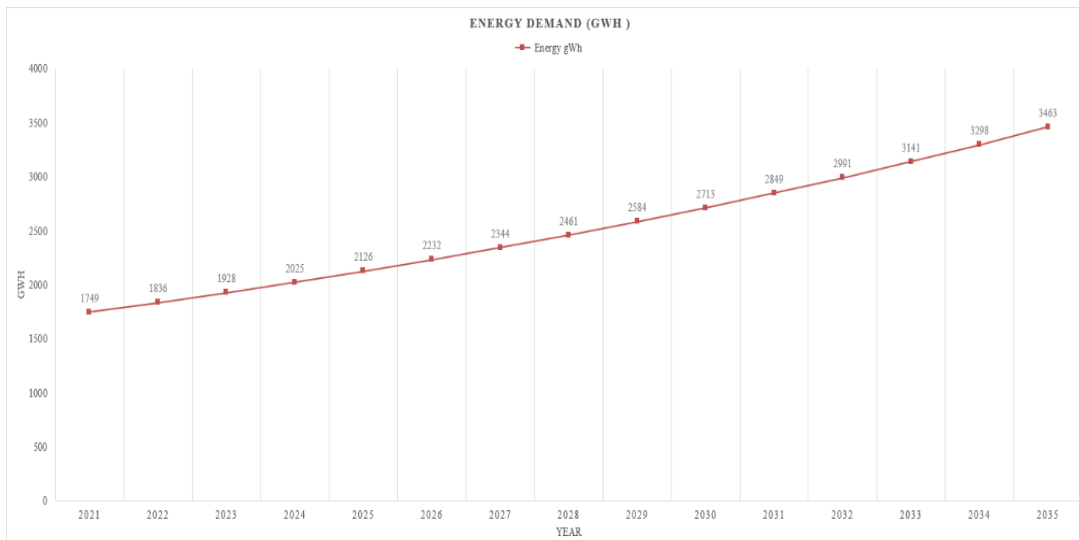


Figure 5.4: TRNC's Energy Demand Forecast 2021-2035

5.2.3 Technical Parameters

Technical details of generation types, fuel costs, investment costs, operating & maintenance costs, and the other inputs used in the study are provided in this section.

Table 5.1: Parameters used in this study.

PARAMETERS		REFERENCE		REFERENCE	
LOAD FACTOR	56%	[29]	Cable initial investment cost million \$	363.2	[25]
Back-up (of total capacity without back-up)	15%	[29]	Cable initial investment cost with cost overruns million \$	363.2	[25]
Freight Fuel Oil \$/tonne	33	[29]	Cable annual O&M cost million \$	12.50	
Freight LNG \$/tonne	30	[13]	Discount rate for Cable Investment	10.0%	[25]
Current fuel cost \$/tonne	441	[29]	Cable, LNG and dual-fuel plants pay-back period	15	
Average fuel cost since 01.01.2011 \$/tonne	412	[29]	Annual cable cost for 400 MW million \$	47.75	[25]
Total fuel cost with freight \$/tonne	449		Cost conversion factor from 400 MW to 800 MW	1.47	[25]
Average LNG cost since 01.01.2011 \$/tonne	232	[12]	Annual cable cost for 800 MW million \$	70.19	
Total LNG cost with freight \$/tonne	262		Tetaş wholesale price including transmission €/kWh	5.63	[30]
S.T. fuel consumption (including oil) gr/kWh	285	[29]	Cable losses %	3.5	[25]
T. D. fuel consumption (including oil) gr/kWh	210	[29]	Investment cost overrun (for cable)	0%	
LNG fuel consumption with T.D. (including oil) gr/kWh	160	[33]	Investment cost overrun (for LNG regasification)	0%	
LNG fuel consumption with S.T. (including oil) gr/kWh	220	[33]	Fuel - LNG price correlation	0.945	STRONG
LNG fuel consumption with CCGT (including oil) gr/kWh	140	[33]	Fuel - TC sale price correlation	0.861	STRONG
Expected increase in electricity demand	5%	[29]			
Investment cost of a NEW dual-fuel 17.5 MW plant \$	11,000,000	[29]	Price of solar energy \$/kWh	0.06	
NEW T. D. annualized capital cost \$/MW	73,436		% solar of the total installed capacity with no back-up	20%	
Investment cost of the EXISTING 17.5 MW plant \$	5,000,000	[29]	Solar load factor	19%	
EXISTING T. D. annualized capital cost \$/MW	33,380				
CCGT investment cost \$/MW	900,000	[33]	LCOE WITH CABLE (\$/kWh)	0.1271	-113,422,002
CCGT annualized capital cost \$/MW	105,147	[33]	LCOE WITHOUT CABLE (\$/kWh)	0.1014	331,991,712
Total CCGT capacity (2022-2023) MW	150		DIFFERENCE (\$/kWh)	0.0257	
Total CCGT capacity (2024-2030) MW	300		TOTAL DIFFERENCE (\$)	459,732,832	
Total CCGT capacity (2031-2035) MW	450		TOTAL DIFFERENCE (TL)	3,861,755,792	
CCGT load factor	80%	[33]			
T.D. (existing plants) conversion cost to LNG \$	34,000,000	[33]			
T.D. (existing plants) conversion annualized cost to LNG \$	3,972,205	[33]			
S.T. (existing plants) conversion cost to LNG \$	10,000,000	[33]			
S.T. (existing plants) conversion annualized cost to LNG \$	1,168,295	[33]			
Investment cost of LNG \$	350,000,000	[33]			
Investment cost of LNG with cost overruns \$	350,000,000	[33]			
LNG annualized capital cost \$	48,390,341				
Annual Operating Cost of LNG FSRU \$	7,500,000	[11]			
S.T. variable cost (excluding fuel and labor) \$/kWh	0.003	[29]			
T. D. variable cost (excluding fuel and labor) \$/kWh	0.009	[29]			
CCGT variable cost (excluding fuel and labor) \$/kWh	0.006	[33]			
KIB-TEK total labor cost (excluding overtime, etc.) \$	9,450,371	[29]			
AKSA annual purchase guarantee (gWh)	700				
AKSA rental price \$/kWh	0.0382				
US CPI	2.50%	[35]			
Exchange rate \$/TL	8.4	[37]			
Discount rate for KIB-TEK investments	8.0%	[29]			

5.2.4 Investment Cost (CAPEX)

There are five types of investments in the project:

- Investment cost of Submarine Cable Interconnector
- Investment cost of FSRU & LNG
- The conversion cost of the existing diesel plants.
- Investment cost of CCGT Power Plant
- Investment cost of New Diesel Generators

5.2.5 Operational Expenditure (OPEX)

The operation cost of the project is divided into two categories of fixed and variable expenses. Fixed costs do not change during the project's lifespan, like the Operating and Maintenance with long-term contracts, regasification costs, and conversion costs of the existing plants to LNG. On the other hand, the variable costs depend on the

amount of energy generated. Fixed and Variable Costs are listed below tables for each Generation Type.

Table 5.2: Fixed & Variable Costs (Interconnector Scenario)

Year	FIXED COST mil. \$						VARIABLE COST mil. \$						Total Costs mil. \$					
	S.T.	T. D.	Aksa	Solar	Cable	Total	S.T.	T. D.	Aksa	Solar	Cable	Total	S.T.	T. D.	Aksa	Solar	Cable	Total
2021	2.7	11.0	26.7		60.3	100.8	39.3	75.9	74.1	7.7	0.0	196.9	42.1	86.9	100.8	7.7	60.3	297.7
2022	1.8	16.8	27.4		60.3	106.2	26.2	90.9	74.1	8.1	0.0	199.2	28.0	107.7	101.5	8.1	60.3	305.4
2023	1.6	21.7	28.1		60.3	111.7	26.2	99.8	74.1	8.4	0.0	208.6	27.8	121.6	102.2	8.4	60.3	320.3
2024	2.4	28.7	28.8		60.3	120.1	13.1	31.0	31.7	8.8	68.7	153.4	15.5	59.7	60.5	8.8	128.9	273.5
2025	2.4	30.4	29.5		60.3	122.5	13.1	31.0	0.0	11.5	89.5	145.1	15.5	61.4	29.5	11.5	149.7	267.7
2026	2.4	32.2			60.3	94.8	13.1	31.0	0.0	14.4	92.9	151.4	15.5	63.2	0.0	14.4	153.1	246.3
2027	2.4	34.2			60.3	96.8	13.1	31.0	0.0	17.3	96.6	158.0	15.5	65.2	0.0	17.3	156.9	254.8
2028	2.4	36.2			60.3	98.8	13.1	31.0	0.0	20.2	100.6	164.9	15.5	67.2	0.0	20.2	160.9	263.7
2029	2.4	38.3			60.3	100.9	13.1	31.0	0.0	21.6	106.4	172.1	15.5	69.3	0.0	21.6	166.7	273.0
2030	2.4	40.5			82.7	125.6	13.1	31.0	0.0	22.6	113.0	179.7	15.5	71.5	0.0	22.6	195.7	305.3
2031	2.4	42.8			82.7	127.9	13.1	31.0	0.0	23.5	120.0	187.6	15.5	73.9	0.0	23.5	202.7	315.5
2032	2.4	45.3			82.7	130.4	13.1	31.0	0.0	25.0	126.9	196.0	15.5	76.3	0.0	25.0	209.6	326.3
2033	2.4	47.9			82.7	132.9	13.1	31.0	0.0	26.9	133.8	204.8	15.5	78.9	0.0	26.9	216.5	337.7
2034	2.4	50.6			82.7	135.6	13.1	31.0	0.0	28.8	141.1	214.0	15.5	81.6	0.0	28.8	223.8	349.6
2035	2.4	53.4			82.7	138.5	13.1	31.0	0.0	30.7	148.8	223.7	15.5	84.4	0.0	30.7	231.5	362.1

Fixed Costs for such Technologies includes these parameters;

ST: K1b-Tek total labor cost

T.D.: K1b-Tek total labor cost, New T.D. Annualized capital cost, Existing T.D. annualized capital cost

AKSA: Aksa annual purchase guarantee, Aksa rental price, US CPI

Cable: Cable annual O&M cost, Annual cable cost for 400 MW & 800 MW.

Variable costs for these Technologies includes these parameters;

S.T.: S.T. variable cost, S.T. fuel consumption, Total fuel cost with freight

T.D.: T.D. Variable cost, T.D. fuel consumption, Total fuel cost with freight

AKSA: Total fuel cost with freight

Solar: Price of solar energy

Cable: Tetaş wholesale price including transmission, Cable losses.

Table 5.3: Fixed and Variable Costs (CCGT – LNG Scenario)

Year	FIXED COST mil. \$						VARIABLE COST mil. \$						Total Costs mil. \$					
	S.T.	T. D.	Aksa	Solar	Cable	Total	S.T.	T. D.	Aksa	Solar	Cable	Total	S.T.	T. D.	Aksa	Solar	Cable	Total
2021	17.9	49.4	26.7			94.1	18.2	37.3	75.4	7.7	0.0	138.6	36.1	86.7	102.2	7.7	0.0	232.7
2022	11.9	60.2	27.4			99.5	12.1	44.7	75.4	8.1	0.0	140.3	24.0	104.9	102.8	8.1	0.0	239.8
2023	11.1	61.0	28.1			100.2	12.1	49.2	75.4	8.4	0.0	145.1	23.2	110.2	103.5	8.4	0.0	245.3
2024	15.6	56.5	44.6			116.7	6.1	15.3	85.4	8.8	0.0	115.5	21.7	71.7	129.9	8.8	0.0	232.2
2025	15.6	56.5	45.3			117.4	6.1	15.3	89.5	9.1	0.0	119.9	21.7	71.7	134.8	9.1	0.0	237.3
2026	15.6	56.5	31.5			103.6	6.1	15.3	74.8	9.5	0.0	105.7	21.7	71.7	106.4	9.5	0.0	209.3
2027	15.6	56.5	31.5			103.6	6.1	15.3	79.4	9.9	0.0	110.6	21.7	71.7	111.0	9.9	0.0	214.3
2028	15.6	56.5	31.5			103.6	6.1	15.3	84.2	10.3	0.0	115.8	21.7	71.7	115.8	10.3	0.0	219.5
2029	15.6	56.5	31.5			103.6	6.1	15.3	89.3	10.7	0.0	121.3	21.7	71.7	120.8	10.7	0.0	224.9
2030	15.6	56.5	47.3			119.4	6.1	15.3	94.6	11.0	0.0	127.0	21.7	71.7	142.0	11.0	0.0	246.4
2031	15.6	56.5	47.3			119.4	6.1	15.3	100.2	11.5	0.0	133.1	21.7	71.7	147.5	11.5	0.0	252.5
2032	15.6	56.5	47.3			119.4	6.1	15.3	106.2	12.0	0.0	139.5	21.7	71.7	153.5	12.0	0.0	258.9
2033	15.6	56.5	47.3			119.4	6.1	15.3	110.5	12.5	0.0	144.3	21.7	71.7	157.8	12.5	0.0	263.7
2034	15.6	56.5	47.3			119.4	6.1	15.3	116.9	13.0	0.0	151.2	21.7	71.7	164.3	13.0	0.0	270.6
2035	15.6	56.5	47.3			119.4	6.1	15.3	123.7	13.4	0.0	158.5	21.7	71.7	171.0	13.4	0.0	277.9

Fixed Costs for such Technologies includes these parameters;

ST: Kib-Tek total labor cost

T.D.: Kib-Tek total labor cost, New T.D. Annualized capital cost, Existing T.D. annualized capital cost

AKSA: Aksa annual purchase guarantee, Aksa rental price, US CPI

CCGT: CCGT annualized capital cost, Total CCGT capacity.

Variable costs for such Technologies includes these parameters;

S.T.: S.T. variable cost, S.T. fuel consumption, Total fuel cost with freight

T.D.: T.D. Variable cost, T.D. fuel consumption, Total fuel cost with freight

AKSA: Total fuel cost with freight

Solar: Price of solar energy

CCGT: CCGT variable cost, LNG fuel consumption with CCGT, Total LNG cost with freight.

Unit Costs for each Technology are calculated using Total Costs & Total Productions for each year in terms of ¢/kWh. Also, by dividing the variable and fixed costs by annual energy production, Unit Costs per Cost Type (Fixed-Variable) was calculated.

5.2.6 Unit Costs per Cost Type

Fixed and Variable Unit Costs are listed below tables for each Scenario.

Table 5.4: Unit Costs per Cost Type (Interconnector Scenario)

Year	Unit Costs per Technology ¢/kWh						Unit Costs per Cost Type ¢/kWh	
	S.T.	T. D.	Aksa	Solar	Cable	Total	Fixed Costs	Variable Costs
2021	14.02	11.84	14.40	6.00		17.02	5.76	11.26
2022	13.98	12.25	14.50	6.00		16.63	5.78	10.85
2023	13.92	12.58	14.60	6.00		16.61	5.79	10.82
2024	15.47	19.89	20.18	6.00	10.95	13.51	5.93	7.58
2025	15.47	20.47		6.00	9.76	12.59	5.76	6.83
2026	15.47	21.08		6.00	9.62	11.03	4.25	6.78
2027	15.47	21.72		6.00	9.47	10.87	4.13	6.74
2028	15.47	22.39		6.00	9.33	10.72	4.01	6.70
2029	15.47	23.10		6.00	9.14	10.57	3.90	6.66
2030	15.47	23.84		6.00	10.10	11.25	4.63	6.62
2031	15.47	24.62		6.00	9.85	11.08	4.49	6.59
2032	15.47	25.44		6.00	9.64	10.91	4.36	6.55
2033	15.47	26.29		6.00	9.44	10.75	4.23	6.52
2034	15.47	27.20		6.00	9.25	10.60	4.11	6.49
2035	15.47	28.14		6.00	9.08	10.46	4.00	6.46

Unit Costs per Tech. = Total Cost of each Tech. / Total Production of each Tech.

Table 5.5: Unit Costs per Cost Type (LNG – CCGT Scenario)

Year	Unit Costs per Technology €/kWh						Unit Costs per Cost Type €/kWh	
	S.T.	T. D.	Aksa	Solar	Cable	Total	Fixed Costs	Variable Costs
2021	12.04	11.81	14.60	6.00		13.30	5.38	7.93
2022	12.00	11.94	14.69	6.00		13.06	5.42	7.64
2023	11.60	11.40	14.79	6.00		12.72	5.20	7.53
2024	21.69	23.91	8.34	6.00		11.47	5.76	5.71
2025	21.69	23.91	8.15	6.00		11.16	5.52	5.64
2026	21.69	23.91	6.06	6.00		9.38	4.64	4.73
2027	21.69	23.91	5.96	6.00		9.14	4.42	4.72
2028	21.69	23.91	5.86	6.00	*	8.92	4.21	4.71
2029	21.69	23.91	5.77	6.00		8.70	4.01	4.69
2030	21.69	23.91	6.40	6.00		9.08	4.40	4.68
2031	21.69	23.91	6.28	6.00		8.86	4.19	4.67
2032	21.69	23.91	6.17	6.00		8.65	3.99	4.66
2033	21.69	23.91	6.09	6.00		8.40	3.80	4.59
2034	21.69	23.91	5.99	6.00		8.21	3.62	4.59
2035	21.69	23.91	5.90	6.00		8.02	3.45	4.58

Unit Costs per Cost Type (Fixed C.) = Total Fixed Cost / Total Production

Unit Costs per Cost Type (Variable C.) = Total Variable Cost / Total Production

5.2.7 Discount Rate

The evaluation of the proposed project is based on the economic point of view, and the discount rate used in the model is considered to be 8% in the CEA calculations.

5.3 Cost-Effectiveness Analysis

In the CEA method, the gain to the economy is the difference between the cost of two alternatives with the same goal. Therefore, the cost of each option is their LCOE, which are;

- The LCOE of the Interconnector is: 0.1271 \$/kWh
- The LCOE of the Diesel Scenario is: 0.1267 \$/kWh
- The LCOE of the LNG Project is: 0.1014 \$/kWh

If the project has been carried out, the saving over the lifespan of the proposed project (2021-2035) is 459.733 USD'M.

Chapter 6

LEVELIZED COST OF ELECTRICITY

6.1 Introduction

The Levelized Cost of electricity refers to the cost of energy. It accounts for all lifetime costs of the system, including operation, maintenance, construction, taxes, insurance, and other financial obligations of the project. They are then divided by the expected total energy outcome in the system's lifetime (kWh). Cost and benefit estimates are adjusted to account for inflation and are discounted to reflect the time value of the money. It is indeed a precious tool to compare different generation methods. Lower LCOE values resemble low energy cost, which reflects high financial profit to the investors and vice versa.

LCOE Formula;

$$\text{LCOE} = \frac{\text{sum of costs over lifetime}}{\text{sum of electrical energy produced over lifetime}} = \frac{\sum_{t=1}^n \frac{I_t + M_t + F_t}{(1+r)^t}}{\sum_{t=1}^n \frac{E_t}{(1+r)^t}}$$

I_t : investment expenditures in the year t

M_t : operations and maintenance expenditures in the year t

F_t : fuel expenditures in the year t

E_t : electrical energy generated in the year t

r : discount rate

n : expected lifetime of system or power station

6.2- Levelized Cost Of Electricity

The total cost of a system brought back to its present value (NPV) and divided by the total amount of energy it produces is called Levelized Cost of Electricity (LCOE). LCOE's for both scenarios (with & without cable) are calculated below by using this equation.

Table 6.1: Levelized Cost of Electricity (Interconnector and CCGT Compared)

LCOE WITH CABLE (\$/kWh)	0.1271
LCOE WITHOUT CABLE (\$/kWh)	0.1014
DIFFERENCE/(\$/kWh)	0.0257
TOTAL DIFFERENCE (\$)	459,732,832
TOTAL DIFFERENCE (TL)	3,861,755,792

Table 6.2: Levelized Cost of Electricity (Interconnector and Diesel Compared)

LCOE WITH CABLE (\$/kWh)	0.1271
LCOE WITHOUT CABLE (\$/kWh)	0.1267
DIFFERENCE/(\$/kWh)	0.0005
TOTAL DIFFERENCE (\$)	8,536,896
TOTAL DIFFERENCE (TL)	71,709,928

From the LCOE calculations;

- The LCOE of the Interconnector is: 0.1271 \$/kWh
- The LCOE of the Diesel Scenario is: 0.1267 \$/kWh
- The LCOE of the LNG Project is: 0.1014 \$/kWh

The project with the lowest LCOE is LNG, which is 1.014 \$/kWh.

LCOE of LNG compared to the LCOE of the Diesel, the gain to the economy will be 451,195,936 \$.

LCOE of LNG compared to the LCOE of the Interconnector, the gain to the economy will be 459,732,832 \$.

So, the ranking of the projects according to the gain to the economy become;
First LNG, Second Diesel, Third Interconnector.

Chapter 7

SENSITIVITY ANALYSIS

7.1 Introduction

Sensitivity analysis is a financial model that determines how target variables are affected based on changes in other variables known as input variables. This model is also referred to as what-if or simulation analysis. It is a way to predict the outcome of a decision given a specific range of variables. By creating a given set of variables, an analyst can determine how changes in one variable affect the outcome. Sensitivity analysis allows for forecasting using historical, actual data.

In the sensitivity analysis, the effects of changes in the critical parameters calculated are Average Fuel Cost (\$/tonne), Investment Cost Overrun for Cable, Investment Cost Overrun for LNG Infrastructure, and Price of Solar Energy (\$/kWh) on the model.

7.2 Average Fuel Cost

One of the most critical variables of the sensitivity analysis is the fuel price. Figure 7.2 illustrates the price correlation between HFO and LNG (2010-2020) based on the data provided by KIB-TEK (HFO Prices) and BOTAŞ (LNG NBT Prices).

When the last ten years average prices of Heavy Fuel Oil (\$/ton), Liquified Neutral Gas (\$/sm³), T.C. Wholesale Electricity (\$/MWh) are examined, it clearly shows that;

-There is a strong relation between HFO & LNG Prices with having 0.945 correlation,

-There is a strong relation between HFO & TETAŞ Prices with having 0.861 correlation,

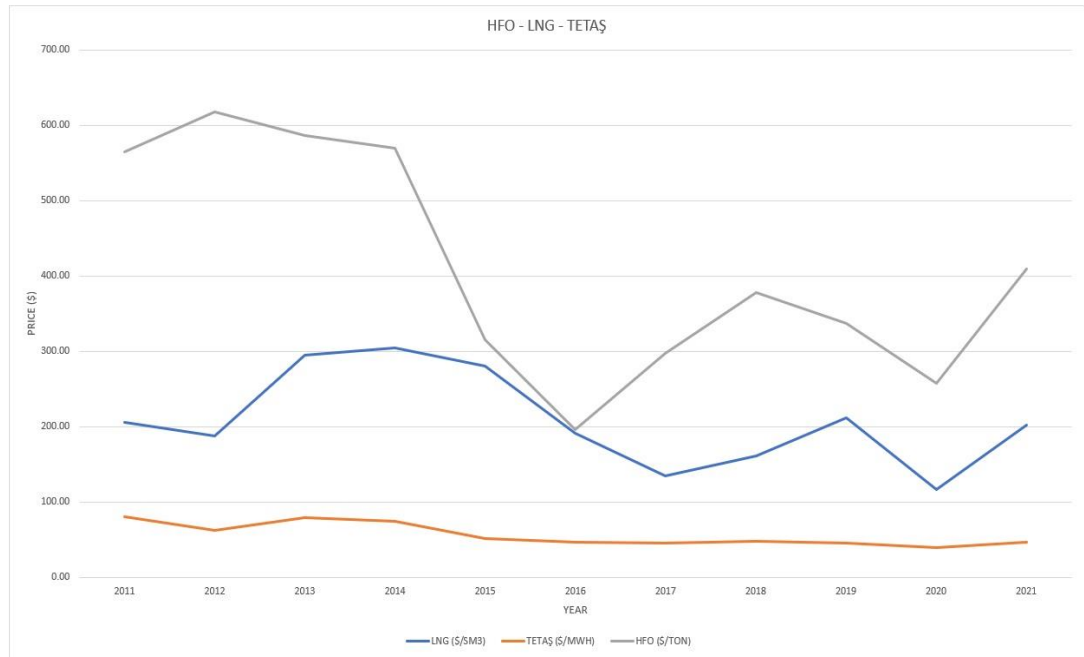


Figure 7.1: HFO - LNG – TETAŞ Prices

Sensitivity Analysis of Average Fuel Cost is below,

Table 7.1: Sensitivity Analysis of Average Fuel Cost

	LCOE WITH CABLE	LCOE WITHOUT CABLE	DIFFERENCE/kWh	TOTAL DIFFERENCE
	0.127	0.101	0.026	459,732,832
500	0.139	0.110	0.029	526,960,165
450	0.132	0.105	0.027	488,806,174
412	0.127	0.101	0.026	459,732,832
350	0.119	0.096	0.023	412,498,191
300	0.112	0.091	0.021	374,344,200

Average fuel cost since 01.01.2011 \$/tonne

Because of the strong relation and high correlation between the HFO-LNG-TETAŞ prices, the prices move together. Whether the Fuel Cost increases or decreases more than 20%, LCOE changes only 10% at most, and still, the LNG project has a lower LCOE than the Cable project in both cases.

7.3 Investment Cost Overrun

Investment cost over-run implies the unforeseen costs that exceed the initial budget estimates at each stage over the project implementation. To find whether the project is affected by the change in the investment cost, the relationship between the measured factors must be added to the model's formulas to ensure the sensitivity analysis is carried out correctly. Usually, in a project, investment cost overrun can go up to 20% more at worst.

Table 7.2: Sensitivity Analysis of Investment Cost Overrun (Interconnector)

	LCOE WITH CABLE	LCOE WITHOUT CABLE	DIFFERENCE/kWh	TOTAL DIFFERENCE
	0.127	0.101	0.026	459,732,832
40%	0.136	0.101	0.035	624,418,104
30%	0.134	0.101	0.033	583,246,786
20%	0.132	0.101	0.030	542,075,468
10%	0.129	0.101	0.028	500,904,150
0%	0.127	0.101	0.026	459,732,832

Table 7.3: Sensitivity Analysis of Investment Cost Overrun (LNG)

	LCOE WITH CABLE	LCOE WITHOUT CABLE	DIFFERENCE/kWh	TOTAL DIFFERENCE
	0.127	0.101	0.026	459,732,832
40%	0.127	0.108	0.019	335,163,116
30%	0.127	0.107	0.020	366,305,545
20%	0.127	0.105	0.022	397,447,974
10%	0.127	0.103	0.024	428,590,403
0%	0.127	0.101	0.026	459,732,832

Although the LNG's investment cost overrun increases 40%, the LNG project still has a lower LCOE than the base case Interconnector project.

7.4 Price of Solar Energy

Table 7.4: Sensitivity Analysis of Price of Solar Energy

	LCOE WITH CABLE	LCOE WITHOUT CABLE	DIFFERENCE/kWh	TOTAL DIFFERENCE
	0.127	0.101	0.026	459,732,832
0.10	0.132	0.104	0.027	488,755,623
0.08	0.129	0.103	0.027	474,244,228
0.06	0.127	0.101	0.026	459,732,832
0.04	0.125	0.100	0.025	445,221,437
0.02	0.123	0.099	0.024	430,710,042

The price of the Solar in the base case is 0.06 \$/kWh. If the cost of solar increases up to 0.10 \$/kWh or decreases down to 0.02 \$/kWh, but the impact of change in solar prices is not reflected in the LCOE of projects. The LNG project has a lower LCOE than the Cable project in both cases.

7.5 Break-Even Analysis

The break-even point is the point at which total revenue and total cost are equal. It can be an excellent tool to use when you're starting up a new investment, as it helps you to decide whether the project is viable or not.

"Break-Even Price for T.C. Wholesale Prices" while holding the other parameters constant, "Break-Even Price for Fuel Prices" while keeping the other parameters constant, and "Break-Even Price for Cable Investment" while holding the other parameters constant, calculated.

Table 7.5: Break-Even Prices

BREAK EVEN PRICE FOR TC SALES PRICE HOLDING OTHER THINGS CONSTANT	0.87 ¢/kWh
BREAK EVEN PRICE FOR FUEL WHEN TC SALES PRICE AND LNG PRICE CORRELATED	-191 \$/tonne
BREAK EVEN PRICE OF CABLE	-42,361,378 \$

-TETAŞ Wholesale Price in base case was 5.63 \$/kWh, and if the wholesale price decreases to 0.87¢/kWh, then rather than the LNG Project, Cable Project becomes more feasible.

-The Fuel Price in the base case was 441\$/tonne, and if the fuel price decreases to 191\$/tonne, then rather than the LNG Project, Cable Project becomes more feasible.

-If the Cable's CAPEX in the base case decreases to -42,361,378\$, then Cable Project becomes more feasible rather than the LNG Project.

Chapter 8

CONCLUSIONS AND RECOMMENDATIONS

In the face of the increasing energy demand globally, new investments are made to meet the demand, and efforts are made to develop existing technologies and increase their efficiency. On the other hand, efforts are made to discover new technologies. The main goal of all these is to ensure the security of supply in electrical energy, which is an indispensable part of our lives, with the developing technology, and to reduce costs while providing uninterrupted and high-quality electrical power.

According to the data of the past 15 years, there is an increasing electricity demand of TRNC with 5% annually. Existing power plants become insufficient day by day to meet the demand, and these plants have low efficiencies, which also causes significant environmental problems. So, new investments need to be made to meet the increasing electricity demand.

This study focuses on Cost-Effectiveness Analysis of TRNC's electricity generation by source, with three alternatives:

1. Submarine Cable Interconnector Investment
2. LNG – FSRU Investment
3. Diesel Generator Investment

From the LCOE calculations;

- The LCOE of the Interconnector is: 0.1271 \$/kWh
- The LCOE of the Diesel Scenario is: 0.1267 \$/kWh
- The LCOE of the LNG Project is: 0.1014 \$/kWh

The project with the lowest LCOE is LNG, which is 1.014 \$/kWh.

LCOE of LNG compared to the LCOE of the Diesel, the gain to the economy will be 451,195,936 \$.

LCOE of LNG compared to the LCOE of the Interconnector, the gain to the economy will be 459,732,832 \$.

The transition from fuel oil electricity generation to natural gas generation model will have indisputable benefits in the environment, health and economy. On the other hand, both the geopolitical location of our island, the steps Southern Cyprus has taken in the natural gas field, and the large-scale natural gas field discoveries that are likely to take place around Cyprus will take the natural gas issue to a whole new level. It should not be forgotten that Malta and Southern Cyprus, which have similar country and network structures, have also taken steps in this direction.

The CEA results implied that LNG – FSRU investment is the best choice of generation technology that could significantly reduce the cost of electricity generation in the TRNC.

APPENDICES

Appendix A: Parameters

Table A.1: List of Parameters

PARAMETERS			
LOAD FACTOR	56%	Cable initial investment cost million \$	363.2
Back-up (of total capacity without back-up)	15%	Cable initial investment cost with cost overruns million \$	363.2
Freight Fuel Oil \$/tonne	33	Cable annual O&M cost million \$	12.50
Freight LNG \$/tonne	30	Discount rate for Cable Investment	10.0%
Current fuel cost \$/tonne	441	Cable, LNG and dual-fuel plants pay-back period	15
Average fuel cost since 01.01.2011 \$/tonne	412	Annual cable cost for 400 MW million \$	47.75
Total fuel cost with freight \$/tonne	449	Cost conversion factor from 400 MW to 800 MW	1.47
Average LNG cost since 01.01.2011 \$/tonne	232	Annual cable cost for 800 MW million \$	70.19
Total LNG cost with freight \$/tonne	262	Tetay wholesale price including transmission ¢/kWh	5.63
S.T. fuel consumption (including oil) gr/kWh	285	Cable losses %	3.5
T. D. fuel consumption (including oil) gr/kWh	210	Investment cost overrun (for cable)	0%
LNG fuel consumption with T.D. (including oil) gr/kWh	160	Investment cost overrun (for LNG regasification)	0%
LNG fuel consumption with S.T. (including oil) gr/kWh	220		
LNG fuel consumption with CCGT (including oil) gr/kWh	140	Fuel - LNG price correlation	0.945 STRONG
Expected increase in electricity demand	5%	Fuel - TC sale price correlation	0.861 STRONG
Investment cost of a NEW dual-fuel 17.5 MW plant \$	11,000,000		
NEW T. D. annualized capital cost \$/MW	73,436	Price of solar energy \$/kWh	0.06
Investment cost of the EXISTING 17.5 MW plant \$	5,000,000	% solar of the total installed capacity with no back-up	20%
EXISTING T. D. annualized capital cost \$/MW	33,380	Solar load factor	19%
CCGT investment cost \$/MW	900,000		
CCGT annualized capital cost \$/MW	105,147	LCOE WITH CABLE (\$/kWh)	0.1271
Total CCGT capacity (2022-2023) MW	150	LCOE WITHOUT CABLE (\$/kWh)	0.1014
Total CCGT capacity (2024-2030) MW	300	DIFFERENCE/(\$/kWh)	0.0257
Total CCGT capacity (2031-2035) MW	450	TOTAL DIFFERENCE (\$)	459,732,832
		TOTAL DIFFERENCE (TL)	3,861,755,792
CCGT load factor	80%		
T.D. (existing plants) conversion cost to LNG \$	34,000,000		
T.D. (existing plants) conversion annualized cost to LNG \$	3,972,205		
S.T. (existing plants) conversion cost to LNG \$	10,000,000		
S.T. (existing plants) conversion annualized cost to LNG \$	1,168,295		
Investment cost of LNG \$	350,000,000		
Investment cost of LNG with cost overruns \$	350,000,000		
LNG annualized capital cost \$	48,390,341		
Annual Operating Cost of LNG FSRU \$	7,500,000		
S.T. variable cost (excluding fuel and labor) \$/kWh	0.003		
T. D. variable cost (excluding fuel and labor) \$/kWh	0.009		
CCGT variable cost (excluding fuel and labor) \$/kWh	0.006		
KIB-TEK total labor cost (excluding overtime, etc.) \$	9,450,371		
AKSA annual purchase guarantee (gWh)	700		
AKSA rental price \$/kWh	0.0382		
US CPI	2.50%		
Exchange rate \$/TL	8.4		
Discount rate for KIB-TEK investments	8.0%		

Appendix B: Similar Projects

The situation is similar in Southern Cyprus and Malta. Cyprus & Malta had been dependent on heavy oil as their primary source of energy production. They are making a series of investments to achieve the environmental targets of the European Union, increase the share of renewable energy in production while producing with cleaner and more environmentally friendly fuels, and reduce production costs and ensure energy supply security.

In this context, they gave up production with Diesel Generators and Fuel Oil, which we are using in the Turkish Republic of Northern Cyprus; instead, they invested in FSRU for the supply of Natural Gas in the form of LNG, investment in the conversion of power plants to natural gas and Combined Cycle Gas Turbine. At the same time, they attach importance to Submarine Interconnected Cable Projects.

Vasilikos FSRU – LNG Terminal

The LNG project includes a Floating Storage and Regasification Unit (FSRU), a jetty for mooring the FSRU, a jetty-borne gas pipeline, and the related infrastructure. The total cost is €289 Million. FSRU will have 5 Tanks with an overall LNG storage capacity of 136,141 m³. [34]

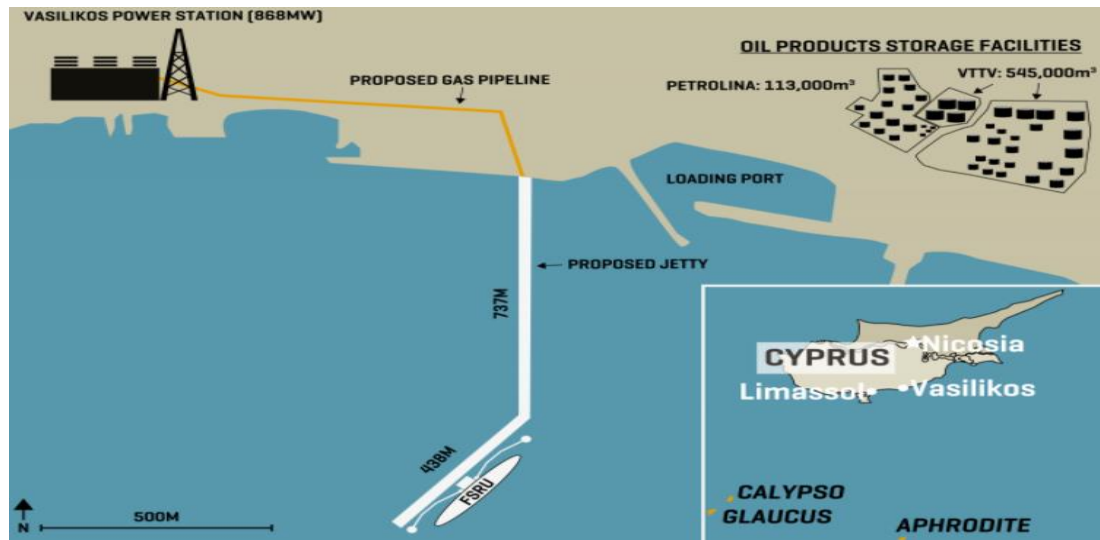


Figure B.1: Vasilikos FSRU LNG Terminal

EuroAsia Interconnector

EuroAsia interconnector is a high-voltage, direct current (HVDC) Submarine power cable between Israel-Cyprus-Greece with a total length of 1,208 km and a power rating of 2,000 MW with DC voltage ± 500 kV. The interconnector will have 1000 MW capacity in the first stage and will cost €2.5 Billion. [31]

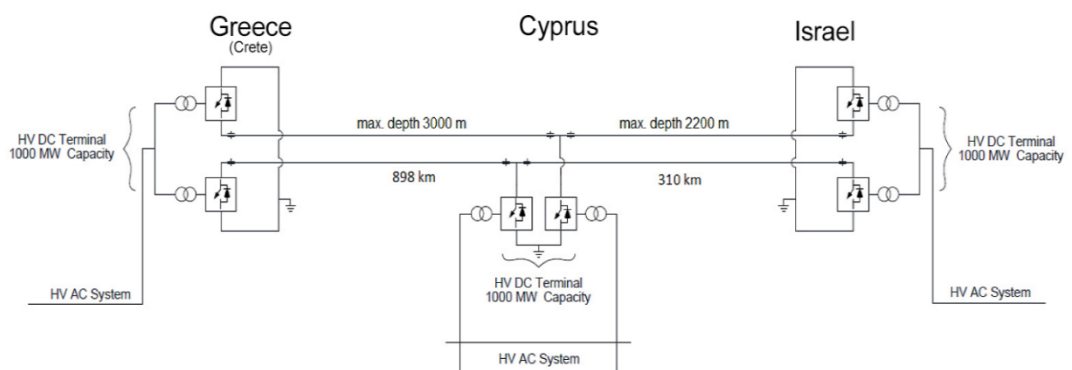


Figure B.2: EuroAsia Interconnector Stage-1



Figure B.3: EuroAsia Interconnector

EuroAfrica Interconnector

EuroAfrica interconnector is a high-voltage, direct current HVDC Submarine power cable between Egypt-Cyprus-Greece with a total length of 1,396 km and a power rating of 2,000 MW with DC voltage ± 500 kV. The interconnector will have 1000 MW capacity in the first stage and will cost €2.5 Billion. [32]

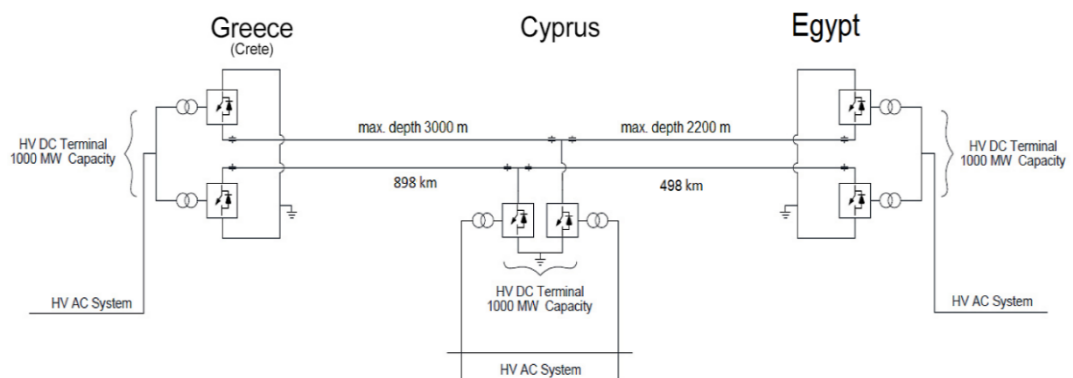


Figure B.4: EuroAfrica Interconnector Stage-1

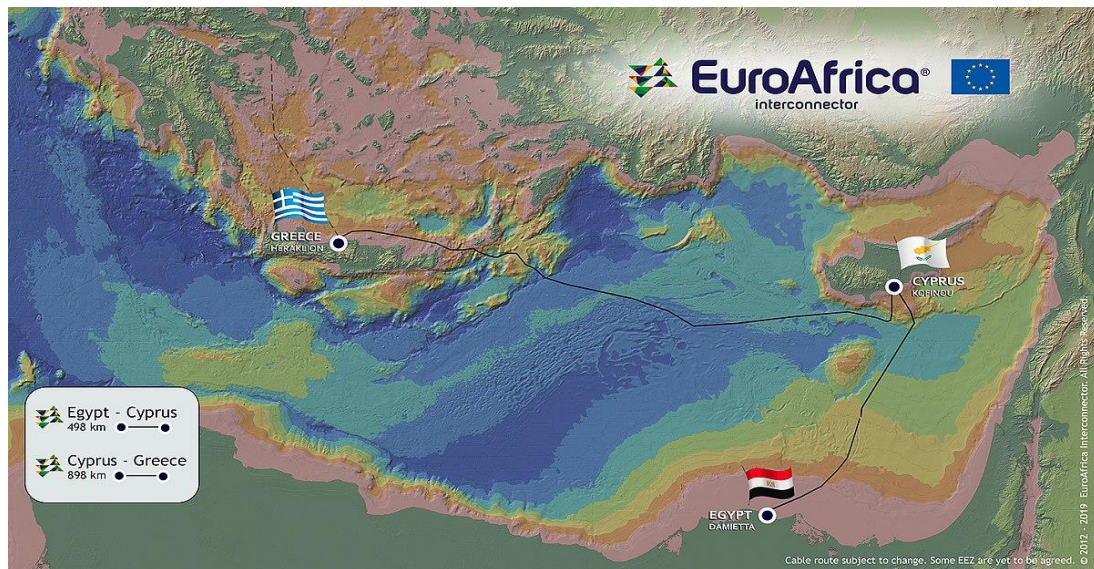


Figure B.5: EuroAfrica Interconnector

Delimara FSU – LNG Terminal

The LNG project includes a Floating Storage Unit (FSU) and an On-Shore Regasification, a jetty for mooring the FSU, a jetty-borne gas pipeline, and the related infrastructure under a \$300 million contract and is capable of storing 125,000 m³ of LNG. [42]



Figure B.6: Delimara FSU - LNG Terminal

Malta – Sicily Interconnector

Malta – Sicily interconnector is a high-voltage, alternating current HVAC Submarine power cable between Malta-Sicily with a total length of 120 km, power rating 200 MW with AC voltage 220 kV. The interconnector costs €182 Million. [41]



Figure B.7: Malta – Sicily Interconnector

REFERENCES

- [1] U.S. Energy Information Administration (EIA), Office of Energy Analysis, U.S. Department of Energy, Washington DC, *Annual Energy Outlook 2020 with projections to 2050*. (January 2020). Retrieved from <https://www.eia.gov/outlooks/aeo/>
- [2] U.S. Energy Information Administration (EIA), Office of Energy Analysis, U.S. Department of Energy, Washington DC, *Annual Energy Outlook 2021*. (February 2021). Retrieved from <https://www.eia.gov/outlooks/aeo/>
- [3] U.S. Energy Information Administration (EIA), Office of Energy Analysis, U.S. Department of Energy, Washington DC, *Levelized Costs of New Generation Resources in the Annual Energy Outlook 2021*. (February 2021). Retrieved from <https://www.eia.gov/outlooks/aeo/>
- [4] European Commission, DG ENERGY UNIT, Study on energy costs, taxes and the impact of government interventions on investments in the energy sector, *Final Report Cost of Energy (LCOE)*. (October 2020). Retrieved from <https://europa.eu/>
- [5] British Petroleum (BP), *Energy Outlook 2020 Edition*. (February 2020). Retrieved from <https://www.bp.com/>
- [6] British Petroleum (BP), *Statistical Review of World Energy 2020 - 69th edition*. (June 2020). Retrieved from <https://www.bp.com/>

- [7] International Energy Agency (IEA), *Key World Energy Statistics 2020*. (August 2020). Retrieved from <https://www.iea.org/data-and-statistics>
- [8] International Energy Agency (IEA) & Nuclear Energy Agency (NEA), *Projected Costs of Generating Electricity 2020 Edition*. (2020). Retrieved from <https://www.oecd-neo.org/>
- [9] International Energy Agency (IEA), *World Energy Outlook 2020*. (October 2020). Retrieved from <https://www.iea.org/>
- [10] Royal Dutch Shell, *Shell LNG Outlook 2021*. (2021). Retrieved from <https://www.shell.com/>
- [11] The Oxford Institute for Energy Studies, *The Outlook for Floating Storage and Regasification Units (FSRUs)*. (January 2018). Retrieved from <https://www.oxfordenergy.org/>
- [12] The Oxford Institute for Energy Studies, *A Comparative History of Oil and Gas Markets and Prices: is 2020 just an extreme cyclical event or an acceleration of the energy transition*. (April 2020). Retrieved from <https://www.oxfordenergy.org/>
- [13] ARGUS, Methodology and specifications guide, *Turkish energy markets*. (June 2020). Retrieved from <https://www.argusmedia.com/>
- [14] Nations Online, *Map of Cyprus* (September 2021). Retrieved from https://www.nationsonline.org/oneworld/map/cyprus_map2.htm

- [15] The Oxford Institute for Energy Studies, *Developments in the 'LNG to Power' market and the growing importance of floating facilities* (July 2021). Retrieved from <https://www.oxfordenergy.org/>
- [16] European Commission – JRC Technical Reports, *HVDC Submarine Power Cables in the World*. (2015). Retrieved from <http://europa.eu>
- [17] MED-TSO, *Mediterranean Masterplan 2020* (2020). Retrieved from <https://www.med-tso.com/>
- [18] International Renewable Energy Agency (IRENA), *Renewable Power Generation Costs In 2019*. (2020). Retrieved from <https://www.irena.org/>
- [19] ENTSO-E, *Interconnections Grid Map* (2019). Retrieved from <https://www.entsoe.eu/>
- [20] LNG 2019 SHANGAI, *The Role of LNG in the Euro-Mediterranean Region* (2019). Retrieved from <https://www.irena.org/>
- [21] ZTT Group, *Submarine Cable*. (2018). Retrieved from <https://www.zttcable.com/upload/201811/29/201811291535489466.pdf>
- [22] Nexans, *Submarine Power Cables*. (2013). Retrieved from https://www.nexans.co.uk/Germany/2013/SubmPowCables_FINAL_10jun13_english.pdf

- [23] ABB, *XLPE Submarine Cable Systems*. (2021). Retrieved from <https://new.abb.com/docs/default-source/ewea-doc/xlpe-submarine-cable-systems-2gm5007.pdf>
- [24] Caledonian, *Submarine Cable*. (2021). Retrieved from <http://www.caledonian-cables.co.uk/products/submarine-cable/XLPE-AC-MV-With-Fibre-Optic.shtml>
- [25] TEİAŞ, Planlama ve Yatırım Yönetimi Dairesi Başkanlığı, *Türkiye-KKTC Denizaltı Kablo Bağlantısı Teknik ve Ekonomik Ön Değerlendirme Raporu*. (2020). Retrieved from <http://www.teias.gov.tr>
- [26] GIIGNL, The International Group of Liquefied Natural Gas Importers, *Global LNG prices by select region 2021*. (2021). Retrieved from <https://giignl.org/>
- [27] FRED, Federal Reserve Economic Data, *Global price of Natural gas, EU, U.S. Dollars per Million Metric British Thermal Unit*. (2021). Retrieved from <https://fred.stlouisfed.org>
- [28] International Energy Agency (IEA), *“LNG Imports Prices In Selected Countries 2010-2018*. (2019). Retrieved from <https://www.iea.org/>
- [29] Cyprus Turkish Electricity Authority (Kıb-Tek), *Elektrik Enerjisi Üretim Senaryoları Raporu*. (November 2018). Retrieved from <https://www.kibtek.com/wp-content/uploads/2019/03/Uretim-Senaryolari-14.11.2018-Revson.pdf>

- [30] EPİAŞ Şeffaflık Platformu, *Piyasa Takas Fiyatı (PTF) (USD/MWh)*. (August 2021). Retrieved from <https://seffaflik.epias.com.tr/transparency/piyasalar/gop/ptf.xhtml>
- [31] EuroAsia Interconnector. (2021). Retrieved from <https://euroasia-interconnector.com/about-us/>
- [32] EuroAfrica Interconnector. (2021). Retrieved from <https://www.euroafrica-interconnector.com/about-us/>
- [33] Cyprus Turkish Electricity Authority (Kıb-Tek), *Elektrik Üretiminde Doğalgaz kullanılması ve Doğalgaza dönüşüm çalışmalarının planlanması*. (2020). Retrieved from <https://www.kibtek.com/>
- [34] Natural Gas Public Company - DEFA, *Cyprus LNG Import Project - A Milestone for The Cyprus*. (2019). Retrieved from <https://defa.com.cy/assets/editors-folders/uploads/pdfs/Presentation%20Dr.%20M.%20Andreou%205.12.19.pdf>
- [35] US. Bureau of Labor Statistics, *USD CPI*. (2021). Retrieved from <https://www.bls.gov/>
- [36] King & Spalding, *An Overview of LNG Import Terminals in Europe*. (2018). Retrieved from https://www.kslaw.com/attachments/000/006/010/original/LNG_in_Europe_2018_-_An_Overview_of_LNG_Import_Terminals_in_Europe.pdf?1530031152

- [37] Central Bank of TRNC, *Exchange Rates*. (2021). Retrieved from <http://www.kktcmerkezbankasi.org/en>
- [38] Enerdata, *World LNG Database*. (2021). Retrieved from <https://www.enerdata.net/research/lng-trade-terminals-and-plants-database.html>
- [39] Knoema, *Liquefied Natural Gas: Multibillion Dollar Investments at Risk*. (2021). Retrieved from <https://knoema.com/mcuutn/liquefied-natural-gas-multibillion-dollar-investments-at-risk>
- [40] Total Energy, *Liquefied Natural Gas (LNG)*. (2021). Retrieved from <https://marinefuels.totalenergies.com/products-and-services/liquefied-natural-gas>
- [41] ENEMALTA, *Malta-Italy Interconnector* (2021). Retrieved from <https://www.enemalta.com.mt/about-us/malta-italy-interconnector/>
- [42] ENEMALTA, *Delimara Power Plant FSU Project* (2021). Retrieved from <https://www.enemalta.com.mt/about-us/delimara-power-station/>
- [43] Jenkins G.P., Özbafli A. (2015). *The willingness to pay by households for improved reliability of electricity service in North Cyprus*.
- [44] Rasheed A., (August 2019). *Feasibility Analysis of Turkey - North Cyprus Submarine Electric Interconnector Cable Including Externalities*.

[45] Zubair O.U., (July 2021). *Modeling Renewable Electricity Generation for
aaaaNorthern Cyprus (TRNC)*

[46] National Renewable Energy Laboratory (NREL), *Renewable Energy and Inter-
aaaaisland Power Transmission Power Transmission* (2011). Retrieved from
aaaa<https://www.nrel.gov/>