FEASIBILITY ANALYSIS OF TURKEY-NORTH CYPRUS SUBMARINE ELECTRIC INTERCONNECTOR CABLE INCLUDING EXTERNALITIES

A THESIS SUBMITTED TO THE BOARD OF GRADUATE PROGRAMS

OF

MIDDLE EAST TECHNICAL UNIVERSITY, NORTHERN CYPRUS CAMPUS

BY

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IN PARTIAL FULFILLMENT OF THE REQUIREMENTS

FOR

THE DEGREE OF MASTER OF SCIENCE

IN

SUSTAINABLE ENVIRONMENT AND ENERGY SYSTEMS

AUGUST 2019

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ABSTRACT

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M.Sc. Sustainable Environment and Energy Systems

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August 2019, 78 pages

Heavy dependency of electrical industry on fossil fuels have led to overexploitation of natural resources, which causes emission of greenhouse gases and climatic change. This depletion urged the exploration of renewable energy resources and its integration in electric grid system, thus the current infrastructure of grid systems needs a transition towards renewable energy to make the most of it. Small islands and remote areas, which are highly depended on fossil fuels have a chance to reduce their carbon emission by connecting their electric grid systems to a mainland grid system, thus allowing them to explore their available renewable resources. Similarly, Turkish Republic of Northern Cyprus has an isolated electric power system. Being stretched on indigenous energy resources, the energy demands are solely met by imported fossil fuels that make the electricity price vulnerable by heavily depending on volatile oil price. On the other hand, Turkey's geographical location makes it highly enriched in natural resources that decreases the reliance on imported fossil fuels. The idea of electrically interconnecting Northern Cyprus grid to that of Turkey's has been proposed. Interconnecting North Cyprus electricity grid to a mainland will help exploring and relying on renewable energy resources of the northern part of island.

Subsequently, the feasibility of submarine electric interconnector cable between Turkey and Northern Cyprus is theoretically analyzed and numerically evaluated based on economic and environmental aspects. Ultimately, a better option among the suggested scenarios is evaluated for further research.

Keywords: Submarine interconnector, Isolated grid, TRNC, carbon emission, Merit order curve, Sustainability.

ÖZ

TÜRKİYE – KUZEY KIBRIS DENİZALTI ELEKTRİK KABLO BAĞLANTISININ DIŞSALLIKLARI İÇEREREK FİZİBİLİTE ANALİZİ

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Tez Yöneticisi: Doç. Dr. Murat Fahrioğlu

Ağustos 2019, 78 sayfa

Elektrik endüstrisinin fosil yakıtlara olan yoğun bağımlılığı, doğal kaynakların sömürüsüne yol açmakla birlikte sera gazlarının yüksek emisyonuna ve iklim değişikliğine sebep olur. Kaynakların tükenmesi, yenilenebilir enerji kaynaklarının keşfi ve elektrik şebeke sistemlerine de entegrasyon çağrısında bulundu, bu yüzden mevcut şebekelerin altyapısının verimli üretim sağlaması için yenilenebilir enerjiye geçiş yapması gerekir. Tam anlamıyla fosil yakıta bağlı olarak elektrik üreten küçük ada ve uzak bölgelerde bulunan elektrik şebekelerinin daha büyük bir ana şebeke sistemine bağlanması karbon emisyonunu azaltmak ve bölgenin mevcut yenilenebilir kaynaklarını keşfetmesi için bir olanaktır. Benzer şekilde, Kuzey Kıbrıs Türk Cumhuriyeti bir ada olarak izole bir elektrik enerjisi sistemine sahiptir örneğin adanın şebekesi herhangi başka bir ana şebekeye bağlı değildir. Sınırlı enerji kaynakları, adanın genel enerji ihtiyacının yalnızca ithal edilmiş fosil yakıt ile karşılanmasına sebep olmakla birlikte petrol fiyatlarına bağlı olan elektrik fiyatlarını savunmasız kılar. Öte yandan, Türkiye'nin coğrafi konumu ithal fosil yakıtlara olan bağlılığını azaltmakla birlikte doğal kaynakların korunması ve zenginleştirilmesini sağlıyor. Kuzey Kıbrıs elektrik şebekesini Türkiye'nin elektrik şebekesi ile bir arabağlantı oluşturma fikri önerilmiştir. Bu arabağlantı, adanın yenilenebilir enerji kaynaklarını geliştirmesi ve kullanımını artıracaktır. Daha sonra Türkiye ile Kuzey Kıbrıs arasında denizaltı elektrik ara bağlantı kablosunun fizibilitesi teorik olarak analiz edilmekte ve ekonomik ve çevresel yönlere göre sayısal olarak değerlendirilir. Sonuç olarak, önerilen senaryolar arasından daha iyi bir seçenek daha sonraki araştırmalar için değerlendirilir

Anahtar Kelimeler: Denizaltı bağlantı, izole şebeke, KKTC, karbon emisyonu, Merit Order Eğrisi, sürdürülebilirlik

DEDICATION

I dedicate this work to my parents.

ACKNOWLEDGEMENT

First and foremost, I would like to express gratitude to my advisor, Dr. Murat Fahrioğlu, for his extensive knowledge, utmost patience, continuous support, and guidance during my studies at METU, NCC. It goes without saying that I have learnt a lot under his mentorship, working in a unique and pleasant experience. I thank him for provision of all the data and foundation of model for the completion of study. I would like to extend my gratitude towards Dr. Hayriye Kahveci Özgür and Dr. Hasan Güngör for their invaluable suggestion, constructive criticism and support during this study. My gratitude to Senior Research Officer Nouman Ali at NIE, Pakistan for his help in this research study.

Special thanks to my parents, who sacrificed their needs for my pursuit of knowledge. My sincerest gratitude to my brother and mentor Jawad Rasheed, who has always looked out for me no matter what. May thanks to my siblings, Hina Rasheed and Huma Rasheed, Javaria Jawad whose support and prayers have helped me achieve my goals.

I would like to express my deepest gratitude to my brother like friend Ahmet Faruk, whose endless support, ever since I moved to island of Cyprus, has helped me to finish this study. I would also like to acknowledge the help and support of my friend Mohammad A. M. Abujubbeh, Melis Erhun, Berkay Koyuncu, Haroon Rashid, Zakria Qadir, and Arman Malekloo.

Last but not the least, I would like to express my greatest thanks to a special person, Pınar Tekşen, whose active support and understanding helped me finish this study within time.

TABLE OF CONTENTS

DECLARATION i

ABSTRACT ii

ÖZ iv

DEDICATION vi

ACKNOWLEDGEMENT vii

TABLE OF CONTENTS viii

LIST OF FIGURES xii

LIST OF TABLES xiv

CHAPTER 1 INTRODUCTION: 1

1.1 Electricity Market of an isolated electric grid of Northern Cyprus 3

1.2 Problem Identification 4

1.3 Aim of the study: 6

1.4 Study Approach 7

1.5 Summary 7

CHAPTER 2 NORTH CYPRUS: COUNTRY CONTEXT 8

2.1 Turkish Republic of Northern Cyprus: An Isolated Territory 8

2.2 North Cyprus: Electric Power Grid 8

2.3 Summary 14

CHAPTER 3 LITERATURE REVIEW 16

3.1 Electricity Generation 16

3.1.1 Diesel Power Plants 16
3.1.2 Steam Power Plants 17
3.1.3 Combined Cycle Gas Power Plant 18
3.2 Sustainable Energy Systems 19
3.2.1 Social Cost of Carbon 20
3.3 Turkey’s Energy Portfolio 21
3.4 Submarine Electricity Power Cables 23
3.4.1 Types of Submarine Power Cables 24
3.5 Submarine Electric Interconnector Cable Projects 25
3.5.1 Malta - Sicily Interconnector 26
3.5.2 Ireland – UK Interconnector 27
3.5.3 Gotland – Sweden Interconnector 28
3.5.4 Mallorca – Spain Interconnector 28
3.5.5 Sardinia – Italy Interconnector 28
3.6 Gap 29
3.7 Contribution 29
3.8 Summary 30
CHAPTER 4 RESEARCH DATA ANALYSIS 31
4.1 North Cyprus Demand Characteristics: 31
4.2 North Cyprus Electricity Production Characteristics: 33
4.3 North Cyprus Demand versus Production 33
4.4 Summary 37

CHAPTER 5 METHODOLOGY 38
5.1 Merit order concept: 38
5.2 Turkey - North Cyprus interconnector characteristics: 39
5.3 Merit order curve for Cyprus's electricity market 41
5.4 Marginal Electricity Generation Cost 41
5.5 Average Electricity Production Price 42
5.6 Summary 42
CHAPTER 6 RESULTS AND DISCUSSION 43
6.1 Case 1: Merit Order Curve for TRNC's Isolated Electricity Network 44
6.2 Case 2: Merit Order Curve for TRNC Electricity Network with Interconnector 45
6.2.1 Interconnector with Turkey's Investment 45
6.2.2 Interconnector with Shared Investment of Turkey & TRNC 47
6.2.3 Interconnector with Solely TRNC's Investment 48
6.3 Electronic Merit Order Calculator 49
6.4 Carbon Emissions of TRNC Electricity Production 49
6.4.1 CO_2 Emissions after Submarine Interconnector 52
6.5 Summary 55
CHAPTER 7 CONCLUSION & FUTURE WORK 57
7.1 Conclusion 57
7.2 Future Work 59
REFERENCES 60
APPENDIX 67

Appendix A: Table of Total Production Data for Year 2008-2018 67

Appendix B: Electronic Merit Order Curve Calculator 78

LIST OF FIGURES

Figure 1.1 TRNC Electricity production for year 2008-2018 [14] 4

Figure 2.1 Map of Island of Cyprus [20]. 8

Figure 2.2 Electrical Transmission Network of North Cyprus [20]..........................10

Figure 2.3 Electricity Production and Consumption of TRNC - 2008......................10

Figure 2.4 Electricity Production and Consumption of TRNC - 2009......................11

Figure 2.5 Electricity Production and Consumption of TRNC – 2010.....................11

Figure 2.6 Electricity Production and Consumption of TRNC – 2011.....................12

Figure 2.7 Electricity Production and Consumption of TRNC – 2012.....................12

Figure 2.8 Electricity Production and Consumption of TRNC – 2013.....................12

Figure 2.9 Electricity Production and Consumption of TRNC – 2014.....................13

Figure 2.10 Electricity Production and Consumption of TRNC – 2015...................13

Figure 2.11 Electricity Production and Consumption of TRNC – 2016...................13

Figure 2.12 Electricity Production and Consumption of TRNC – 2017...................14

Figure 2.13 Electricity Production and Consumption of TRNC – 2018...................14

Figure 3.1 General Layout of Steam Power Plant [24]..17

Figure 3.2 Simplified flow diagram of Combined Cycle Power Plant [28]..............18

Figure 3.3 CO_2 Emission for Various Energy Sources [23]. 20

Figure 3.4 Percentage Contribution of Sources in Production of Turkey (2018) [44]

....21

Figure 3.5 Electric Energy Production of Turkey 2018 [44] 22

Figure 3.6 EU Submarine Electric Interconnection Map (modified from [49]) 25

Figure 3.7 Demand Characteristics of Malta [55]..27

Figure 4.1 Demand Characteristics of TRNC 2016 32

Figure 4.2 Demand Characteristics of TRNC 2017 32

Figure 4.3 Demand Analysis 2016 34

Figure 4.4 Demand Analysis 2018 35

Figure 4.5 Demand Analysis 2020 36

Figure 4.6 Demand Analysis 2024 37

Figure 5.1 Merit Order Concept [85] 38

Figure 5.2 TR – TRNC Submarine Cable Route (modified from [90]) 40

Figure 6.1 Merit order curve for Cyprus's isolated electric power system 44

Figure 6.2 Merit order curve with full Turkey's investment 46

Figure 6.3 Merit Order Curve with shared investment of TRNC and Turkey. 47

Figure 6.4 Merit Order Curve with Sole Investment of TRNC 48

Figure 6.5 Total Carbon Emissions Associated with Electricity Production for TRNC 50

Figure 6.6 Carbon Emissions associated to Diesel Turbine 50

Figure 6.7 Carbon Emission Associated with Steam Turbine 51

Figure 6.8 Carbon Emissions associated to Gas Turbine 51

Figure 6.9 Maximum CO_2 Emission from 200 MW 54

Figure 6.10 Minimum CO_2 Emission from 200 MW 54

Figure 6.11 Marginal Costs for Cyprus Electricity Production 56

Figure 6.12 CO_2 Emissions of Submarine Cable and Local Production of TRNC ... 56

LIST OF TABLES

Table 2.1 Existing Installed Electric Capacity of Northern Cyprus [13] 9

Table 4.1 Installed Electric Capacity of North Cyprus with Specification 33

Table 6.1 CO_2 Emissions Comparison 53

Table 6.2 Percentage Reduction in Carbon Emission and Social cost for 200 MW Interconnector and Local production. 55

CHAPTER 1 INTRODUCTION:

The importance and application of submarine cables date back to more than four decades, when they were not only used to connect the offshore nuclear generating stations or transmitting the offshore generated power to mainland as a substitution for oil or gas pipeline, but also for connecting several islands electrically to the mainland. The importance of these interconnections was anticipated at much larger voltage and power range, as the application of interconnecting the islands to mainland was steadily increasing [1] . After all these years, the application of submarine interconnector is still developing, and will continue to play vital role for interconnecting various power grids [2].

Although initiating a submarine electric interconnector project requires a substantial amount of money, it is still logical and economically viable to connect an isolated electric grid of an island to a nearby mainland, especially in a case if island's demand growth is excessive comparative to its inadequate electric demands which is solely met by fossil fuels [3]. A project of such nature shall be initialized after a detailed feasibility analysis, since the consequences of any damage affects a large group of public (for instance, prolonged power outage) as well as government (high repairing cost) [4].

One of the reasons for such high interest and development in interconnectors, especially interconnecting electric grids, is driven by the 20-20-20 plan of European Commission with a target to reduce the greenhouse gas emission (GHG) by 20% from 1990 levels, generate 20% of electricity from renewable resources and improve energy efficiency by 20% [5] [6]. In addition to that, the frame work of 2030 climate and energy includes the key target of 40% GHG reduction (from 1990 level), 32% share of renewable generation and at least 32.5% improvement in energy efficiency [7]. In 2018, a long term strategy for climate-neutral economy by 2050 was presented, illustrating the methods to of realistic technological solutions, in the key areas of industry, finance and research, for the climatic neutrality. With EU, contributing 10% of global GHG emissions, is a global leader in the transition towards net zero GHG economy [8].

The biggest factor involved in the agenda of global warming is emission of greenhouse gasses, for which the European Network of Transmission System Operators for Electricity (ENTSO-E) aims to increase the energy security by solidifying the European Internal Energy Market. This market, representing 43 electricity transmission system operators (TSOs) from 36 different countries, ensures the optimal functioning of electricity transmission system while integrating high degree of renewable energy sources in European energy system [9]. Third energy package, an EU energy market legislation formed in 2009, aims to improve the operation of internal energy market. This legislation covers the unbundling, independent regulators, agency for cooperation of energy regulation, cross-border cooperation, and lastly open and fair retail market for ensuring the improvement of internal market [10].

With the support of an already existing electric system, a country can take chances for renewable energy integration into its electric power system, thus reducing its greenhouse gas emission to a significant level depending on availability of its renewable resources. The support of an interconnector can be exceptionally beneficial if the local production is entirely dependent on fuel oil, making the production cost high, while the supplier (through interconnector) has means of renewable energy and relatively low fuel oil prices.

The countries facing Mediterranean area have a better chance of exchanging resources, particularly energy resources, which will help in the betterment of peace and prosperity and provide mutual benefits to community. The countries facing Mediterranean Sea, with healthy political and economic conditions, may easily pull off an electric interconnector thus providing more security of supply, economic savings, market opportunities and competition [11]. Turkish Republic of Northern Cyprus is one of the islands in Mediterranean, divided into two territories governed by Cypriots of Greek and Turkish ethnicity, facing a plethora of problems in term of electric power production market. North Cyprus's energy demands are solely met by the power generation from fossil fuel oils with a very minor contribution from renewable resources [12]. A very few or almost no effort has been seen in past from authorities of North Cyprus in the betterment of the electric power grid infrastructure or energy security.

1.1 Electricity Market of an isolated electric grid of Northern Cyprus

The energy demand of Northern Cyprus is majorly met by electric plants being fed on heavy fuel oil no. 6. Currently there are two fossil fuel plants in working condition known as Teknecik Power Plant owned by Kıbrıs Türk Elektrik Kumru (KIB-TEK) and Kalecik Power Plant owned by AKSA. KIB-TEK also had installed gas turbines which are deactivated presently due to their low efficiency and high operational cost. The only renewable source that feeds the national electric grid system is a Solar Power plant located at Serhatköy with a capacity of 1.3 MW [13].

According to Grunwald [13], the economic operational times for Teknecik steam and diesel turbines are 10 and 15 years respectively. Meanwhile the annual electricity production and peak demand increased by 5.7% during 1995 – 2015. The electricity production for TRNC for the year 2008 – 2018 is illustrated in Figure 1.1. Even with current production and increasing demand, the demand is expected to exceed the production in near future.

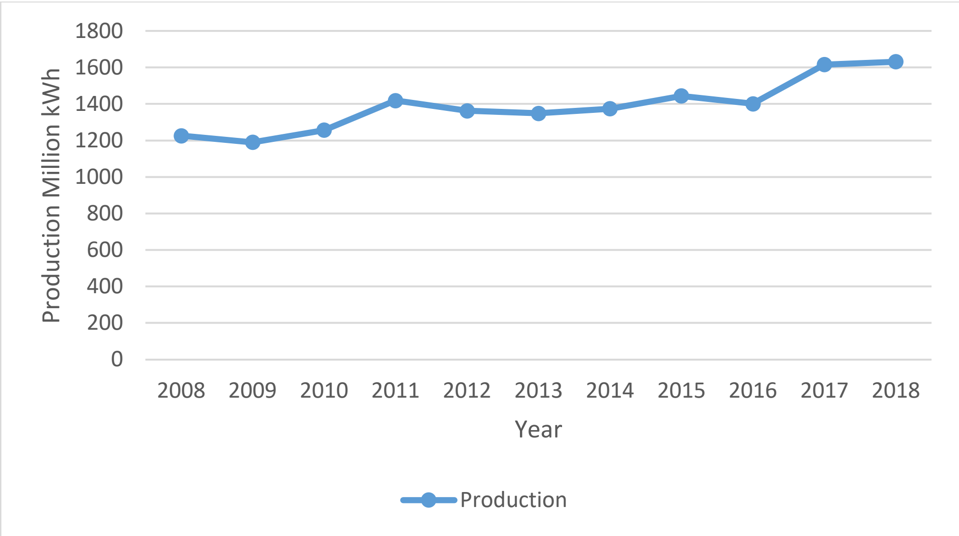

Figure 1.1 TRNC Electricity production for year 2008-2018 [14]

1.2 Problem Identification

Sole dependency of Northern Cyprus's electrical generation on fossil fuels makes it vulnerable to highly volatile prices of fuel, exchange rate and disruption of fuel delivery, whereas on the other hand, electricity demand of North Cyprus is increasing over the period of time. As like any other Mediterranean island, electricity consumption of Cyprus as a whole is highly dependent on seasonal variation, as the temperature variates the electricity consumption increase or decrease accordingly [15]. Being an island, Cyprus entertains a large number of tourists every year which are majorly during the summer season due to which the electricity consumption increases significantly, particularly during the hottest month of July and August compared to the coldest months of the year are December and January [16].

Despite the fact that Northern Cyprus is an unrecognized state (only recognized by Turkey), it attracts a great amount of tourists, and international students. The remarkable development in the education system of North Cyprus started to attract international students in the decade of 90s. The increase in tourist and students led to construction of new hotels and buildings, resulting into growth of energy consumption [17]. In 2004, a referendum was held on Annan Plan, where the two communities were to vote for the approval of fifth revision of UN proposal for reuniting the island. The proposal was rejected by the Greek Cypriots whereas accepted by Turkish Cypriots. [18]. After 2004, as a post Annun Plan referendum dynamic, an increase in the development of construction sector was observed, which is expected to grow even more in the coming decades [19]. This steady development in tourism, education and other sectors is leading to rapid increase in energy consumption which can be foreseen to increase even more.

The inadequate natural resources of Northern Cyprus do not meet the energy demand of the growing population. Since North Cyprus's electrical grid is not connected to any other mainland, the energy demands are met by the use of fossil fuels. The yearly consumption data provided by KIB-TEK shows the peak demand of 312 MW in the year of 2016 whereas 333 MW in year 2017 [14]. In the light of data, it can be seen that peak demands for previous years were very close to the nominal capacity. On top of the increasing demand, the agreement with AKSA power plant for energy production is ending by the year of 2024 driving AKSA out from electrical market of TRNC. With continuous increase in demand and AKSA leaving the electricity market, resulting into even less nominal production capacity, a huge fall back can be seen ahead of time. Under these circumstances North Cyprus has very few options such as: extend the power plant capacity of KIB-TEK or AKSA, or extending AKSA contract of energy production, connecting the electric grid system to a mainland with the means of a submarine electricity cable. All proposed methods have its pros and cons based on different factors such as political, financial and environmental risks etc.

The former method still keeps North Cyprus vulnerable to volatile fuel prices as well as expects to have major shutdowns in case of disruption of fuel oil whereas the later proposed method requires a substantial investment and also includes some political risks but considering the environmental factor, i.e. Turkey's electricity mix (renewable energy resources being used for power generation), provides a much cleaner energy compared to sole reliance on fossil fuel production in TRNC.

1.3 Aim of the study:

The fundamental aim of this research is to analyze the feasibility of proposed submarine electric interconnector cable between Republic of Turkey and Northern Cyprus in comparison to reliance on local electricity production.

At the end of the research, the study results will be able to answer following questions:

i. Is it financially feasible to install and operate a submarine electric interconnector cable between Turkey and Northern Cyprus in comparison to local production?

ii. Which of the aforementioned methods will be environmental friendly by contributing less greenhouse gasses and how much reduction in GHG is expected?

iii. What are the anticipated pros and cons of both proposed methods?

1.4 Study Approach

Merit order concept is used to analyze whether the submarine cable project is financially feasible comparative to local production along with potential risks of both options. Merit Order curve helps in the selection of better electricity mix based on cost. The generators classified in a curve, based on their marginal costs of electricity production, helps to easily visualize the cheaper energy source. The cheapest source in the curve helps setting the starting point where as the last generator which satisfies the peak demand, helps to set the hourly spot price.

Other benefits, such as reduction in greenhouse gasses, security of supply, impact on consumers etc. for the submarine cable will be determined from the literature.

1.5 Summary

Submarine cables technology have developed a lot over the years and have yet to see more advancement. Interconnecting islands, with high dependency on fossil fuels, to grid systems of mainland with healthier energy mix helps the islands to reduce greenhouse gas emission and explore renewable resources. Turkish Republic of Northern Cyprus, in Mediterranean Sea, depends heavily on fossil fuels with only 1% of electricity production via renewables. A submarine electrical interconnector will connect the isolated grid of TRNC to Turkey to help reduce the carbon foot print. The study will theoretically analyze and numerically evaluate the economic feasibility and environmental impact of the submarine cable.

CHAPTER 2 NORTH CYPRUS: COUNTRY CONTEXT

2.1 Turkish Republic of Northern Cyprus: An Isolated Territory

The island of Cyprus has been a center of dispute for a very long period now. This island in the middle of eastern Mediterranean is led by two administrations. The south of the island is led by the Greek Cypriots whereas the north part of the island is led by the Turkish Cypriots with a United Nations-administered buffer zone in the middle [20]. The current land administration is explained in the Figure 2.1

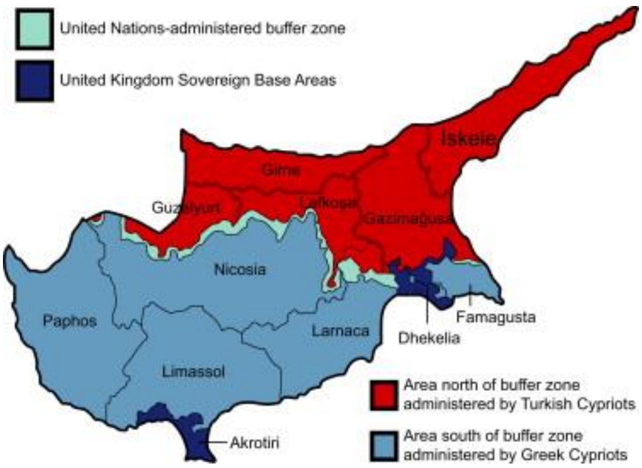

Figure 2.1 Map of Island of Cyprus [20].

2.2 North Cyprus: Electric Power Grid

The national power company known as Kıbrıs Türk Elektrik Kurumu a.k.a. KIB-TEK (Cyprus – Turkish Electricity Authority) is the vertical authority in North Cyprus handling the production, generation and distribution of electricity. KIB-TEK has steam turbines and diesel-electric generators. It also has an agreement of flat band power purchase with a private company known as AKSA [21]. A small portion of electricity is generated by renewable energy, by Serhatköy photovoltaic power plant, which was installed in 2011. This renewable source of energy only covers estimated 1% of electricity production of North Cyprus.

Over the period of time, both companies have increased their capacities as the demand started to grow. It has been seen in the recent past that the installed capacity is eventually falling short to fulfil the demand of North Cyprus with a local resident of around 300,000. The breakdown of existing installed capacity of North Cyprus is shown in Table 2.1.

Table 2.1 Existing Installed Electric Capacity of Northern Cyprus [13]

Service Provider (Location)	**Type**	**Number and Size of Units**	**Total Installed Capacity (MW)**	**Net Useable Capacity (MW)**
KIB-TEK (Teknecik)	Steam Turbine	2 × 60 MW	120	110
KIB-TEK (Teknecik)	Diesel Turbine	8 × 17.5 MW	140	120
AKSA (Kalecik)	Diesel Turbine	8 × 17.5 MW	140	120
AKSA (Kalecik)	Steam turbine	1 × 8 MW	8	6
Serhatköy	Solar	1.2 MW	1.3	-
Total			**409.3**	**356**

The transmission nexus of North Cyprus, handled solely by KIB-TEK, is operated at 132 kV and 66kV for high voltage, and 22 kV and 11kv for medium voltages. The electricity network of North and South Cyprus is interconnected at 4 different points, and synchronized at 3 points. Figure 2.2 illustrates the transmission network of TRNC.

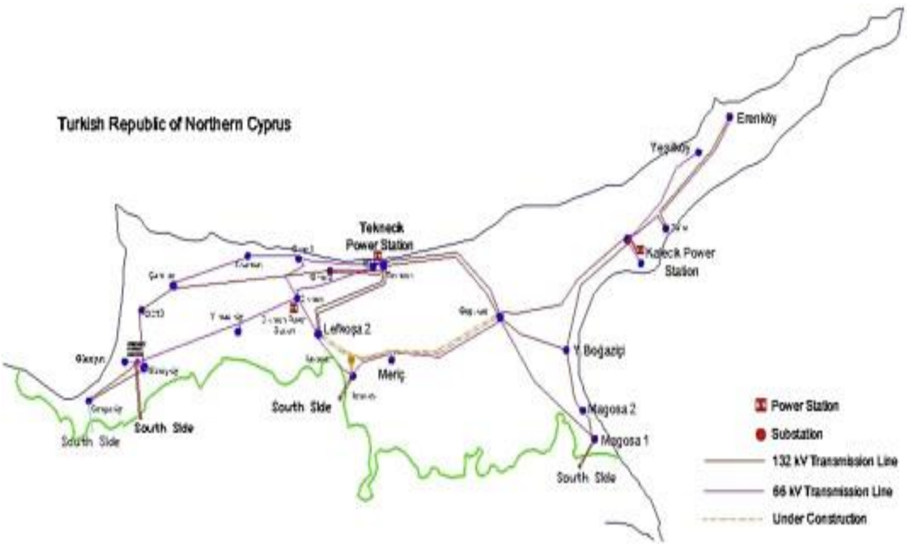

Figure 2.2 Electrical Transmission Network of North Cyprus [20]

Reviewing the electricity production of TRNC, dated from year 2008 - 2018, shows a gap between electricity production and consumption. The ample production satisfies the consumption of TRNC, which, after the line losses and power plant internal consumption, was still enough to meet the local demand. The condition remained the same up until 2010 as it can be seen in Figure 2.3, 2.4 and 2.5.

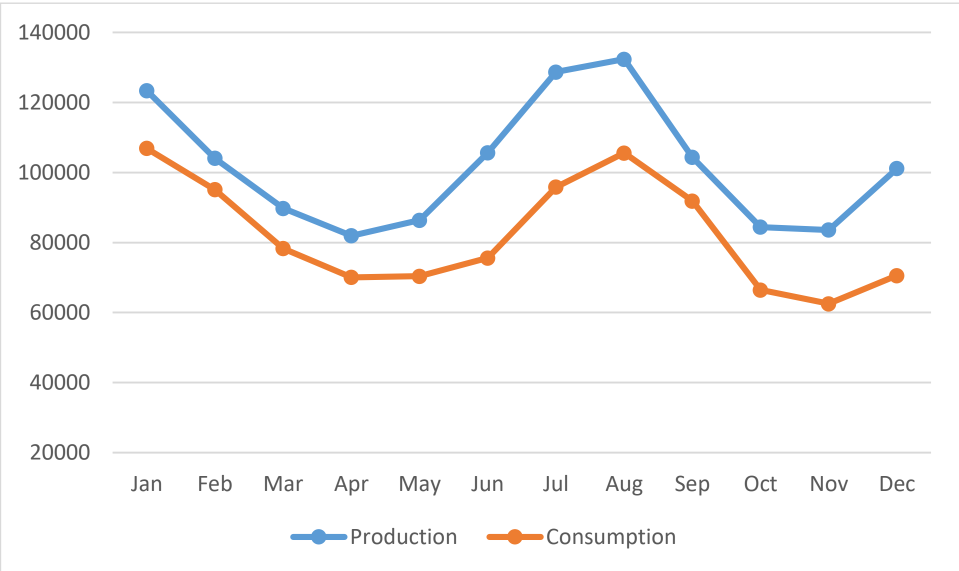

Figure 2.3 Electricity Production and Consumption of TRNC - 2008

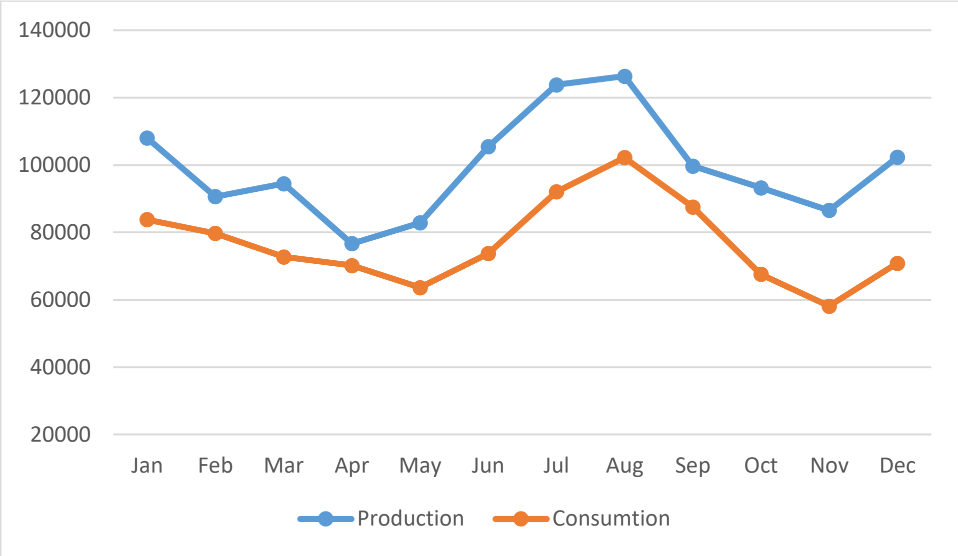

Figure 2.4 Electricity Production and Consumption of TRNC - 2009

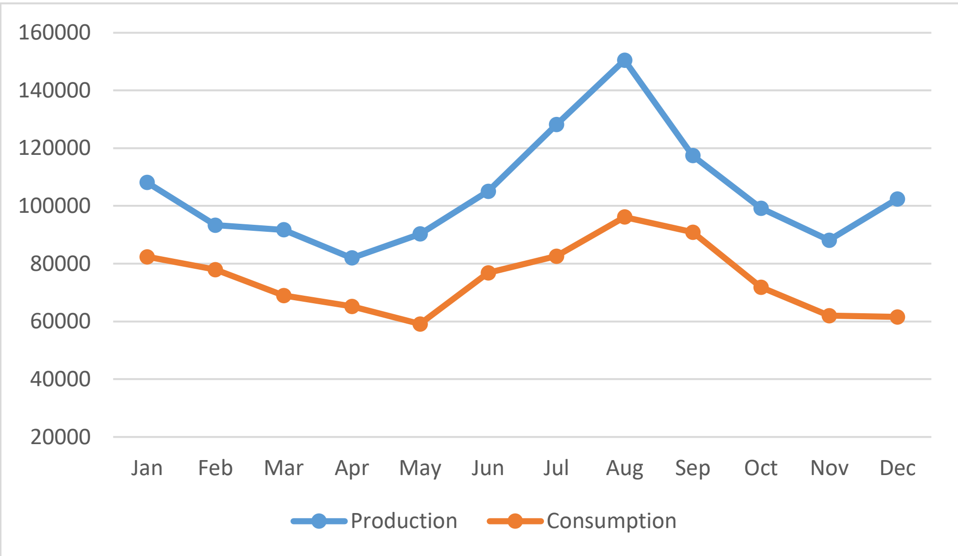

Figure 2.5 Electricity Production and Consumption of TRNC – 2010

After 2010, the gap between the production and consumption started to decline, which is also illustrated in Figure 2.6 – 2.13 for year 2011-2018. Along with it, over the period of time, the efficiency of available generation sources also started to decline. Due to sole dependence of generation on fuel oil, the electricity authority of TRNC announced recurring and mandatory power cuts in 2016 [22].

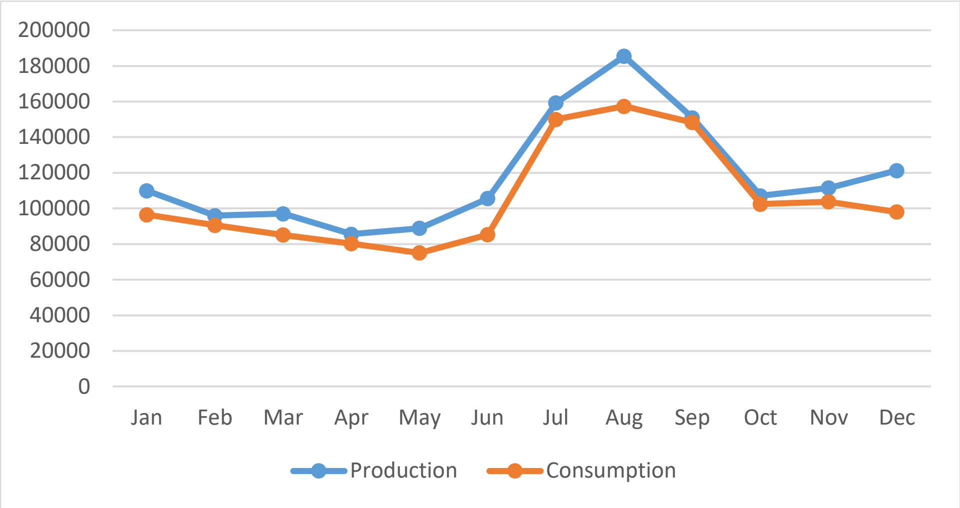

Figure 2.6 Electricity Production and Consumption of TRNC – 2011

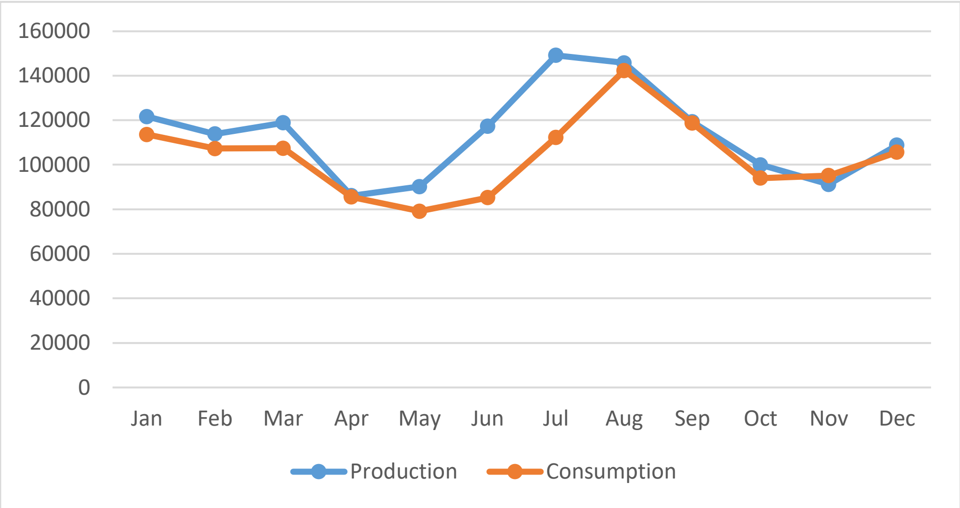

Figure 2.7 Electricity Production and Consumption of TRNC – 2012

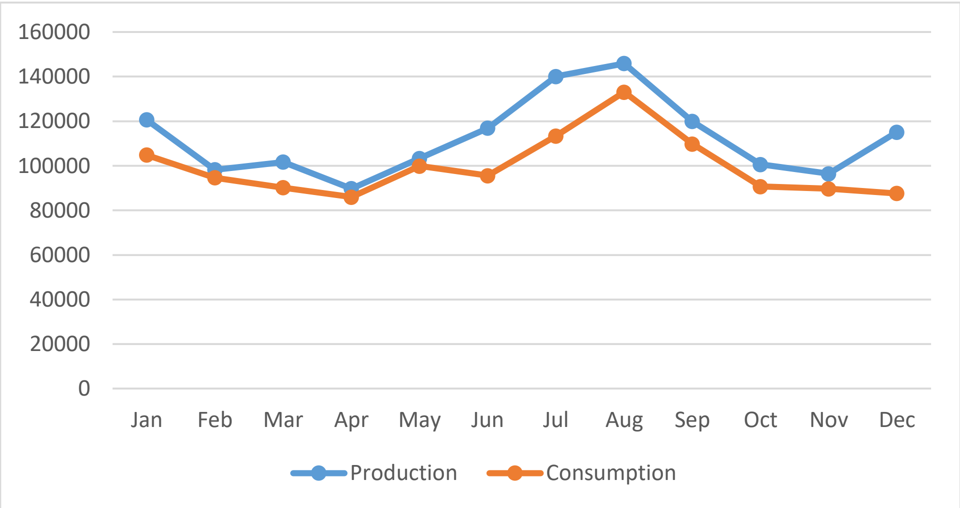

Figure 2.8 Electricity Production and Consumption of TRNC – 2013

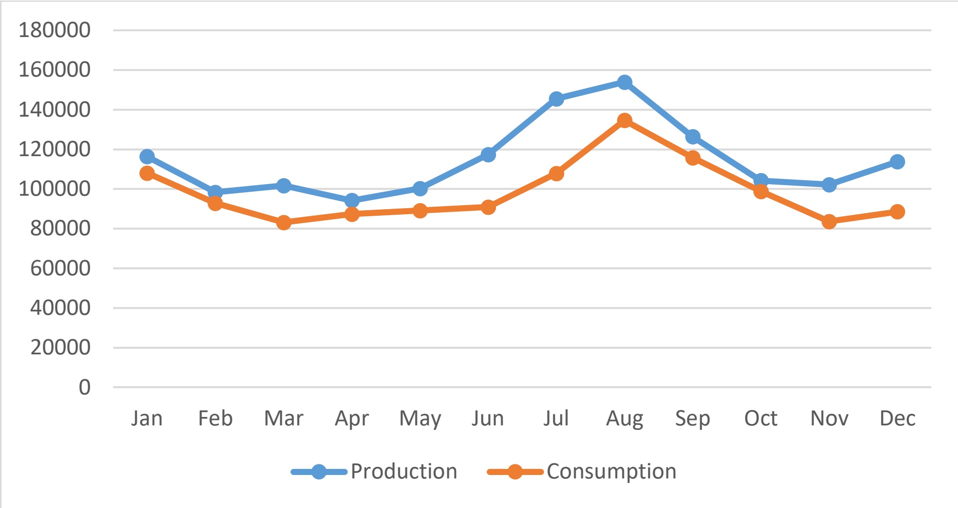

Figure 2.9 Electricity Production and Consumption of TRNC – 2014

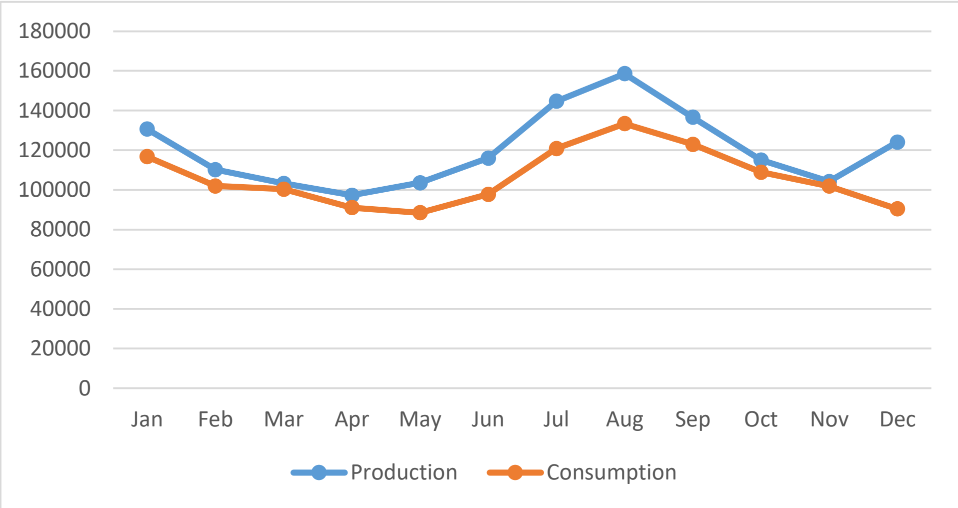

Figure 2.10 Electricity Production and Consumption of TRNC – 2015

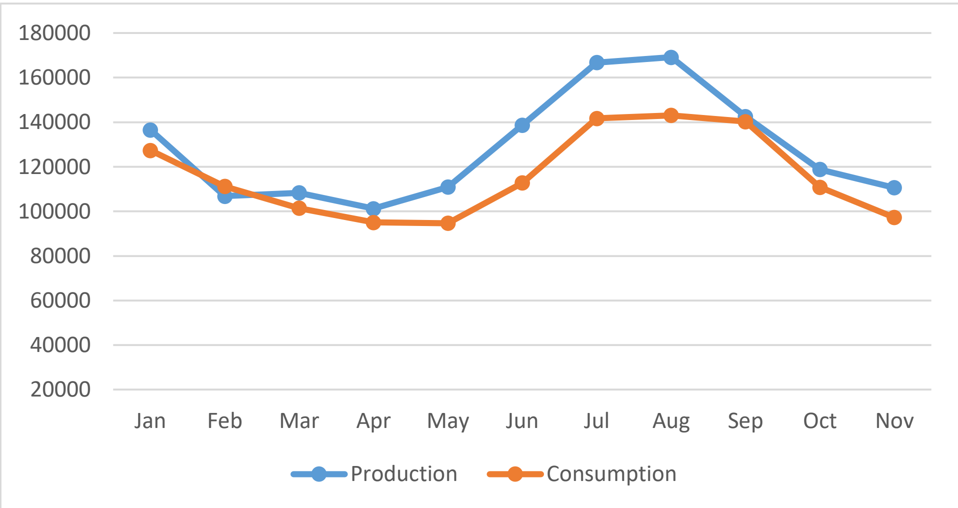

Figure 2.11 Electricity Production and Consumption of TRNC – 2016

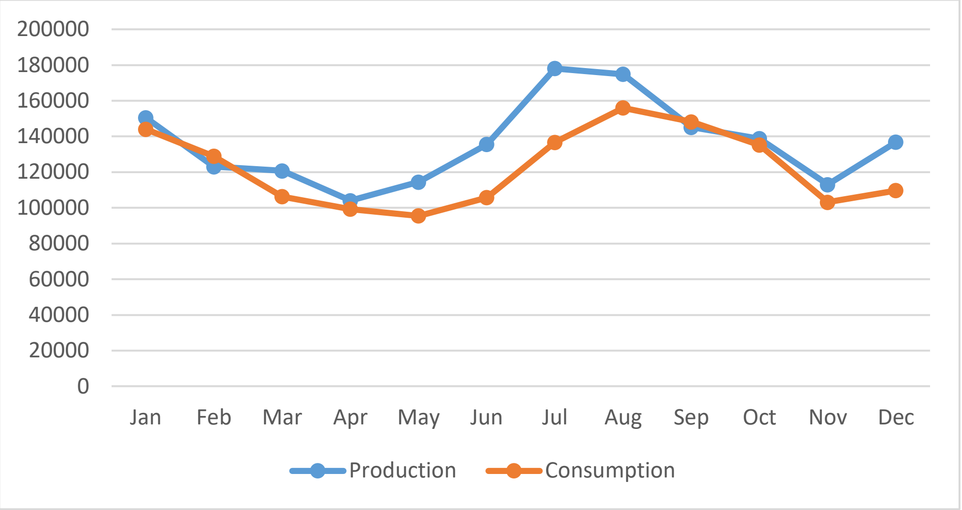

Figure 2.12 Electricity Production and Consumption of TRNC – 2017

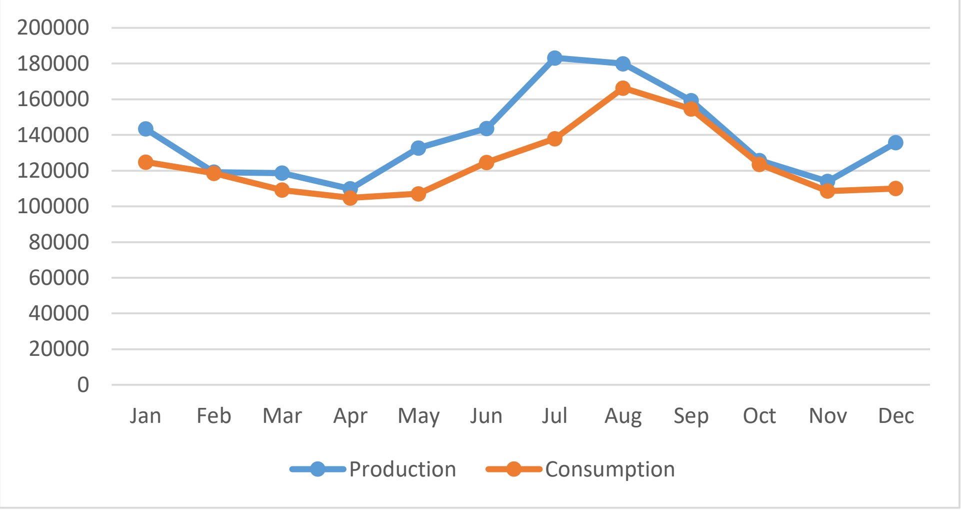

Figure 2.13 Electricity Production and Consumption of TRNC – 2018

Maltini and Minder [20] states that North Cyprus faces system vulnerability due to lack of backup or auxiliary capacity, low power factor and unbalanced demand. High seasonal variation causes the day time peak and demand side management techniques are required for the load shifting to balance the load.

2.3 Summary

Cyprus is led by two different administrations, and electric grid of both sides is isolated from any mainland grid but interconnected with each other at 4 different points. TRNC has 409.3 MW installed capacity with only 356 MW net useable capacity. Over the past few years, the consumption has started to increase whereas the power production capacity is consistent. KIB-TEK is vertical authority of production and transmission, and also have a flat band purchase contract with private company named AKSA.

CHAPTER 3 LITERATURE REVIEW

3.1 Electricity Generation

The process of converting the sources available in nature into electric power is called electricity generation [23]. There are multiple sources of power generation classifying mainly into two types as

- Electricity generation based on thermal processes
- Non-Thermal electricity generation based on renewable resources.

North Cyprus is using conventional sources of electricity production, which is oil based thermal process, along with only solar power generation from non-thermal based renewable resources [13], due to which we will only be reviewing the oil based thermal process of electricity power generation.

3.1.1 Diesel Power Plants

The prime movers of electric generator being driven by diesel engine is the electricity production source for the diesel power plants. Usually these engines are used for back up either for emergency or as a startup of auxiliaries of other power plants [24]. Currently, in North Cyprus, diesel generators are being used dedicatedly for the production of electricity rather than as a backup [13].

The four stroke diesel engine was patented by Rudolf Diesel in February 23, 1893 which later on with time saw various technological advancements but the basic working principle remains the same, comprising of four strokes named as inlet, compression, combustion and exhaust strokes. Due to downward motion of pistons, during the first stroke (inlet), the inlet valve allows the external air to enter the cylinders which is then compressed during second stroke (compression) as the pistons move upwards. During the third stroke (combustion) diesel fuel is injected in combustion chamber where it as ignited when exposed to highly compressed drastically heated air, and resultant heat energy is used to create power. During the last stroke (exhaust), the exhaust gasses are drained through exhaust valve generally seen as a black smoke from diesel engines [25]. The diesel engines are better in terms of flexibility, robust and hard-wearing design and does not require any spark plugs which reduces one of the maintenance cost [26]

3.1.2 Steam Power Plants

The basic principle of steam power plant follows the process of converting heat energy into mechanical and then to electrical energy. Water being the cheapest and abundant fluid is used in boiler to produce steam. In order to heat the water, different fuels such as coal, gas, oil etc. are used in furnace [27]. The steam produced from water is used to operate prime movers of steam power plants. Figure 3.1 illustrates a general layout of steam power plants.

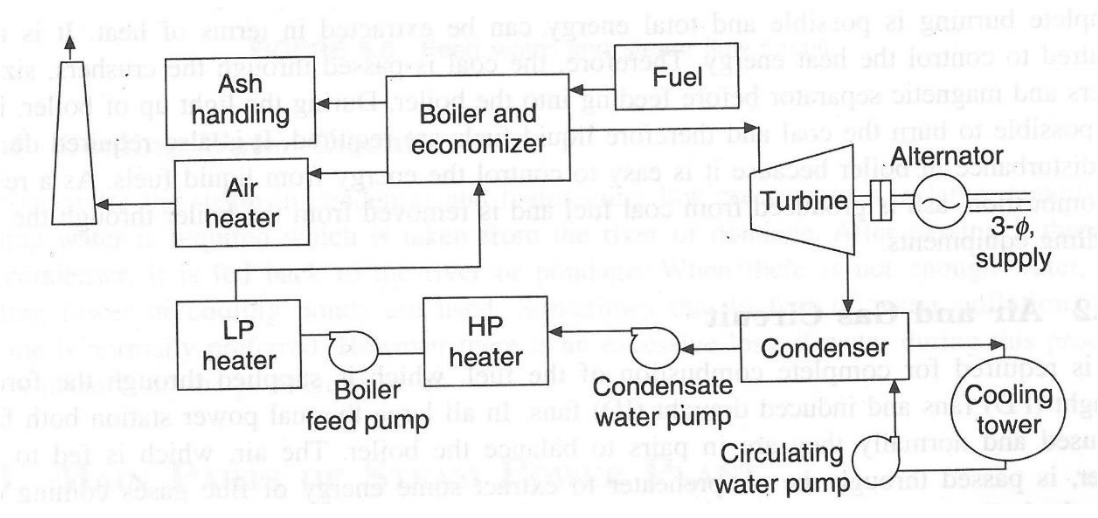

Figure 3.1 General Layout of Steam Power Plant [24]

3.1.3 Combined Cycle Gas Power Plant

A combined cycle power plant (CCPP), as the name suggests, is combination of two thermal cycles. In a combined cycle gas power plant, Brayton and Rankine cycles are used for gas and steam turbine systems respectively, which allows high thermal efficiency [28]. A simple gas turbine is connected to recovery heat exchanger known as Heat Recovery Steam Generator (HRSG), recovering heat from the turbine or compressor outlet exhaust gasses. This recovered heat is used to produce steam to drive a steam turbine called combined cycle. Combined cycle power plants are known to be the most efficient power plants in power grid system. The efficiency of CCPP is known to be ranging between 45% to 57% [29]. A simplified flow diagram of a Combined-Cycle Power Plant can be seen in Figure 3.2. The temperature of exhaust gasses from the gas turbine ranges between 900° F to 1100° F which can also be increased by supplementing the exhaust gases with firing up to increase the temperature up to 1600° F which can result into doubling the steam production thus increasing the efficiency of plant [30].

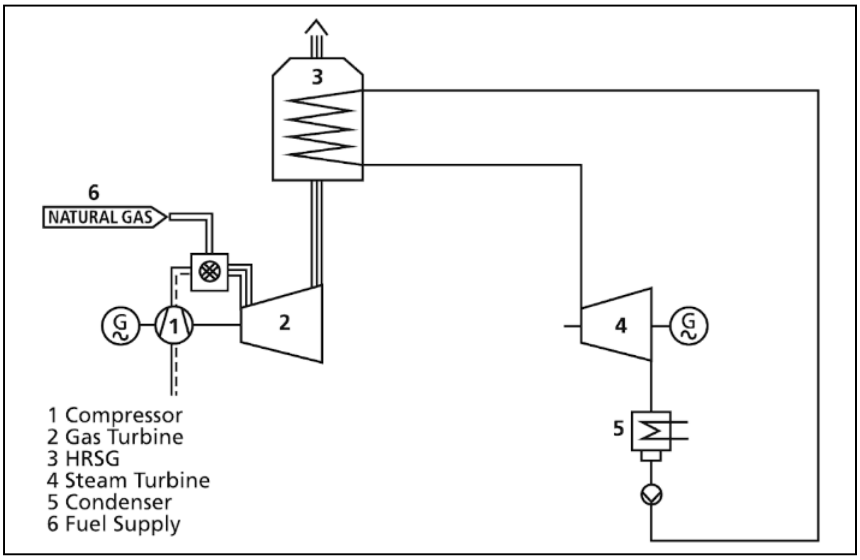

Figure 3.2 Simplified flow diagram of Combined Cycle Power Plant [28]

3.2 Sustainable Energy Systems

The idea of sustainability rose in 1987, when the Brundtland Report titled 'Our Common Future' shed light on an unsettling issue of human nature [31]. The report, issued by World Commission on Environment and Development, show its concern on human nature to dream of luxurious and technological life in comparison with the natural limitations [32]. The idea or definition of sustainability differs in every aspect of life for every individual, but the origin of the term sustainability is a German word *Nachhaltigkeit* (sustainability) which was used in forestry, in terms of not harvesting more than yielding [33]. The term has not branched in every sector encompassing all social, economic and environmental dimensions.

Possibility of climatic change due to over exploitation of natural resources and emission of greenhouse gasses and its impacts on social, environmental and economic aspects of life has put the human activities into questioning. This debate also has led the technological exploration from fossil fuels to renewable energy sources [34]. According to statistics, as of 2017, the installed renewable capacity for the whole world was 2,179,426 MW [35]. Provided the fact, that 80% of world's total energy is produced by fossil fuel causing greenhouse gas emission, the transition towards renewable energy is found to be onerous [34].

The idea of being 'green' may seem to involve a great deal of effort, but technologically we are provided with a number of options, but the clean, affordable and reliable energy seems to be a great concern with the growing population, which is expected to be 9 billion by 2050 [36]. Figure 3.3 illustrates the CO_2 emissions for the different power plants operated on fossil fuels, as well as the CO_2 emission during the construction stages of renewable power plants.

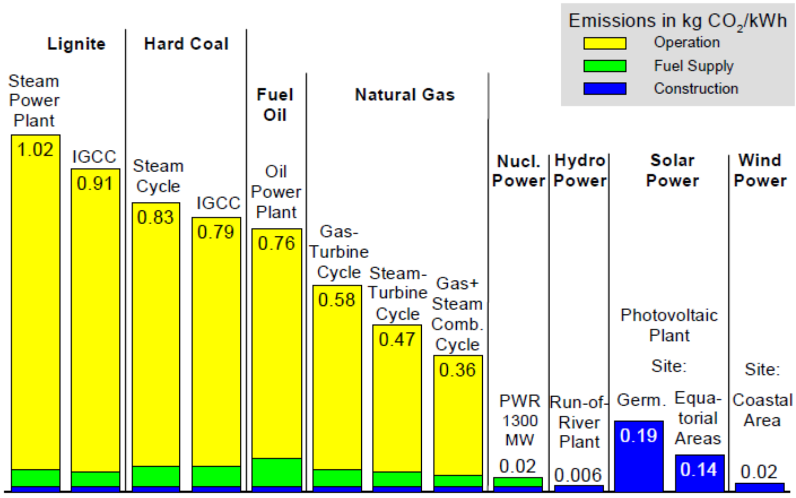

Figure 3.3 CO_2 Emission for Various Energy Sources [23].

A number of sustainable energy production techniques, such as solar, wind, hydro, geothermal, and tidal etc. are available but along with the sustainable production, sustainable consumption has to come hand in hand [37]. A country on its own, or a group of countries all together, however, need to take initiative for the reduction in carbon emission, as it is no longer a debate.

3.2.1 Social Cost of Carbon

The effects of climate change, such as extreme weathers, sea level rise, flooding etc. are catastrophic. The consequences of these devastating effects are borne by each and every individual including the governments in hundreds and billions of dollars. Quantifying the harm caused by these impacts monetarily is termed as social cost of carbon, i.e. 40 $ for emitting one ton of carbon into atmosphere [38]. This value social cost of carbon, is the most robust value available yet, even though it does not cover a wide range of scientific and economic impacts of climate change. The continuous update of social cost of carbon is necessary to account for climate damages.

3.3 Turkey's Energy Portfolio

The proposed submarine electric interconnector cable connects the isolated grid of TRNC to Turkey's electric grid, it is of sound nature to analyze the Turkey's energy portfolio. Since Turkey will be exporting the electricity, it is in good interest of sustainability issue if the country exporting electricity has a healthier energy mix in comparison with the importer.

Turkey has a much diversified electricity mix, since it is naturally enriched in indigenous sources and has a stable financial condition in comparison to North Cyprus. Although the renewable share of electric power generation is not so high, the hydro does seem to cover a bigger chunk of installed capacity. If a comparison is to be made, the dependency of Turkey on fossil fuels has increased a lot from 1980 to 2014, i.e. 51% to 79 % respectively [39]. Even though the dependency might have increased, Turkey has a great potential of renewable electricity production [40] [41] [42]. Turkey alone has a renewable potential of 13% of EU 27's total renewable potential [43]. Figure 3.4 illustrates the Percentage Contribution of Energy Sources in Installed Electric Capacity of Turkey as of June 2018.

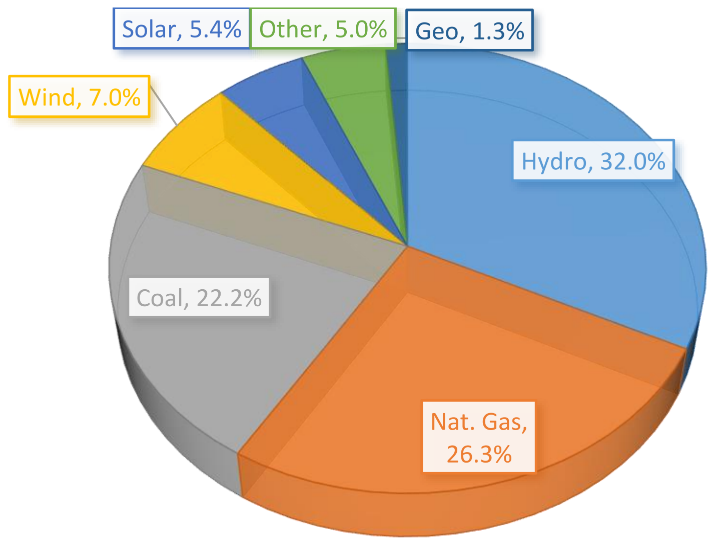

Figure 3.4 Percentage Contribution of Sources in Production of Turkey (2018) [44]

Data retrieved from EPİAŞ [44] reveals the percentage breakdown of installed capacity of Turkey as of June 2018, in which Hydro turns out to be of greatest capacity and covers 32% of total installed capacity followed by Natural Gas, Coal, Wind, Solar, and Geo Thermal with 26.3%, 22.2%, 7.0%, 5.4%, and 1.3% respectively

Even though the installed renewable capacity might be high for Turkey, what matters is the contribution to the production for each energy source. Figure 3.5 illustrates the contribution of all energy sources for electricity production for the year of 2018. The percentage of contribution from energy sources is different from that of installed capacity.

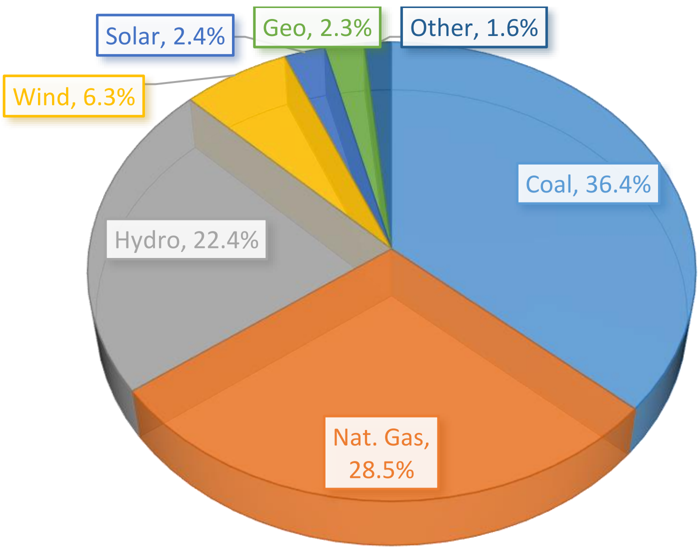

Figure 3.5 Electric Energy Production of Turkey 2018 [44]

Figure 3.5 depicts that even though hydro might have the highest share in the installed capacity, coal stands to be the first in line when it comes to the electricity production. The reason behind this could be that government provides a subsidy to support coal industry. In year 2013, the subsidies provided to coal industry summed up to be around 300 million USD [39]. Even though coal might prevail in production contribution, Turkey's energy mix is still a lot healthier than that of North Cyprus.

3.4 Submarine Electricity Power Cables

Connecting the small islands, stretched in natural resources for the production of electricity generation, with mainland country's grid is a common practice [45]. The submarine electricity cables were introduced in 1811 laid in Bavaria across the river Isar, long before the first submarine telecom cable in 1850, but it never got as much early appreciation as the other one did [46]. Over the period of time, the technological development and sophistication in the submarine electrical cable technology has made the projects more economically feasible at larger scale [47]. The first natural rubber insulated submarine electric power cable was laid in 1811 in Germany and over the years with the advancement until 1952, oil filled insulated submarine cables were introduced [48]. On the other hand, the first HVDC submarine electric power cable was installed to connect island of Gotland with Sweden mainland [49]. It was the first commercial installation of a 20 MW, 100kV HVDC submarine cable deployed by ABB for a distance of 98 km [50].

Submarine power cables are of great importance in terms of power transfer from and to offshore renewable energy scheme, remote areas, and interconnection of multiple grid systems. With the ever growing consumer demand and depleting natural resources, renewable energy reliance is increasing and to utilize offshore based renewable energy resources, submarine power cables has become critical factor in the power systems infra-structure [51]. One of the reason of particular interest towards the renewable energy resulting into implementation of submarine interconnectors to connect power grid systems is said to be the previously mentioned 20/2020 targets set by European Commission as well as the 2030 climate and energy framework whose key targets include 40% decrease in GHG emissions (from 1991 levels), 32% increase in renewable shares and 32.5% improvement in energy efficiency [52].

While considering the case of Northern Cyprus, where the demand is increasing over the time whereas the supply has been persistent without any expected increment, Ghobrani et al. [5] and Worzyk [47] suggests using a submarine cable to connect the isolated island’s electricity grid to mainland power grid as a huge yet feasible project to overcome the problems of insufficient power supply that is fueled up by inefficient diesel and gas generators. As mentioned earlier, that the project is a huge investment of time and financial assets which suggests that a detailed feasibility analysis shall be carried out before the project is initiated.

3.4.1 Types of Submarine Power Cables

When it comes to installation of a submarine electric cable, a huge number of parameters are to be considered before choosing the proper type of cable. The choice of cable sets the initial step of the investment cost. The factors to be considered while choosing the cable include seabed, tides, seismology, trawling, and anchoring etc. the project site and sea bed are to be chosen very carefully since the maintenance and fault detection in case of submarine cables takes much longer than a land buried cable [53]. The types of available cables are

a) HVAC

b) HVDC (Line Commutated Converter)

c) HVDC (Voltage Source Converter)

The study just evaluates the option of an HVDC (VSC) following the methodology discussed later in Chapter 5, as it is the proposed type of cable for the project.

3.5 Submarine Electric Interconnector Cable Projects

A number of submarine interconnector cable projects are commissioned around the world ranging from low to very high voltages. Some of them are used for offshore electricity production, whereas some of them are used for interconnecting the isolated electric grid of islands to mainland grid systems. Since this research study analyze the feasibility of connecting an island to mainland country, the interconnector around the globe of similar nature are reviewed to compare the feasibility to forecast the aftermath of the project.

The scope of submarine electrical interconnector cables has increased from just offshore electricity generation to interconnecting grid systems of remote areas. Figure 3.6 demonstrates the interconnections in EU, which covers the most of the interconnector cables.

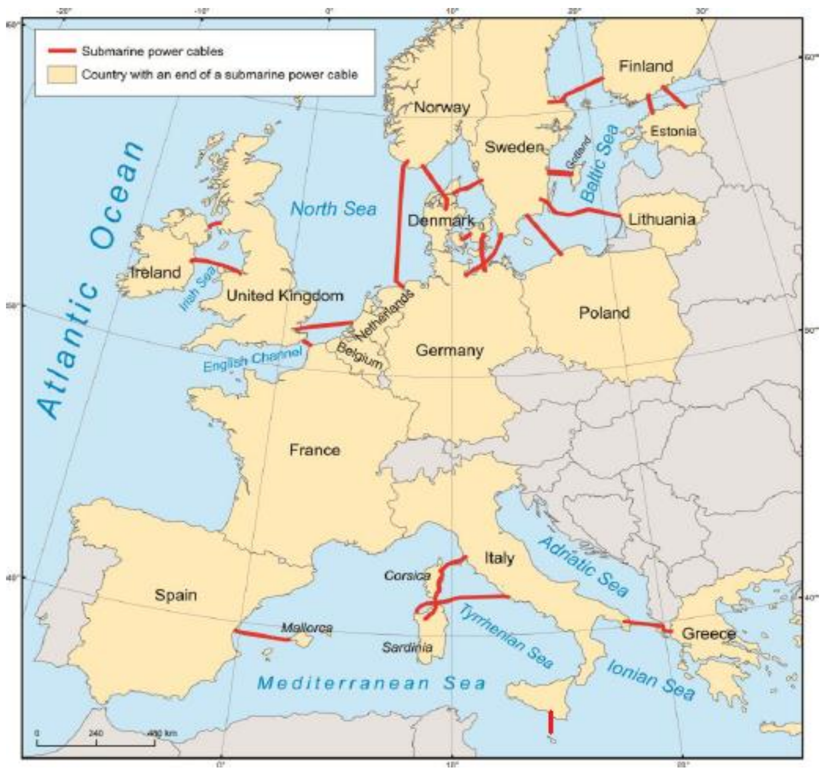

Figure 3.6 EU Submarine Electric Interconnection Map (modified from [49])

European adjacent areas sum up to almost more than 70% of the submarine electric interconnection cables, in context of number and length of the interconnector cables. Usually the interconnector cables are targeted for the countries within the continent, but two intercontinental interconnector cables i.e. Spain-Morocco and Egypt-Jordan interconnectors are exemplary cases, but both of them are HVAC interconnector cables [54].

Considering a large number of interconnectors, among which, majority of them are less than 300 km, we will only be discussing the submarine interconnection of islands to the mainland electric grids.

3.5.1 Malta - Sicily Interconnector

A submarine electric interconnector cable was laid between a Mediterranean Island of Malta and the main land Sicily. The interconnector cable was inaugurated in April 2015 with a nominal capacity of 200 MW. European Union energy policy require the member states, specially the small islands which are exposed to volatile oil prices, to interconnect the existing power systems with mainland power systems. Previously, studies have been done on the feasibility and after math of the interconnector to evaluate the techno economic stance of the interconnector. Reis et al. used the similar approach as our study, by using merit order concept to the existing power system and interconnector [55]. This study is the most similar to ours, firstly because of the geographical location i.e. an island in the Mediterranean. Malta, similar to Cyprus, is also a touristic place with high seasonal variation which makes it demand characteristics of Malta almost similar to that of North Cyprus. Figure 3. Illustrates the demand characteristics of Malta.

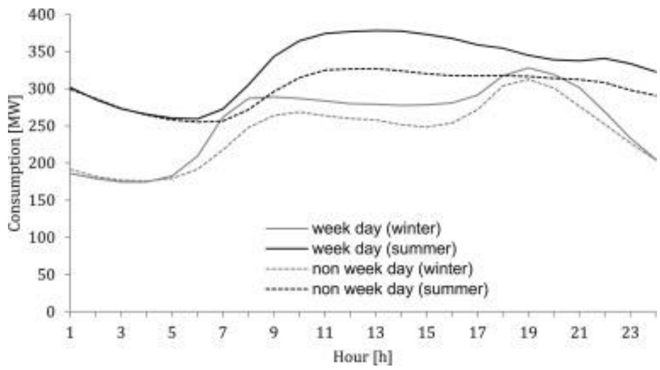

Figure 3.7 Demand Characteristics of Malta [55]

If a comparison was to be made between Figure 3.7 and Figure 4.1, it can be seen clearly that the demand characteristics are of same nature due to seasonal variation. Second reason of this case being similar is the sole reliance of the island on fossil fuels. The total sea and land distance of the cable sums up to around 100 km, which is similar in our case study [56]. Different approaches for optimal operation of line are discussed by Lauria and Palone [57], concluding that an attention to market architecture is needed for potential cost saving. The problem in Malta-Sicily interconnector is the limited capacity of the interconnector cable as well as the connection is HVAC which means to expand the exchange of electricity, a new cable is to be laid thus requiring a large investment from the scratch [58].

3.5.2 Ireland – UK Interconnector

In North Atlantic, the island of Ireland, towards Northwestern Europe, is connected to Britain with EWIC (East – West Interconnector). EWIC is an HVDC interconnector with a nominal capacity of 500 MW, operated by EirGrid, a national grid operator [59].

The Northern Ireland is also connected to Scotland with another 500 MW submarine interconnector cable, known as Moyle Electricity Interconnector, with

Scotland. The interconnector was commissioned in 2001, and is operated by a Northern Ireland company called Mutual Energy [60].

Another 500 MW submarine interconnector, called Green Link, was proposed to connect Ireland with Great Britain. The project is now in advanced stage, co-financed by European Union, and planned to commission in 2023 [61].

3.5.3 Gotland – Sweden Interconnector

The first HVDC interconnector of EU was installed between Gotland, a Swedish island in Baltic Sea, in 1954. It was a 20 MW submarine interconnector, which was later dismantled in 1986 [62]. After which two more of similar projects were installed known as G2 and G3 interconnector in 1983 and 1986 respectively with a total rating of 260 MW and 90 km length [63].

3.5.4 Mallorca – Spain Interconnector

Mallorca is a Spanish island in western Mediterranean, for which an interconnector was proposed to connect the two Balearic Islands electric grid to Spanish electric grid system. The first phase, known as COMETA (COnexión MEditerránea Transporte Alta tensión) or Romulo project, connects Spanish grid system to Mallorca with a 400 MW HVDC submarine electric interconnector cable, followed by the project that connects the isolated electric grid of Ibiza to that of Spanish [64] [65].

3.5.5 Sardinia – Italy Interconnector

A 1000 MW HVDC cable, 1600 ft. below sea level in Tyrrhenian Sea, connects an Italian island of Sardinia to its mainland country. This submarine electric interconnector is known to be the deepest submarine electric interconnector cable in whole world. The cable was commissioned in 2011, and was second of its nature to connect Sardinia to Italy [66]. The first 200 MW submarine electric interconnector cable was laid in 1960 between the island and mainland [67].

3.6 Gap

Similar to previously mentioned cases, there are many other submarine interconnector cables, connecting isolated electrical grid systems of islands with the mainland country and interconnecting the grid systems of countries such as Spain – Morocco, Spain – France, Sweden to Finland, Lithuania, Poland, Germany, Denmark etc. The existing literature [49] [55] [56] [57] [58] [68] [69] [70] [71] [72] [73] [74] discuss in detail the social, political, technical and other various issues of the submarine electric interconnector cables. These studies have been conducted either before the initiation of the submarine cable projects as feasibility study or concluding the aftermath of the projects.

With an expected electric interconnection between Turkey and North Cyprus, a techno-economic analysis is in order. Grunwald [13] has studied the case, but it is a pre-feasibility analysis for the Turkey – North Cyprus submarine electric interconnector with a technical and financial analysis which just covers the expected cost of the project. Any other study fails to provide the techno-economic analysis of the interconnector and its effect on the North Cyprus tariff as well as the environment.

3.7 Contribution

This economic feasibility analysis evaluates the submarine electric interconnector between Turkey and North Cyprus on basis of the marginal costs. It provides a comprehensible detail of possible outcomes of the interconnector and its effect on the existing electric grid network of TRNC. It evaluates the nature of interconnector on the investment plans, and its consequences on the marginal cost of production. Following the different scenarios, through certain method discussed later, it concludes the best possible options for the electricity production in terms of financial and environmental aspects for the foreseeable future.

3.8 Summary

The contributor towards GHG emissions in electricity industry are the thermal power plants among which Diesel, Steam, and Gas power plants are being used in TRNC. Overexploitation of natural resources have resulted into depletion of it with, 80% of world's electricity being produced with fossil fuels. The idea of sustainability was introduced in 1987, which is no longer a debate and needs action to fight against GHG. To avoid the GHG emissions in TRNC, it is suggested to interconnect electric grid of TRNC with Turkey's which runs on a comparatively healthier energy mix, with installed hydro capacity of 32% which contributes 22.4% towards total production. Submarine cables have contributed, for a long time, towards interconnecting distant islands and offshore energy transmission. HVDC is preferred for long distance electricity transmission because of its advantages over HVAC. Many islands across the world have been electrically interconnected using submarine cables, and studies have reviewed their feasibility and aftermath. This study, first of its type for TRNC, will theoretically analyzed and numerically evaluated the submarine electric interconnector between Turkey and TRNC, based on economic and environmental aspects.

CHAPTER 4 RESEARCH DATA ANALYSIS

4.1 North Cyprus Demand Characteristics:

The major revenue generator for North Cyprus is the tourism industry which attracts a considerable number of tourist every year due to which the demand characteristic varies seasonally. Being an island, major portion of tourist is entertained during the summer season due to the beaches and other summer activities around the coastal regions, due to which electricity consumption is higher than other months [15]. During the midday time, the consumption is highest due to cooling needs at residential and commercial buildings. During the first nine months of 2018, a total of 1.4 million tourists visited North Cyprus [75]. Total number of tourists to North Cyprus were calculated to be somewhere near 2 million which was increased from the previous year by a number of 25,241 visitors [76]

The seasonal variation in North Cyprus effects the electricity consumption, based on which data from 4 months, of year 2016 - 2017 each, was retrieved for analysis. These months include July and August which are considered to be the hottest months and January and February which are the coldest months in Cyprus. Consumption data was provided by KIB-TEK, from which the data was classified into four different groups summer weekdays and weekends, and winter weekdays and weekends. Randomly one day (Wednesday of all four months) was chosen for the weekdays and one day (Saturday of all four months) was chosen for weekends. Figure 4.1 illustrates the demand characteristics of year 2016, and Figure 4.2 depicts the demand characteristics of year 2017.

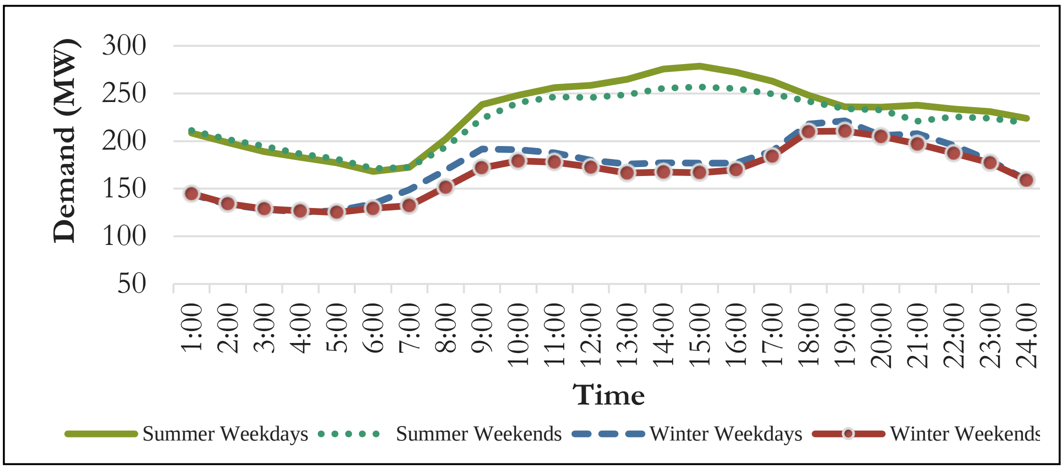

Figure 4.1 Demand Characteristics of TRNC 2016

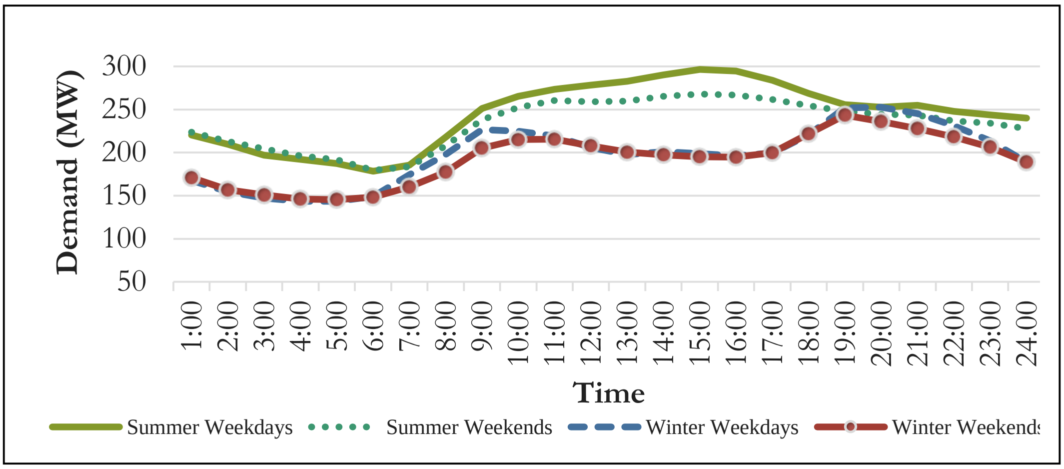

Figure 4.2 Demand Characteristics of TRNC 2017

As it can be seen, the summer weekdays are highest days of electricity consumption, while the peak consumption can be seen during midday of same category. The reason behind this peak consumption is the sizeable cooling needs. The difference between the midday peak of weekdays and weekends of summer is due to the use of electricity in commercial buildings such as offices etc. Whereas, the midday of winter weekdays/weekends is comparatively lower than the rest of the day for same category as the natural source of sun is used for heating purposes. As soon as the evening approaches, the heating needs are shifted from natural source to electricity and peak demand is seen around evening hours

4.2 North Cyprus Electricity Production Characteristics:

As mentioned earlier, Cyprus's electrical power system comprises of two power plants knowns as Teknecik (owned by KIB-TEK) and Kalecik power plant (owned by AKSA), where Teknecik's nominal capacity is 260 MW using Diesel and Steam generators of a total 140 MW and 120 MW respectively, and Kalecik's installed capacity is 140 MW by the means of diesel generators. Table 4.1 presents TRNC's installed capacity characteristics as of 2018.

Table 4.1 Installed Electric Capacity of North Cyprus with Specification

Power Plant	Nominal Capacity	Internal Consumption [%]	Net Usable Capacity [MW]	Fuel Rate [kg MWh^{-1}]	Fuel Price [$ kg^{-1}]	Fosil Fuel Type
AKSA DIESEL	140	3.9	120	195	0.44	HFO (Num 6)
KIB-TEK DIESEL	140	3.9	120	205	0.45	HFO (Num 6)
KIB-TEK STEAM	120	5.5	110	280	0.45	HFO (Num 6)

The generator fuel rate [kg MWh^{-1}] was retrieved from respective generating companies based on the conversion factor, calorific value and thermal efficiency, keeping in mind that both companies are using fuel oil no. 6 for electricity generation.

4.3 North Cyprus Demand versus Production

The demand characteristics of North Cyprus were then assessed across the production characteristics. Figure 4.3 depicts the production versus the monthly peak for TRNC in the year of 2016. The vertical columns illustrate the power capacity of the power plants of TRNC where 126 MW is provided by AKSA, 120 MW by diesel and 110 MW by steam turbines of KIB-TEK. The horizontal lines intersecting the power (columns) are the monthly peak electricity consumption and monthly average electricity consumption for year of 2016. For the aforementioned year, the generation capacity was sufficient to fulfill the commercial and residential electricity needs of TRNC.

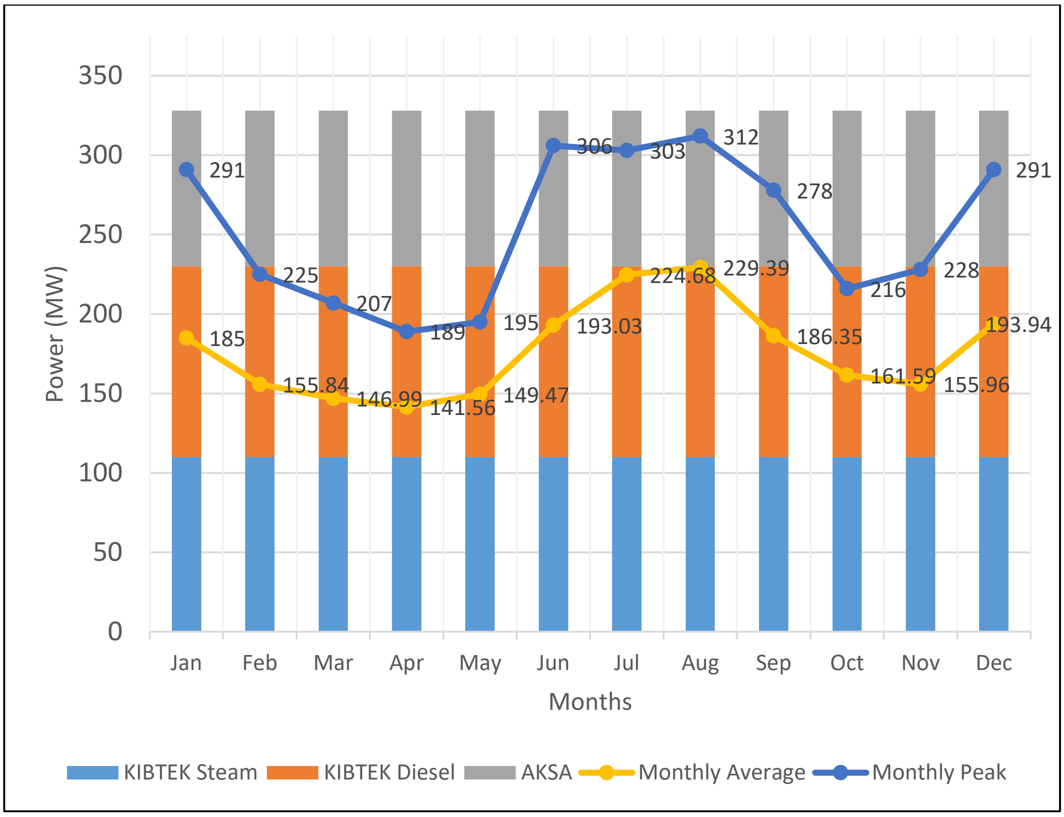

Figure 4.3 Demand Analysis 2016

Based on previous years' consumption data, a constant value of 5% per year was assumed as a safe value for the electricity consumption increment which was employed to forecast the next years' consumption characteristic curve. Even though the year 2018 has already passed, the consumption data is yet to be released by the authorities, so the demand characteristics were forecasted based on the assumed annual increment, which was harvested using the consumption trends of previous years. Based on the predicted data, the production for the year of 2018, does not fulfil the demand for the months of June - August as demonstrated by Figure 4.4.

Line loss is one of the biggest burden of power generation industry which reduces the efficiency of the power system [77]. Keeping in mind that and power plant internal consumption, the actual production for the year of 2018 is not enough to meet the peak demands, especially during the hottest months of summer (June – August) and coldest months of winter December – February).

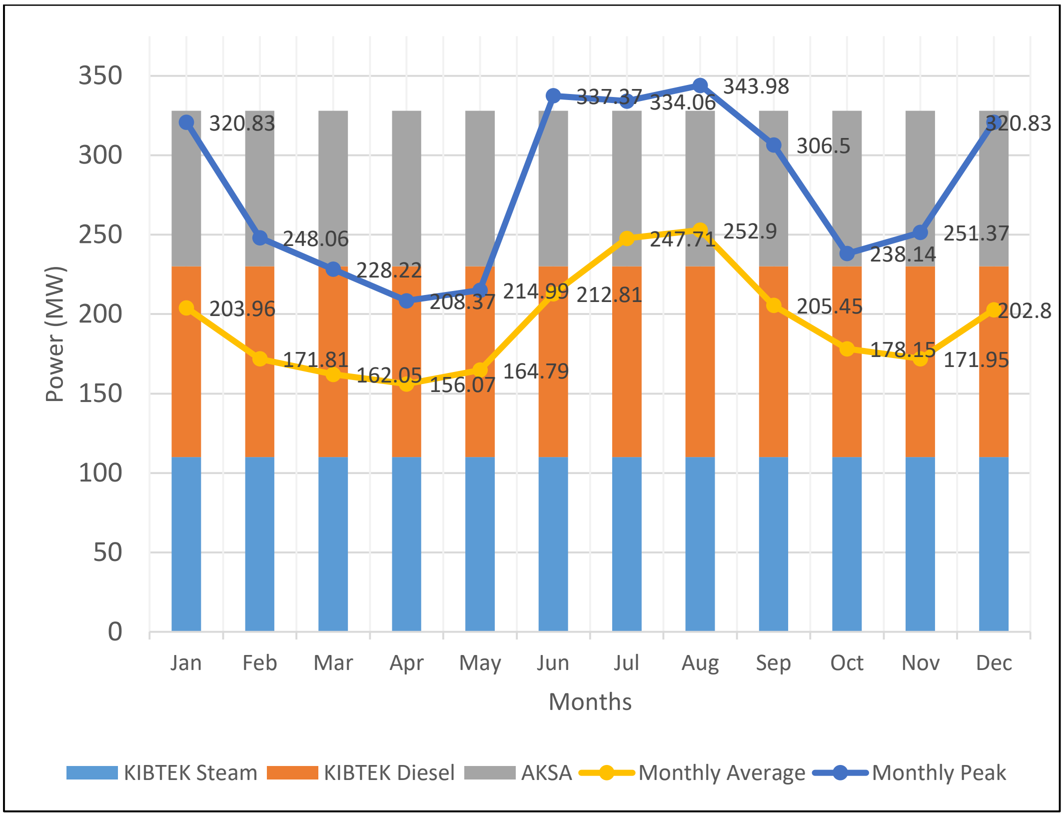

Figure 4.4 Demand Analysis 2018

With the continuity of 5% per year demand increment, and no accretion of power generation, the current power plants fall insufficient to fulfill the electrical demands by the year 2020, as aforementioned months are way beyond the reach of production capacity for the same year, which can also be seen in Figure 4.5. Monthly average demand seems to be met by the existing production capacity, but during the peak hours, TRNC is expected to face electricity shutdowns. These shutdowns potentially have high risk to strike down the economy and also disturb the social life.

In addition to that it causes a disruption in important activities such as medical, and education etc. [78]. The industry suffers a great hit from electric shut downs due to its costly investment and low production [79].

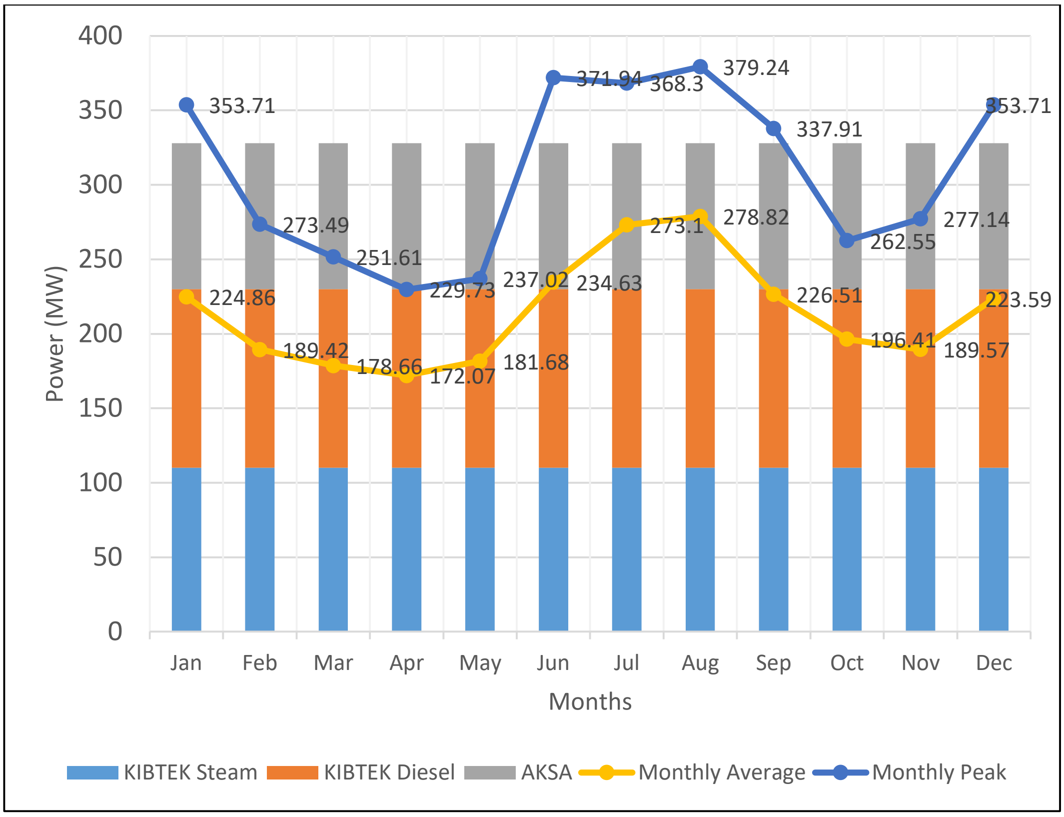

Figure 4.5 Demand Analysis 2020

Previously it has been mentioned that AKSA's contract for electricity production is ending by the year of 2024. In a scenario if the contract with AKSA is not renewed, the electricity production capacity of TRNC reduces by a number of 126 MW, thus leaving KIB-TEK as sole electricity generating company. Over this period of time, when we reach the point where AKSA shuts down its power plant, the steam power plant at KIB-TEK is expected to be at very low efficiency as the studies have shown high sensitivity of efficiency to degradation in diesel and steam turbines [80] [81]. Grunwald [13] estimated the economic life time of KIB-TEK steam power plant to be between 10-15 years. With all of this, the expected demand of electricity is way more than the total generation capacity of KIB-TEK in the year of 2024 as interpreted by Figure 4.6.

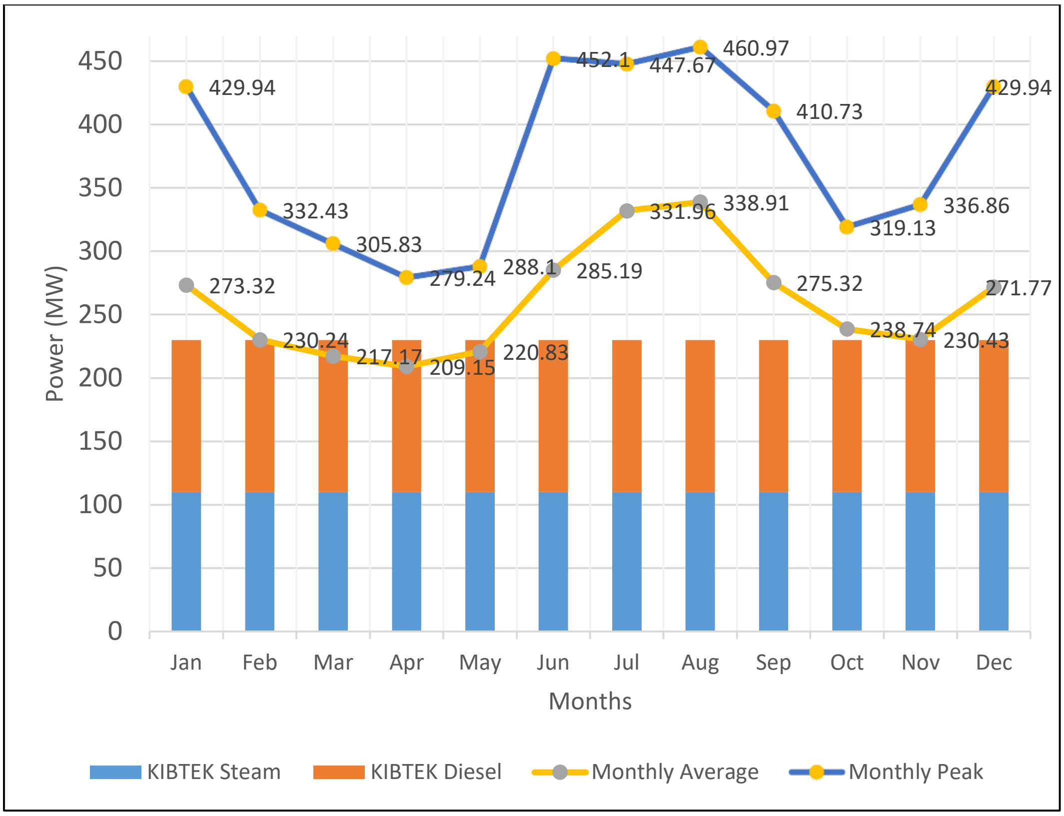

Figure 4.6 Demand Analysis 2024

4.4 Summary

Cyprus is a Mediterranean island dealing with seasonal variation, which also depicts its characteristics in electricity demand curve. The summers are intensely hot, which requires air conditioning in all buildings. Being an island, Cyprus also hosts a huge number of tourists, especially in summer. Peak demands of TRNC are seen during midday in summer due to cooling purposes, and during evening in winters for heating purposes. AKSA, the private generation company, leaves the market in 2024, thus reducing the net capacity to 230 MW only, which is not enough to satisfy the base load.

CHAPTER 5 METHODOLOGY

Using the data available, which includes the TRNC electricity production and consumption for the year of 2016 – 2017, and the electricity spot prices of Republic of Turkey for the same years, our research analyses the economic stance of currently installed power plants across the possible outcomes of submarine interconnector cable.

5.1 Merit order concept:

Merit order curve is a concept of classification of the generating units based on their marginal cost of electricity production. All the generators are lined up in the curve in ascending order of their marginal electricity production cost, which is vital in selection of better electricity mix based on cost. Based on demand characteristic, the last generator, in the merit order curve, which satisfies the demand, determines the hourly spot price of electricity [82] [83]. Thus it is easier to make a comparison between marginal costs, based on demand characteristics by building an hourly stepwise merit order curve, with the help of production characteristics [84]. A visual representation of merit order concept is shown in Figure 5.1

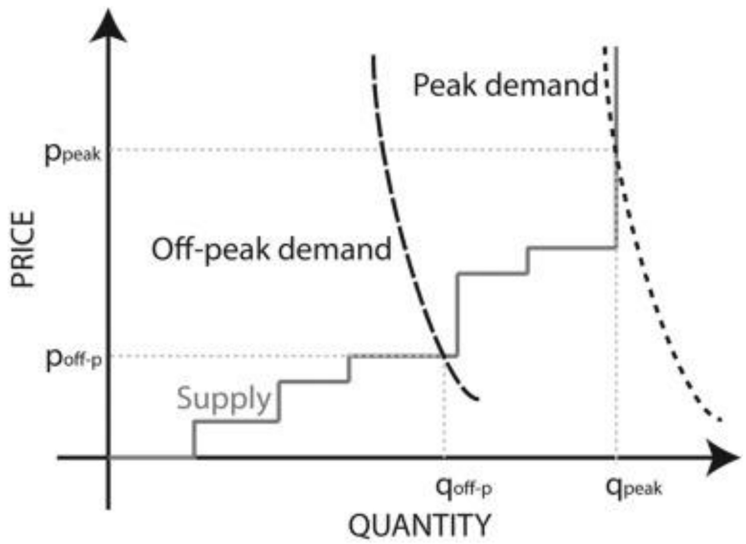

Figure 5.1 Merit Order Concept [85]

With the help of merit order curve, the off-peak and peak demand can be visualized with respect to the supply, based on which a cost effective electricity mix can be selected.

5.2 Turkey - North Cyprus interconnector characteristics:

Turkish republic of Northern Cyprus lacks the indigenous resources and lack of political collaboration from South part adds fuel to the fire of being stretched on natural resources. The electricity grid system of Cyprus, both North and South side, is completely isolated from any mainland grids, thus alienating it from the rest of the world. In recent past, an effort made by Turkey, connected North Cyprus to mainland Turkey with a water pipeline [86].

Another project proposed by Turkish authorities is to connect electrical grid system of Turkish Republic of Northern Cyprus to Turkey's electric grid system [87]. This project comprises of a submarine cable laid over 80 km distance in sea. In October 2016, Economy and Energy Minister Mr. Sunat Atun announced that the submarine electric interconnector cable will be laid between Teknecik (KIB-TEK) and Akkuyu (Mersin) [88]. The Minister Mr. Atun also stated that the final agreement between Turkey and TRNC will be signed before 2018. According to him, this cable will provide environmental and financial stability and sustainability to TRNC since 98% of TRNC's production is via fuel oil [89]. It has been more than 2 years and the deadline has already passed but the final agreement is yet to be signed between these countries. The agreement also includes the renewal and development of current electricity facilities, energy security and mutual collaboration on exploration of renewable resources. Figure 5.2 illustrates the announced route of the submarine electric cable between Turkey and TRNC.

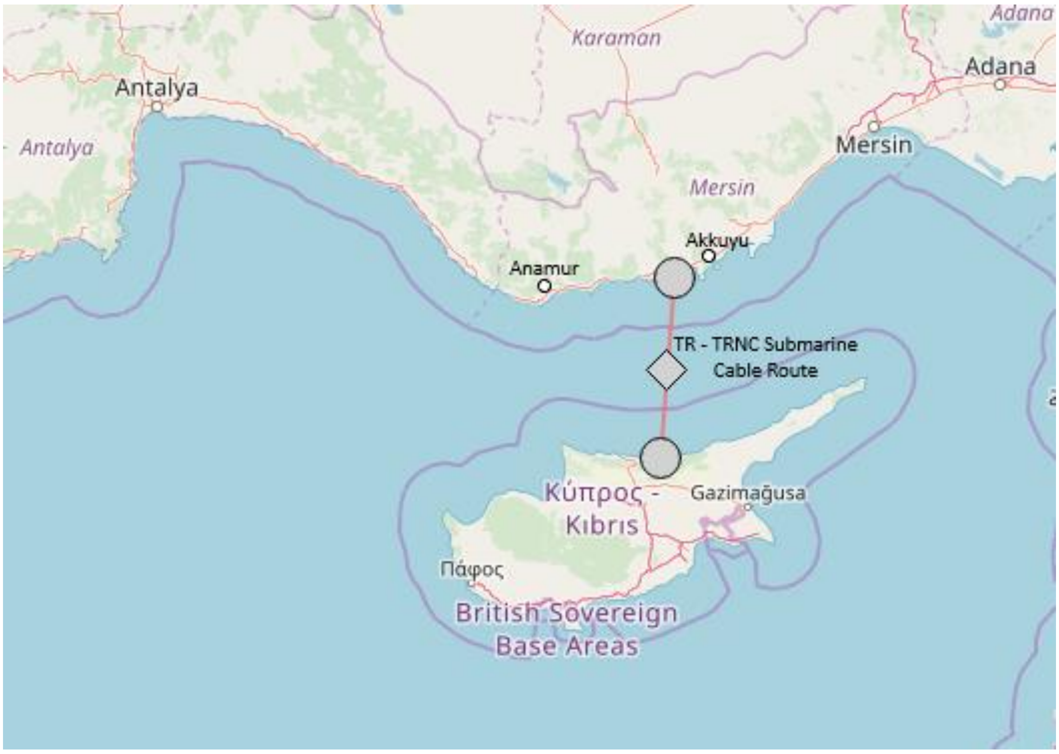

Figure 5.2 TR – TRNC Submarine Cable Route (modified from [90])

The research work analyzes the aforementioned project with an assumed HVDC submarine cable of 80 km length with a rated transmission capacity of 800 MW and 200 MW HVDC VSC substations installed on both ends of cable for the initial start-up. The capacity of the submarine cable is initially set high at 800 MW to keep a margin for any future growth of electricity exchange by simply adding more substations on both sides of cable without replacing the cable.

The research also contributes to the evaluation of environmental aspect of the existing power system in comparison with the installation of submarine cable. Data retrieved by existing literature is used to evaluate the carbon foot print of TRNC power plants, as well as for that of Turkey. The results are then compared to suggest a better electricity mix between aforementioned options.

5.3 Merit order curve for Cyprus's electricity market

The aim of the study is to numerically analyze North Cyprus's electricity market conditions for current power system scenario where the demand is fulfilled by fossil fuel based electricity generation plants, which cover 98% of total production, in comparison with the feasible outcomes of a submarine electricity interconnector with the mainland of Turkey. Merit order method was applied to the existing power plants of North Cyprus and then compared with the feasible outcomes of submarine electric interconnector cable.

Following assumptions were taken while numerical assessment:

a) The import price from interconnector is equal to spot price of Turkey along with transmission cost and installation recovery etc.
b) Electricity spot price of Turkey does not adapt a change after interconnector.
c) The interconnector expenses can be paid by:
   - Turkey
   - Shared by Turkey and TRNC, with a payback period of 15 years.
   - TRNC, with a payback period of 15 years.
d) The submarine interconnector cable will cost somewhere around 360 million USD [13]

5.4 Marginal Electricity Generation Cost

The marginal cost [$ MWh^{-1}] for electricity generation of TRNC, to be used in merit order, is calculated by using Equation (1).

$$\mathrm{MC_i} = f_i \times p_i \times (1 + n_i) \qquad (1)$$

Where: i = type of generator

f = generator fuel rate [kg MWH^{-1}]

p = fuel price [$ $tonn^{-1}$]

n = internal generator fuel consumption [p.u]

5.5 Average Electricity Production Price

The average electricity production price "P_{TRNC}" [$ MWh^{-1}] for TRNC's is calculated from equation (2).

$$P_{TRNC} = \frac{\sum(P \times D)}{\sum D} \qquad (2)$$

Where:

P = TRNC's hourly electricity generation price

D = TRNC's hourly electricity consumption price

Data, for calculation of all above mentioned variables, was retrieved from KIB-TEK, TEİAŞ, and EPİAŞ directly.

5.6 Summary

The methodology adopted by this research, i.e. Merit order curve, evaluates the economic stance of submarine electric interconnector cable, by lining all the existent generating units against interconnector in ascending order of their marginal cost. The last generator which satisfies the demand, decides the hourly spot price. The study evaluates the submarine cable in 3 different scenarios based on the capital investment. The scenarios include North Cyprus solely investing in the project, sharing the capital cost with Turkey, and Turkey solely investing in the project. The study also evaluates the environmental stance of interconnector against currently installed power plants in TRNC using the facts and figures of carbon emission provided in literature.

CHAPTER 6 RESULTS AND DISCUSSION

The power sector of North Cyprus suffers with dependency on fossil fuels, in term of financial and environmental aspects. Ever since the island divided into two parts, TRNC has solely depended on KIB-TEK and AKSA for the electric power generation. A Photovoltaic plant, installed in May 2011, barely contributes 1% to the total power generation capacity of north part of island. In recent past, Turkish authorities, along with TRNC authorities, announced a submarine electric interconnector cable to connect TRNC electric grid system to that of Turkey. The project was announced in 2016, and yet awaits the final agreement between the two involved countries.

A techno-economic feasibility analysis was conducted to evaluate the possibility of better electricity mix, based on financial and environmental aspects. To evaluate the financial stance of existent power plants and interconnector cable, merit order concept was applied on the available data. Merit order curves were constructed in two different scenarios, i.e. Merit order for the existent power plants, Merit order with interconnector installed; which is subcategorized based on investment cost plans.

Previously it has been mentioned that AKSA owns a usable capacity of 126 MW, but back in 2003 AKSA signed a contract with KIB-TEK, according to the which, KIB-TEK assures buying 700,000 MWh/year from AKSA. Despite of the fact that AKSA has a usable capacity of 126 MW, bound by the contract it only uses 98 MW thus contributing 44.37% of total TRNC production. While constructing merit order curve, the net capacity was evaluated, rather than the nominal capacity. Following sections illustrates the merit order curve for all previously mentioned scenarios.

6.1 Case 1: Merit Order Curve for TRNC's Isolated Electricity Network

To analyze the marginal cost of existent power plants in TRNC, merit order curve was constructed for net capacity of AKSA Diesel (98 MW), KIB-TEK Diesel (120 MW) and KIB-TEK Steam (110 MW) power plants. Figure 6.1 illustrates the merit order curve for the aforementioned plants.

The marginal cost calculated using Equation (1), with the data provided by the production company, surrendered diesel generators to be more efficient and cost friendly. AKSA's diesel plant was calculated to have a marginal cost of 89.15$/MWh followed by KIB-TEK diesel and KIB-TEK steam plants with marginal cost as 95.85 $/MWh and 132.93 $/MWh.

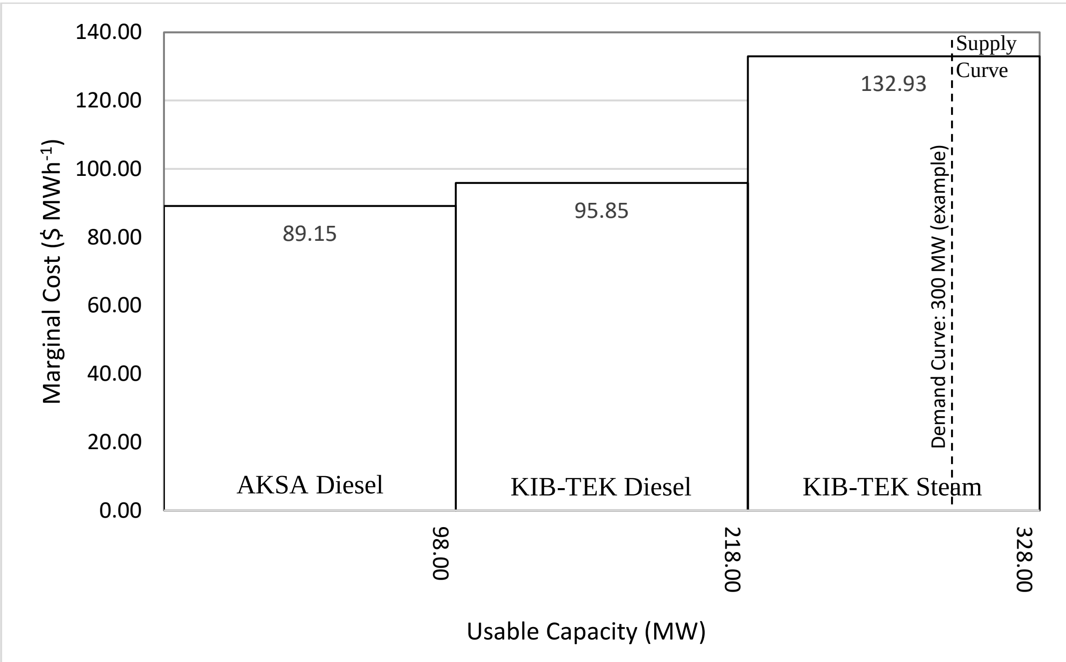

Figure 6.1 Merit order curve for Cyprus's isolated electric power system

Though the peak demand for the years under study (2016-2017) was higher than the available net capacity of fossil fuel power plants, an exemplary case of demand curve around 300 MW is assumed as peak demand. As seen in Figure 6.1, AKSA produces the cheapest electricity with a rate of 8.915 $cents/kWh, KIB-TEK Diesel at 9.585 $cents/kWh, whereas the steam power plant of KIB-TEK is the most expensive with a rate of 13.293 $cents/kWh.

6.2 Case 2: Merit Order Curve for TRNC Electricity Network with Interconnector

Following the proposed method of the research, the merit order curve was constructed to analyze the marginal costs of interconnector which connects TRNC electricity grid system to Turkey's electric grid via HVDC submarine cable of 80 km length with a rated transmission capacity of 800 MW. For initial startup, it was assumed that the project would work with 200 MW HVDC VSC substations. The cable is rated with high capacity to keep a room for future expansion.

To calculate the marginal cost of interconnector, average of Turkish electricity spot prices was used for the year of 2016-2017. To calculate The interconnector merit order curve is categorized into three different scenarios as follows:

a) Turkey pays for the investment cost
b) Turkey and TRNC share the investment cost, with payback period of 15 years
c) TRNC solely bares the investment cost, with payback period of 15 years

6.2.1 Interconnector with Turkey's Investment

Since the final agreement of submarine interconnector cable is yet to be signed, no final decision has been announced on the financial issues. With no final settlement of which country will finance the investment cost, the merit order curve is constructed for different scenarios. Previously, in submarine water pipeline that has been mentioned in the literature earlier, Turkey solely invested in all the project cost while

TRNC's contribution to it was cipher, and if that is to happen again in submarine electric interconnector cable, then the analysis of such a case is in order.

Figure 6.2 illustrates the merit order curve of TRNC electricity network with possible outcome of submarine electricity interconnector when Turkey pays the investment cost of the interconnector. Into the bargain, the yearly maintenance costs are also included while calculating the marginal cost.

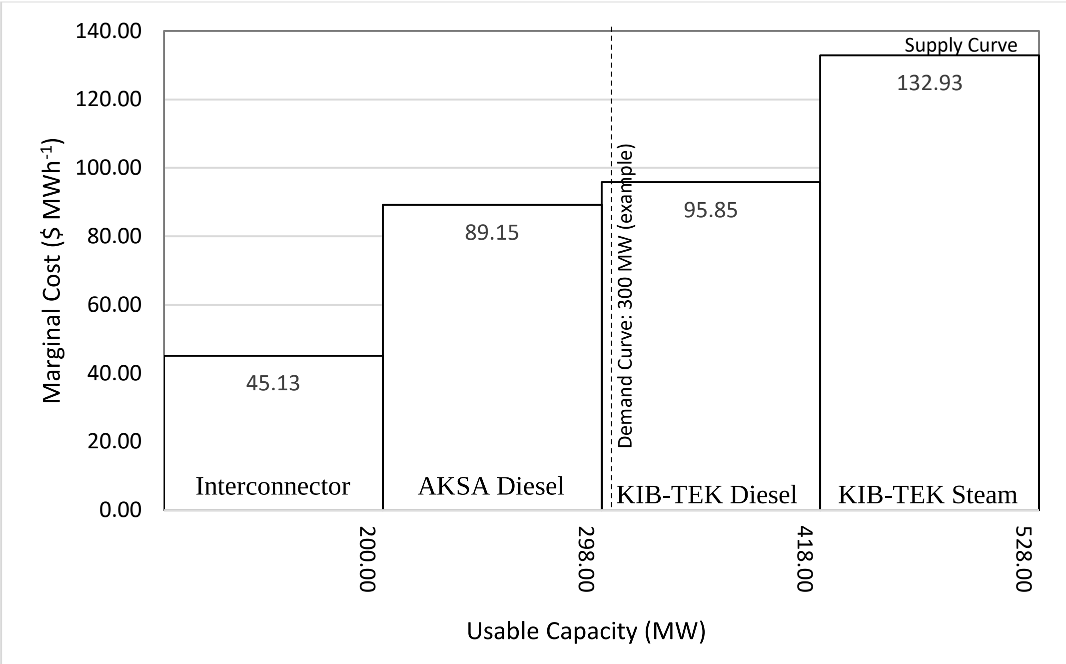

Figure 6.2 Merit order curve with full Turkey's investment

While constructing the merit order, the marginal cost of the interconnector also included the transmission cost and installation recovery. It can be seen in Figure 6.2 that marginal cost of electricity via interconnector (including the losses and recovery) is lower than the cheapest marginal cost of electricity in Cyprus's isolated electricity power system. The interconnector, with a healthier electricity mix, provides cheapest electricity at the rate of 4.513 $cents/kWh. In the exemplary case of demand curve, 75% of need is solely met by the interconnector. Along with the installation of interconnector, the peak demands can also be met with the existent power plants, whereas in case of demand growth the interconnector can further be extended.

6.2.2 Interconnector with Shared Investment of Turkey & TRNC

As mentioned earlier that financial contribution towards the investment cost is yet to be decided, so this scenario evaluates the marginal cost of interconnector in such a way that half of the investment cost (180 million USD) is invested by TRNC itself and rest of the half is contributed by Turkey, with an agreement of over 15-years payback period. The payback also includes a cost of capital at a safely assumed rate of 3.4% for the investment of 360 million USD. Figure 6.3 depicts the merit order curve for such case.

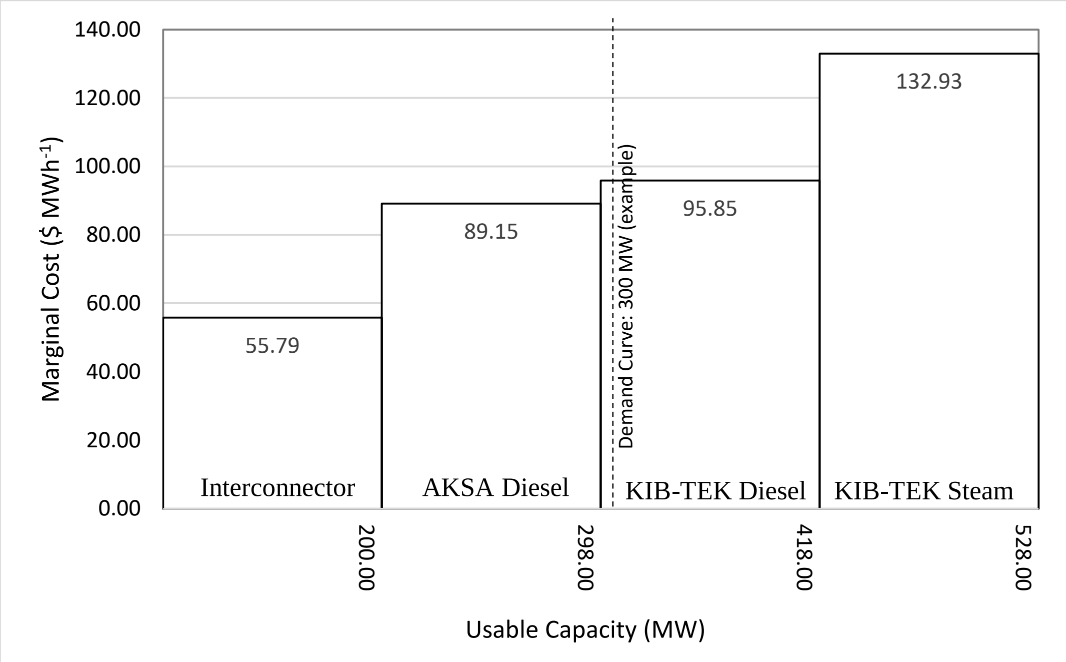

Figure 6.3 Merit Order Curve with shared investment of TRNC and Turkey.

Along with the cost of capital at 3.4% for half of the investment made by TRNC in payback period of 15-years, yearly maintenance and the half investment by North Cyprus, the interconnector results into producing energy at the rate of 5.579 $cent/kWh. The rate of interconnector is determined to be higher if North Cyprus is to invest 50% of the investment cost.

6.2.3 Interconnector with Solely TRNC's Investment

Unlike the case of submarine water pipeline, if Turkey is to disavow any kind of investment in the submarine electric interconnector project, North Cyprus has to bear all the expenses of project investment. Figure 6.4 illustrates the marginal cost when TRNC solely invests for project cost.

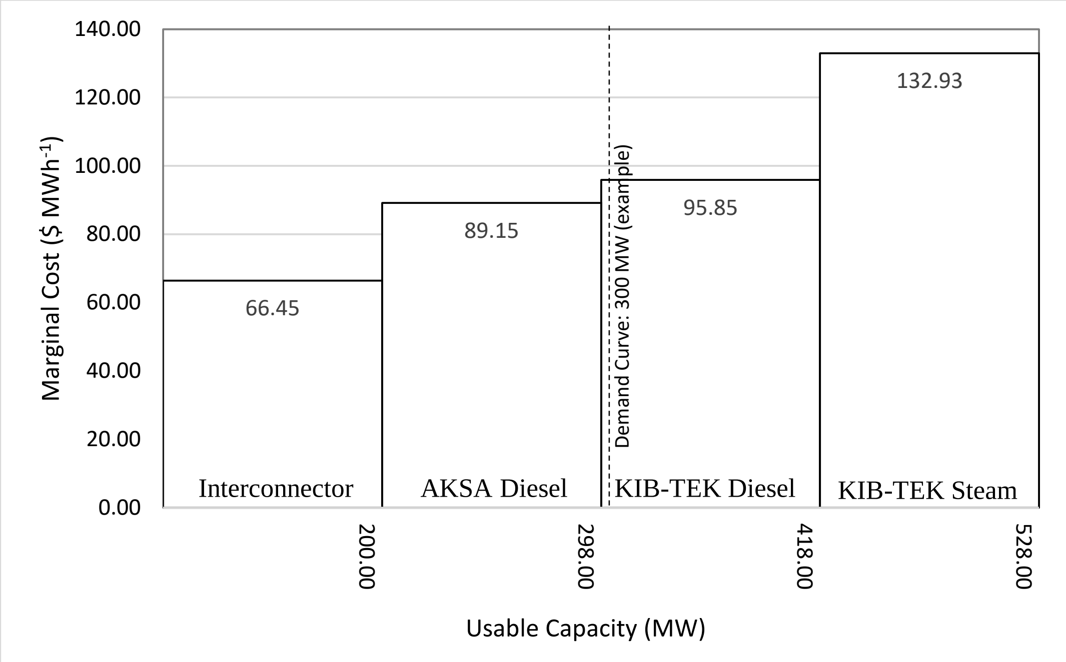

Figure 6.4 Merit Order Curve with Sole Investment of TRNC

In such a case when TRNC is the sole investor of submarine electric cable, the marginal cost is highest, i.e. 6.645 $cent/kWh, as compared to all the other investment scenarios of interconnector. Even with the highest marginal cost, interconnector cable is lined up as first and cheapest among all other options of existent electric power plants of TRNC. In future, with the growth in electricity demand, the interconnector electricity exchange can be expanded by installation of substations. In 2024, when AKSA leaves the electricity market, interconnector can take over to cover the gap.

6.3 Electronic Merit Order Calculator

An electronic merit order curve calculator was developed during the studies, which requires the basic parameters input such as fuel rate, fuel price, and internal consumption rate of generator for the generating units and annual energy transfer, installation cost, payback period, interest rate, annual maintenance cost, electricity price by exporter and transmission cost for the case of interconnector.

Based on these parameters, the electronic calculator devises a merit order curve by calculating the marginal costs of given generators and interconnector. The generating units are lined up in ascending order to develop a curve based on their marginal cost. After the input of parameters, the calculator formulates the graph for selection of electricity mix based on cost.

The electronic merit order calculator was developed using a general purpose, multi-paradigm programming language C#. The calculator is an executable file and the graphical user interface of the electronic calculator is provided in Appendix B.

6.4 Carbon Emissions of TRNC Electricity Production

Electricity generation plants cost a big investment, and if the environmental cost was to be added in it, the value does not just stay monetary. The emission of greenhouse gasses and dust etc. in atmosphere is out of the boundary of financial cost. If the reduction of the most threatening one was to be considered, CO_2 stands first in the line, whose reduction can mitigate huge adverse impacts on atmosphere. Figure 6.5 illustrates the carbon (CO_2) emission from electric power generation in North Cyprus over the period of last 11 years (2008-2018).

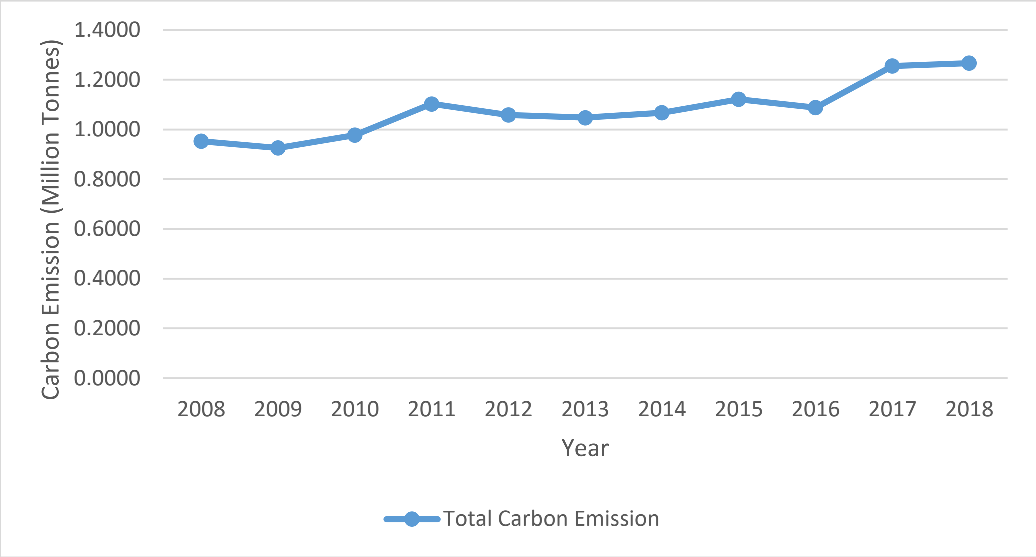

Figure 6.5 Total Carbon Emissions Associated with Electricity Production for TRNC

In 2008, the electricity production of North Cyprus using fossil fuel oils was 1225.8 million kWh with 0.953 million Tonnes of carbon emission. As of year 2018, the electricity production with fossil fuels has reached to 1631.041 million kWh and resulted into 1.27 million Tonnes of CO_2 emission. Figure 6.6, Figure 6.7, and Figure 6.8 illustrates the carbon emissions of North Cyprus, associated to different fossil fuels i.e. diesel generator, steam power plant, and gas power plant respectively.

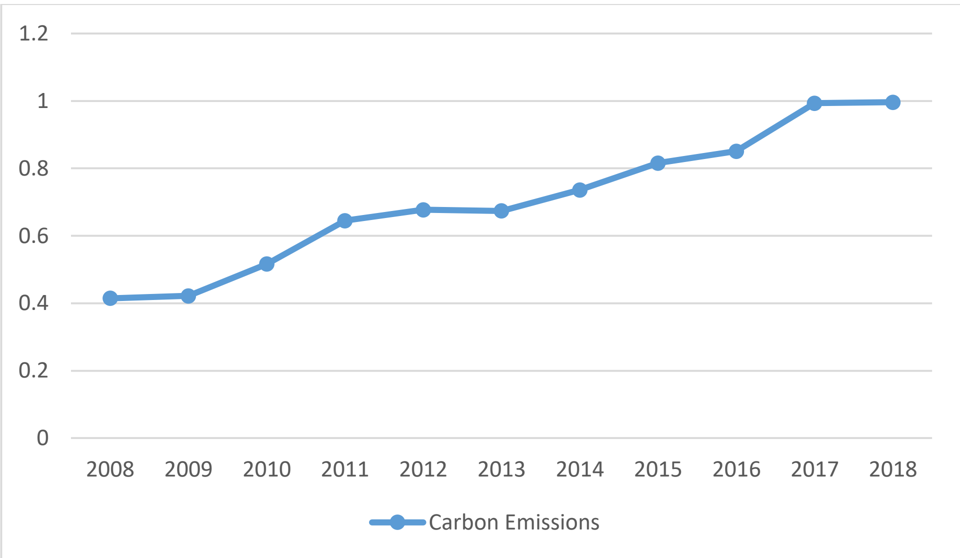

Figure 6.6 Carbon Emissions associated to Diesel Turbine

The emissions from diesel power plant has grown over last 11 years, since the contribution of diesel generators towards total power generation has also grown in these years, and vice versa for the steam power plant.

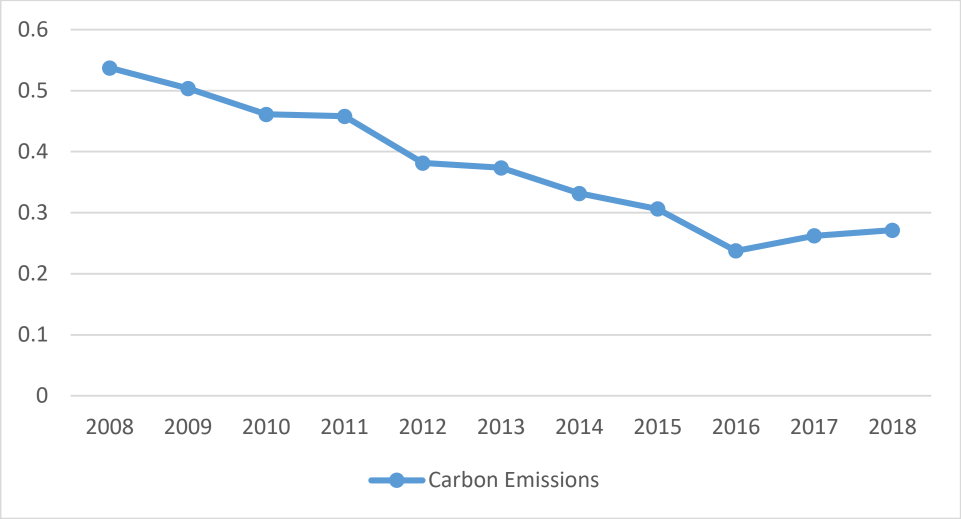

Figure 6.7 Carbon Emission Associated with Steam Turbine

The emissions from the gas turbines have been zero since 2011, as the power plant has been deactivated since then. Even though the CO_2 emission of gas operated power plant is comparatively lower than the aforementioned ones, which is why it is known to be the cleanest one among fossil fuels, the plant has been on shut down for several years due to inefficient production.

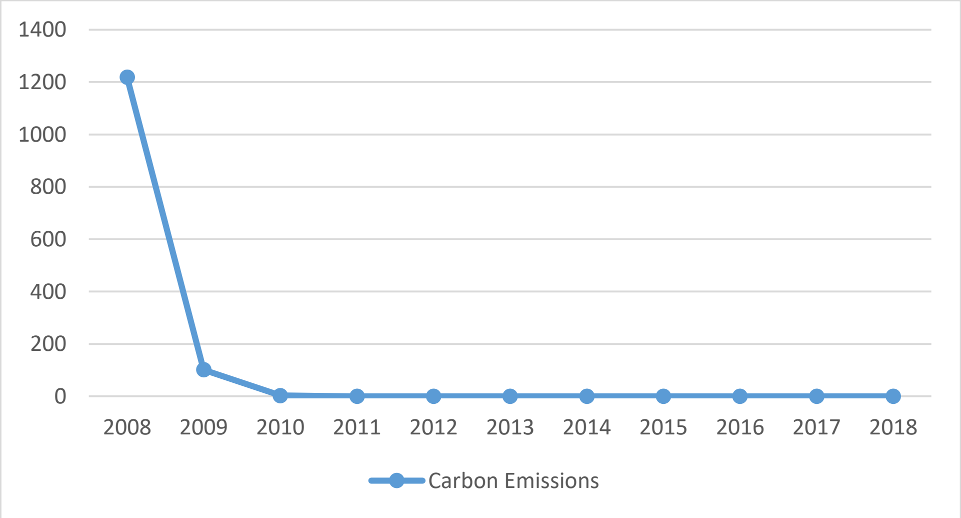

Figure 6.8 Carbon Emissions associated to Gas Turbine

6.4.1 CO_2 Emissions after Submarine Interconnector

If the submarine electric interconnector cable project is to be executed, with the healthier energy mix of Turkey, a significant reduction in carbon dioxide emission can be expected. Table 6.1 calculates the amount of CO_2 emission with and without the cable for North Cyprus. The table takes into account the annual energy production calculated as bellow, and then compare the carbon emissions if the energy was to be produced in North Cyprus with production in Turkey and transmitted by submarine cable.

Annual Energy produced by 200 MW interconnector cable:

$$200 \text{ MW} \times 8760 \text{ h} = 1{,}752{,}000 \text{ MWh} = 1{,}752{,}000{,}000 \text{ kWh}$$

Figure 6.9 and Figure 6.10 further elaborates the results evaluated from Table 6.1. The table calculates the carbon emission for the production of annual energy by 200 MW. In this table, all the energy mix for North Cyprus and Turkey are taken into account, and the maximum and minimum amount of carbon emissions are calculated. Figure 6.9 compare the carbon emission of KIB-TEK from 200 MW which is, as expected, to be much higher than that of Turkey's electricity mix. Maximum CO_2 is calculated by taking the carbon emission of Lignite coal in Steam power plant, Gas turbine cycle run by Natural gas, and geothermal. The total emissions by fossil fuel in North Cyprus are calculated to be 1.363 million Tonnes whereas the maximum carbon emissions from all the aforementioned sources in Turkey sums up to be 0.941 million Tonnes for annual energy produced by 200 MW and transmitted by submarine cable.

Table 6.1 CO_2 Emissions Comparison

Mean of Supply	Energy Produced kWh	Mean of Production	% Contribution	Production Contribution kWh	Type	CO2 Emission (kg/kWh) [23]	Co2 Emission Contribution (Million Ton)
TRNC Local Production		Fuel Oil	100.0%	1752000000	Diesel + Steam	0.778	1.363056000
Interconnector	1,752,000,000	Coal	36.4%	637728000	Lignite (Steam PP)	1.02	0.650482560
					Hard (IGCC)	0.83	0.529314240
		Nat. Gas	28.5%	499320000	Gas Turbine	0.58	0.289605600
					Steam Turbine	0.47	0.234680400
					Gas + Steam Turbine	0.36	0.179755200
		Geo	2.3%	40296000	Thermal	0.038	0.001531248

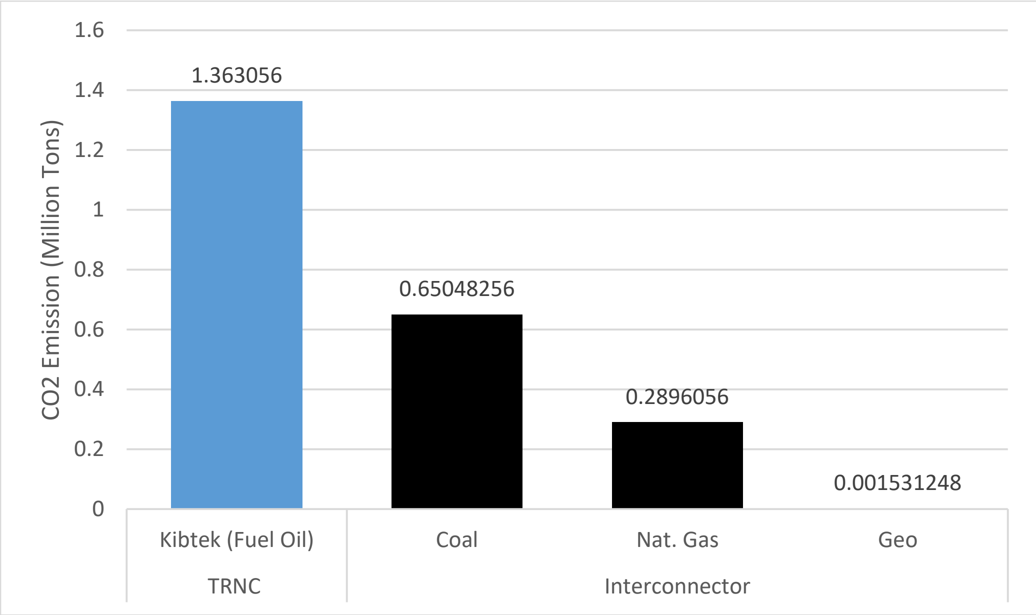

Figure 6.9 Maximum CO_2 Emission from 200 MW

Figure 6.10, on the other hand, illustrates the calculations made from Table 6.1 for the minimum amount of CO_2 emissions when the similar sources i.e. Coal and Natural Gas are used as Hard coal (IGCC) and gas plus steam combined cycle power plant respectively. In such case the CO_2 emissions from Turkey's energy mix are summed up to be 0.710 million Tonnes.

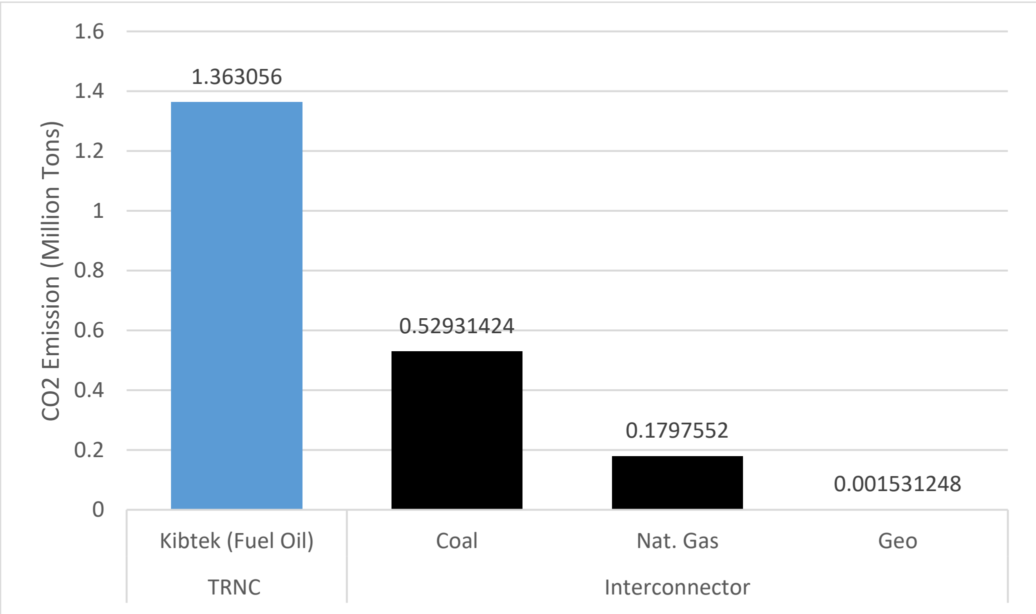

Figure 6.10 Minimum CO_2 Emission from 200 MW

Concluding it, which ever scenario is to be considered, maximum or minimum CO_2 emissions, the amount of carbon emissions from KIB-TEK production in North Cyprus with fuel oil are outrageous from that of Turkey. Table 6.2 calculates the percentage reduction of CO_2 emissions if 1,752,000,000 kWh energy was to be produced in Turkey with 200 MW capacity and its social cost

Table 6.2 Percentage Reduction in Carbon Emission and Social cost for 200 MW Interconnector and Local production.

Scenario	**Carbon Emission (Million Tons)**	**Percentage Reduction (%)**	**Social Cost (Million $)**
KIB-TEK	1.363056000	-	54.522240
Maximum CO_2	0.941619408	30.92	37.664776
Minimum CO_2	0.710600688	47.90	38.424027

An excessive amount of carbon reduction can be noticed ranging between 30-48% if the aforementioned energy was to be produced in Turkey. Whereas the social cost of the electricity generated by up to 38.42 million USD with the interconnector from the value of 54.52 million USD in case of local TRNC production.

6.5 Summary

Using the merit order curve, the study evaluates that, in existent power plants of TRNC, AKSA diesel generators cost the cheapest, followed by KIB-TEK diesel and steam turbine with electricity production rate of 8.915 $cent/kWh, 9.585 $cent/kWh, and 13.293 $cent/kWh respectively. In comparison, submarine interconnector cable costs cheaper than all the aforementioned production rate. In the 3 scenarios previously mentioned, i.e. sole investment by TRNC with a defined payback period, shared investment between Turkey and TRNC, and sole investment by Turkey, the electricity production rate is calculated to be 6.645 $cent/kWh, 5.579

$cent/kWh, and 4.513 $cent/kWh respectively. Figure 6.11 illustrates all the above mentioned calculation

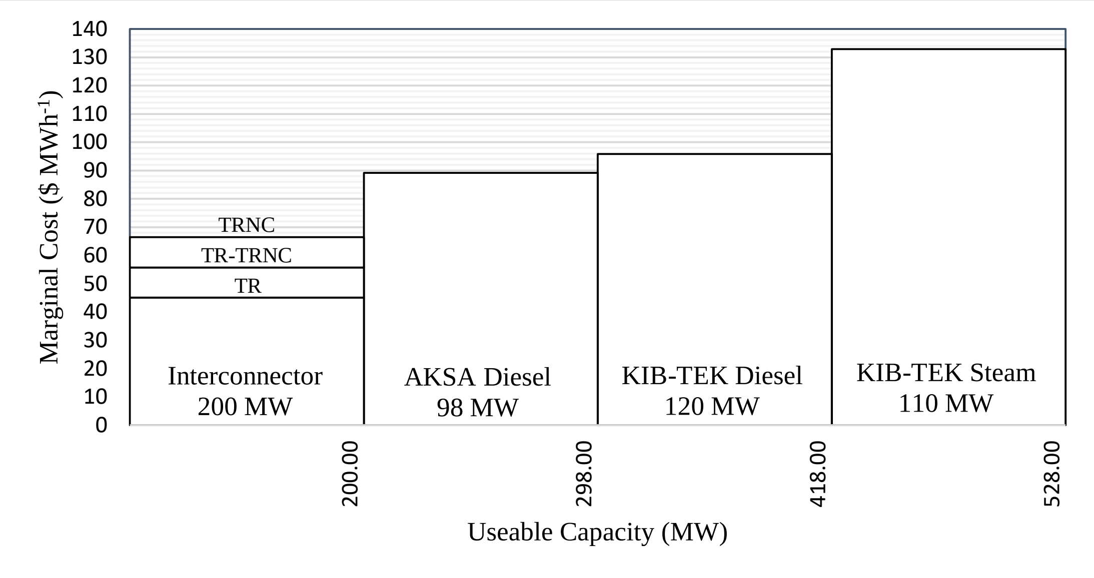

Figure 6.11 Marginal Costs for Cyprus Electricity Production

The environmental analysis of submarine interconnector and TRNC's local power plants is illustrated in Figure 6.12 With the comparative healthier energy mix of Turkey, the interconnector seems to be promising while assuring a carbon reduction of 30.92 % to 47.90. Maximum and minimum carbon reductions are calculated using different carbon emission rates of fossil fuel types and power plants. The social cost of carbon is also reduced to significant level by a value of 26.1 million USD.

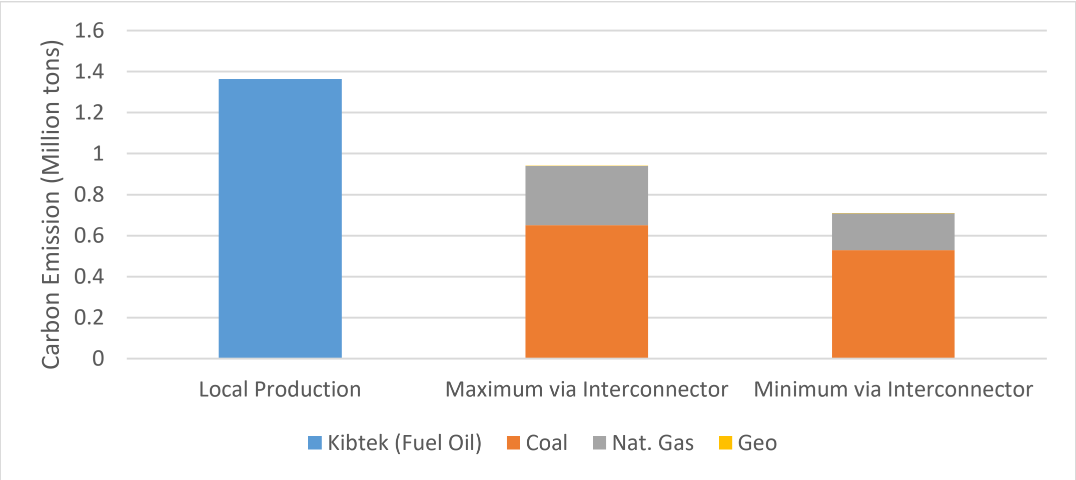

Figure 6.12 CO_2 Emissions of Submarine Cable and Local Production of TRNC

CHAPTER 7 CONCLUSION & FUTURE WORK

7.1 Conclusion

Sustainable development of current electric grid system infrastructure is needed to shelter the short and long-term needs of ecosystems. Sustainable practice in terms of daily electricity consumption, enabling technologies, and public policy is needed to preserve the nature to accommodate the needs of future generation. Sustainability is the solution to the dilemma of harmonizing the energy needs and natural protection.

In this study, the findings from the merit curve supports the hypothesis of interconnector being a cheaper source of energy compared to existing fossil fuel power plants. 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.

As the electric power production of TRNC is not enough to export it, at the moment interconnector will majorly be used to import electricity thus providing sufficient energy to meet the base load. As the cable capacity is 800 MW, in case of expansion in demand, the supply from the mainland can be increased by simply extending the capacity of substation on both ends of cable. If in the future, with the help of increasing solar energy power plants, the interconnector can be used to export electrical energy into the Turkish and European market.

Cheap energy is just one piece of the puzzle, and other branches such as environmental aspects need to be considered while making any final decision. Existing power plants of North Cyprus end up emitting around 1.27 million Tonnes of Carbon Dioxide annually thus contributing significantly towards the greenhouse gasses. With the installation of submarine electric interconnector cable, 30-48 % of reduction in CO_2 emissions is expected as the energy mix for Turkey is much healthier than that of North Cyrus. Thus the submarine interconnector cable turns out to be the cheap and environmental friendly solution in comparison to production within North Cyprus with existing power plants.

The implementation of the submarine cable project will allow North Cyprus to explore renewable resources in northern part of island and invest in the renewable integration to existent grid system as currently the renewable energy contribution towards electricity production is small. Although this project, in the light of this study, seems to be restricted between the political domains of two countries, the project's positive spillover crosses the political boundaries of the involved two countries. The reduction in the greenhouse gas emissions, will surely help in the environmental betterment of North Cyprus, but the positive spillover effect will also contribute to the improvement of environmental conditions in the southern part of Cyprus.

In addition to renewable integration, North Cyprus also needs to focus on demand side management. The data suggests that due to seasonal variation, North Cyprus faces sky rocketed peak demands in the summer during the midday time, and in winter during the evening times. Tariff planning and incentives will help the authorities to devise a better demand side management strategy to achieve load shifting and valley filling methods of DSM.

7.2 Future Work

This is a first of its kind project for Turkey and North Cyprus, so great expertise is required from both sides. The financial and environmental analysis helps to evaluate the theoretical feasibility of the project, but a practical feasibility analysis in terms of seabed, tides, seismology, trawling, and anchoring, and fishing needs to be conducted as well. In the future, firstly a sensitivity analysis can be performed on the results of this study followed by a research on practical feasibility of the project.

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APPENDIX

Appendix A: Table of Total Production Data for Year 2008-2018

Table 1 Production values 2008

Production Plants	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Total	%
Tek. Steam Turbine S.U.1	33,967	30,572	28,840	19,288	34,626	33,817	35,830	36,089	32,373	18,142	31,168	33,124	367,836	29.88%
Tek. Steam Turbine S.U.2	32,278	33,167	29,472	21,885	0	17,208	37,052	35,984	32,835	23,682	26,003	33,273	322,838	26.23%
Dik Gas Turbine S. TG20	1,178	0	0	195	0	0	0	162	0	0	0	0	1,535	0.12%
Tek. Gas Turbine .S. TG20	417	35	0	0	0	0	0	114	0	0	0	0	566	0.05%
Tek. Gas Turbine S. TG16	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00%
Kalecik DG	34,112	30,089	29,496	29,800	30,159	30,173	30,564	28,247	27,663	26,421	17,181	22,412	336,316	27.32%
Teknecik DG	21,445	10,211	1,936	10,779	21,594	24,477	25,232	31,762	11,481	16,172	9,267	12,329	196,684	15.98%
Total TRNC Production	123,397	104,074	89,744	81,947	86,378	105,675	128,678	132,358	104,350	84,416	83,619	101,138	1,225,775	99.59%
South-fed villages	344	294	290	280	276	297	396	359	353	278	272	1,640	5,080	0.41%
GENERAL TOTAL	123,741	104,368	90,035	82,227	86,655	105,972	129,074	132,717	104,704	84,694	83,891	102,779	1,230,855	100%

Table 2 Production Values 2009

Production Plants	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Total	%
Tek. Steam Turbine S.U.1	30,964	31,926	33,745	1,564	21,122	27,903	35,132	35,897	29,503	8,918	28,643	23,089	308,405	25.80%
Tek. Steam Turbine S.U.2	33,214	29,811	32,649	29,359	11671	29,783	34,991	34,475	29,102	30,312	13,620	29,980	338,966	28.36%
Dik Gas Turbine S. TG20	0	0	0	0	0	0	0	137	1	0	0	0	138	0.01%
Tek. Gas Turbine .S. TG20	0	0	24	0	0	0	0	10	0	0	0	0	35	0.00%
Tek. Gas Turbine S. TG16	0	0	0	0	0	0	0	0	0	0	0	0	2	0.00%
Kalecik DG	28,205	21,001	23,574	41,772	40,213	41,989	36,947	38,546	36,889	38,448	38,391	42,840	428,815	35.88%
Teknecik DG	15,607	7,917	4,494	3,965	9,858	5,761	16,736	17,318	4,192	15,550	5,900	6,408	113,708	9.51%
Total TRNC Production	107,991	90,656	94,486	76,660	82,865	105,436	123,807	126,384	99,687	93,228	86,554	102,316	1,190,068	99.57%
South-fed villages	325	269	273	262	262	305	388	399	320	276	249	1,842	5,170	0.43%
GENERAL TOTAL	108316	90925	94759	76923	83127	105741	124194	126783	100007	93504	86802	104158	1195238	100.00%

Table 3 Production Values 2010

Production Plants	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Total	%
Tek. Steam Turbine S.U.1	29,213	23,541	20,784	0	1,734	28,253	35,308	36,099	30,827	31,245	4,523	23,153	264,679	20.98%
Tek. Steam Turbine S.U.2	29,250	23,544	23,079	31,639	33,233	20,928	34,294	36,695	32,950	7,411	28,594	26,540	328,159	26.01%
Dik Gas Turbine S. TG20	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00%
Tek. Gas Turbine .S. TG20	0	0	5	0	0	0	0	0	0	0	0	0	5	0.00%
Tek. Gas Turbine S. TG16	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00%
Kalecik DG	44,370	44,440	45,945	43,705	44,771	45,827	42,864	46,388	44,627	46,492	46,209	45,375	541,012	42.88%
Teknecik DG	5,249	1,816	1,934	6,656	10,566	10,036	15,700	31,270	9,017	14,030	8,819	7,314	122,408	9.70%
Total TRNC Production	108,082	93,342	91,746	82,000	90,303	105,044	128,166	150,453	117,422	99,178	88,145	102,382	1,256,263	99.57%
South-fed villages	308	273	253	304	259	312	359	384	366	286	337	1,957	5,399	0.43%
GENERAL TOTAL	108,390	93,614	91,999	82,305	90,563	105,356	128,525	150,836	117,788	99,464	88,481	104,339	1,261,661	100%

Table 4 Production Values 2011

Production Plants	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Total	%
Tek. Gas Turbines	53283	29134	45385	29955	26955	51611	67920	74456	59007	43001	48796	59281	588784	41.32%
Teknecik DGs	11391	21552	7730	13092	16368	4945	34528	54299	39331	13772	9071	12432	238511	16.74%
Kalecik DGs	45296	45311	43969	42541	45574	48851	56826	56579	52438	50162	53483	49436	590466	41.44%
Serhat köy Solar	0	0	0	0	16	192	1	101	139	185	141	135	910	0.06%
Total TRNC Production	109970	95997	97084	85588	88913	105599	159275	185435	150915	107120	111491	121284	1418671	99.56%
South-fed villages	341	335	228	229	247	225	282	266	345	1100	2198	455	6253	0.44%
GENERAL TOTAL	110,311	96,332	97,312	85,817	89,160	105,824	159,557	185,701	151,260	108,220	113,689	121,739	1,424,924	100.00%

Table 5 Production Values 2012

Production Plants	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Total	%
Tek. Steam Turbine S.U.1	26423	33352	15038	17994	15603	25804	32656	30502	21354	15034	25285	32428	291471	21.31%
Tek. Steam Turbine S.U.2	23679	0	33068	11441	965	19903	32449	23892	28258	13888	0	11525	199067	14.56%
Dik Gas Turbine S. TG20	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00%
Tek. Gas Turbine .S. TG20	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00%
Tek. Gas Turbine S. TG16	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00%
Kalecik DG	55187	53432	47638	51785	49953	49090	54973	58052	55830	55410	55731	48373	635453	46.46%
Teknecik DG	16346	27007	23097	4922	23643	22333	28809	33167	13602	15496	10097	16400	234920	17.18%
serhatköy solar	0	0	0	0	0	200	222	227	211	139	107	86	1192	0.09%
Total TRNC Production	121636	113791	118841	86142	90163	117329	149109	145840	119255	99966	91219	108812	1362104	99.60%
South-fed villages	814	489	513	367	289	414	509	515	398	237	334	641	5520	0.40%
GENERAL TOTAL	122,450	114,280	119,354	86,509	90,453	117,743	149,618	146,355	119,653	100,203	91,553	109,453	1,367,624	100.00%

Table 6 Production Values 2013

Production Plants	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Total	%
Tek. Steam Turbine S.U.1	29507	6006	0	2025	29249	25012	29547	30255	23396	456	26298	25480	227229	16.79%
Tek. Steam Turbine S.U.2	28917	25144	30670	27050	0	17974	30738	27232	23710	23844	383	17386	253049	18.69%
Kalecik DG	53053	59399	58607	50716	54920	57166	59013	59898	56005	58114	55573	57978	680444	50.26%
Teknecik DG	9021	7521	12206	9743	18945	16559	20575	28335	16650	18015	14051	14153	185773	13.72%
serhatköy solar	130	146	193	209	220	213	229	210	186	164	125	116	2142	0.16%
Total TRNC Production	120627	98216	101677	89742	103334	116925	140102	145930	119947	100593	96431	115113	1348638	99.62%
South-fed villages	431	466	290	395	364	382	391	406	384	457	342	790	5097	0.38%
GENERAL TOTAL	121,058	98,682	101,966	90,137	103,699	117,307	140,493	146,336	120,331	101,050	96,773	115,903	1,353,735	100.00%

Table 7 Production Values 2014

Production Plants	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Total	%
Tek. Steam Turbine S.U.1	24343	18089	22652	0	1800	22844	28083	30355	25155	0	18660	26196	218177	15.81%
Tek. Steam Turbine S.U.2	26823	11521	3576	21389	26275	9333	24498	24404	21727	27358	8013	3198	208117	15.09%
Kalecik DG	57945	56680	58916	57168	53912	58833	60261	59493	58589	57474	57006	58781	695059	50.38%
Teknecik DG	7061	11826	16405	15497	18115	26152	32488	39538	20670	19203	18390	25464	250807	18.18%
serhatköy solar	121	182	182	172	172	188	175	110	185	156	131	102	1878	0.14%
Total TRNC Production	116293	98298	101732	94226	100274	117350	145505	153900	126325	104192	102200	113742	1374037	99.60%
South-fed villages	396	375	414	365	357	684	540	556	756	394	396	343	5576	0.40%
GENERAL TOTAL	116,689	98,674	102,146	94,591	100,632	118,033	146,045	154,455	127,081	104,586	102,596	114,085	1,379,613	100.00%

Table 8 Production Values 2015

Production Plants	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Total	%
Tek. Steam Turbine S.U.1	25399	17320	22133	14397	0	0	21384	26350	24609	21808	20371	22166	215937	14.93%
Tek. Steam Turbine S.U.2	25055	21860	4396	11441	25916	25992	24141	27300	8958	0	0	2689	177749	12.29%
Kalecik DG	60875	56469	55522	54365	56039	58292	64572	58743	57957	58209	59243	59199	699484	48.35%
Teknecik DG	19183	14314	21012	16882	21417	31520	34340	46018	44921	34892	24430	39875	348803	24.11%
serhatköy solar	106	210	210	175	190	220	225	136	140	153	137	135	2037	0.14%
Total TRNC Production	130618	110173	103273	97260	103562	116024	144662	158547	136585	115062	104181	124064	1444010	99.81%
South-fed villages	308	237	340	158	167	143	256	226	249	150	280	269	2784	0.19%
GENERAL TOTAL	130,926	110,410	103,613	97,418	103,729	116,167	144,918	158,773	136,834	115,212	104,461	124,333	1,446,794	100.00%

Table 9 Production Values 2016

Production Plants	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Total	%
Tek. Steam Turbine S.U.1	27391	23698	25398	24189	24923	18775	33692	20500	0	0	0		198566	13.98%
Tek. Steam Turbine S.U.2	0	0	0	0	0	17282	22048	13074	27226	8542	18718		106890	7.53%
Kalecik DG	58727	57819	58298	58155	58577	59703	58830	63351	58320	58282	58497		648558	45.68%
Teknecik DG	50330	25206	25114	18659	27210	42723	51995	72017	46865	51791	33276		445185	31.35%
serhatköy solar	106	105	184	210	208	194	196	199	188	175	175		1939	0.14%
Total TRNC Production	136554	106828	108993	101213	110918	138677	166761	169141	132599	118790	110665	0	1401139	98.68%
South-fed villages											18718		18718	1.32%
GENERAL TOTAL	136,554	106,828	108,993	101,213	110,918	138,677	166,761	169,141	132,599	118,790	129,383	0	1,419,857	100.00%

Table 10 Production Values 2017

Production Plants	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Total	%
Tek. Steam Turbine S.U.1	0	0	0	0	4546	18117	31717	31021	24575	0	792	28097	138865	8.60%
Tek. Steam Turbine S.U.2	31052	25702	26261	3768	1837	15030	34026	32438	7938	7813	0	12232	198097	12.26%
Kalecik DG	62128	59447	59043	59087	60201	60002	60118	60306	60671	58847	58879	58251	716980	44.39%
Teknecik DG	57256	37830	35316	41079	47697	42239	51995	50946	51848	51950	53294	38107	559557	34.64%
serhatköy solar	111	110	155	144	178	180	180	172	150	173	81	85	1720	0.11%
Total TRNC Production	150547	123089	120775	104078	114459	135568	178036	174883	145183	118783	113046	136772	1615220	100.00%
GENERAL TOTAL	150,547	123,089	120,775	104,078	114,459	135,568	178,036	174,883	145,183	118,783	113,046	136,772	1,615,220	100.00%

Table 11 Production Values 2018

Production Plants	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Total	%
Tek. Steam Turbine S.U.1	25552	12213	23116	0	0	4387	31522	31984	11380	0	0	8599	148753	9.12%
Tek. Steam Turbine S.U.2	25908	23577	1303	0	10459	30383	33177	31328	16317	0	9457	18197	200106	12.26%
Kalecik DG	59470	59114	58604	59699	60397	60207	60844	60533	58819	58339	57606	58718	712351	43.65%
Teknecik DG	32351	24128	35427	49967	61715	48523	57430	55929	52478	53220	46783	50065	568016	34.81%
serhatköy solar	113	111	166	199	174	176	189	173	171	170	95	79	1816	0.11%
Total TRNC Production	143394	119144	118616	109865	132746	143676	183162	179947	139165	111729	113941	135658	1631041	99.95%
South-fed villages	0	0	0	0	0	0	0	0	0	0	594	146	740	0.05%
GENERAL TOTAL	143,394	119,144	118,616	109,865	132,746	143,676	183,162	179,947	139,165	111,729	114,534	135,804	1,631,781	100.00%

Appendix B: Electronic Merit Order Curve Calculator