MARMARA UNIVERSITY
INSTITUTE FOR GRADUATE STUDIES
IN PURE AND APPLIED SCIENCES

SMART GRID AND ENERGY STORAGE SYSTEMS FOR END-USE ENERGY EFFICIENCY AND TRANSITION TO 100% RENEWABLE ENERGY IN CITIES

SEÇKİN BAKIRCI

MASTER THESIS

Department of Electrical and Electronics Engineering

Thesis Supervisor

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Seçkin BAKIRCI, a Master of Science student of Marmara University Institute for Graduate Studies in Pure and Applied Sciences, defended his thesis entitled "Smart Grid and Energy Storage Systems for End-Use Energy Efficiency and Transition to 100% Renewable Energy in Cities", on July 1, 2019 and has been found to be satisfactory by the jury members.

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APPROVAL

Marmara University Institute for Graduate Studies in Pure and Applied Sciences Executive Committee approves that Seçkin BAKIRCI be granted the degree of Master of Science in Department of Electrical and Electronics Engineering Program on 10/07/2019.

(Resolution no: 2019/14-22).

Director of the Institute

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ACKNOWLEDGEMENT

First of all, I would like to thank my supervisor Prof. Dr. Tanay Sıdkı Uyar for his support and guidance. I would also like to thank my co-supervisor Asst. Prof. Dr. Egemen Sulukan for sharing his precious time, knowledge and experience.

I am also grateful to my beloved family, especially my mother, for their endless support throughout my education.

Finally, I would like to mention my gratitude for my friends İbrahim Selçuk Bağcı, Doğancan Beşikci, due to their help and support during this project and Mr. Ekrem Akgül for sharing generously his acknowledgement with me during my stay in Çanakkale.

June 2019 **Seçkin Bakırcı**

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ÖZET

ŞEHİRLERDE %100 YENİLENEBİLİR ENERJİYE GEÇİŞ VE SON KULLANICI VERİMLİLİĞİ İÇİN ENERJİ DEPOLAMA VE AKILLI ŞEBEKE SİSTEMLERİ

1970'lerdeki petrol krizi alternatif enerji kaynağı arayışlarını tetiklemiştir. Artan küresel enerji talebi ve bu ihtiyacı karşılamak için fosil enerji kaynaklarının kullanılması sera gazı emisyonlarını arttırarak ekolojik dengenin bozulmasına (küresel iklim değişikliği) sebep olmuştur. Alternatif ve sürdürülebilir/temiz enerji kaynağı arayışları yenilenebilir enerji kaynaklarına olan ilgiyi ve merakı arttırmıştır. Hızlanan yenilenebilir enerji çalışmaları, zamanla kurulum ve üretim maliyetlerindeki düşüşlerle ivme kazanmıştır.

Artan nüfusun ve kişi başı kullanılan enerji miktarının büyük bir ivmeyle yükseldiği 2000'li yıllar temiz enerjiye olan ihtiyacın önemini arttırmıştır. Bu yıllarda yenilenebilir kaynakların olmazsa olmaz olduğu anlaşılmakla kalmamış bu temiz enerji kaynaklarının tüm enerji ihtiyacımızı karşılayabileceği fikri kabul görmeye başlamıştır. Ülkeler günümüzde %100 yenilenebilir enerji hedefine yönelik çalışmalar yürütmeye başlamıştır. Elbette %100 yenilenebilir enerjiye geçiş planları yapılırken şebekeye entegrasyon ve bu kaynakların bazılarının sürekli olmaması sebebiyle ortaya çıkan enerjinin depolanma ihtiyacı gibi zorluklarla da karşılaşılabilmektedir.

Hızla artan nüfus ve bu nüfusun artan enerji tüketimi kesintisiz enerji arzını zorunlu kılmaktadır, bu enerji talebi yüksek oranda fosil kaynaklardan sağlanmakta olup, yakın dönemlerde yenilenebilir enerji kaynakları ile üretim ivme kazanmıştır. Günümüzde, Dünya'da %100 yenilenebilir enerji hedefine yönelik çalışmalara paralel olarak, Türkiye'de de ulusal ve yerel ölçekte enerji modelleme çalışmaları yürütülmektedir.

Bu çalışmada akıllı şebekeler (şebekeye entegrasyon probleminin çözümü için) ve enerji depolama sistemlerinden yararlanarak Çanakkale ilinin %100 yenilenebilir enerjiye geçişi ve son kullanıcı verimliliği ile enerjinin etkin kullanımı çalışmaları incelenmiştir. Bununla birlikte Çanakkale'nin TIMES enerji modeli oluşturularak bölgenin %100 yenilenebilir enerjiye geçişi için senaryolar oluşturularak sonuçlar incelenmiştir. Sonuçlara istinaden Çanakkale'nin %100 yenilebilir enerjiye geçişinin mümkün olabileceği görülmüştür.

ABSTRACT

SMART GRID AND ENERGY STORAGE SYSTEMS FOR END-USE ENERGY EFFICIENCY AND TRANSITION TO 100% RENEWABLE ENERGY IN CITIES

Because of the oil crisis in the 1970s, the search for alternative energy sources increased. In addition, increasing global energy demand and the use of fossil energy sources to meet this need increased greenhouse gas emissions and caused the deterioration of ecological balance. The search for alternative and sustainable energy sources has increased the interest and curiosity for renewable energy sources. Increasing renewable energy studies have gained momentum with decreases in installation and production costs over time.

The increase in the population and the amount of energy used per capita in the 2000s increased the importance of the need for clean energy. In these years, renewable resources have been understood to be indispensable, and the idea that these clean energy sources can meet our energy needs has started to be accepted. While countries were planning to increase the share of renewable energy in their energy action plans, nowadays they have been working on achieving towards 100% renewable energy target. Some difficulties are encountered when making transition plans to 100% renewable energy. Integration of renewable energy into the grid and the need for storage of energy since some of these resources are not continuous, are the main challenges.

Rapidly rising population and increasing energy consumption of the population in Turkey necessitates continuous energy supply. This energy demand in Turkey is provided from a high proportion of fossil resources, renewable sources have recently started to increase its share in this rate. Today, parallel to work towards 100% renewable energy target in the world, energy modeling studies have been conducted at national and local level also in Turkey.

In this study, by using smart grids and energy storage systems, the transition of Çanakkale province to 100% renewable energy, end-use efficiency and efficient use of energy were examined. In addition, the TIMES energy model of Çanakkale was created and scenarios were developed for the transition of the region to 100% renewable energy and the results were examined. According to the results, the transition to 100% renewable energy in Çanakkale is possible.

SYMBOLS

TWh	: Terawatt hour
CO_2	: Carbon Dioxide
MW	: Megawatt
GW	: Gigawatt
PJ	: Petajoule
MWh	: Megawatt hour
$	: United States dollar
km^2	: Kilometer square
m/s	: Meter per second
KWh/m^2	: Kilowatt hour per square
TEP/year	: Tone Equivalent of Petroleum Per Year

ABBREVIATIONS

CAES	**:**	Compressed Air Energy Storage
COMPOSE	**:**	Compare Options for Sustainable Energy
DKK	**:**	Danish Krone
EMCAS	**:**	Electricity Market Complex Adaptive System
EMPS	**:**	EFI's Multi-area Powermarket Simulator
EWS	**:**	Efficiency World Scenario
FC	**:**	Fuel Cell
FES	**:**	Flywheel Energy Storage
GTMax	**:**	Generation and Transmission Maximisation Tool
HOMER	**:**	Hybrid Optimization of Multiple Energy Resource
IEA	**:**	International Energy Agency
INFORSE	**:**	International Network for Sustainable Energy
LA	**:**	Lead-Acid
LEAP	**:**	Long Range Energy Alternatives Planning System
Li-ion	**:**	Lithium Ion
MARKAL	**:**	Market Allocation
Mesap/PlaNet	**:**	Modular Energy-System Analysis and Planning Environment/Planning Network
MESSAGE	**:**	Model for Energy Supply Strategy Alternatives and Their General Enviromental Impact
NaS	**:**	Sodium Sulphur
NEMS	**:**	National Energy Modeling System
Ni-Cd	**:**	Nickel Cadmium
NPS	**:**	New Policies Scenario
ORCED	**:**	Oak Ridge Competitive Electricity Dispatch
PCM	**:**	Phase Change Materials
PERSEUS	**:**	Programme-Package for Emission Reduction Strategies in Energy Use and Supply-Certificate Trading
PHES	**:**	Pumped Hydro Energy Storage
PHSS	**:**	Pumped Hydrostorage System

PV	**:**	Photovoltaic
RES	**:**	Reference Energy System
RETScreen	**:**	RETScreen Clean Energy Management Software
SC	**:**	Super-Capacitor
SMES	**:**	Superconducting Magnetic Energy Storage
SNG	**:**	Synthetic Natural Gas
TCES	**:**	Thermo Chemical Energy Storage
TCS	**:**	Thermo-Chemical Energy Storage
TES	**:**	Thermal Energy Storage
TIMES	**:**	Time Integrated Markal-Efom System
UEDAŞ	**:**	Uludağ Elektrik Dağıtım Anonim Şirketi
VRB	**:**	Vanadium Redox Battery
ZnBr	**:**	Zinc Bromine

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1. INTRODUCTION

After the industrial revolution (1765), the traditional social structure based on agriculture underwent a major change. With the new technologies that have emerged, small productions in the houses and hand looms have been moved to the factories. As a result of this mass production, the way of life of society has changed. The houses, which started to concentrate around the factories, started urbanization. Industrial revolution has caused a great change in sociological structure of societies [1].

The increasing industrialization process has caused the need for energy to increase day by day. Initially, fossil fuels, especially coal, were used to meet this increase. These energy sources, which diversified over time, were not sufficient to meet the rapidly increasing energy demand. This situation caused crises and even wars between countries. The need for alternative sources of energy has increased as a result of the limited nature of fossil resources (the cause of energy crises and wars) and the damage caused to the ecological balance. This need has begun to increase the share of renewable resources in meeting the energy needs. Renewable energy is the energy generated by using the energy flow as a result of the movement of the earth around its axis and its movement on the orbit. (Solar energy, water energy, wind energy, wave energy, biomass etc.)

Due to the rapid development of technology, production from some renewable energy sources has become cheaper than fossil power plants. The fact that renewable energy sources are infinite, become cheaper, and most importantly, does not harm the ecological balance by following an environmentalist production method, has led to the emergence of "100% Renewable Energy" concept. When we mention about 100% renewable energy; it means that the productions depend on renewable resources, the process does not harm the environment and its greenhouse gas emissions are zero.

In this respect, some countries have begun to create national energy action plans and set achievable targets and increase the share of renewable energy in their energy production. In fact, there are many action plans for the transition to 100% renewable energy, especially in urban scale. There are a variety of energy modeling tools that can be used in these action plans that are created at a city or national scale. These tools are computer programs that can be selected according to the needs of the city / region and can present plans for the future.

There are many challenges in transition to 100% renewable energy. The main challenges are integration to the grid and the need for energy storage. Since electricity generation from renewable sources is much more diffuse than conventional methods and has a very wide range in terms of production capacity, smart grids are essential for the seamless integration of this energy into the grid. In addition, renewable sources such as wind, solar, hydro ... etc. vary depending on the season or the time of day, thus requiring the storage of energy at times when production is concentrated.

In view of these reasons, it is aimed to examine the importance of smart grids and energy storage in transition to 100% renewable energy and the effects of end-use efficiency and improvements in energy consumption. In addition, it is one of the aims of this study to analyze the transition of Çanakkale (case city) to 100% renewable energy with various scenarios by forming the “TIMES Energy Model of Çanakkale” province.

2. BACKGROUND

2.1. Turkish Electricity Sector

Industrialization, changing lifestyles and the result of the growing population, Turkey's energy demand is increasing rapidly. The installed capacity of Turkey is 85,200MW in 2017. Which is about 18 times higher than the 1977 value [2].

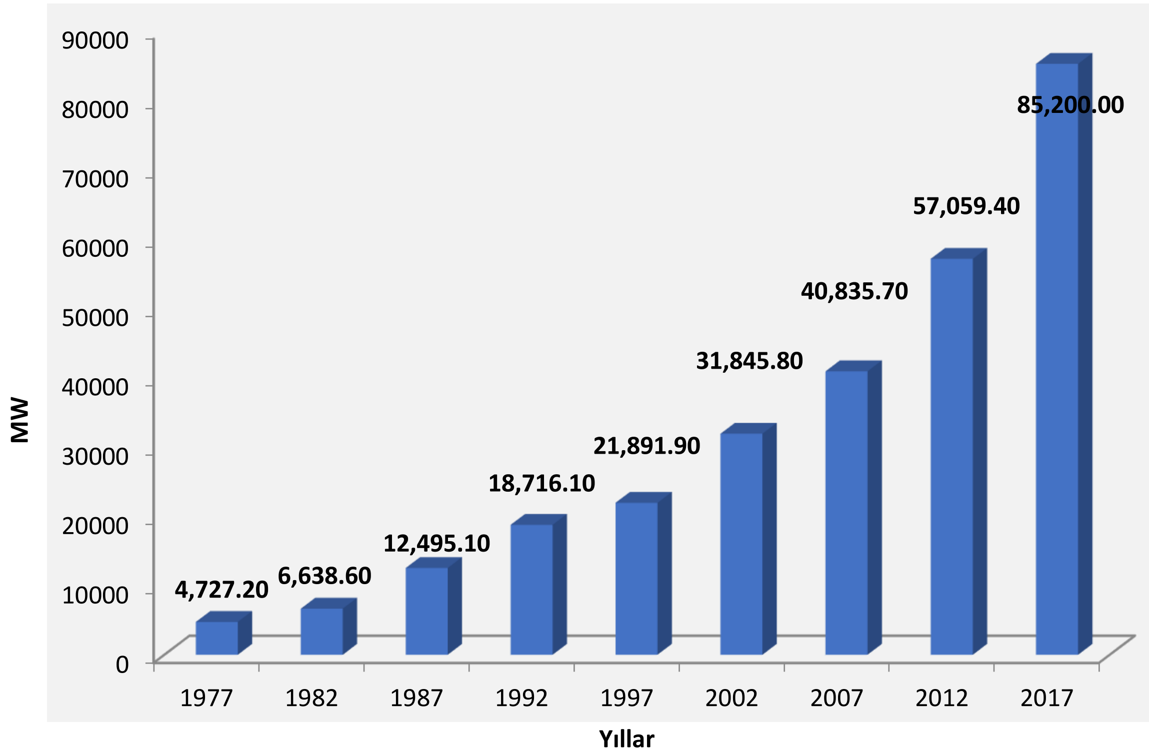


Figure 1. Installed Capacity of Turkey [2].

In 2017, total electricity consumption of Turkey was 292TWh. As it shown in table 1, increase in consumption is not proportional. Increase rates are between 2014-2015 is 3,3% between 2016-2017 is 5,22%. The increase in demand and capacity increase are close to each other [3].

Table 1. Licensed and Unlicensed Installed Capacity, Peak Demand, Licensed and Unlicensed Electricity Generation, Consumption, Import and Export Data [3].

	Unit	2014	2015	2016	Change (%) 2015→2016	2017	Change (%) 2016→2017
Licensed Installed Capacity	MW	69.520	73.146,90	77.563,44	6,04	81.563,32	5,16
Unlicensed Installed Capacity	MW	29,99	359,04	1.048,21	191,95	3.173,32	202,74
Peak Demand	MW	41.003	43.289,00	44.733,98	3,34	47.659,65	6,54
Licensed Generation	GWh	251.962	261.783,30	272.563,63	4,12	292.574,58	7,34
Unlicensed Generation	GWh	3,92	222,72	1.137,87	410,89	3.031,56	166,42
Consumption	GWh	257.220	265.724,40	277.522,01	4,44	292.003,54	5,22
Import	GWh	7.953	7.411,10	6.400,13	-13,64	2.729,06	-57,36
Export	GWh	2.696	2.964,60	1.442,08	-51,36	3.300,10	128,84

Figure 2 shows the changes of installed capacity between 2007 to 2017 in MW. Total installed capacity is almost doubled in ten years.

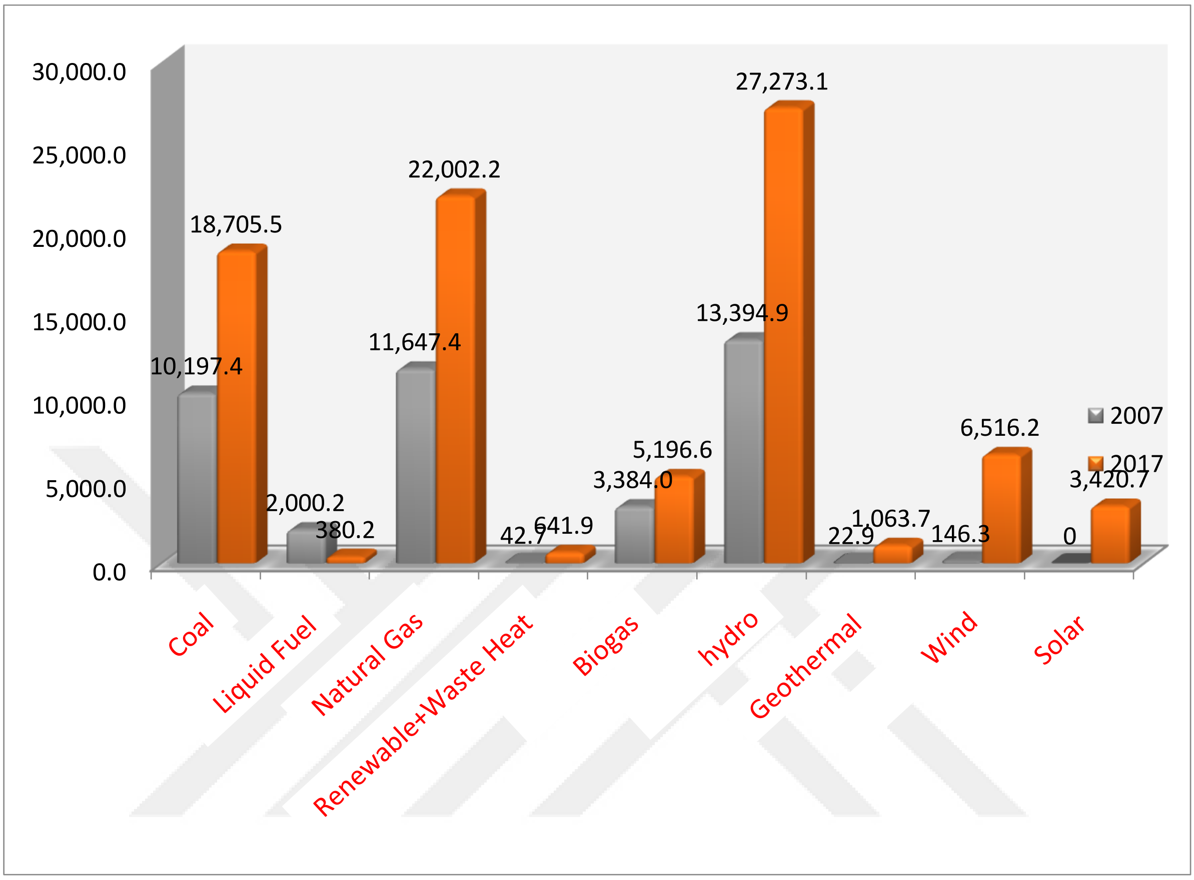


Figure 2. 2007 and 2017, Installed Capacity of Turkey according to Primary Energy Sources *[2]*.

Table 2. 2007 and 2017, Installed Capacity of Turkey according to Primary Energy Sources (MW) *[2]*.

	2007	**%**	**2017**	**%**
Coal	10.197,4	24,97	18.705,5	21,95
Liquid Fuel	2.000,2	4,90	380,2	0,45
Natural Gas	11.647,4	28,52	22.002,2	24,33
Renewable +Waste Heat	42,7	0,10	641,9	0,75
Biogas	3.384,0	8,29	5.196,6	7,59
Hydro	13.394,9	32,80	27.273,1	32,01
Geothermal	22,9	0,06	1.063,7	1,25
Wind	146,3	0,36	6.516,2	7,65
Solar	-	-	3.420,7	4,01
Total	40.835,7	100,00	85.200,0	100,00

According to Renewable Energy Action Plan of Turkey, in 2023 energy demand will increase %75,4. To meet this demand, it is planned to increase the share of renewable resources. The planned 2023 renewable targets are; Increase total installed capacity of Hydro to 34,000MW, Wind to 20,000MW, Geothermal to 1,000MW, Solar to 5,000MW and Biomass to 1,000MW [4].

From table 2, when we look at the rise of these resources from in the last 10 years, it is seen that the targets are modest. It can be seen that these goals can be exceeded.

Table 3. Annual Development of Renewable Based Installed Capacity Share in Turkey Total Installed Capacity 2000-2017 (MW) *[5]*.

Years	**Hydro**	**Geothermal**	**Wind**	**Solar**	**Biomass***	**Renewable Installed Capacity**	**Turkey Total Installed Capacity**	**Renewable Share %**
2000	11,175.2	17.5	18.9		10.0	11,221.6	27,264.1	41.2
2001	11,672.9	17.5	18.9		10.0	11,719.3	28,332.4	41.4
2002	12,240.9	17.5	18.9		13.8	12,291.1	31,845.8	38.6
2003	12,578.7	15.0	18.9		13.8	12,626.4	35,587.0	35.5
2004	12,645.4	15.0	18.9		13.8	12,693.1	36,824.0	34.5
2005	12,906.1	15.0	20.1		13.8	12,955.0	38,843.5	33.4
2006	13,062.7	23.0	59.0		19.8	13,164.4	40,564.8	32.5
2007	13,394.9	23.0	147.5		21.2	13,586.6	40,835.7	33.3
2008	13,828.7	29.8	363.7		38.2	14,260.4	41,817.2	34.1
2009	14,553.3	77.2	791.6		65.0	15,487.1	44,761.2	34.6
2010	15,831.2	94.2	1,320.2		85.7	17,331.3	49,524.1	35.0
2011	17,137.1	114.2	1,728.7		104.2	19,084.2	52,911.1	36.1
2012	19,609.4	162.2	2,260.6		147.3	22,179.5	57,059.4	38.9
2013	22,289.0	310.8	2,759.7		178.0	25,537.5	64,007.5	39.9
2014	23,643.2	404.9	3,629.7	40.2	227.0	27,945.0	69,519.8	40.2
2015	25,867.8	623.9	4,503.2	248.8	277.1	31,520.8	73,146.7	43.1
2016	26,681.1	820.9	5,751.3	832.5	363.8	34,449.6	78,497.4	43.9
2017	27,273.1	1,063.7	6,516.2	3,420.7	477.4	38,751.1	85,200.0	45.5

* Includes Industrial Waste

It is a fact that because of its climate, natural resources and geographical structure, Turkey's renewable energy potential is high enough to take big steps for transition to clean and sustainable energy.

2.2. Renewable Sources

In 2016, the global total final energy consumption share of renewables was %18,2 [6]. The share of these resources that have the capacity to meet the energy needs of the whole world is increasing day by day. We can divide renewable energy into 6 main headings according to their sources which are; wind, solar, biomass, marine, geothermal and hydro.

2.2.1. Solar energy

Among the renewable sources, solar energy has by far the highest potential. The sun, which has been the source of life by heating and illuminating our planet for billions of years, is capable (theoretically) of giving the energy we need by itself. The methods we use to obtain energy from the sun are basically two different types. The first one is by heating another substance with the sun rays and then using this temperature. The heat obtained by this method can be used for producing electricity by convenient methods or just as heating. The second is the method of converting the sun's rays into direct electricity current by reflecting them on Photovoltaic panels (PV Panels, basically semiconductor devices).

2.2.2. Wind energy

Wind energy is a resource that we have been using for centuries in different ways in transportation with ships' sailing system, grinding wheat or pumping water with windmills etc. Nowadays, in modern technologies such as windmills, wind power is turned into mechanical energy by rotating the propellers and electrical energy is obtained from this mechanical energy. In addition, wind turbines play an important role in ensuring that electricity reaches the points where there is no electricity grid. Small islands are among the best examples of this.

2.2.3. Hydro power energy

The hydropower is basically the same as the wind power. As in the wind, it is obtained by using the flow force of the water to obtain electrical energy with the rotating propellers. Dams are among the most widely used hydropower plants. It also has the largest share in global renewable energy installed capacity.

2.2.4. Biomass energy

Agricultural wastes, animal wastes, domestic wastes, etc. all organic wastes are converted into electrical energy, temperature or liquid fuel by appropriate methods. It is a kind of recycling of the wastes that are produced as a result of photosynthesis or as a result of the vital activities of other living things. And converting these wastes into energy.

2.2.5. Geothermal energy

Geothermal energy has been exploited since ancient times. The use of this energy source in the production of electrical energy is based on more than a hundred years. The first generation of electricity from geothermal energy took place in 1904. The first significant amount of production was made in Larderello (Italy) in 1911 with the establishment of the power plant [7]. Geothermal energy is the use of hot water sources or trapped steam beneath the earth's crust. They can be used in small scale regional heating systems as well as in the production of electrical energy with the power plants installed near these resources.

2.2.6. Marine energy

Waves, tidal range, ocean current, tidal current, salinity gradient and ocean thermal energy conversion sources can be classified as six main marine energy type. All of these sources have different conversion technologies. All marine technologies, except wave dam technology, are undergoing intensive research and development or are in prototype phase. Theoretically, marine energy has the potential to meet the current and future energy needs of human beings [8]. Although production with Marine energy technologies is very small, it is inevitable that more efficient and cheap systems will develop and have a significant share in the sector over time as in PV panels.

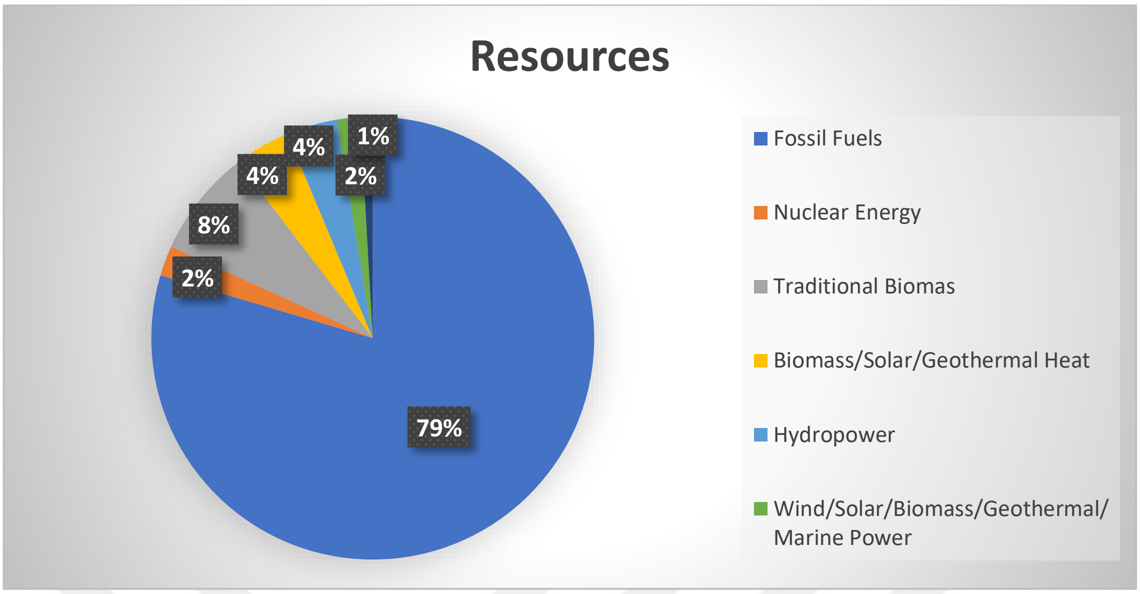


Figure 3. Estimated Renewable Share of Total Global Final Energy Consumption, 2016 *[6]*.

2.3. Technologies

2.3.1. Smart grids

Built in 1882 by Edison in Manhattan, the power plant was essentially the first electrical system. This system on Pearl Street was basically a microgrid. [9] While the electricity networks were initially designed to be close to the production facilities and the consumers, as the number and demand of the consumers increased, the smaller networks expanded and became more complex [10].

The diversity of renewable energy sources, differences in production stages and intermittency of renewable sources increase the importance of energy storage as well as the importance of transmission of this energy. Conventional electricity power grids fail to manage this complex energy supply-demand system of the twenty-first century. In a simple way, the system that provides this energy flow by using communication technologies and information technologies is called “Smart Grids".

Facilitate the integration of various renewable resources; supporting individual / discrete power generation; the emergence of a new business model through improved information flow, improved system control and consumer involvement; and increasing the flexibility of demand and so on. In various respects, smart grids make a significant contribution to the transition to a sustainable energy future [11].

Since smart grid technologies are still in development phase so there is no universal consensus on the features of this technology. However, it is understood the necessity of 4 basic technologies that provide flexibility and efficiency to the system such as information assembler, information collector, information-based controller and Energy/Power resources [11].

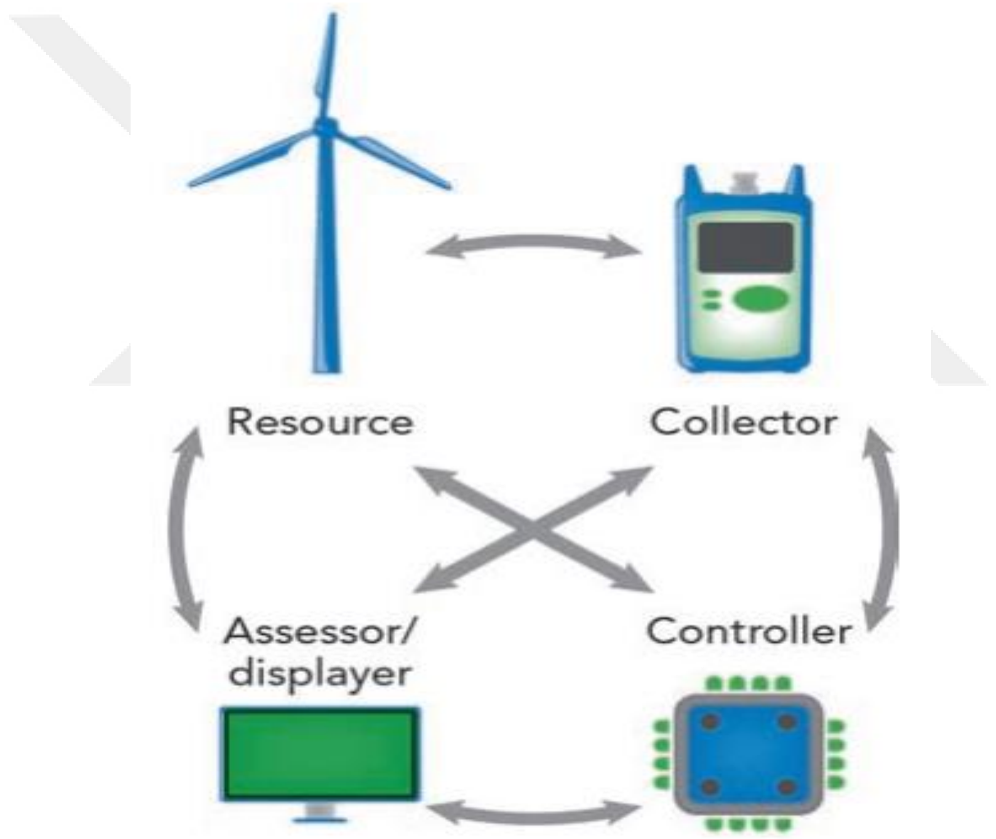


Figure 4. Main Technologies of Smart Grids *[11]*.

Denmark, which supplies 30% of its electricity from wind energy, plans to increase this rate to 50% in 2025. According to a study conducted for this; while the amount to be spent on smart grids is DKK (Danish Krone) 1.6 billion, the amount needed to upgrade the existing grid is DKK 7.7 billion which is way much than to transited to smart grids [11].

In addition to all its benefits, smart grids are extremely complex systems. Even, it requires drastic changes in public policies, business models, social behavior and even engineering [12]. Conventional grids cannot and should not be replace with smart grids. In other words, smart grids should be integrated into existing electricity grids to improve their functions, capacities and capabilities [13].

Table 4. Conventional Grid Compared to Smart Grid *[13]*.

Conventional Grid	Smart Grid
One-Way Communication	Two-Way Communication
Few Sensors	Sensors Throughout
Centric Generation	Distributed Generation
Electromechanical	Digital
Hierarchical	Network
Limited Control	Extensive Control
Manual Check/Test	Remote Check/Test
Blind	Self-Monitoring
Manual Restoration	Self-Healing
Few Customer Choices	Many Customer Choices
Failures and Blackouts	Adaptive and Islanding

There are some areas which expected to upgrade through smart grids. Which are;

1. Electrical energy, which is usually produced at long distance locations from users, there are big losses when transmitting to the end user with high voltage lines. Smart grid technologies could enhance the monitoring and operating, it controls the current flowing through the line more precisely and prevents energy loss in high voltage transmission lines.
2. It will facilitate the control and automation of the substations in the distribution network. In this way, distribution companies that increase their connection to each other can ensure fewer customers to be affected in case of any disruption (disasters or malfunctions).
3. Probably the most widely known feature of smart grids is smart meter systems. Smart meters enable two-way communication between customers and utility companies. In

this way, utility companies can send price information to customers, customers can strengthen the flexibility of demand by not using electricity during peak hours. In addition, companies can make more consistent assumptions about their usage habits by collecting data [12].

According to the results of the modeling work with EnergyPLAN for the transition of Zagreb city to smart energy system or traditional(non-integrated) renewable energy system; The analysis shows that intelligent energy systems are more preferable to Zagreb for three main reasons: Sustainable biomass consumption and a lower share of initial energy providers, competitive cost level with traditional renewable energy systems and increased energy security with reduced energy dependence on specific technologies as a result of greater energy diversity [14].

Suggestions for the development of the existing smart grid system are as follows; Energy storage capacity and integrated systems should be increased by utilizing existing and renewable resources. Communication and information technologies should be much more advanced for the management of power supply systems. In order to improve the existing general system with intelligent equipment, the communication network needs to be centralized. As a result; It is seen that smart grids, which are currently used in many countries and will be used in many, have great potential for the efficient use of renewable energy [15].

2.3.2. Energy storage

Industrialization and rapidly increase in the human population result with increasing demand to energy for meeting the needs of living. Continuous energy supply becomes more important because of this increasing energy demand. In todays, different type of sources such as conventional and renewable sources are currently using together to meet the energy demand [16]. It is also demanded to reduce pollution, CO2 level and global warming by people and governments while producing energy from different sources. Energy production from renewable energy sources like solar, wind and hydropower are gaining importance due to their compliance with the environmental constraints and expectations of people [16].

While meeting the environmental concerns, it is crucial to implement renewable power which may create some operational necessities into the system without compromising energy supply reliability [17]. However, the output of renewable power sources may not always meet the required energy. For this reason, storage of energy becomes a developing area with the renewable energy.

Energy storage can keep the produced energy when production is higher than demand and can release that kept energy when demand is higher than production [16]. Because of that, energy storage which supports the stability of system and equilibrates the production from different sources is a crucial part of an energy system [17]. Storing energy provides short-term and long-term advantages to the energy systems. In short-term, fluctuations in voltage and short faults, can be deferred with energy storages [16]. Storages also provide a rise in efficiency of plants and effectiveness of energy usage which increase the productivity of operations and reduce the need of new plants in long-term [16].

Energy storage systems which are currently using for different objectives can be applied into voltage control systems, power flow managements, energy restoration when faults occurred, energy network managements and energy markets directly [18]. There are also various practically energy storage methods and systems to meet these objectives. Renewable energy systems can be implemented with different kind of storage technologies which are chemical, electrochemical, mechanical, electrical or thermal [19]. Table 5 in below, shows details about these storage system categories and methodologies.

Table 5. Classifications of Energy Storage Systems and Methodologies *[20] [21]*.

Chemical	**Electrochemical**	**Mechanical**	**Electrical**	**Thermal**
Synthetic Natural Gas (SNG)	Lead-Acid Batteries	Flywheel System	Capacitor	Sensible Heat System
Biofuels	Lithium-ion Batteries	Pumped Hydro Storage System (PHSS)	Supercapacitor	Latent Heat System
Thermo-chemical Energy Storage (TCES)	Flow Batteries	Compressed Air Energy Storage System (CAES)	Superconducting Magnetic Energy Storage	Absorption and Adsorption System
	Hydrogen			

Energy storage systems and technologies which have different advantages and disadvantages in application, offer lots of benefits to its users from producer to end-user [22]. Storage systems can keep the energy when there is no need to use and release it when a gap occurs in supply. All energy storage technologies need some parameters such as duration of charge-discharge, storage capacity, usage of energy, energy efficiency, durability and lifetime of storage for evaluation [23]. Cost of storage implementation and operation is also another additional factor while evaluating the system. All these factors affect the decision of which storage technology will be used and how it will be implemented in the system.

Renewable energy production level can fluctuate from time to time according to conditions of weather, environment and climate [16]. Storage systems can be a great solution to reduce effects of these fluctuations. Uninterrupted energy supply can be possible with the right implementation of energy storage systems. It is also possible to reach %100 renewable energy with using renewable energy sources and storage systems together.

There are different technologies that are currently using to apply energy storage systems. Some of the applications suitable for large scale storage needs are;

Sodium nickel chloride batteries which operate over 270 degree Celsius, work with conversion of sodium chloride and nickel to nickel chloride and sodium while it is charging and reversely while it is discharging [19]. These batteries present high energy and power density with high efficiency and long lifecycle as advantage, however their requirements to high temperature and safety concerns about molten sodium can be considered as their disadvantages [22].

Lithium-ion batteries which are widely using and the most popular storage technology work with transferring the Lithium ions from positive electrode to negative electrode or inversely [19]. Lithium-ion batteries offer high energy storage capacity with low internal resistance and efficiency mostly over %90 [23]. Moreover, these batteries currently have the highest power density per unit of volume in between all commercial type of batteries [22]. Lithium-ion batteries are already using in the personal electronic devices such as laptop computers or mobile phones to provide required working power [23]. Despite of these advantages, there are some drawbacks of lithium-ion batteries. First of all, lifecycle of these batteries starts with when they are manufactured, and their lifespan are shortened even if lithium-ion batteries are not charged [23]. Secondly, lithium-ion batteries have minimum 300 cycle discharge/charge cycle or two years lifespan from production [22]. Therefore, it should be installed right tracking system into the energy storage system for following the life time of batteries and to interfere when a battery died. Lastly, temperature control should be provided with this type of batteries because of explosions of some were reported [19] [22].

Hydrogen energy storage systems are based on storing the produced energy from different sources like solar or wind using with hydrogen sources. Hydrogen has the highest energy per mass despite of its lower density in comparison with other type of fuels [19]. Hydrogen become salient element for long term energy storage because of these specifications [20]. There are different types of energy storage models such as compressed, liquefied or metal hydride which are using hydrogen as storage source [19]. However, electrolysis which is decomposition of water to hydrogen and oxygen should be applied as first step to store energy with hydrogen [20].

Pumped hydro energy storage (PHES) systems are another type of energy storage technologies. PHES systems includes two water reservoirs that one of them is at higher altitude from another, motor/generator electric machine, water pump and turbine [23]. When energy consumption is low and production is high, water pumps become active to pump water from lower altitude reservoir to higher one for storing the energy surplus in PHES [23]. When energy demand increases and production does not meet the demand stored energy should be used. At this time, water at the higher altitude reservoir transfers to lower reservoir with passing in turbine to produce energy via electric machine [23]. PHES system has limitations such as stored energy amount is limited with the volume of stored water in reservoirs and needs high investment capital at first [19] [23].

Compressed air energy storage (CAES) systems are based on compressing the air with compressors under high pressure when there are energy surplus in the system and expanding the air to gas turbines when energy deficit exists [19] [22] [23]. Air can be stored in underground cavities with carrier pipes or special tanks according to dimension of required CAES [19].

Thermal energy storage (TES) systems are based on keeping thermal energy of different kind of instruments by heating or cooling [19]. This type of storages increases the energy efficiency and provide saving from conventional fossil fuels [23]. TES systems are also required for utilizing waste heat and renewable energy sources [23]. Hot water tanks are widely used TES systems to store energy [20]. Sensible heat storages which is the basic TES method are based on heating or cooling of a liquid or solid instrument [19].

The other method is **Latent Heat Storage and Thermo-chemical Storage (TCS)**. Latent Heat Storage is based on changing of phases of special phase change materials (PCM) [19]. TCS is based on bilateral thermo-chemical processes to keep or release heat and cold for energy storing purposes [19].

The energy storage methods have different installation and operation costs because of implementation differences between them. Table 4 in below, shows the cost of all type of storage technologies. According to table, PHES and CAES systems offer lower costs than other energy storage methods. While installing renewable energy sources, usability and cost advantage of any energy storage systems should be considered to maximize the efficiency and effectiveness of energy production system.

Table 6. Capital Cost of Energy Storage Technologies *[24]*.

System	Capital Cost		
	$ (kW)	**$ (kWh)**	**$ (kWh Per Cycle)**
PHES	600-2000	5-100	0.1-1.4
CAES	400-8000	2-50	2-4
SC	100-300	300-2000	2-20
FES	250-350	1000-5000	3-25
Ni-Cd	500-1500	800-1500	20-100
LA	300-600	200-400	20-100
NaS	1000-3000	300-500	8-20
VRB	600-1500	150-1000	5-80
ZnBr	700-2500	150-1000	5-80
Li-ion	1200-4000	600-2500	15-100
FC	10,000+	-	6000-20,000
SMES	200-300	1000-10,000	-

2.4. End-Use Efficiency

The importance of end-use efficiency in countries' energy policies usually underestimate. Approximately 300,000 petajoules of the 400,000 petajoules energy supplied in a year reaches the consumer while 150,000 petajoules is utilized because of the conversion in end-use devices. That means; more than half of the energy produced is lost as heat [25].

When energy efficiency is mentioned, it is thought that the devices should be made more efficient by considering the loss in the energy cycle stages. However, the loss of this energy with some new technologies is one of the most important parts that should not be ignored. New generation building coverings, window systems, heavy materials used in vehicles and so on. increases energy loss [25].

One of the mistakes made about end-use efficiency is that developed countries sell their old, inefficient technologies to developing countries.

Without energy efficiency studies since 2000, the energy consumed in 2017 would be 12% more. This means 12% more greenhouse gas emissions [26].

In an end-use efficiency study for Germany in 2003, the planned activities were divided into three titles. Firstly, areas with high energy saving potential were identified. (These three areas are; "Residential"," Commercial and Public" and "Industry"). In the second stage, 18 end-use efficiency areas were identified and 70 energy efficiency technologies and measures were selected to divide these three sectors into groups. In the third stage, the cost and benefit analysis of each technology and measure was made and savings potentials were calculated. As a result of these analyzes, it is calculated that two thirds of these technologies have amortization periods of less than four years. It was also calculated that these additional technological investments had an internal return of more than 30% [27].

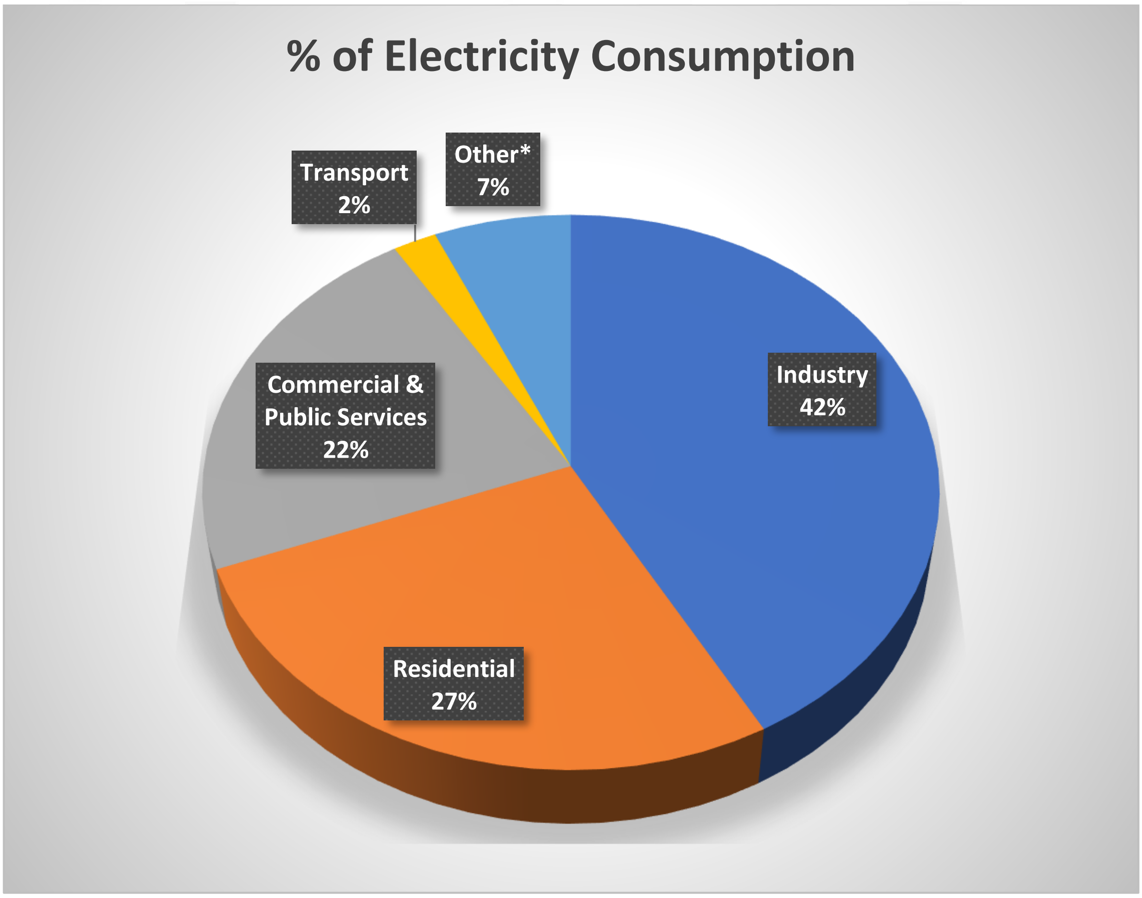


Figure 5. Shares of World Electricity Consumption, 2015 *[28]*.

**Includes Agriculture and forestry, fishing, and other non-specified.*

According to Efficiency World Scenario (EWS) 2040, which is prepared from IEA World Energy Outlook data, the results that will be obtained when the planned measures are taken are [26];

1.Energy-induced greenhouse gas emissions will drop by 12% below 2017 level.

2. Early deaths resulting from indoor air pollution will decrease by one third with the decrease in environmental / air pollution.

3. Households' expenditures (Transport and non-transport expenditures) will save 566 billion dollars globally. (EWS compared to New Policies Scenario (NPS))

4. With the decline in imports of fossil fuels, the European Union will save 190 billion USD, China 300 billion USD and India 189 Billion USD. (EWS compared to NPS)

Table 7. Largest end uses of energy by sector in IEA, 2014 *[28]*.

Transport	Manufacturing	Residential	Services	Other Industries
%35	%24	%20	%14	%7

For the Efficiency world scenario 2040, what governments should do for three major area (global end use ratio of these areas can be seen in table 3) can be summarized as follows [26]:

Transport: Taxation of vehicles according to efficiency classes, financial support for electrification of alternative transportation options, support for maritime transport and aviation, sustainability of global objectives, development and promotion of efficient vehicle procurement, training to support more efficient transport practices and determination of fuel economy standards.

Buildings: Financial incentives to encourage consumers to use high-efficiency devices and attempt big energy renovations, increasing the scope and strength of building energy regulations and standards for both new and existing buildings, extended and improved standards for equipment and devices like electrical heat pumps and air conditioners, market-based tools that upgrade investment and business model innovation, enhancing the quality and accessibility of energy performance instruction and tools, development and accreditation of vocational training programs.

Industry: Promote market-based investment and business model innovation tools, increasing awareness and capacity through mechanisms such as industry networks, training and case studies, to ensure the collection and recycling of scrap metals with compulsory measures, strengthened and expanded standards for major industrial equipment (Including electrical heat pumps and motors), facilitate the adoption of energy management systems with appropriate incentives.

2.5. Towards %100 Renewable

Until recently, the concept of “100% Renewable Energy Systems” was mostly discussed in academic or intellectual settings. With the acceleration in technological developments and the acceleration in the renewable energy market (especially PV panels and wind turbine technologies), the concept of 100% Renewable has become tangible. Under the influence of successful practices around the world, policies and studies have been started to be carried out [29].

Production before the industrial revolution was carried out in narrower spaces. People lived a life based on agriculture by consuming what they produced. The main energy source of this period was wood. Later, coal was discovered and replaced wood in the early 1900s. However, the leadership of coal did not last long and after the second half of the twentieth century oil became the main energy source [29].

The relationship between fossil fuels and global warming has been discussed for many years. In the early nineteenth century, Joseph Fourier discovered the greenhouse gas effect. At the end of the same century, Svante Arrhenius argued that the $CO2$ produced by the combustion of fossil fuels was large enough to cause global warming [30].

The concept of renewable cities began to be discussed in the 1990s and gained great momentum in the 21st century. Among the reasons behind this rapid transformation are radical energy efficiency efforts, investments in renewable energy, and especially fast-growing solar power systems that can easily be installed in roofs and adapt to cities [31].

Looking at the cities/countries that have advanced in the transition to renewable energy, it is seen that the basis of this effort is related to socio-economic development. 67% of global energy consumption occurs in cities and that is the source of 70% of greenhouse gas emissions. And this value is expected to rise to 75% by 2030, when the global urbanization rate will reach two-thirds [32].

The following figure shows the steps from the smallest unit to the largest in the transition to 100% renewable energy using renewable resources and materials. The unit that we call single-user here can be a residential or commercial building that tries to generate its own energy along with the existing distributed generation. The multiple-user-community is a group of users who create a so-called microgrid or energy station to meet their own energy needs [29].

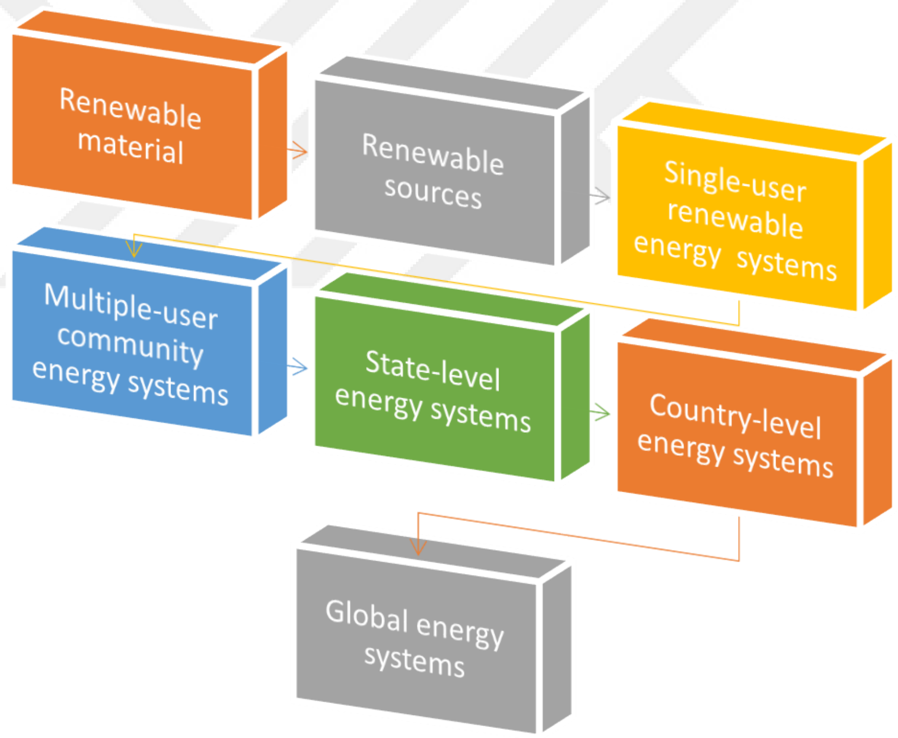


Figure 6. Multiple scales in 100% renewable energy research *[29]*.

As the aim of this study, some examples from cities that work/plans for the transition to renewable energy are given below:

Stockholm: The city plans to move to 100% renewable energy by 2030. The process started with the first group of buses operating with ethanol in 1996 and ended with the retirement of the last diesel-operated bus in Stockholm in 2018. Since then, all public transport systems have been operated with renewable energy. Continuing its efforts to achieve the 2030 target, Stockholm plans to make its historic boats, which are used in public transportation, work with renewable energy [33].

Barcelona: Planning to switch to 100% renewable energy by 2050, the city plans to reduce energy demand by 10% with energy efficiency and effective use of energy by 2020 in the first phase. The plan, considering the needs of the residents, also plans to generate renewable energy using the roofs of the citizens [32].

Frankfurt: The first city to create a 100% renewable energy roadmap from Germany, which has important work on the transition to renewable energy. By saving 50% energy, it plans to produce half of the remaining 50% of the energy it needs from the city center and the other half from the region with renewable resources. Necessary feasibility studies were carried out before the creation of this road map, all needs were simulated on a sectoral basis, and many scenarios such as population growth, demand and price increase were calculated and possible scenarios were created. The plan, which aims to switch to 100% renewable energy in 2050, includes solar, biomass and a limited amount of wind energy. But the biggest goal of this plan is a giant heating plan, which also extends the existing regional heating network [32].

Malmö: The efforts of 5 different groups established by the municipality in 2007 to create sustainable energy solutions have formed the city's energy strategy plan in 2009. Efficient use of energy, smart waste management, strengthening public transport, bicycle paths and smart grids are some of steps to save 50% energy. It is planned to meet the remaining energy need by generating renewable energy from the city. Malmö, which has the potential to benefit from many sources such as solar, wind, biogas and hydro energy, plans to diversify these resources to secure the future of energy and to reach 100% renewable energy target by 2050 [32].

2.6. Case City: Çanakkale

Çanakkale is a province that is located at northwest of Turkey and the southern part of Marmara region. Çanakkale province positioned in between two continents, Europe and Asia, like İstanbul and Çanakkale Strait exists in between the part of province. As geographically, Çanakkale province located in between 25° 40′ - 27° 30′ east longitude and 39° 27′ - 40° 45′ north latitude [34]. Çanakkale has coastlines with Aegean and Marmara seas and borders with Balıkesir, Edirne and Tekirdağ provinces. Total coastline length of Çanakkale is about 671 km long and it is one of the six provinces of Turkey which has a coastline on two seas [34].

Çanakkale province has 9.817 km² surface area with population of 519.793 that means the population density of Çanakkale is 52 people per km² according to 2016 population data [35]. Çanakkale has 12 districts which are named as Ayvacık, Bayramiç, Biga, Bozcaada, Çan, Çanakkale, Eceabat, Ezine, Gelibolu, Gökçeada, Lapseki and Yenice. There are also 574 villages and 11 towns exist in Çanakkale province [35]. 211.652 people live in these towns and villages, in other words urbanization rate of Çanakkale is about 59.28% in 2016 [35]. It is expecting that Çanakkale will reach at least 836.290 people in 2040 [35].

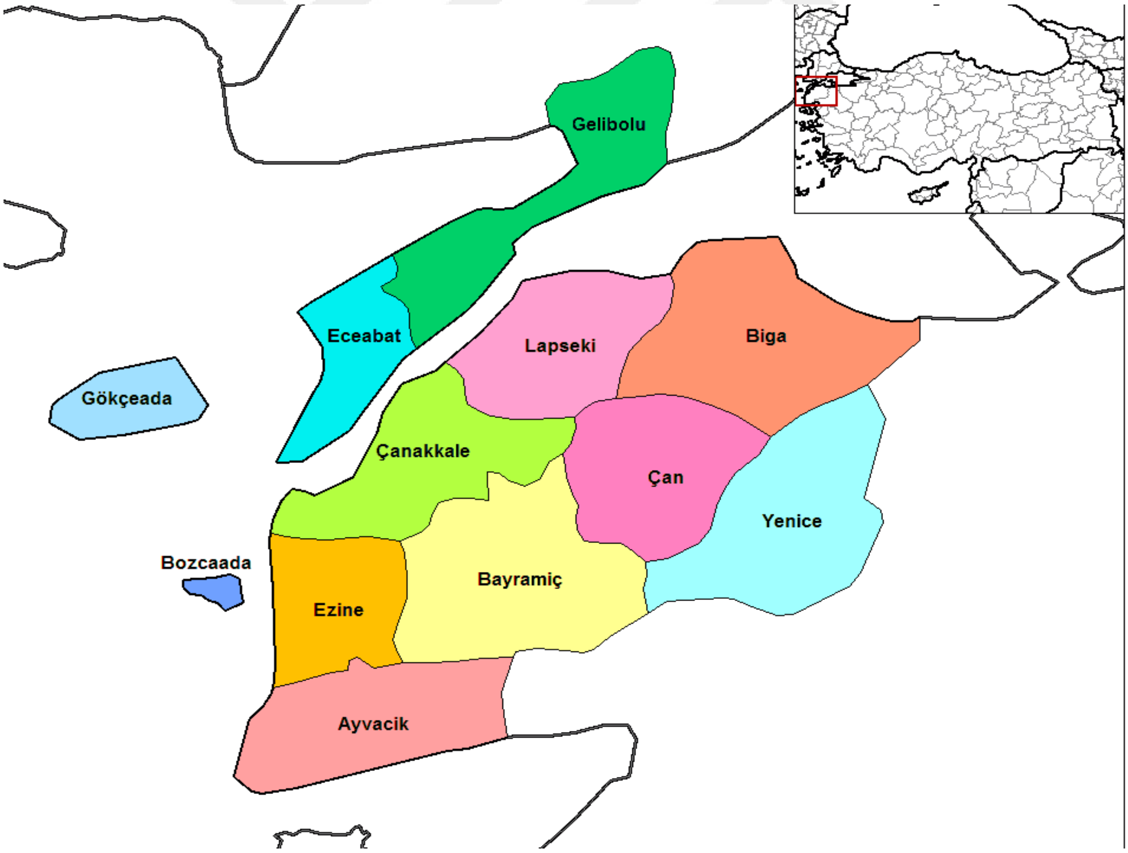


Figure 7. Çanakkale Province’s Position in Turkey Map and It’s Districts *[36]*.

Çanakkale has also very advantageous position thanks to its own geographical position. It is very close the most industrialized cities, hubs and metropolitans of Turkey and more than 26 million people lives in at a distance of up to 400 kilometers [34] [35]. Çanakkale has also two airports for air transportation and five commercial sea-ports that provides the connection of Çanakkale to the world [35].

Çanakkale has high renewable energy potential for researchers with its own natural energy sources such as wind, solar and biomass energy [35]. Çanakkale's convenient geographic position and agricultural activities in the province provide required conditions to implement renewable energy within higher percentage than other provinces.

Specifications of Çanakkale province mostly satisfy required minimum needs which are 7 m/s wind speed and 35% capacity factor at 50 meters to implement wind power stations. Wind energy potential of a region changes with wind velocity and continuity of wind. Wind energy potential of Çanakkale has a determined maximum capacity that is about 13.012,56 MW with 2.602 km² total determined area to implement wind power stations [35]. Total installed wind power stations in Çanakkale represented about 5% of Turkey total in 2016 and these were provided 316.5 MW energy [35]. Wind energy potential maps of Çanakkale is shown in the below at Figure 9 and Figure 10.

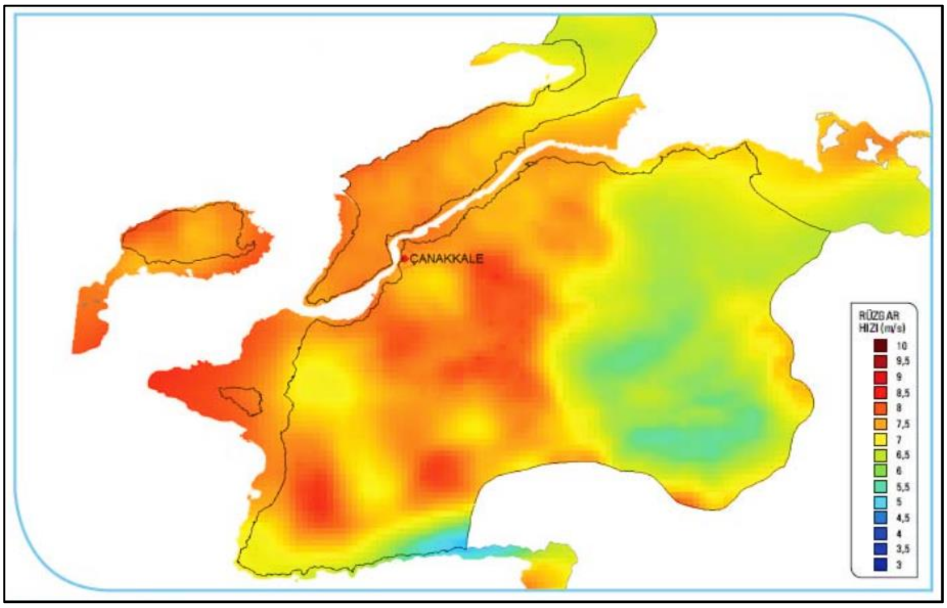


Figure 8. Wind Velocity Potential Map of Çanakkale Province *[37]*.

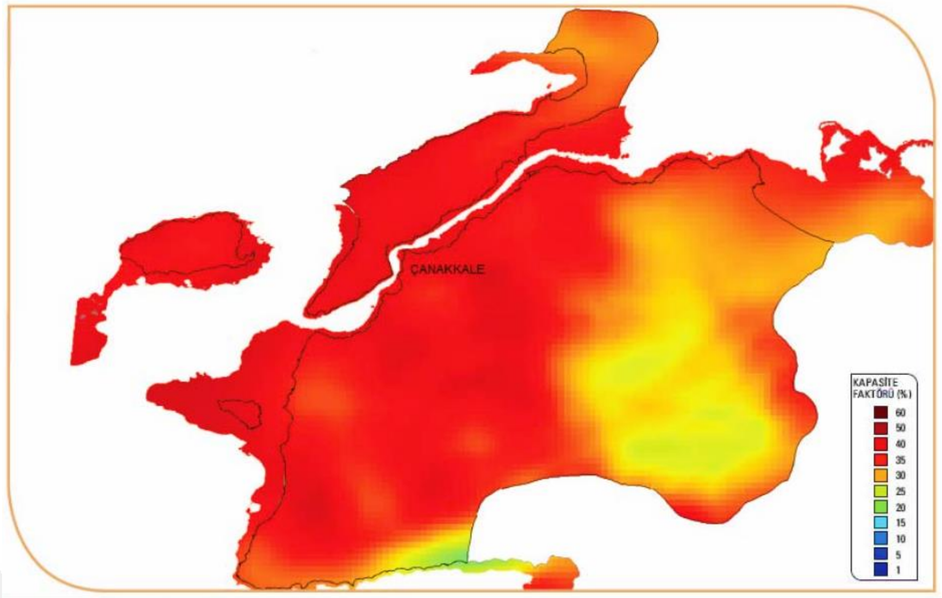


Figure 9. Wind Capacity Factor Potential Map of Çanakkale Province *[37]*.

Energy production from biomass is another renewable and climate-friendly energy production method. Biomass can be defined as organic material masses of non-fossil biologic organisms. Çanakkale region offers good potential for energy production from biomass with its amount of animal and organic waste. It is registered that there are 922.330 sheep and cattle population live in Çanakkale region in 2017 [34]. Total produced animal waste from these animals were about 2.951.537,06 ton per year that corresponded potentially to 25.489,29-ton energy produced from petroleum sources per year [35]. Vegetal waste amount of the region was about 2.993.976,10 ton per year in 2017 that corresponded potentially 331.645,43 ton energy produced from petroleum sources per year [35]. Biomass energy potential maps of Çanakkale is shown in the below at Figure 10.

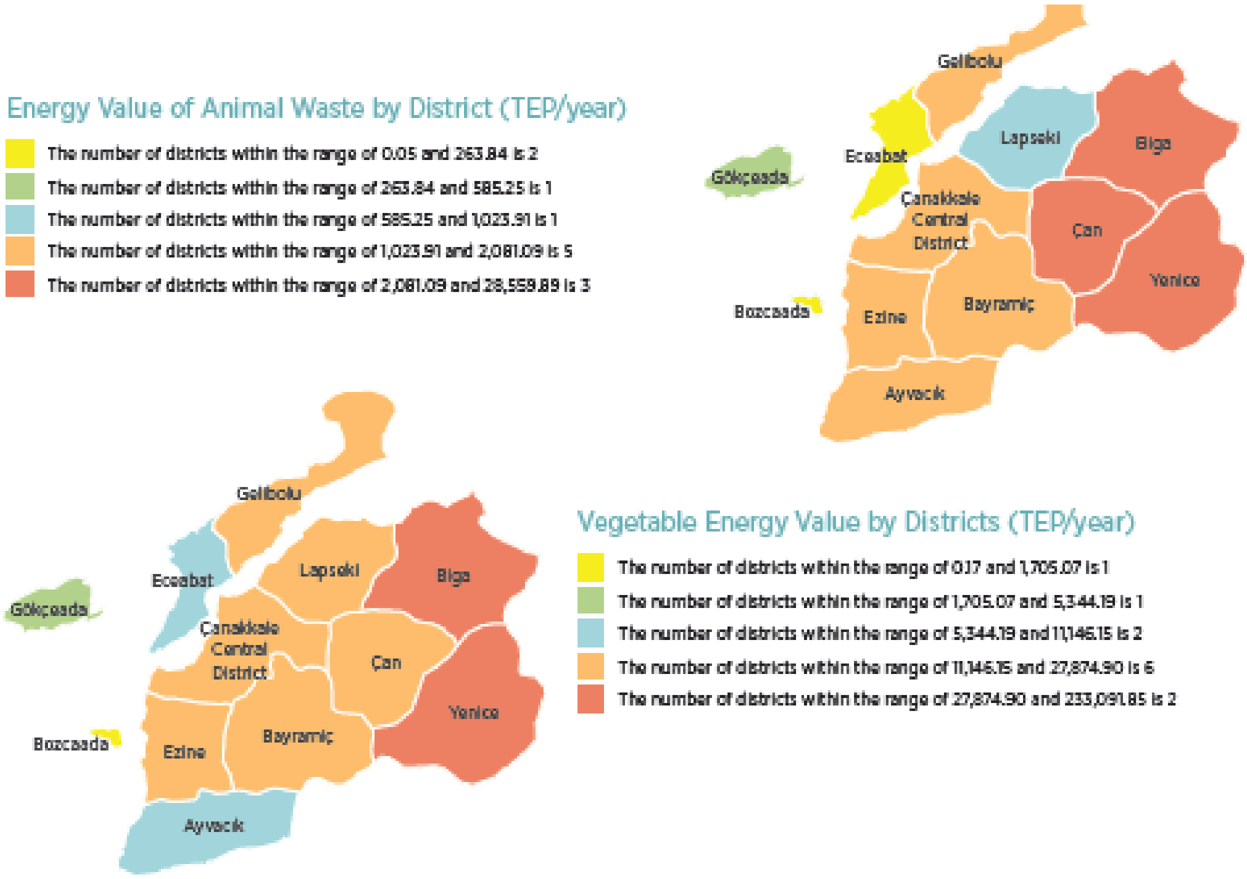


Figure 10. Biomass Potential of Çanakkale Province *[35]*.

Average sunshine duration per year determines the solar energy potential of any area. Çanakkale region has averagely 1400 KWh/m² annual solar radiation according to solar energy potential atlas in below Figure 12. In addition to sunshine duration, another important factor to establish a solar power plant is condition of territory. It is prohibited to set up solar power plants over the agricultural territories in Turkey. So that, Çanakkale province has about 1.044,4 km² area (10,5% of overall area) that is convenient to implement solar power plants on it [34]. Çanakkale province is highly forested and agricultural territory and has about over 86,3% area covered with forests or separated for farming [34]. Despite of limited conditions for solar energy, Çanakkale offers good potential for solar power plant establishments.

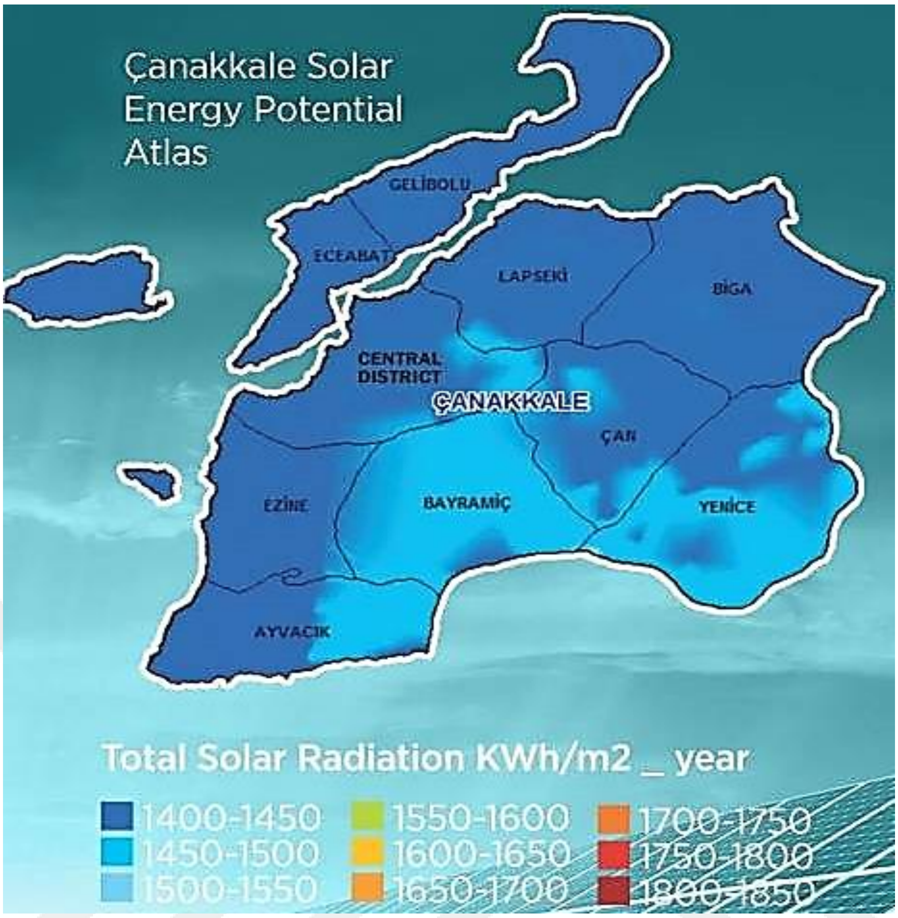


Figure 11. Solar Energy Potential of Çanakkale Province *[35]*

As a result, Çanakkale province offers high energy production potential from renewable resources. This potential of Çanakkale makes it worth for evaluating and researching. It is also assuming that Çanakkale can easily reach 100% renewable energy target thanks to huge renewable energy production potential of Çanakkale province. This research will examine the current energy production status of the region and create models about Çanakkale's 100% renewable energy target with alternative scenarios.

2.7. Energy Modelling Tools

Energy modeling studies are carried out in order to determine the future energy demand and supply of a country or region. They are often used in an exploratory manner by addressing conditions such as population growth, energy prices and the development of economic activities in the world markets, along with many other factors. They can also simulate policy and technology choices that could affect future energy demand, energy efficiency policies and even energy investments. Modern macroeconomic energy modeling, which originated in the late 1950s, has emerged as energy suppliers and managers need to make decisions about future demands. More detailed techno-economic models emerged in the early 1970s, especially after the 1973 oil crisis [38].

There are many modeling tools in the market in terms of the features it offers according to the intended use. The table below shows the capabilities of some of them.

Some of these tools are paid for and some are offered to users for free. When the most preferred vehicles in the table are listed, the first three are RETScreen, HOMER and LEAP respectively (by number of downloads or purchases) [39].

Table 8. Types of some modeling tools *[39]*.

Tool	Type						
	Scenario	Simulation	Equilibrium	Top-down	Bottom-up	Operation optimization	Investment optimization
MARKAL/TIMES	Yes	-	Yes	Partly	Yes	-	Yes
LEAP	Yes	Yes	-	Yes	Yes	-	-
EnergyPLAN	Yes	Yes	-	-	Yes	Yes	Yes
RETScreen	Yes	-	-	-	Yes	-	Yes
HOMER	-	Yes	-	-	Yes	Yes	Yes
energyPRO	Yes	Yes	-	-	-	Yes	Yes
IKARUS	Yes	-	-	-	Yes	-	Yes
AEOLIUS	-	Yes	-	-	Yes	-	-
BALMOREL	Yes	Yes	Partial	-	Yes	Yes	Yes
BCHP Screening Tool	-	Yes	-	-	Yes	Yes	-
COMPOSE	-	-	-	-	Yes	Yes	Yes
E4cast	Yes	-	Yes	-	Yes	-	Yes
EMCAS	Yes	Yes	-	-	Yes	-	Yes
EMINENT	Yes	-	-	-	Yes	-	-
EMPS	-	-	-	-	Yes	Yes	-
ENPEP-BALANCE	Yes	-	Yes	Yes	-	-	-
GTMax	-	Yes	-	-	-	Yes	-
H2RES	Yes	Yes	-	-	Yes	Yes	-
HYDROGEMS	Yes	-	-	-	-	-	-
INFORSE	Yes	-	-	-	-	-	-
Invert	Yes	Yes	-	-	Yes	-	Yes
Mesap PlaNet	Yes	-	-	-	Yes	-	-
MESSAGE	Yes	-	Partial	-	Yes	Yes	Yes
MiniCAM	Yes	Yes	Partial	Yes	Yes	-	-
NEMS	Yes	-	Yes	-	-	-	
ORCED	Yes	Yes	Yes		Yes	Yes	Yes
PERSEUS	Yes	-	Yes	-	Yes	-	Yes
PRIMES	-	-	Yes	-	-	-	-
ProdRisk	-	Yes	-	-	-	Yes	Yes
RAMSES	-	Yes	-	-	Yes	Yes	-
TRNSYS16	Yes	Yes	-	-	Yes	Yes	Yes
UniSyD3.0	Yes	-	Yes	-	Yes	-	-

3. METHODOLOGY

3.1. Answer-Times Energy Modelling

Answer-TIMES is an energy system modeling program that aims to produce economic model for different size of energy systems by providing a technology-rich basis for demonstrating energy dynamics in a given time-period. The size of modelled energy systems with Answer-TIMES can be any size from local to global. Answer-TIMES can be used for either analyzing whole energy system or single energy line. In basically, user of Answer-TIMES is obligated to provide estimates of existing stocks of energy, end-user energy demands, and current energy sources with future potential energy sources and technologies to run a reference scenario [40].

MARKAL that name was based on a market allocation modeling and EFOM are two energy model tools. These tools were created a base for TIMES and provide the name with abbreviation of The Integrated MARKAL-EFOM System [40]. Answer-TIMES is a mouse-driven, visual-based and interactive Windows operating system interface for TIMES energy system models. It is developed for increasing the intelligibility and availability of any TIMES energy model [41].

Energy system modeling with Answer-TIMES has a complex mechanism. Collected data is entered by researcher using with the Answer-TIMES interface into the TIMES model generator program. Modeling is optimized and resolved by GAMS and other solvers in TIMES to create convenient solutions for different scenarios that are determined beforehand by researcher. In last, convenient solutions and feasibility of scenario are shown over Answer-TIMES interface for end-user evaluation. Figure 13 illustrates basically the complex mechanism in behind Answer-TIMES and TIMES energy model.

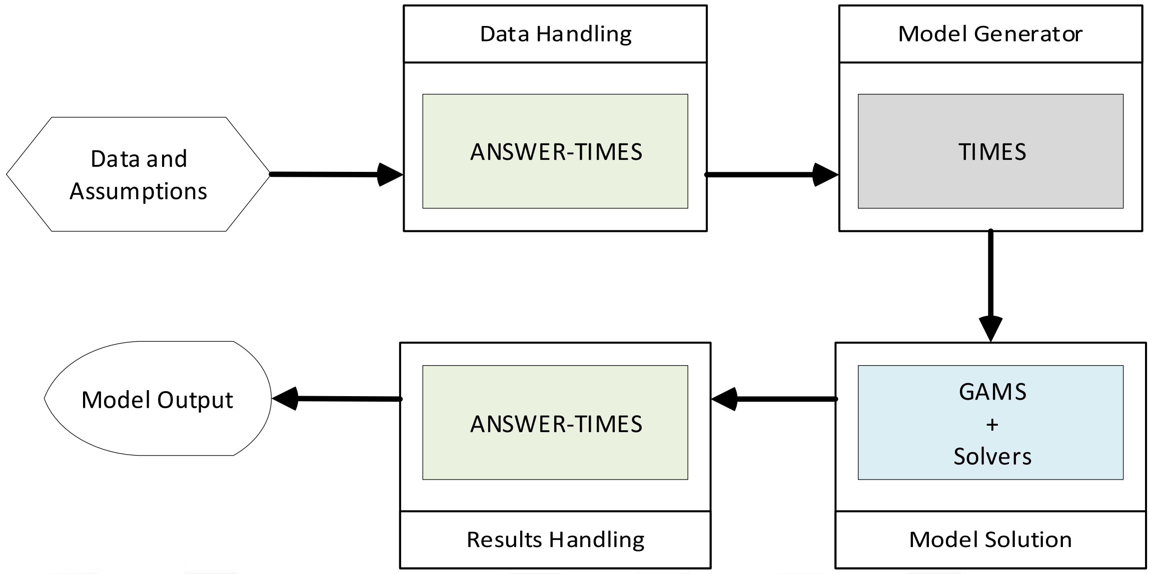


Figure 12. Mechanism of Answer-TIMES with TIMES Energy Model.

TIMES energy modeling needs four different types of input which are required to complete any scenario. These are energy demand, energy supply resources, current policy situation and illustration of all energy technologies [40]. TIMES model and Answer-TIMES interface provide advanced analysis structure of capacity, costs, technical and environmental parameters with constraint effects of regulations, policies or subsidies to researchers. In addition to the many other additional benefits, Answer-TIMES and TIMES modeling has been selected appropriate tool for this research.

3.1.1. Reference energy system (RES)

TIMES energy modeling includes three types of assets which are technologies, commodities and commodity flows. Technologies include vehicles, devices or plants which convert commodities to another kind of commodities. Technologies can be named as processes in other word. Commodities include materials, energy services and providers, energy carriers, emissions and monetary flows. Commodity flows represent the links between technologies and commodities. Relationships in between technologies, commodities and commodity flows show in a network diagram that is named as Reference Energy System (RES) [40].

RES includes 6 main columns to indicate the network. The first column indicates the resources that will be used in the model. Primary energy carriers are shown in second column, next to resources. Process conversion technologies and final energy carriers are other two columns in the network. End-user demand technologies and all kind of demands are shown in the last two columns. Figure 13 Illustrates the reference energy system columns basically.

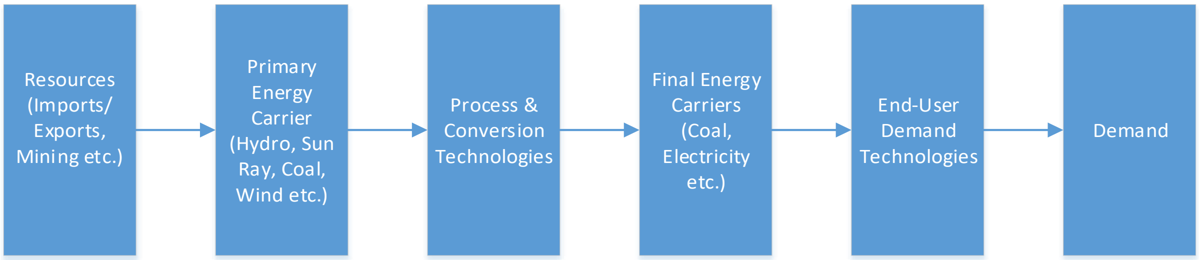


Figure 13. Reference Energy System Columns.

The first column includes the resources that are produced in, imported or exported to the selected region. These resources are using into commodities that are named as Primary Energy Carrier in second column. The third column indicates the technologies that are using to convert or process resources from primary energy carriers to final energy carriers. Fourth column includes the processed/converted energy carriers such as electricity. Fifth column of RES indicates the technologies that are currently using by the end-users in the selected region and creates the demand for energy. And the last, sixth column includes demands that are demanded by end-user demand technologies column.

3.1.2. Objective function and mathematical background

In TIMES modeling, the surplus maximization target is converted to an equivalent cost minimization target, taking the excess negatively. So that, TIMES aims to minimize total cost of the system. All cost elements are discounted according to a year chosen by the user. Special attention is paid to fully monitor cash flows related to process investments and disassembly during each year of the period in TIMES. There will occur an objective function of TIMES as a result of considerations mentioned above. Objective function starts with the calculation of net present value of system in selected region. So that the first equation consists as in below [40]:

$$NPV = \sum_{r=1}^{R} \sum_{YEARS} \left(1 + d_{r,y}\right)^{REFYR-y} xANNCOST(r,y) \quad (1)$$

In this equation:

- **NPV:** Objective function that shows net present value of the system for every defined region of TIMES.
- **R:** Set of regions in research
- **YEARS:** Set of all years in time period with past years that are before the initial period.
- **REFYR:** Indicates the reference year to start discounting.
- **dr,y:** Indicates general discount rate.
- **ANNCOST (r,y):** Indicates the total annual cost, region "r" and year "y".

The objective function in TIMES is the sum of all regional objectives which are discounted to the same chosen base year. So, for this summation, second equation of TIMES objective function occurs [42]:

$$VAR\_OBJ_{(z)} = \sum_{r \in REG} REG\_OBJ(z,r) \quad (2)$$

REG_OBJ(z,r) indicates regional objective and includes sum of nine elements with the subtraction of one element. At last, salvage value is subtracted from all other variables to find out regional objective result. It represented in equation in below [42]:

$$REG\_OBJ_{(z,r)} = \sum_{y \in (-\infty,+\infty)} DISC\ (y,z) x \{\mathrm{INVCOST(y)} + \mathrm{INVTAXSUB(y)} + \mathrm{INVDECOM(y)} + \mathrm{FIXCOST(y)} + \mathrm{FIXTAXSUB(y)} + \mathrm{SURVCOST(y)} + \mathrm{VARCOST(y)} + \mathrm{VARTAXSUB(y)} + \mathrm{ELASTCOST(y)} - \mathrm{LATEREVENUES(y)}\} - \mathrm{SALVAGE(z)} \quad (3)$$

Variables in equation 3 is explained in below [42]:

- **INVCOST(y):** Indicates the investment costs, which occur right after the investment decision and/or construction period.
- **INVTAXSUB(y):** Indicates taxes and subsidies which are occur at the same time with the investment.
- **INVDECOM(y):** Decommissioning cost of the facilities.

- **FIXCOST(y), SURVCOST(y):** FIXCOST(y) indicates fixed annual costs which occurs each unit of capacity is still operating. SURVCOST(y) is a cost that occurred for surveillance of the facility before its demolition.
- **FIXTAXSUB(y):** Indicates annual fixed tax/subsidy cost which are paid or accrued at the same period as the fixed annual costs.
- **VARCOST(y):** Indicates variable costs are that changes by the output.
- **ELASTCOST(y):** It represents cost of demand reductions.
- **VARTAXSUB(y):** It represents the variable annual taxes or subsidies.
- **SALVAGE(z):** Indicates the salvage costs that occur when the facility exceeds its technical lifetime.
- **LATEREVENUE(y):** Indicates the late revenues which only obtained with resale of materials and/or energy at decommissioning time.

3.2. Çanakkale TIMES Model Development

For the energy modeling study of Çanakkale, firstly, the energy modeling studies carried out at the city scale were examined and preliminary information was obtained. Then, the reference energy system (RES) of Çanakkale was established and the required data were determined. Since the accuracy and diversity of these data will increase the sensitivity of the results obtained from the model, the data has been carefully collected. In this direction, Çanakkale was visited and various non-governmental organizations, private sector organizations and governmental institutions were visited. Some of these organizations are: Çanakkale Special Provincial Administration, South Marmara Development Agency, Provincial Directorate of Agriculture and Livestock, Çanakkale Chamber of Industry and Commerce, Çanakkale Municipality, Uludağ Electricity Distribution Company (UEDAŞ) and so on. The collected data was classified into excel tables after a long period of time, and then entered into the Çanakkale TIMES model. In the model, after obtaining optimal results for the base scenario, alternative scenarios were created. With these alternative scenarios, many scenarios have been created for Çanakkale, including the transition to 100% renewable energy. Most of these scenarios were developed based on Turkey's energy policy. Reference energy system of Çanakkale province is shown in Figure 14.

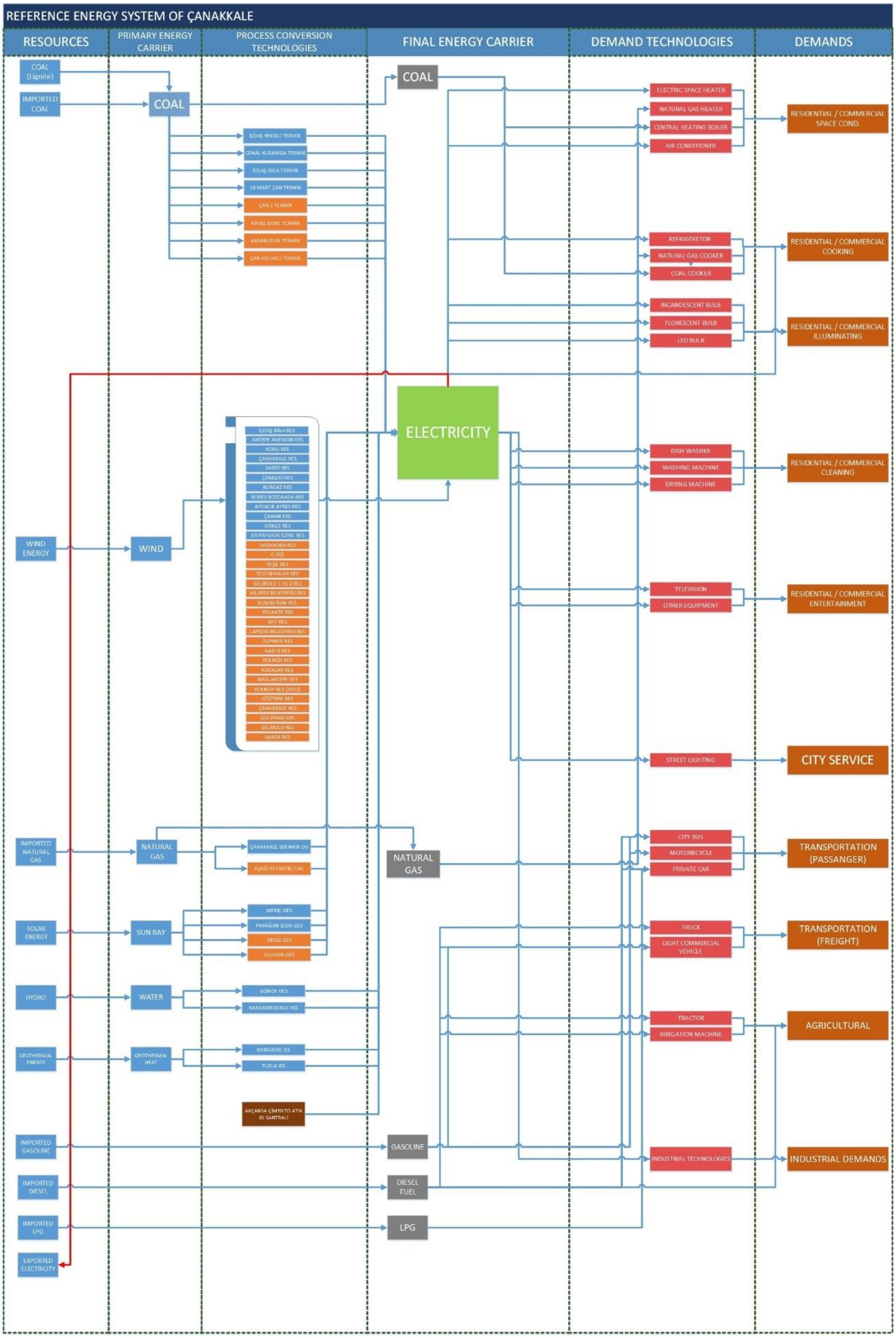


Figure 14. Reference Energy System of Çanakkale Province.

3.3. Base Scenario

The base scenario is based on 2016 data. In this scenario, the energy outlook by 2030 is seen only if the current situation continues. The annual energy consumption increase was accepted as 4%.

3.4. Alternative Scenarios

In addition to the base scenario, 5 different scenarios were created for different purposes. Different perspectives were created with these scenarios and alternative results regarding the energy future of Çanakkale province were examined. In addition, a 100% renewable energy scenario has been created for the transition to 100% renewable energy in cities, which is one of the main objectives of this thesis.

3.4.1. Vision 2023 scenario

This scenario is based on the energy action plan of Turkey (2023) study. According to this study, it is planned to double the renewable energy installed capacity by 2023 and to reduce the primary energy consumption by 14%. In this respect, Çanakkale which has an installed capacity of 308MW of renewable energy, has been doubled by adding another 308MW of renewable power plant. In addition, energy consumption was reduced by 14% in all demands. Among the renewable energy sources in Çanakkale, wind has been selected for the new power plants since wind energy has the highest potential among the other renewable sources.

3.4.2. Scenario of shut down lignite power plants

In this scenario, it is planned to shut down two lignite coal power plants with a total installed capacity of 550 MW until 2030. Furthermore, lignite plants with high CO_2 emissions are among the first preferred plants in the world in terms of closure. It will be seen how much emission reduction will occur after the closure with the emission values we have defined for these two plants.

3.4.3. 20% more efficient technologies scenario in residential

Worldwide, approximately 30% of total electricity is consumed in residentials. Although this rate is much lower in Çanakkale, an energy efficiency of 20% in an area with such a large energy consumption will provide a significant decrease in cumulative consumption. In this scenario where the importance of end-use energy efficiency in residentials is sought, as a result of replacing all electrical technologies used in residential with 20% more efficient technologies the effects of changes in general consumption will be analyzed.

3.4.4. 200 MW storage scenario

In today's world where there is an uninterrupted demand for energy, the importance of storage is increasing day by day. As the share of renewable energy in the total energy production increases, this need increases. Although storage costs are decreasing day by day, they have not reached the desired levels yet. In this scenario, taking into consideration the high costs, the cost of establishing a 200MW storage system for Çanakkale will be examined. The cost of the Li-ion battery selected for installation is given in table 5.

3.4.5. 100% renewable scenario

The 100% renewable energy scenario is one of the main objectives of this study. In this scenario, by 2030, a city that meets all the energy it needs from 100% renewable sources is targeted. The potential of the province of Çanakkale, which is selected for this target, is quite diverse in terms of renewable energy, but the wind energy potential is quite high among them. To obtain more reasonable results, wind energy was chosen to meet the energy required by the city. Therefore, wind power plants were preferred in this scenario. While creating a city model that can fully benefit from renewable energy in 2030, it is foreseen that existing power plants will continue and export the energy they produce. Considering the high level of foreign dependence on energy, it is foreseen that the closure of existing power plants at a time will cause a huge cost and instead, the power plants that have completed their lifetime will be shut down over time.

4. RESULTS & DISCUSSIONS

4.1. Base Scenario Results

According to current energy production data, Çanakkale is a city that can meet its own energy needs and even export most of its production to other provinces. The base scenario continued until 2030 with the current production without any increase or decrease in the city's energy production. As shown in figure 15, the city which exports approximately 750 million dollars of electrical energy in 2016, the amount of exports decreases to 657 million dollars in 2030. Similarly, the exported electrical energy in terms of petajoules has decreased at the same rate. Since the growth rate was chosen as 4% annually, the increase in energy consumption was realized at this rate. As a result of this cumulative increase, the energy requirement by 2030 is much higher than in 2016. Since there was no capacity increase, the electrical energy exported by the city decreased by about 10 petajoule.

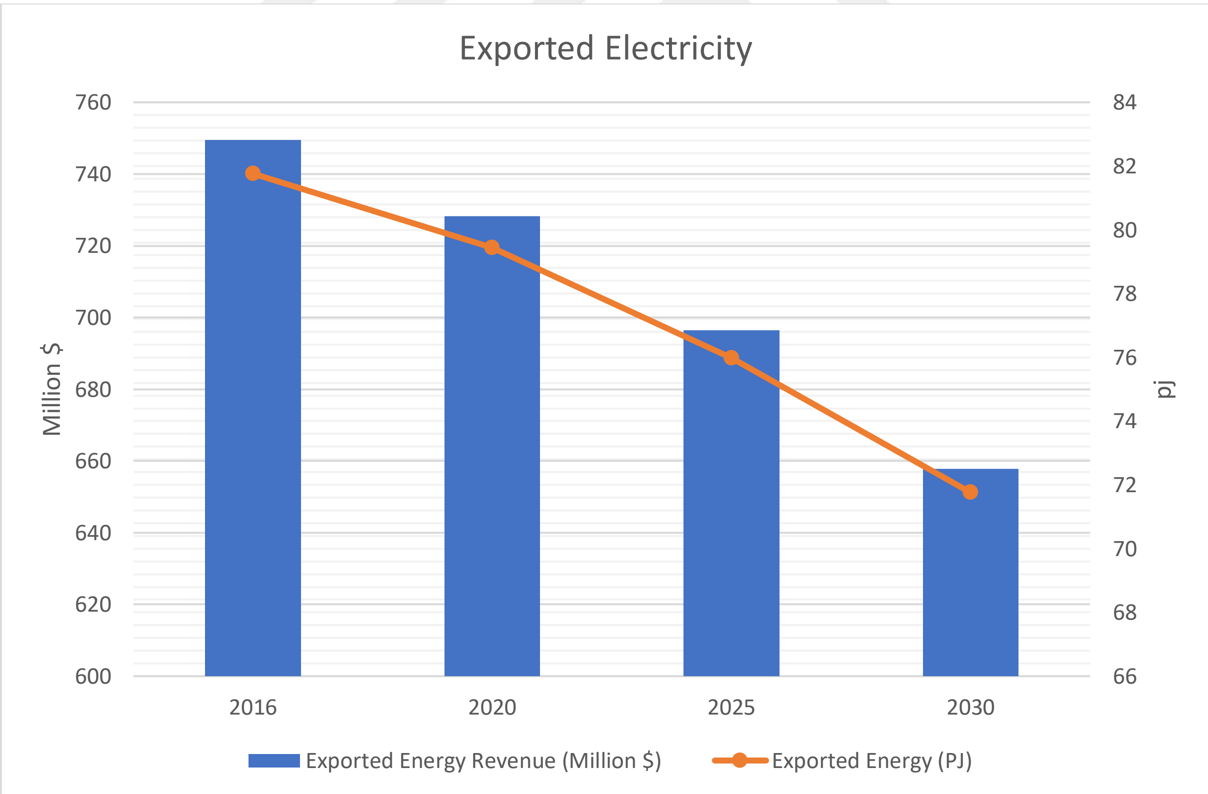


Figure 15. Base Scenario Exported Electricity Values.

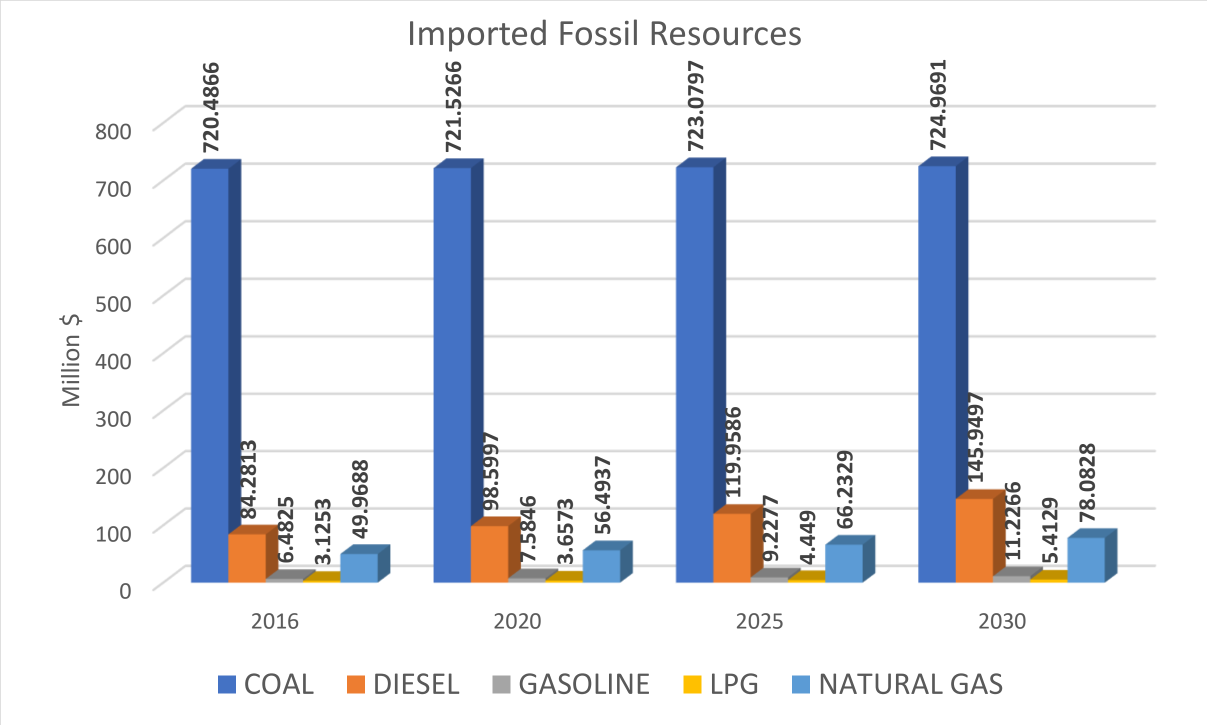


Figure 16. Base Scenario Imported Fossil Resources (Million $).

When Figure 16 and Figure 17 are considered together, it can be understood that the increase in imported fossil resources has increased the costs of these acquisitions over the years. However, it should be noted that while there is a slight increase in the purchase of coal proportionally, other fossil sources show a significant increase. The reason is, most of the coal consumption is takes place in the power plants but there is no increase in the operation of the power plants in our base scenario. However, other fossil fuels have increased by 4% annually.

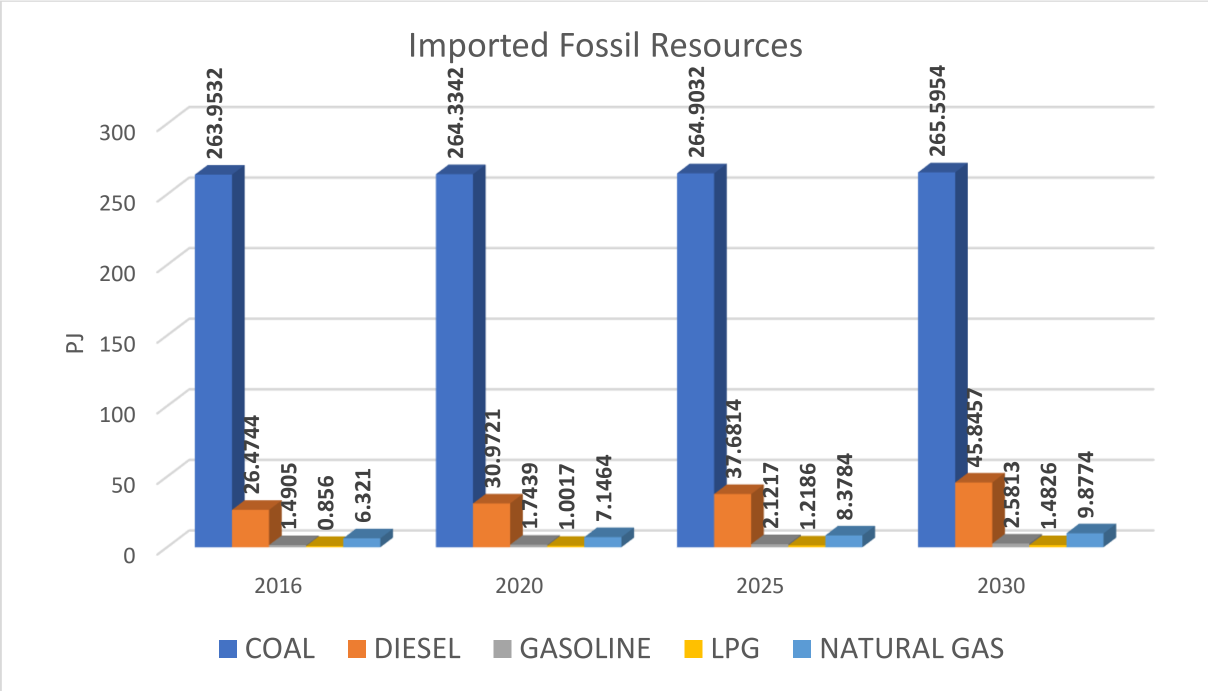


Figure 17. Base Scenario Imported Fossil Resources (PJ).

When the increase rates in demand in Figure 18 are examined, the reason for the increase in the import of fossil resources can be understood. For example, as a result of the doubling of the total transport demand seen in figure 18, it is seen that the gasoline, diesel and LPG import given in figure 17 has almost doubled too.

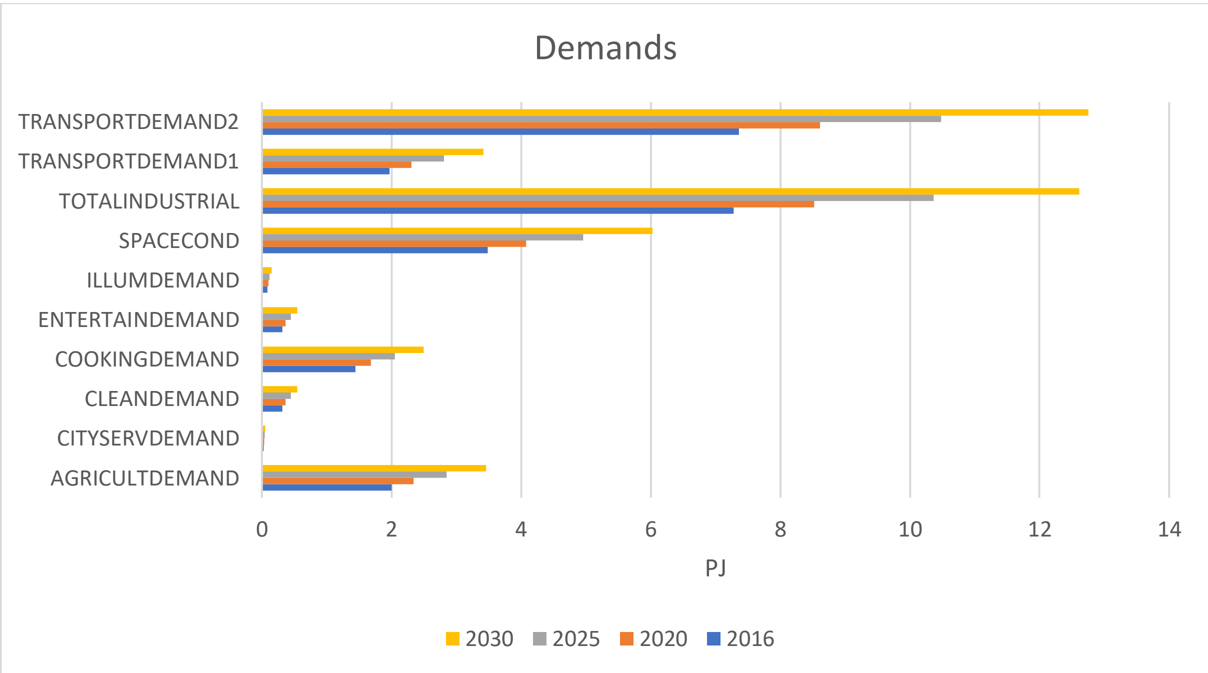


Figure 18. Base Scenario Demands (PJ).

4.2. Alternative Scenario Results

4.2.1. Vision 2023 scenario

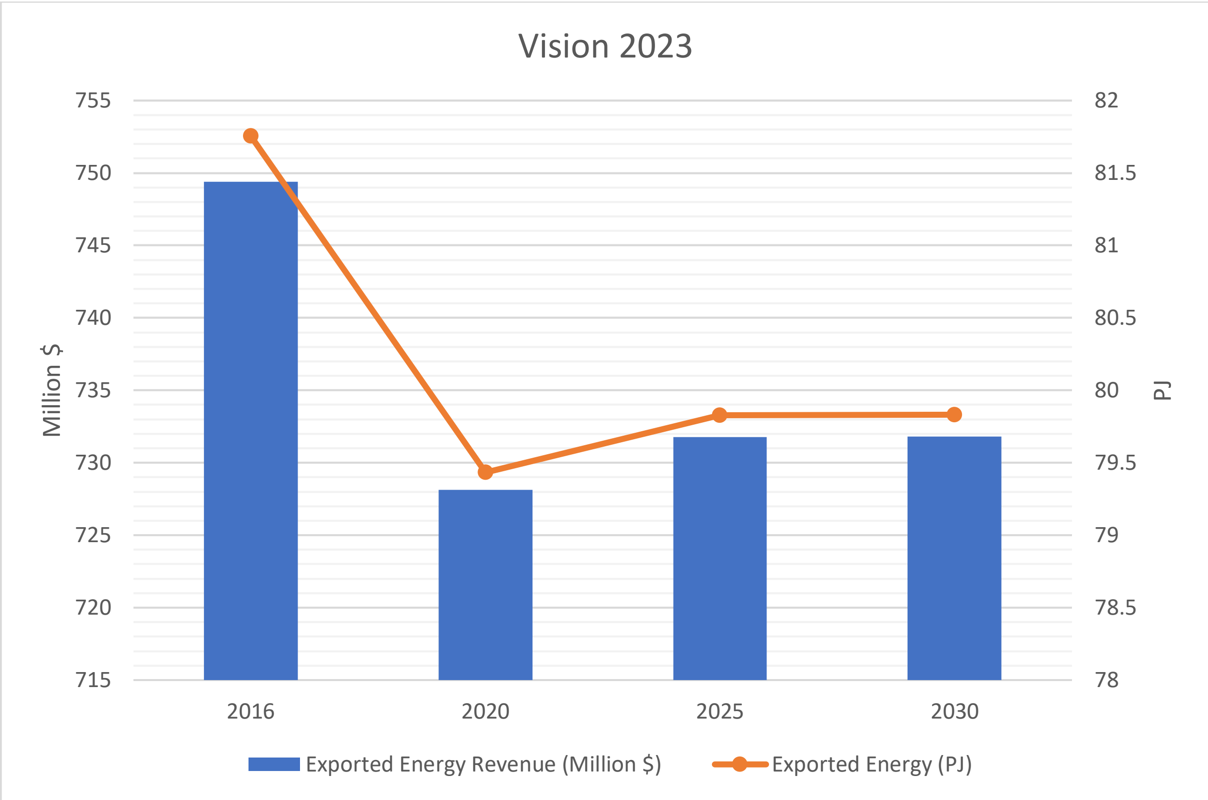


Figure 19. Vision 2023 Scenario Exported Electricity Values.

The energy export data resulting from this scenario, in which total primary energy consumption decreased by 14% and doubled the energy production capacity from existing renewable sources, is shown in figure 19. Compared to the base scenario, with the contributions of both energy efficiency and wind power plant with a total installed capacity of 308 MW added by 2030; the total exported electrical energy decreased slightly. (Compared to year 2016 level) This improvement and capacity increase from renewable energy is almost at the level of meeting the increase in the energy demand of Çanakkale from 2016 to 2030.

4.2.2. Scenario of shut down lignite power plants

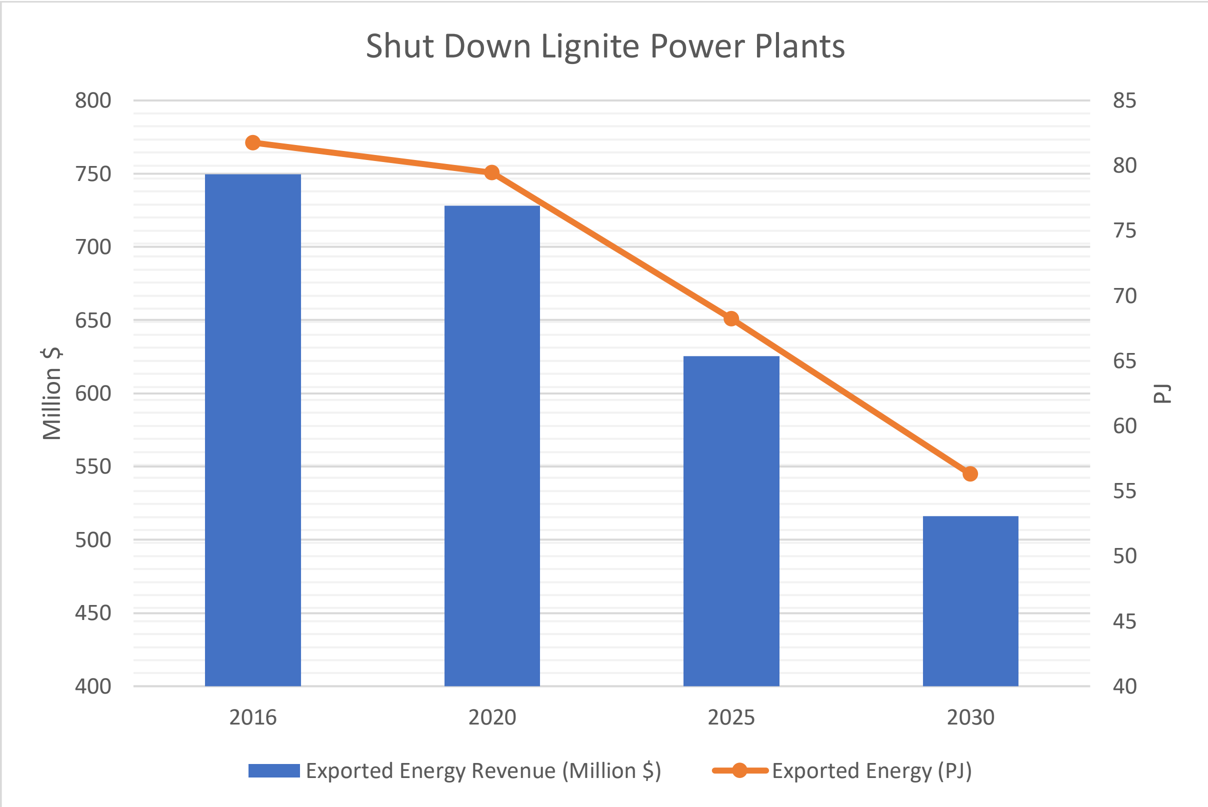


Figure 20. Shut Down Lignite Power Plants Scenario Exported Electricity Values.

Lignite coal plants, which are among the ones with the highest carbon emissions, are rapidly being shut down in developed countries or plans are being made to shut them down as soon as possible. Based on this reason, this scenario includes two lignite coal power plants with a total capacity of 550 MW in Çanakkale and plans to shut down by 2030. According to figure 20, compared to the base scenario, the amount of electricity exports in 2030 decreased considerably. Although this decline is economically bad, the emission data entered into the model for these two plants shows that when these plants are shut down, a total of approximately 1500,000 tons of CO_2 emissions will be reduced.

4.2.3. 20% more efficient technologies scenario in residential

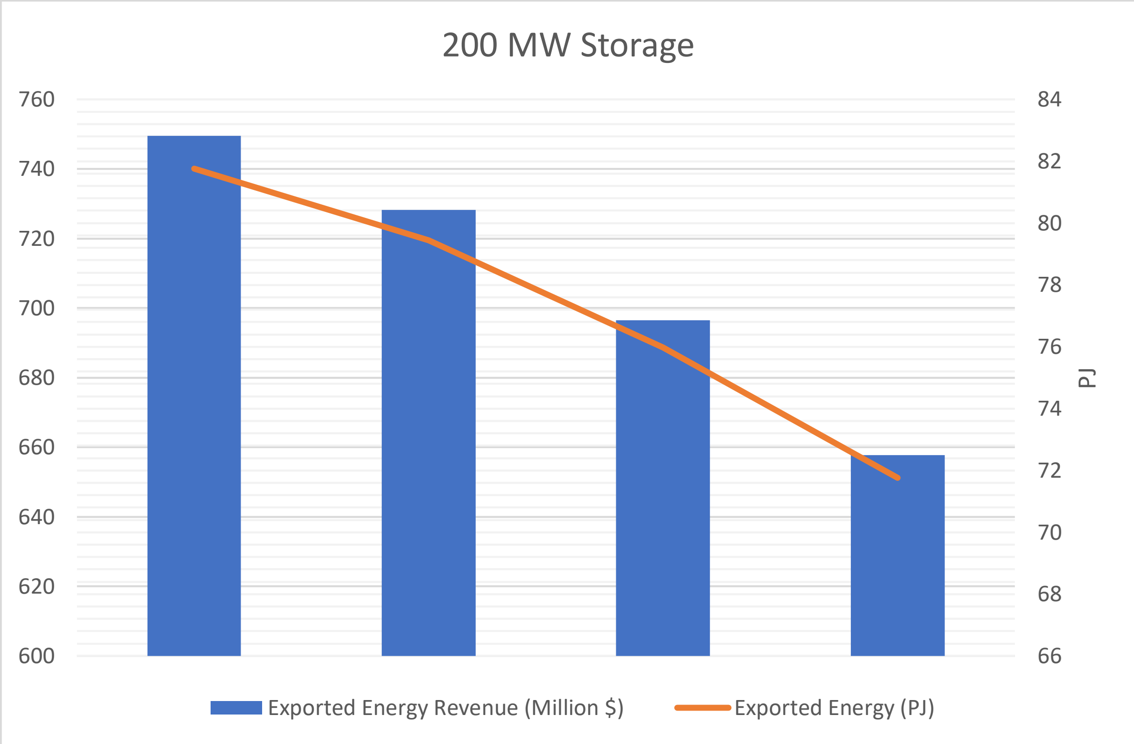
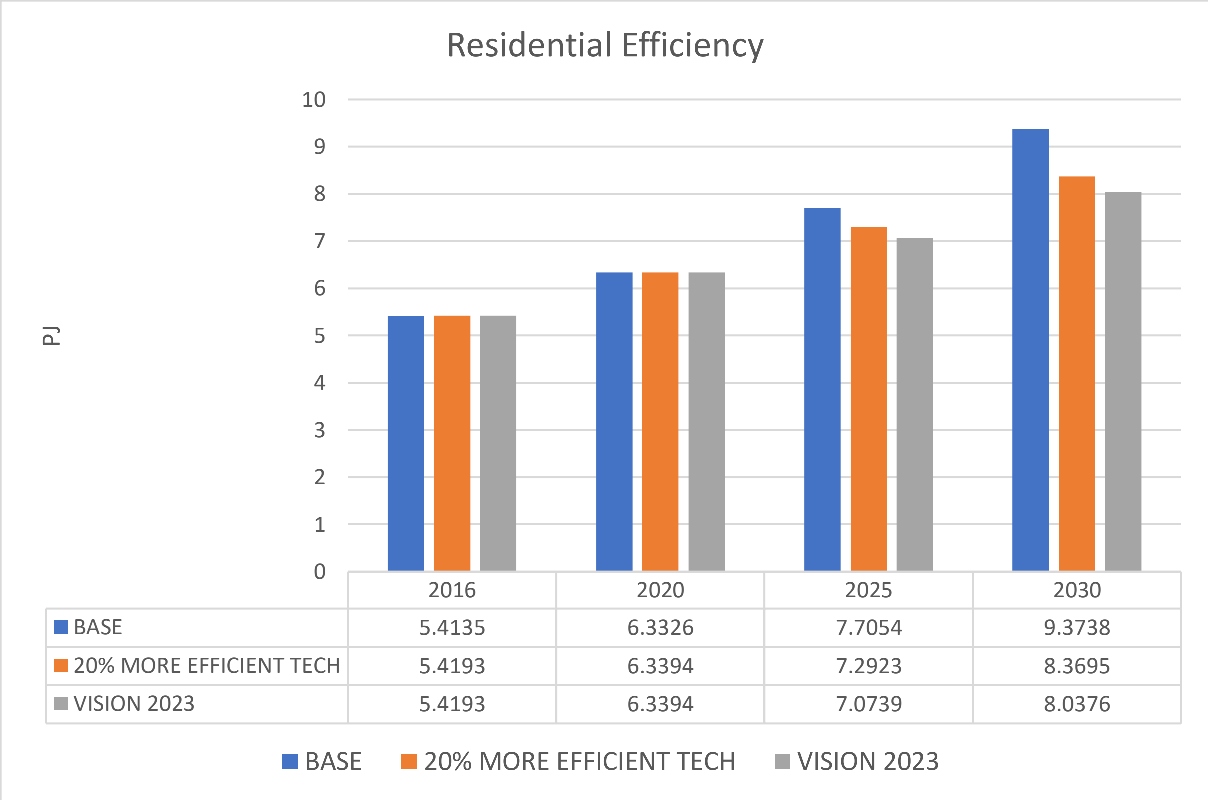


Figure 21. 20% More Efficient Technologies Scenario-Exported Electricity Values.

In this scenario, the aim is to make it possible to see what can be done through energy efficiency studies in houses whose share in total electricity consumption is increasing day by day. When the results in Figure 21 are compared with the other scenarios, the year 2030 is slightly better than the base scenario. Table 22 shows the comparison of residential energy demands with Vision 2023 scenario and base scenario. Table 22 shows the comparison of housing energy demands with Vision 2023 scenario and base scenario. As can be seen, compared to the base scenario, a saving of approximately 1 petajoule was achieved in residential energy consumption. However, the vision 2023 scenario seems to be a little more successful.



	2016	2020	2025	2030
BASE	5.4135	6.3326	7.7054	9.3738
20% MORE EFFICIENT TECH	5.4193	6.3394	7.2923	8.3695
VISION 2023	5.4193	6.3394	7.0739	8.0376

Figure 22. 20% More Efficient Technologies Scenario-Residential Energy Consumption.

4.2.4. 200MW storage scenario

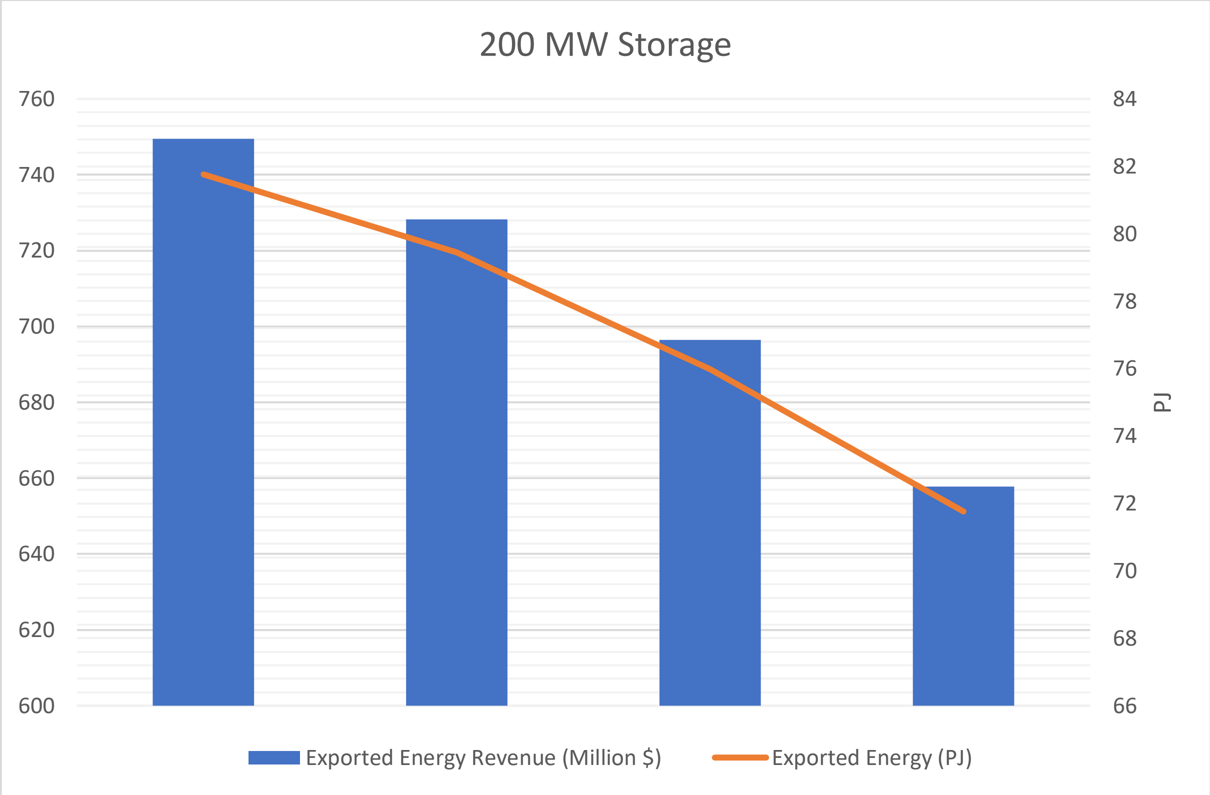


Figure 23. 200MW Storage Scenario Exported Electricity Values.

As can be seen in Figure 23, when Çanakkale has an electricity storage system with a capacity of 200 MW until 2030, this has no effect on energy consumption. The results are exactly the same as the base scenario. The storage system to be installed can be used as a precaution against interruption of renewable energy. The cost of a storage of this scale to the system is 307 million dollars. 300 million of this is the investment cost and 7 million is the cost of maintenance and repair.

4.2.5. 100% renewable scenario

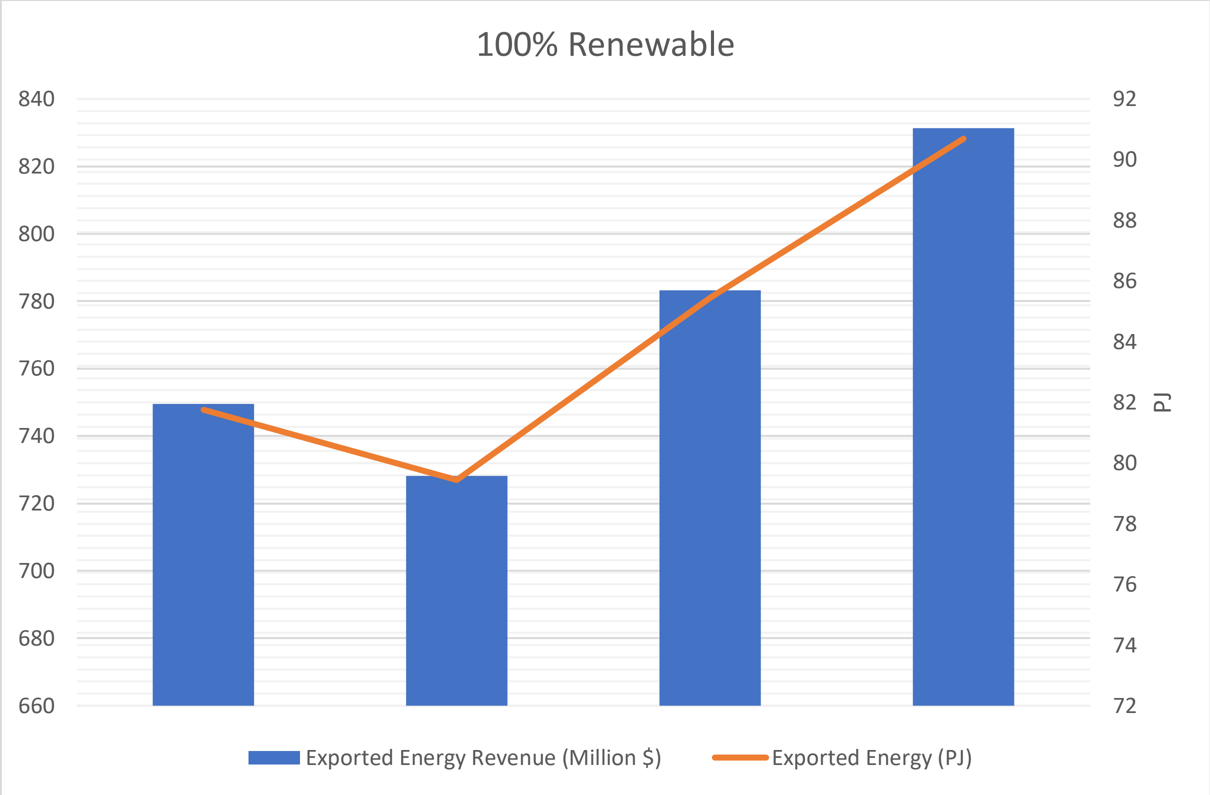


Figure 24. 100% Renewable Scenario Exported Electricity Values.

One of the main objectives of this study is transition of Çanakkale province to 100% renewable energy, the created scenario for this case shows that Çanakkale has the potential of transition to 100% renewable energy. Considering the high level of foreign dependence on energy, it is foreseen that the closure of existing power plants at a time will cause a huge cost and instead, the power plants that have completed their lifetime will be shut down over time. That's why the other power plants which uses fossil sources have not preferred to closure. This is why the amount of exported energy seen in figure 24 is so high compared to the base scenario. Canakkale is a province that exports most of the electricity it produces. In 2030, it needs a renewable installed capacity of approximately 19 petajouls for a 100% renewable energy target. The province of Çanakkale has rich geographical features in terms of renewable energy sources. Among these sources, wind energy has the highest potential. For this reason, it has been found appropriate to establish wind farms in a 100% renewable energy scenario.

5. CONCLUSION

The need for clean energy is increasing day by day and investments in renewable energy in our era are continuing rapidly. Even small-scale projects (It has been carried out) on transition to 100% renewable energy, and much larger projects that are planned to be achieve can be seen. This study addresses some of the steps that can be taken in this regard.

Firstly, the importance of smart grids in the integration of renewable energy to the grid is mentioned. Smart grid systems, which are still developing and do not have a common idea about their technologies, will have a greater importance for future smart cities and integration of renewable energy into the system.

As a solution to the problems that may arise in the continuity of renewable energy sources, storage systems are examined in detail under a separate title. The systems that can be stored on a large scale within the existing methods of storage are examined and a table is presented about the costs. Storage systems, which have been decreasing day by day, will gain more space in our living spaces with residential type storage in the very near future.

In addition, the problem of energy can be solved not only by producing but also by using more efficiently, it is explained under the title of end-use efficiency.

Finally, the TIMES Energy Model of Çanakkale was created with the Answer-TIMES energy modeling tool. In the base scenario, a perspective has been created for the changes that will take place until 2030 in the event that Çanakkale continues in the current situation. In addition, five different scenarios were created and examined separately. All scenarios and Base scenarios were implemented in the 2016-2030 time interval. As a result of the investigations made about each scenario, various predictions were obtained. For example, whether the transition of Çanakkale province to 100% renewable energy is possible is the goal of one of the scenarios. And the result of this scenario has shown us that this is possible. In Figure 25 and table 9 below, comparisons are made about the costs of these scenarios.

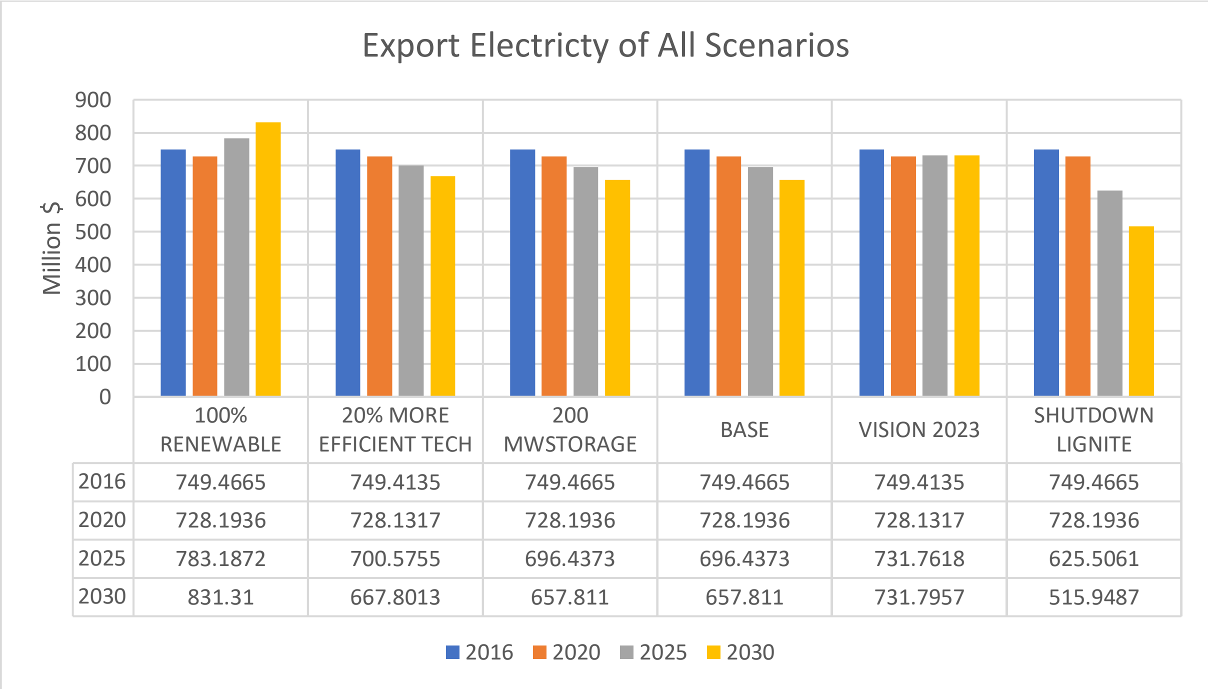


Figure 25. Exported Electricity of All Scenarios.

When we look at Figure 25, it is seen that the least electricity export occurs in lignite scenario which is also most cost-effective scenario. The most expensive scenario is 100% Renewable Energy scenario, because existing fossil source plants chosen to be work as usual.

Table 9. Total Imported Fossil Resources Costs for All Scenarios.

	Million $			
	2016	2020	2025	2030
100% Renewable	864.3445	887.8619	922.9479	965.6411
20% More Efficient Tech	864.3445	887.8619	922.9479	965.6411
200 MW Storage	864.3445	887.8619	922.9479	965.6411
Base	864.3445	887.8619	922.9479	965.6411
Vision 2023	862.9612	886.2438	893.1089	904.3142
Shutdown Lignite	864.3445	887.8619	862.6003	844.946

Table 9 shows that Vision 2023 and Shutdown Lignite scenarios can reduce the CO2 emissions. Because in both scenario total imported fossil sources have reduced. In fact, the lowest carbon emissions will of course occur in a 100% renewable energy scenario.

However, the closure of the power plants operating in a country where energy dependency is high is not preferred because it will cause great economic damage. The aim of the study has been realized by proving that Çanakkale could make transition to 100% renewable energy.

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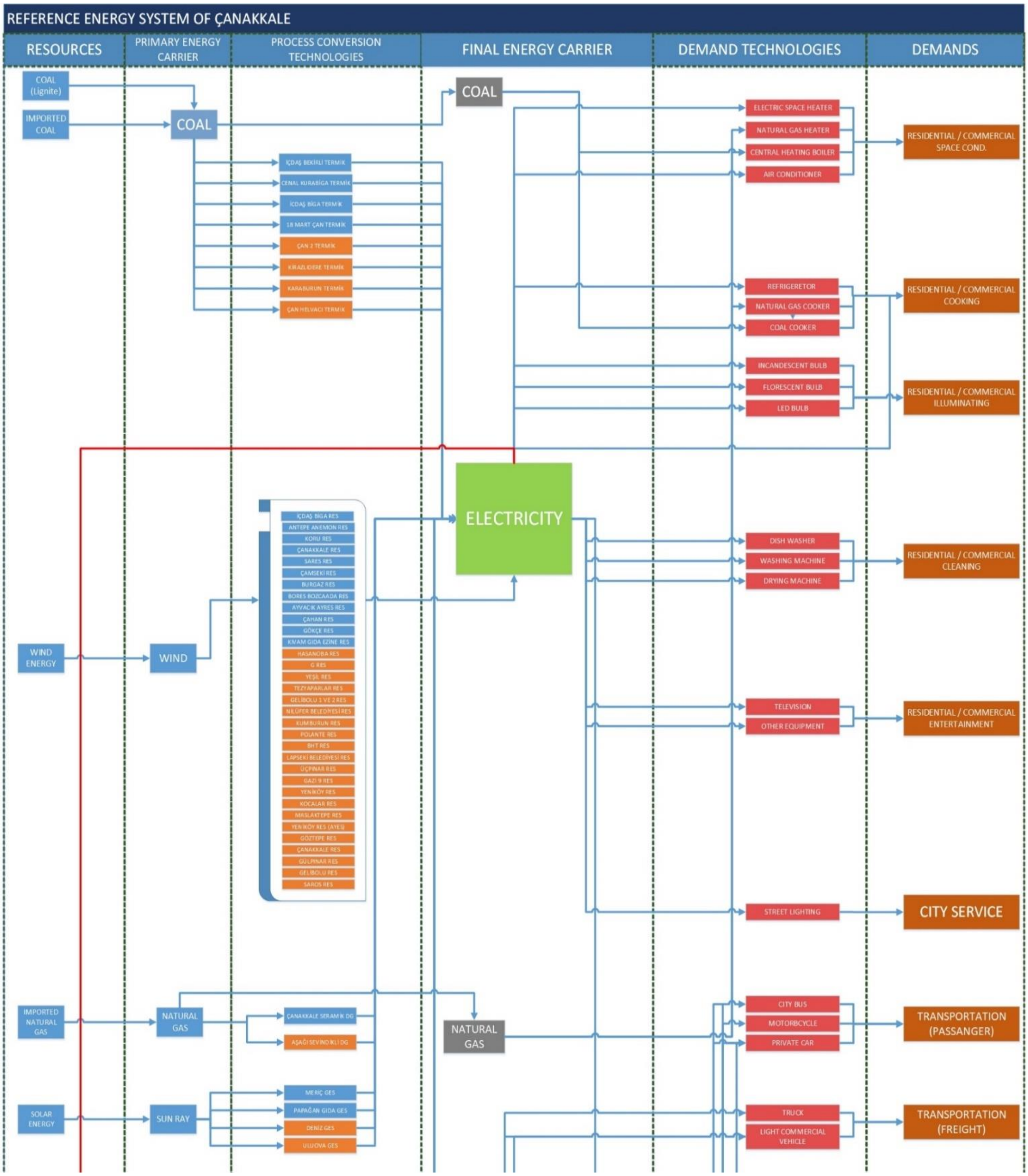
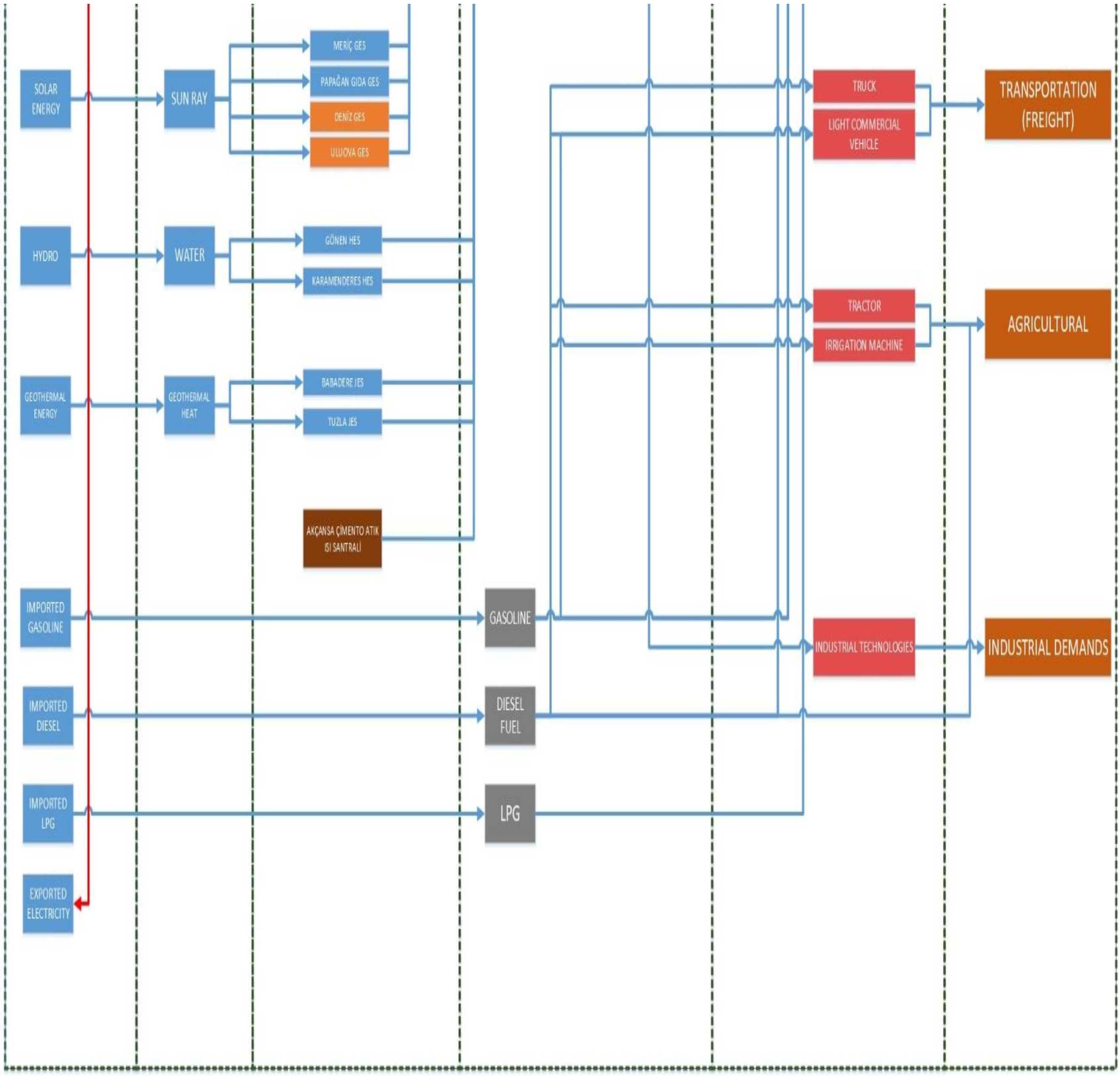
APPENDIX -1-

Reference Energy System of Çanakkale Province



Reference Energy System of Çanakkale Province (cont'd)



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