Analysis of Turkish Electricity System: Focusing on Smart Grid Concept

A thesis submitted to the
Graduate School of Natural and Applied Sciences

by

Ahmet Tuğrul BAKIR

in partial fulfillment for the
degree of Master of Science

in

Industrial and Systems Engineering

İSTANBUL ŞEHİR ÜNIVERSITY

This is to certify that we have read this thesis and that in our opinion it is fully adequate, in scope and quality, as a thesis for the degree of Master of Science in Industrial and Systems Engineering.

APPROVED BY:

Asst.Prof. Hatice Tekiner Moğulkoç ....
(Thesis Advisor)

Asst.Prof. Erkan Erdemir ....

Asst.Prof. Emre Çelebi ....

This is to confirm that this thesis complies with all the standards set by the Graduate School of Natural and Applied Sciences of İstanbul Şehir University:

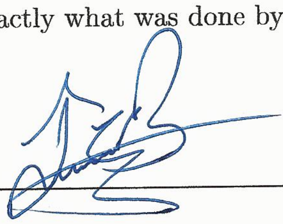
DATE OF APPROVAL: 19 February 2018

SEAL/SIGNATURE:

Declaration of Authorship

I, Ahmet Tuğrul BAKIR, declare that this thesis titled, 'Analysis of Turkish Electricity System: Focusing on Smart Grid Concept' and the work presented in it are my own. I confirm that:

- This work was done wholly or mainly while in candidature for a research degree at this University.
- Where any part of this thesis has previously been submitted for a degree or any other qualification at this University or any other institution, this has been clearly stated.
- Where I have consulted the published work of others, this is always clearly attributed.
- Where I have quoted from the work of others, the source is always given. With the exception of such quotations, this thesis is entirely my own work.
- I have acknowledged all main sources of help.
- Where the thesis is based on work done by myself jointly with others, I have made clear exactly what was done by others and what I have contributed myself.

Signed: 

Date: 19.02.2018

" "Direnmek" fiilini çok seviyorum. Bizi hapsedene, önyargılara, aceleyle varılan yargılara, yargılama arzusuna, tek isteği açığa çıkmak olan içimizdeki kötüye, vazgeçme isteğine, kendini beğendirme ihtiyacına, başkasını kötüleyerek kendinden bahsetme ihtiyacına, modalara, tehlikeli hırslara, etrafımızı kuşatan karmaşaya direnmek. Direnmek ve... gülümsemek."

Emma Dancourt

Analysis of Turkish Electricity System: Focusing on Smart Grid Concept

Ahmet Tuğrul BAKIR

Abstract

The electricity grid that is used today mostly uses old systems and methods, and often consumes fossil fuels. Using high rate of fossil fuels causes both the danger of depletion of fossil fuels and the harm to the environment and the atmosphere. There is also a risk of not being able to meet the rising energy demand because of the increasing of the world population and urbanization life. All these reasons lead to the necessity of a new system. Smart grid concepts are being developed aiming to use more renewable energy resources and meet energy demand more efficiently in response to these needs. Smart grid concept covers a very wide area and each country focus on the different areas of smart grid depending on their primary needs. Therefore, it is quite difficult to compare smart grid status of countries.

This study aims to realize this comparison in the most comprehensive way possible for Turkish electricity grid by using the data obtained. The key indicators for smart grid presented in the literature are expanded and then used for the comparison. Despite the difficulty of finding data on many criteria, as a result of the comparisons, it was observed that Turkish electricity grid is far behind the leading countries in the area. However, in certain areas, studies and investments are promising. This study generally presents analyzes of these comparisons.

Keywords: Smart Grid, Electricity Grid, Comparison, Renewable Energy

Türkiye Elektrik Sisteminin Akıllı Şebeke Konseptine Odaklanılarak Analizi

Ahmet Tuğrul BAKIR

Öz

Günümüzde kullanılan elektrik şebekesi hem eski sistemleri ve yöntemleri kullanmakta, hem de çoğunlukla fosil yakıtlar tüketmektedir. Dolayısıyla hızla artan dünya nüfusu ve buna bağlı olarak artan enerji talebini karşılayamama problemleri ortaya çıkmaktadır. Ayrıca büyük oranda fosil yakıtlar kullanılması atmosfere ve çevreye ciddi zararlar vermektedir. Bu sorunlar yeni sistemlerin geliştirilmesi ihtiyacını doğurmuştur. Bu ihtiyaçlara istinaden yenilenebilir enerji kaynaklarını daha fazla kullanmayı, enerji talebini daha verimli karşılamayı hedefleyen akıllı şebeke kavramları geliştirilmektedir. Çok geniş bir alanı kapsayan bu yeni kavramlara her ülke ve kurum farklı açılardan yaklaşmaktadır. Bu sebepten ülkelerin akıllı şebeke durumlarını karşılaştırmak oldukça güçtür.

Bu çalışma, Türkiye elektrik şebekesi için, bu karşılaştırmayı mümkün olan en kapsamlı şekilde gerçekleştirmeyi amaçlamaktadır. Bu sebeple elde edilen veriler doğrultusunda, belirlenen ve genişletilen kriterlere göre karşılaştırma yapılmaya çalışılmıştır. Bunun için, bu alanda yapılmış projeler ve belirlenmiş kriterler kullanılmıştır. Birçok kriter bazında veri bulma güçlüğü çekilmiş olsa da, yapılan karşılaştırmalar sonucunda, Türkiye Elektrik şebekesinin, alanında öncü ülkelerin oldukça gerisinde olduğu gözlemlenmiştir. Ancak yapılan çalışmalar ve yatırımlar, belirli alanlarda umut vericidir. Bu çalışma genel olarak bu karşılaştırmaların analizlerini sunmaktadır.

Anahtar Sözcükler: Akıllı Şebekeler, Elektrik Şebekesi, Karşılaştırma, Yenilenebilir Enerji

Tâhâ'ya ...

Acknowledgments

First of all, I would like to thank to my thesis advisor Asst. Prof. Hatice Tekiner Moğulkoç for all her effort, useful remarks, directions and teaching me patience in this process. I also thank my thesis committee; Asst. Prof. Erkan Erdemir for the selection of the thesis topic and valuable comments and to Asst. Prof. Emre Çelebi for his valuable comments and his contribution with the expert opinion.

Besides, I also thank Ahmet and İsmail for their technical support and all of my friends at İstanbul Şehir University for their patience and support.

Seda who helps and gives the her support unflaggingly to me whenever I need support, Dilara who does not spare her support without regarding time, Baraa who give moral support, Betül who always interested in my study and giving opinions to me from the other side of the world, and Arsalan who give technical assistance especially the last period of my study, and Gizem who has the academic, moral and spiritual support when I say that could not go on are deserve endless praise.

My dear relatives who make me feel they have always been by my side with their moral support and prays, my friends who did not even call me for the activities not to disturb my studies deserve to thank.

I am grateful my father İsmail Hakkı, my mother Hatice, my sister Esra, my brothers Ömer and Sevban, my nephew, my playmate, my lifeblood Taha; the ones who has the biggest role while I'm standing where I am. The things they provide me both in the process of preparing this thesis and in my 28 years of life that I am not able fit in any thanking.

Thank you, I grow up with you...

Contents

Declaration of Authorship ii

Abstract iv

Öz v

Acknowledgments vii

List of Figures x

List of Tables xii

1 Introduction 1

2 Background and Literature Review 3
- 2.1 Electric Power System . . . 3
  - 2.1.1 Electricity Generation System . . . 4
  - 2.1.2 Transmission and Distribution . . . 6
- 2.2 Smart Grid . . . 7
  - 2.2.1 What is Smart Grid? . . . 7
  - 2.2.2 Differences between Traditional Grid and Smart Grid . . . 8
  - 2.2.3 Smart Grid Features and Technologies . . . 10
  - 2.2.4 Benefits of Smart Grid . . . 14
  - 2.2.5 Barriers of Smart Grid . . . 16
- 2.3 Literature Survey . . . 17
- 2.4 Contribution of Study . . . 23

3 Comparing Turkish Electricity System with Other Countries Considering Smart Grid Concept 24
- 3.1 Turkish Electricity System . . . 24
  - 3.1.1 Installed Power . . . 24
  - 3.1.2 Generation and Consumption . . . 26
  - 3.1.3 Transmission System . . . 28
  - 3.1.4 Distribution System . . . 30
- 3.2 Overview of Smart Grid Studies in Turkey . . . 31
  - 3.2.1 General Energy Investments . . . 32
  - 3.2.2 Renewable Energy Investments . . . 34
  - 3.2.3 Environment . . . 34
  - 3.2.4 Energy Efficiency . . . 35

3.2.5 Distribution Companies Studies . . . 35
3.3 Comparison of Turkey with Some Countries . . . 36
3.3.1 Smart Grid Projects Supported by European Union . . . 36
3.3.2 Enable Informed Participation by Customers . . . 47
3.3.3 Accommodate All Generation and Storage Options . . . 50
3.3.4 Sell More Than kWhs . . . 52
3.3.5 Provide Power Quality for the 21st Century . . . 55
3.3.6 Optimise Assets and Operate Efficiently . . . 55
3.3.7 Operate Resiliently to Disturbances, Attacks and Natural Disasters 57
3.3.8 Renewable Energy Sources . . . 59

4 Conclusion and Future Works 61

A Indicators Table 63

List of Figures

2.1 General Schematic of Electric Network [1] 3
2.2 Turbine and Generator in Some Plants [2] 5
2.3 Smart Grid Technologies Effect Areas in Power Systems [3] 11

3.1 Total Installed Power Capacity in Turkey (1975-2017) 25
3.2 Installed Power Capacity According to Institution, 2017 25
3.3 Installed Power Capacity According to Sources, 2017 26
3.4 Amounts of Generation and Consumption (1975-2017) 26
3.5 Monthly Comparison of Generation and Consumption, 2017 27
3.6 Instantaneous Peak Load, 2017 27
3.7 Annual Development of Electricity Generation by Energy Sources (2006-2016) 28
3.8 Generation Rates According to Sources, 2017 28
3.9 Loss Rates According to Distribution Companies in 2016 30
3.10 Rates of Total Investments According to Source Type Between 2008-2017 34
3.11 The Number of Projects per Country (1994-2016) 37
3.12 The Number of Projects Started in Each Year in Europe (1994-2015) . . . 38
3.13 The Number of R&D and Demonstration Projects per Country (1994-2016) 38
3.14 The Number of Projects in Turkey (1994-2016) 39
3.15 Comparison of Number of Projects between Germany vs Turkey (1994-2016) 40
3.16 Number of Projects in Turkey vs Average Number of Projects According to Countries in SNM (1994-2016) 40
3.17 Comparison of Number of Projects between Spain vs Turkey (1994-2016) . 41
3.18 Number of Projects in Turkey vs Average Number of Projects According to Countries in DSM (1994-2016) 41
3.19 Comparison of Number of Projects between the United Kingdom vs Turkey (1994-2016) 42
3.20 Number of Projects in Turkey vs Average Number of Projects According to Countries in IoDGS (1994-2016) 43
3.21 Comparison of Number of Projects between Denmark vs Turkey (1994-2016) 44
3.22 Number of Projects in Turkey vs Average Number of Projects According to Countries in IoLSRES (1994-2016) 44
3.23 Comparison of Number of Projects between France vs Turkey (1994-2016) 45
3.24 Number of Projects in Turkey vs Average Number of Projects According to Countries in E-Mobility (1994-2016) 45
3.25 Comparison of Number of Projects between Austria vs Turkey (1994-2016) 46
3.26 Number of Projects in Turkey vs Average Number of Projects According to Countries in Others Domain (1994-2016) 46

3.27 Number of Meters in UK and Turkey (2017) 48
3.28 Percentages of Smart Meters in UK and Turkey (2017) 48
3.29 Number of PHEV's According to Countries (2010-2016) 50
3.30 Percentage of PHEV's in Total Vehicles in 2016 51
3.31 Number PHEV's Charge Stations According to Countries in 2017 51
3.32 Amount of Being Eligible Consumer Limits and Number of Eligible Consumer According to Years (2009-2017) 53
3.33 Amounts of RES Investments According to Resources for Turkey (2008-2017) 54
3.34 Cumulative Amounts of RES Investments According to Sources for Turkey (2008-2017) 54
3.35 Comparison of Peak Loads and Averages in Total Capacity between Turkey and UK (2012-2016) 56
3.36 Comparison of Distribution Losses Between Turkey and United Kingdom (2014-2015) 56
3.37 Rate of UK Energy Efficiency Based on Fuel Output-Input (2010-2016) . . 57
3.38 Percentages of Renewable Energy Sources in Total Installed Power Capacity According to Sources (2008-2017) 59
3.39 Percentages of Renewable Energy Sources in Total Electricity Generations According to Sources (2008-2017) 59
3.40 Comparison of Percentages of RES in Total Installed Power Capacities & RES in Electricity Generations According to Countries in 2015 60

A.1 Characteristics, Categories, and Key Performance Indicators of a Smart Electricity Grid [4] 64

List of Tables

2.1 Differences between TD and SG [5–7] 9
2.2 Technologies–Key Value Area Relationships 15
2.3 Summary of Literature Survey 21
2.4 Summary of Literature Survey Cont'd 22

3.1 Number of Transformers & Power of Transformers[8] 29
3.2 Developments of Transmission Lines Lengths[8] 29
3.3 Numbers and Power Amounts of Substations and Length of Power Lines According to Voltage [9] 29
3.4 Number of Consumer According to Distribution Company [9] 30
3.5 Amount of Investments According to Fuel Types, Between 2008-2017[10] . 33
3.6 Number of Consumers According to Distribution Company per Years[11] . 52
3.7 Amount of Average Interruption Times According to Distribution Company[12] 58

Chapter 1

Introduction

The power systems used today and electricity generation grids that are built based on these systems emerged in the 1800s. Electricity demand is often met by one-way transmission from a central source where electricity generated from fossil fuels. It is predicted that the intense use of energy resulting from urbanization and increasing population will become an important problem in the coming years. The danger of depletion of fossil fuels, the damage to the environment and the atmosphere due to the use of fossil fuels, and the risk of not meeting the energy demand due to the rising world population have necessitated the emergence of new systems. As a result, the smart grid concept has been established with the connection of today's electrical grids to computer, automation and network systems, thanks to the technological developments that have been increasing rapidly in recent years. Since there is no single definition of the Smart Grid concept and it covers a wide range of improvements, each country develops this concept in the direction of its own needs.

For these concerns, many countries have developed various policies and measures, and to put them into practice they have made an effort to make their energy and power networks smarter. For example, the European Union's targets, which are designated as "20-20-20" for 2020, is one of the projects proposed to make the grid smarter. These targets are reducing 20% of the CO2 emissions by 2020 compared to 1990 values, providing 20% of the energy consumption from renewable sources and improving energy efficiency by 20%. To reach these targets, they are engaged in integrating smart grid concepts into their systems. Some of the benefits expected to be brought about by the integrating the smart grid components into electrical systems are the reduction of fossil fuel consumption, energy efficiency, the more efficient supply of demand through bi-directional information flow between all units in the grid, more reliable electricity supply and more sustainable systems.

The aim of this thesis is to define the current situation of Turkey's electricity grid and to analyze and compare the status of the Turkish electricity grid in terms of the smart grid concept. In this study, the current situation of Turkey is analyzed, and it is followed by comparing Turkey's situation with the other countries in the world based on the studies that have been done. Just as there is not only one definition of the smart grid, there is not only one criterion temple to measure the progress made on the smart grid. For this reason, a study [4], which is thought to be the most comprehensive among various criteria and indicators, has been taken as a reference. This list is expanded to include the smart grid project supported by European Union and renewable energy sources. In terms of smart grid concept, Turkish Electricity and Power System were compared with various countries in categories such as smart meters, distributed energy generation and electric vehicles, services offered to customers, operations and asset efficiency, power quality and durability based on this study. Also, there is a comparison made in terms of smart grid projects that are found in European Commission-Joint Research Centre database, which keeps projects from several countries including Turkey.

In the second part of this thesis, background information and literature survey about electricity grid and smart grid systems are presented. In Chapter 3, Turkish Electricity Grid was explained. After that, an overview of Turkey's Smart Grid studies was carried out. Finally, a general comparison of Turkey and other countries was made, in terms of smart grid, based on the characteristics of the selected study which expanded with adding Renewable energy sources and projects supported by European Union. The conclusion contains the results of this study, difficulties encountered throughout the study and the future works.

Chapter 2

Background and Literature Review

2.1 Electric Power System

Electricity is the energy generated by the movement of electrons, negatively charged particles of the atom [13]. Electricity could be considered as a kind of nutrient source for feeding all the electronic devices we use and to do their jobs. The electric power system is a composite network created to transmit generated electricity to the users. There are three main components of this network: Electricity Generation System, Transmission Lines and Distribution Lines (Figure 2.1). There are also transformers, substations, and distribution transformers to change the voltages to the appropriate levels for the lines and end users. In this section, the components of the network and related terminologies are explained in more details.

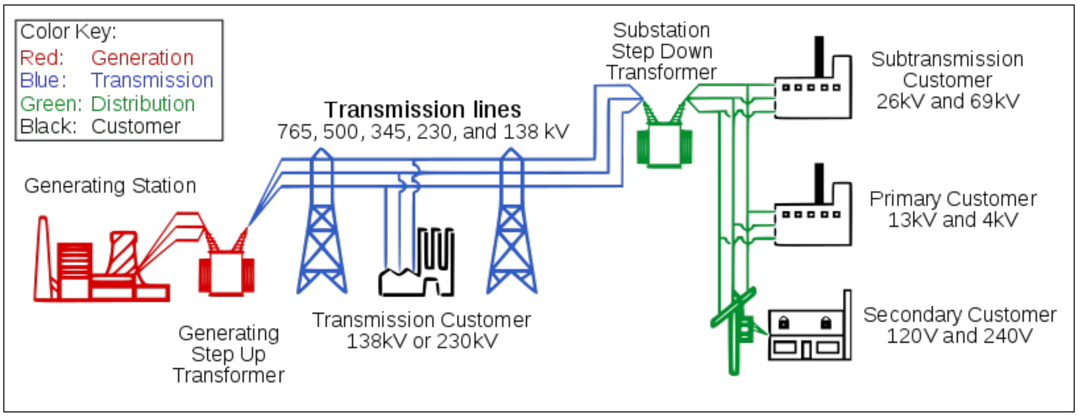


FIGURE 2.1: General Schematic of Electric Network [1]

2.1.1 Electricity Generation System

Electricity generation is defined as the process of generating electricity from the primary energy resources. This process starts with the inclusion of raw materials into the system and ends with transferring the resulting electricity to the transmission lines. Since electricity cannot be stored as large amounts, it has to be transported to the use areas when it is produced.

There are different technologies in order to convert different forms of energy into electricity. Electricity generation is done by rotation of electric generators, photovoltaic systems, and electrochemistry. Turbine-Generator system could be explained in three steps. First, by burning the fuel, water boils and turns into steam. Then the obtained steam rotates the steam turbine so the mechanical energy is generated. Finally, as the turbine rotates, a magnet in the generator rotates a cable bobbin, so that electricity is generated by the generator. In addition, steam is used in steam turbines. On the other hand, resources can also be given directly to turbine such as direct rotation of turbines in hydroelectric power plants by water or in wind power plants by wind as depicted in Figure 2.2. Electrochemistry is the direct conversion of chemical energy into electricity. Batteries are the well-known form of this technology. This is especially important in portable and mobile applications. While some types are used as power supplies, they often function as storage systems. In the photovoltaic system, the solar radiation is converted by means of solar panels. The energy obtained is made suitable for use by inverter device.

Electricity generation is provided by power plants and distributed generation units. Power plants are usually located outside the city center and usually have high capacity. Distributed generation units are usually located closer to city centers. Distributed Generation technologies can generate electricity up to 100 MW, while power plants can have generation capacities up to 1000 MW [14]. Each type of generation points could use not only fossil fuels but also renewable resources. Power plants that using fossil fuels, such as coal, natural gas, petroleum, are called thermal power plants. In thermal power plants, heat energy is generated as a result of the burning of fossil fuels. In practice, thermal power plants use "turbine-generator" generation technology. The plant which using nuclear energy is called as the nuclear power plant. Nuclear power plants use the same system which is used in thermal power plants, the only difference is that they consume nuclear resources as fuel. Power plants that use renewable resources have different names. The plants which use the power of water are named hydroelectric power plants. Hydroelectric power plants convert water movement energy into electricity. There are two types of hydroelectric power plants as dam plants and river power plants. In dam plants, an appropriate height difference is created for the water accumulated in the dams and is passed through the turbine. The potential energy of the water in the turbine is converted into kinetic energy to provide shaft rotation. Electric energy is also obtained with the help of the same shaft generator. River power plants consist of a tube-shaped propeller turbine and a generator placed on the stream [15]. Geothermal is the hot water, steam, and gas that contain chemicals, which are formed by the accumulated heat at various depths of the earth's crust. Geothermal energy is also generated from these geothermal sources that are cleaned from the harmful gases and sediments. Geothermal generation is performed by turbine-generator technology [16]. Another power plant that uses renewable sources is wind power plant, called also wind turbines. These plants generate energy with the power of wind by using turbine-generator technology [17]. Sunlight is the source of solar energy plants. These plants use two kinds of technologies for generating electricity. These are turbine-generator technology and photovoltaic technology. Turbine-generator technology in solar power plants' principle is vaporization of water by the power of sunlight. In the photovoltaic system, process is the same as mentioned above [18, 19]. Biomass power plants have the same principle of thermal power plants. In addition, biomass is classed as the renewable source. Namely, biomass resources are non-fossilized agricultural residues, animal manures and organic wastes [20].

The amount of generation can be controlled for fossil fuel and biomass fuel-using plants or units since these sources are dispatchable. However, the amount of generation in units or plants that use renewable resources, such as solar, wind etc. cannot be controlled. Because the resources are non-dispatchable.

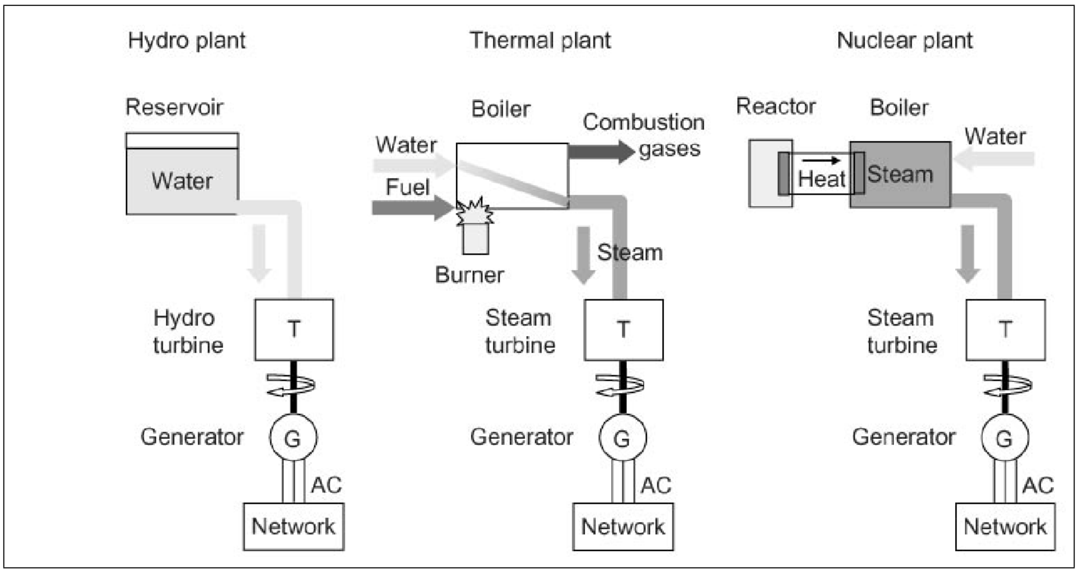


FIGURE 2.2: Turbine and Generator in Some Plants [2]

2.1.2 Transmission and Distribution

Power plants where electricity is generated are usually located far away from consumption points, which are residential or industrial areas. Transmission and distribution system is the component of the electric power system, which moves electricity from production facilities to consumption points. Main components of this network are power lines and substations. Power lines can be classified as underground and overhead. Electricity generated in power plants is transmitted and distributed through high voltage, medium voltage, and low voltage lines. High-voltage lines usually provide transmission between the interconnected network and the residential units, while medium-voltage and low-voltage lines are used to distribute electricity within the settlement. High-voltage and medium voltage lines are not always used for the connection but are also used for some factories and for some needs of cities, such as traffic lights and streetlights. Transmission lines operate at high voltages due to a huge amount of power and transmitting through long distances [21].

The detection, finding location and repair of the power failure is easier in the overhead lines. They have the disadvantages of lack of durability, reliability, and security. In addition, they may be affected easily by weather conditions. In contrast, underground lines have disadvantages because of the detection, finding location and repair of the power failure while they have advantages in terms of reliability, durability and weather resistance.

Substations have three functions in the network: they are the interconnection points between lines, control, protection and measurement points of network and transformation points for the system by transformers. Transformers are technological facilities that reduce or increase the voltage for lines or consumption points [2].

Distribution systems transfer the energy to the end users, with the most suitable voltage level. Usually, the distribution system is known as low voltage networks. There are also two types of power lines which are overhead and underground as mentioned above. The most appropriate and common used transmission and distribution systems, as known as distribution feeder systems, according to the distribution patterns are Radial, Parallel, Ring, and Meshed (interconnected) systems [22].

Radial systems are widely used. They are fed from a single source and their shapes resemble tree branches. It is the simplest and lowest cost system in terms of construction and protection system. However, too many consumers could be exposed to power cut if there is a fault. In parallel feeder systems, greater reliability is achieved with a higher cost. Even when a fault occurs, the system may continue to be fed with the parallel line. This doubles the construction cost but increases the reliability factor. This system may be used in places that do not tolerate energy interruption. Such as hospitals, major production facilities etc. The type of network that the feed is made with more than one transformer and all the transformers form a closed system that parallel to each other is called ring grid. In case of a failure in the ring, the faulty part will be disabled because the ring grid is powered by more than one transformer. Interconnected is an electrical feeder system that provides interregional or international connectivity between two or more systems or networks for energy supply and exchange. It is also known as Meshed System. In this type of networks, all electricity production and consumption means in that region are included in the system without major or minor distinctions. In the event of a fault in the interconnected system, only the fault part is de-energized. The interconnected network is also called the national electricity network.

2.2 Smart Grid

The world population is increasing day by day. According to projections, the world population is expected to reach nine billion in 2040 [23]. As the population increases, the energy demand increases accordingly. The increased energy demand of the consumers at different level cannot be completely met by the existing electricity network due to the excessive use of fossil fuels in energy production, the insufficient integration of renewable resources into the system and the power losses arising from technological reasons. The new generation of the electricity network, called Smart Grid Technologies, is being developed to meet this demand. A smart grid is a collection of technologies that includes all processes of electric power system such as generation, transmission, distribution. Smart grid concept has been established for not only to meet these demands but also to decrease the carbon emissions, increase the efficiency of all parts of the grid and the security of the consumers, monitor and control the whole system [24].

2.2.1 What is Smart Grid?

The smart grid concept has been collaboratively criticized and developed by research institutes, famous organizations, universities and government agencies. However, there is no single definition of the smart grid due to its wide range concept. Therefore, every country or government can approach the issue from a different point, so different definitions have emerged. Hossain *et al.* [25] define Smart Grid as "The Smart Grid can be described as the transparent, seamless, and instantaneous two-way delivery of energy information, enabling the electricity industry to better manage energy delivery and transmission and empowering consumers to have more control over energy decisions." The European Technology Platform [26] defines the Smart Grid as "A Smart Grid is an electricity network that can intelligently integrate the actions of all users connected to it–generators, consumers and those that do both–in order to efficiently deliver sustainable, economic and secure electricity supplies." In addition, according to the U.S. Department of Energy [27] "A smart grid uses digital technology to improve reliability, security, and efficiency (both economic and energy) of the electrical system from large generation, through the delivery systems to electricity consumers and a growing number of distributed-generation and storage resources."

2.2.2 Differences between Traditional Grid and Smart Grid

There are life-enhancing differences between the traditional grid and the smart grid as shown in Table 2.1. Listed items can provide satisfied partners and help using energy more efficiently. One of the most distinctive and significant of these differences; smart grid uses advanced information and communication technologies. Besides that, the traditional grid having one-way communication while the smart grid having two-way communication is also a distinguishing difference. In comparison to the measurement, the traditional grid uses electromechanical technology while the smart grid uses digital technology. Thus, real-time pricing and net metering are performed. Moreover, because the traditional system does not have excellent measuring capability, the system becomes very vulnerable to electricity theft. Real-time and instant metering in smart grid can preclude this.

While equipment control is maintained and repaired manually in the traditional grid, this operation is carried out at periodical intervals by remote control and monitoring in the smart grid. In addition, in case of malfunction occurred, it could be repaired after consumer notification by manually in the traditional grid. However, thanks to the remote monitoring on the smart grid, location of the malfunction could be detected easily and repaired quickly as self-healing. In this way, the blackout that may occur during the detection and repair of the malfunction in the conventional network is prevented. This makes intelligent networks more reliable. From a generation point of view, Smart Grid is also suitable for the integration of distributed generation to the centralized generation, where only centralized generation is carried out in the traditional grid. Traditional grids usually have radial and unidirectional energy flow. The most expensive and complex difference of the smart grid is that the energy flow is multiple ways. There is also a difference in the result of this interaction; while in the traditional grid the customer gets service passively from the system, it is part, participant and stakeholder of the system in the smart grid.

Due to the energy market that will be formed by the diversity of generation and integrating renewable energy sources into the system, in smart grid, the consumer has the right of choosing. In addition, with the dynamic pricing of electricity, customers can set their own hours of use and set a fee policy for themselves. In the traditional network, the customer usually does not have the right to choose supplier because the market is the monopoly and they are also not able to set their own fee policy because of the lack of dynamic pricing [5, 6].

TABLE 2.1: Differences between TD and SG [5–7]

Criteria	Traditional Grid	Smart Grid
Generation	Centralized	Integrated distributed as well as centralized generation
Communication Pattern And Interacting With Consumer	One way, limited interaction and passive consumer	Mutual information exchange (for consumer and distribution grid), comprehensive interaction and active participant/-consumer
ICT Usage	Not using	Using advanced ICT
Economy	It can lead to huge economic losses due to unpredictable interruptions and failures and a huge amount of losses and leaks	New markets, prevention of interruptions and failures, decreasing of the losses and leaks can bring great benefit to the economy
Metering Technology And Equipment	Electromechanical metering	Digital metering (real-time pricing and net metering)
Maintenance	Manual	Remote control and monitoring in periodical intervals
Reliability	Vulnerable to interruptions or failures	Automated and proactive protection equipment which prevent interruptions
Repair	Manual fault locating and repairing, usually after consumer notification	Fault locating by remote technologies and self-healing
Power Flow	One way	Multiple power flow pathways
Efficiency	Less efficient due to losses and leaks and old types of equipment in the grid	More efficient thanks to fewer losses and leaks and high-quality types of equipment
Renewable Energy Integration	Ineligible for renewable energy integration	Favorable for renewable energy integration
Environment	More carbon emissions cause of fossil fuels from generation and cars	Fewer carbon emissions thanks to renewables sources and automation technologies
Options For Consumers	Monopoly market;No choice for consumers,	With digital market trading, more choice for consumers
System Operation	Worn power assets, inefficient operation	Optimized assets operating, decreased power loss
Protection	Only manual protection devices	Capability of self-healing
Security	Vulnerable to physical attack	Increased reliability for public security and human safety

2.2.3 Smart Grid Features and Technologies

The Smart grid is a new generation power system. Smart Grid has too many features, components and technologies to achieve improvement in reliability, economics, efficiency, environmental, safety and security qualifications. According to National Energy Technology Laboratory (NETL) some of these technologies are shown below [5, 6];

1. Advanced Metering Infrastructure (AMI)
2. Customer Side Systems (CSS)
3. Demand Response (DR)
4. Distribution Management System/Distribution Automation (DMS)
5. Electric Vehicle Technology (EV)
6. Integration with renewable energy and Distributed Energy Resources (DER)
7. Wide Area Monitoring and Control
8. Transmission Enhancement Applications (TA)
9. Asset/System Optimization (AO)
10. Information and Communication Technology Integration (ICT)

These technologies could affect all processes of power system from generation to consumption as shown in Figure 2.3:

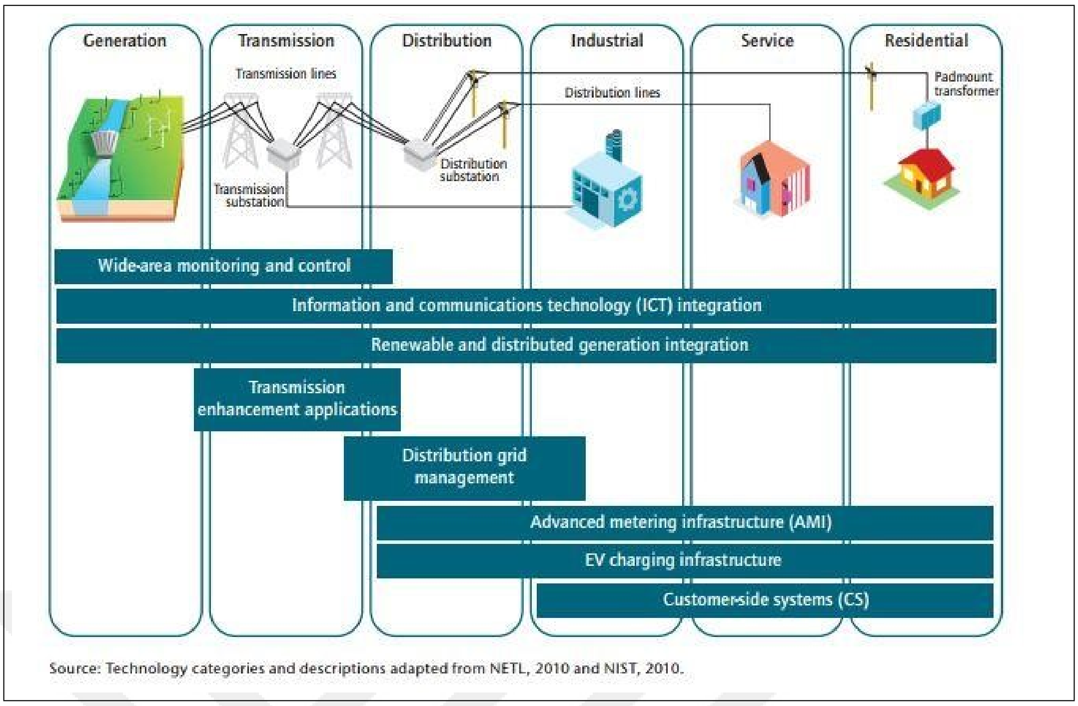


FIGURE 2.3: Smart Grid Technologies Effect Areas in Power Systems [3]

Advanced Metering Infrastructure (AMI)

Two-way information and data transfer, one of the main features of the Smart Grid, is provided by AMI. AMI interacts with the consumer. Thus it provides real-time pricing and consumption information to the consumer, then allowing the consumer to make intelligent usage decisions and increase the variety of consumer's options. Furthermore, real-time consumption information helps to detect theft and power losses. AMI performs all these benefits together with various technologies such as smart metering, home area networks, data management applications etc. The consumer is connected to the distribution network by the smart meter. The distribution network is also connected to the transmission network, distributed generation systems and other generation plants by AMI technology.

However, integrating the AMI into the system could have negative consequences for the consumer side and energy market, such as the health of society, communication-related risk, trust to the government and economy depending on housing prices. This makes it vitally important to provide security and reliability for the Smart Grid.

Customer Side Systems (CSS) and Demand Response (DR)

These technologies are particularly relevant to the benefit of energy management in consuming levels like industrial, residential consuming level etc. There are four elements of CSS technology and these are energy management systems, energy storage devices, intelligent electronic devices and distributed generations systems. These technologies are important tools for energy balancing in the grid. For example, consumers can see their consumption through intelligent home appliances and smart displays and dashboards, as well as the help of distributed energy sources that are included in the system, they can make more economic and more affordable choices for themselves. Electricity use from grid and electricity production at peak times can be distributed over other hours thanks to the inclusion of storage devices in the system. Consumer-controlled devices and automatic devices are able to connect to the energy management system and controlled by signals.

Distribution Management System/Distribution Automation (DMS)

It is one of the smart grid technologies that enables the management and control of the power source that the customers need. This technology allows for dynamic decision making with real-time monitoring of grid statistics. This helps prevent outages and failures that may occur in the power system. This ensures that the grid will be more efficient and reliable. As a result, customer satisfaction also increases. The Geographical Information System (GIS) is one of the technologies that helps this technology. Providing of customer data privacy must be considered in order for this technology and smart grid technologies to be used on a global scale.

Distributed Energy Resources (DER)

Distributed Energy Resources are decentralized energy sources at different scales. Storage and/or generation could be done in these sources. When they are large or medium-sized, they are included in the network at the level of transmission or distribution, while small-sized ones can be directly used by the customers themselves. These technologies do not only provide electrification support to the central systems, but they also participate in the network as new players. In this way, they can reduce the peak load by increasing the reliability of the network. Most common examples of DER's are wind and solar generation resources.

Electric Vehicle Technology (EV)

The Smart Grid's objective is not only to meet electricity demands but also to achieve environmental objectives such as reducing greenhouse gas emissions, global warming and fossil fuel use. Therefore, it is important to use electric vehicles instead of fossil fuel consuming vehicles. Electric vehicles use electricity as a fuel and they receive electricity from the grid, besides they could also be used as a distributed energy storage unit for the grid if needed. For instance, they can connect to the home network and meet the electricity demand of the house, temporarily. In this way, they can contribute to the stabilization of the grid during peak demand hours.

Wide Area Monitoring and Control

Wide Area Monitoring and Control technology observe the entire power system rather than the small parts (or details). This allows to see, control and optimize all the components connected to the system and their performance. As a result, it can see and respond to any interruptions or failures anywhere in the system. In addition, this technology helps to integrate the renewable resources to the system. As a result of the data gained by this technology, to make a decision, to wide area malfunction and to improve transmission and reliability are easier for system operators.

Transmission Enhancement Applications (TA)

Improvement of transmission lines has vital importance to prevent power losses, increase transmission efficiency and provide controllability in transmission. There are four main applications to do this. These are; Flexible AC Transmission Systems (FACTS): A technology that improves the controllability of lines and maximizes the power transfer capability. High Voltage DC Systems (HVDC): A technology which is used to connect distant sources from the load center to large power areas. For example; connecting the offshore wind and solar farms to large power areas. Dynamic Line Rating (DLR): It is the technology that real-time capacity measurement of the transmission line by the sensors. Thus, it optimizes the components so that transmission is seamless without overloading. High-Temperature Superconductors (HTS): A technology that significantly reduces transmission losses in the line with high performance.

Information and Communication Technology Integration (ICT)

Information and Communication Technology is one of the most important technologies that used in the Smart Grid. Most of the technologies include data sharing, mutual communication and information transfer. All these processes are carried out thanks to Information and Communication Technology. Therefore, some sources call to this technology not only Information and Communication Technology, but they also refer it as Smart Grid's backbone. Due to the Information and Communication Technology, stakeholders could use and manage the power grid system more efficiently.

Asset/System Optimization (AO)

Asset/System Optimization focuses on all assets of the system have the best and most efficient circumstance. It also focuses on maximizing the efficiency of operations while achieving maximum efficiency from assets. It aims to reduce losses, interruptions, defects caused from assets. It also allows the system and its components to operate at maximum capacity with constant monitoring of assets and system. If there are more capacities available at the moment, the AO allows them to be used at higher loads.

2.2.4 Benefits of Smart Grid

The benefits of all the technologies used in the Smart Grid are examined in six key areas defined by NETL [28]. These areas are; Reliability, Economics, Efficiency, Environment, Security and Safety. This examination is shown in the Table 2.2. The dependence on fossil fuels for energy supply has been going on for decades. For this reason, some countries are politically dependent on other countries. By these technologies, energy supply could be liberalized, thus the dependency between these countries could be removed and security & safety in energy supply could be provided. In addition, they can benefit to supply security and economy by increasing productivity. By integrating these technologies into the system, the environmental benefits that is one of the Smart Grid's main objectives could also be achieved. As a result of all this, it is easy to meet the electricity demands and the consumer is able to satisfy which is the biggest and primary stakeholder of the power system [29]. Some of the other benefits are improved metering equipments which are metering whole system, more satisfied customers, better visibility for utility operation, better historical and instant data availability for digital summary and strategic planning, more secure communication, improved end-to-end power delivery, accurate information for rate cases etc.

Benefits of smart grid for each aspect is detailed in this section. Reduction of operational costs caused by equipment faults, additional expenses for consumers such as illegal usage by other consumers, interruptions or failures especially those affecting large consumers, the increase of employee safety and consumer pleasantness, virtual elimination of interruptions and black-outs, and support to economic growth could be some examples of benefits in terms of reliability.

Reduction of the maintenance and the operational cost at base-load generating plant, the shipping charges, reduction of the energy costs and the consumption bills, increase of the incomes due to the minimization of service theft, the share of solar and wind energy generation, the employment opportunities, purchasing of consumer-generated electricity by the grid and creating new markets with distributed energy generation and storage technologies are some parts of economic benefits.

Rising asset usage, increasing employee and generation efficiency, decreasing losses in lines, postponement of capital investments, expanding the lifespan of system assets, reducing inefficient generation caused by consumption habits, less compulsory outages, more effective consumers, sustainability of improvements are some of the benefits of the efficiency key area.

Increasing the integration capacity of renewable energy resources and electric vehicles, reducing greenhouse gas emissions through the integration of renewables and electric vehicles, fires in substations and petroleum spills, creating a positive environmental impact by changing energy consumption behavior, transforming to green economy from carbon-based, and increasing community health care are some of the environmental benefits.

Reducing the possibility of intentional physical attacks by wireless technologies, property theft caused by illegal electricity usage, work accident risks, the risk of people's accidents and injuries related with the grid; provides rapid recovery after breakdowns, failures and natural disasters, protection of generation facilities through safer transmission systems, last but not least is the increase in national security are some examples of benefits in term of safety and security.

Table 2.2: Technologies–Key Value Area Relationships

Technology	Reliability	Economics	Efficiency	Environmental	Safety	Security
AMI	√	√	√	√	√	√
CSS & DR		√	√	√		
DMS	√		√	√	√	√
DER	√	√	√	√		√
EV	√	√	√	√		
TA	√		√	√		√
ICT	√	√	√	√	√	√
WAMC	√		√	√	√	√
AO	√		√	√	√	√

2.2.5 Barriers of Smart Grid

Smart Grid is a developing and promising technology concept for electricity grids. However, there are barriers that affect the implementation and development of smart grid. These barriers can be technical, political, and financial and consumer based. More details can be found about the smart grid challenges and barriers below.

The integration of communication network into the electricity grid causes some issues. Due to the cybersecurity vulnerability, wrong messages could be inserted into the power grid and this could cause the power blackouts. Besides, deficiencies in the self-healing technology may bring some problems in case of natural disaster and physical attack. Since the outputs of renewable energy sources are intermittent and random, this could lead to malfunction in the smart grid generation. Due to the two-way energy flow, grid complexity increases. The lack of advanced meters and communication infrastructure is also a technical barrier to the smart grid.

When it comes to the economical barriers, the introduction of smart grid could make the electricity cheaper. However, the initial cost to build the new grid is high and utilities may be concerned about the balance between the benefits and the costs. Therefore, financial support is an important issue in order to reduce economic barriers.

Another important issue about the development of smart grid is the lack of regulations and standards. The establishment of smart grid standards provides interoperability between different players. The organizations such as The American National Institute of Standards and Technology (NIST), Institute of Electrical and Electronics Engineers (IEEE) have important studies to develop the smart grid standards. In addition to this, the uncertainties between the market players are regulatory barriers to the smart grid. Regulators require determining the responsibilities and roles of market players.

When it comes to the social barriers, one of the crucial challenges to the smart grid is the lack of consumer awareness. Consumers' lack of knowledge about the smart grid technologies, concerns about the increase of their electricity bill, lack of awareness about the environmental benefits of the smart grid are factors, which affect the introduction of the smart grid. Consumers delay or avoid the installation of smart grid technologies because of these reasons. Even when they tend to adopt smart grid, they have concerns about sharing their private information with the utilities.

2.3 Literature Survey

There are many studies about Smart Grid in the literature. After a comprehensive study, the articles dealing with the Smart Grid on the basis of countries or specific geographical regions are summarized in this section. Some articles examined one or more countries and some compared countries or specific geographies. In addition, some of the articles reviewed the smart grid first and then made the comparison between countries in the light of these reviews. In some studies, smart grid is examined and compares in general, whereas in some other studies, a technology or feature of this system is examined. In addition to these, politics that governments or countries set for the transition to smart networks are also included. Studies examining the situation of Turkey and presenting pilot projects around the world are also reviewed in this section.

Di Santo *et al.* [30] refer to the Smart Grid concepts in their literature review. They carry out a comprehensive study containing generation, transmission, distribution, and consumption. They perform Smart Grid analysis in Brazil through policies and regulations. By referring to the projects that have been done, they compare these projects according to the locations, the used technologies, and the electrical services' objectives. In this respect, they observe similarities or differences between locations according to the two criteria. The first criterion is that the project is reproducible and valid, while the second one is if the location is a tourist destination, whether this project is sustainable and there is national visibility.

In their study, Mallet *et al.* [31] compare the U.S. and Canada's Smart Grid approach over the news and articles in nationally popular newspapers. They stated that the news in the media includes public discourse and also shapes the public opinion. Despite the similarities between the two countries in terms of policies and distribution strategies on the Smart Grid, they point out differences in public discourse that are believed to be based on cultural differences. They mentioned that, as a result of this, the public affect policymakers and technology supporters as a driving force.

Brandstätt *et al.* [32] investigate Smart Grid visions and pilot projects in four selected countries. These countries are U.K., Denmark, France and the U.S. They compare them as centralized versus decentralized and full versus partial liberalization. As a result of the comparisons, they argue that different countries have different shareholders of Smart Grid responsibilities. They state that this is influenced not only by the characteristics of the countries, but also by their motivation. At the same time, they analyze the relationship between responsibility assignments and motivations. They point out that, while the UK is heading towards sustainable energy supply and reform in the sector, Denmark is focusing on renewable energies and decentralized generation and France aims to provide centralization with high modernization and technology.

Simoes *et al.* [33] discussed the historical and technical events in U.S and Europe that make the electricity network more modern. At the same time, this study compares two regions in terms of comparative metrics. They analyze the milestones and developments of the smart grid. According to this study, while Europe is emphasizing research and development with European Union's support, U.S prioritizes the dissemination of smart technologies and the providing information and control capability to consumers at the same time. As a result, the smart grid is accepted as the official policy for the modernization of the electricity grid.

Acharjee [34] refers to the necessity of diversifying in energy supply, and challenges and obstacles about this diversification in the global electric power industry, by studying in India. India's power grid situation and possible energy options are analyzed in his work. The effects of the smart grid are discussed in various areas such as social, economic, political and environmental. He addresses Government of India's initiatives on smart grid and suggested other steps to be taken.

Karali *et al.* [35] work on Smart Grid demonstration projects, such as quantifying performance and monetization after making the necessary investments. Two approaches are used for this. First one is the benefit analysis method with EPRI and JRC approach, the second one is Analytic Hierarchy Process and fuzzy logic decision-making method. Both methods are applied to the three case studies in each of the three countries, by considering the uncertainty of each project. These countries are the U.S., China, and Italy. According to the results, both approaches showed various deficiencies in evaluating the advantages.

In a study by Litos Strategic Communication [36], the US Department of Energy's (DOE) duties and responsibilities about the Smart Grid are mentioned. It is talked about the works done to better introduce to the stakeholders for not only the smart grid but also its benefits. Among the stakeholders are both consumption groups, technology companies and regulators, and politicians. Among the benefits are energy saving, money saving, as well as protection of consumers and the environment.

Gangale *et al.* [37] conducted a study that analyzes the participation of consumers in European-wide studies. At the same time, they pointed out that projects which involve consumers are classified according to two main objectives. While the first one is analyzing the behavior of consumers and having an idea about it, the other objective is trying to motivate the consumers to be active customers of the power grid. The study also refers to the projects and strategies that include the structures for these objectives, the obstacles faced, and the struggling against obstacles.

In this study for Switzerland, Kaufmann *et al.* [38] analyzed the value of smart metering, a feature of the smart grid, and studied convincing customers to this value.

The study of Lin *et al.* [39] includes a comparison of innovation policies on the Smart Grid of two industries on both sides of the Pacific, China and the U.S. The study based on Rothwell and Zegveld's innovation policy [40] framework as a starting point. The study also examines the relations and differences of preferences in power system to the state while defining Smart Grid policy instruments.

Fadaeenejad *et al.* [41] unlike other studies, they did a study on developing countries, not developed countries, on smart grid strategies. In this article, developing countries are categorized into two groups as pioneer developing countries, China, India, Brazil and other developing countries, Malaysia, Egypt, Thailand, and Iran, for their studies in Smart Grid field. According to findings, some countries have reached the level of research works, while others have achieved academic research levels which can be supported by the state and organizations. The fact that the countries in the pioneer group came to levels that can be compared with the developed countries has been stated that it may be a role model for the other developing countries.

Hashmi *et al.* [42] also produced a report about Smart Grid concepts and architectures in various parts of the world, including India and China. The report also presents countries' vision and road maps. In the report, comparisons are made as commercially, technologically and regulatory. Finally, the difficulties for implementing smart grid in Finland is examined.

Attar *et al.* [43] 's work for a region in Iran contains the Smart Grid road map of Iran. First, the smart grid and the smart transmission grid are defined, then the national grid of Iran is defined. Later on, the needs and challenges of Khorasan Regional Electricity Company, KREC, Iran's largest regional electricity company, to be able to have a smart grid were explained and a road map was drawn up to implement the smart grid in the future.

Suryanarayanan *et al.* [44] compare the growth of U.S. and Brazil's electrical infrastructure in their work. Basing on the Smart Grid initiative, the study examines the similarities and differences between the two countries' Smart Grid studies.

Akçanca *et al.* [45] analyzed the Turkey power grid and feasibility applicability of Smart Grid in Turkey. They researched generation, consuming, diversity and proportion of energy generation resources and real-time monitorability of consuming. They made suggestions for creating the infrastructure of Smart Grid in Turkey. In addition, plannings from worldwide are presented as examples, in their paper.

Colak *et al.* [46] examine the studies about the integration of Turkey's grid system with the European grid system. Firstly, the quality parameters of grid systems are mentioned. Then besides Turkey, they analyzed the criteria of synchronization and energy quality of Turkey's two contiguous countries, Greece and Bulgaria. Finally, they referred to identify the needs of Turkey's Power System by the concept of Smart Grid. Again, Colak *et al.* [47] analyzed the projects in Europe in the Joint Research Center - European Commission database. This analysis was based on the number, country and duration of the projects, and whether they were included in any corporation. In addition to this, the number of projects that started/ completed/planned to be completed and numbers of the participant are among the analysis criteria. In another study, Colak *et al* [48] presented an outline of projects in Europe and referred to infrastructures of Turkey's Generation, Transmission and Distribution companies and their Smart Grid applications. Turkey's Smart Grid infrastructure is examined by the SWOT analysis in this study.

Şanlı *et al* [49] tried to quantify the benefits of such a system to the consumer and the grid with multi-time tariffs in Turkey, after reviewing projects worldwide.

In his study, Kırmızıoğlu [50] examined Turkey's 2023 strategic vision and development plans, and [51] also explained the smart grid projects and strategies of many countries, analyzed the smart grid vision of different countries. These studies try to create a road map for smart grid works in Turkey. Recommendations are also presented to the shareholder corporations. In these studies, Kırmızıoğlu describes the projects of some countries such as Italy, Malta, Japan, South Korea, China, Canada and Australia.

The summary of literature survey is shown in Table 2.3 and Table 2.4.

Table 2.3: Summary of Literature Survey

Project	**Author**	**Focus**	**Type**	**Country**
A review on smart grids and experiences in Brazil	Di Santo *et al.*	Policies, regulations, projects and locations	Review	Brazil
Smart grid projects in Europe: Current status, maturity and future scenarios	Colak *et al.*.	Analyze the projects in Europe in the JRC	Review	EU
Strategy and implementation of Smart Grids in India	Acharjee, P.	Diversifying in energy supply and challenges and obstacles about this diversification	Review	India
What the smart grid means to americans	Litos Strategic Communication	Duties and responsibilities of DOE	Review	U.S
Consumer engagement: An insight from smart grid projects in Europe	F Gangale et. al	Analyzes the participation of consumers in European wide studies	Review	U.S
Customer value of smart metering: Explorative evidence from a choice-based conjoint study in Switzerland	S Kaufmann et al.	Analyze the value of smart metering	Review	Switzerland
Implementations of Smart Transmission Grid in Iran	Attar *et al.*.	Smart grid road map of Iran	Review	Iran
Developments of Turkish Grid System Infrastructure for Integration With Europe	Colak et. al	Integration of Turkey's grid system with the European grid system	Review & Comparison	Turkey
Smart Grid (Akıllı Şebekeler) : Türkiye'de Neler Yapılabilir?	Şanlı *et al.*.	Benefits of such a system to the consumer and the grid with multitime tariffs	Review & Comparison	Turkey & U.S
Smart grid opportunities and applications in Turkey	Colak *et al.*.	Outlined projects in Europe and referred to infrast. Of Turkey's electric companies	Review & Comparison	EU & Turkey
Smart-Grid Technologies and Progress in Europe and the USA	Simoes *et al.*.	Discussed historical and technical events	Review & Comparison	USA & EU
The present and future of smart power grid in developing countries	Fadaeenejad *et al.*.	Developing countries and their studies in smart grid field	Review & Comparison	China, India, Brazil, Malaysia, Thailand, Egypt, and Iran
Survey of Smart Grid Concepts, Architectures, and Technological Demonstrations Worldwide	Hashmi *et al.*.	Report smart grid concepts and achitechtures and countries' vision adn roadmaps	Review & Comparison	EU & US & China & India & Finland

TABLE 2.4: Summary of Literature Survey Cont'd

Project	**Author**	**Focus**	**Type**	**Country**
Akıllı Şebeke Uygulanabilirliği Açısından Türkiye Elektrik Enerji Sisteminin İncelenmesi	Akcanca *et al.*.	Turkey power grid and feasibility apicability of smart grid in Turkey	Review & Comparison	Turkey
Electric (dis) connections: Comparative review of smart grid news coverage in the United States and Canada	Mallett *et al.*.	News and articles	Comparison	U.S & Canada
Roles and Responsibilities in Smart Grids: A Country Comparison	Brandstatt *et al.*.	Projects as centralized vs decentralized and full vs partial liberalization	Comparison	UK & Denmark & France & U.S
Uncertainity in Beneft Cost Analysis of Smart Grid Demonstration-Projects in the U.S, China, and Italy	Karali *et al.*.	Quantifying performance and monetization of projects	Comparison	U.S & China & Italy
ülkemizin 2023 Stratejik Vizyonu Doğrultusunda Akıllı Şebekeye Geçilmesi için Öneriler	Kırmızıoğlu, E.	Turkey's 2023 strategic vision and development plan, smart grid visions of different countries	Comparison	EU & US & Japan
A comparison of innovation policy in the smart grid industry across the pacific: China and the USA	CC Lin *et al.*.	Comparison of innovation policies on the smart grid	Comparison	China & U.S
Grid Modernization Efforts in the USA and Brazil- Some Common Lessons Based on the Smart Grid Initiative	Suryanarayanan *et al.*	Compare the growth of US and Brazil's electrical infrastructure	Comparison	U.S & Brazil
Akıllı Şebeke Stratejileri ve Örnek Projeler	Kırmızıoğlu, E.			

2.4 Contribution of Study

In this study, the electricity generation processes, the general characteristics of the traditional grid and the differences of the smart grid were explained. The biggest difference of this study from other studies is that it is examined in a wide perspective from the generation of electricity to the most detailed bench marking metrics of smart grid. In the literature, that we utilized, Turkey either is mentioned in the general informations about projects, or it is subjected to comparison based on narrow-scoped criteria. In this study, in terms of projects, Turkey is compared with the pioneer country in six key areas, such as smart network management, demand side management, integration of distributed generation and storage, integration of large-scale renewable energy sources, e-mobility and others, also the number of projects carried out in Turkey compared with the average number of projects in these areas that are carried out by all the countries in the database. Unlike other comparison or benchmarking studies, comperative metrics were tried to be set as wide and comprehensive as possible. Some additions were made to the specified criteria. Thus, the projects, the defined criteria and the added new criteria were used in one study.

Chapter 3

Comparing Turkish Electricity System with Other Countries Considering Smart Grid Concept

3.1 Turkish Electricity System

In this section, the current situation of Turkish Electricity System is explained in detail. The installed power, generation and consumption amounts of the electrical energy in recent years are given in this section. In addition, analysis of the peak demand amounts and loss rates in electricity transmission and distribution grid are also provided.

3.1.1 Installed Power

Data is obtained from Turkish Electricity Transmission Company (TEİAŞ), the total installed capacities between 1975-2017 are shown in Figure 3.1. The installed power capacity, which was 4186.6 MW in 1975, increased by 20 times in 2017 to 85,200 MW. The increased capacity has gained momentum after 2009. According to projections, it is expected to reach 108,000 MW in 2021 [8, 52] .

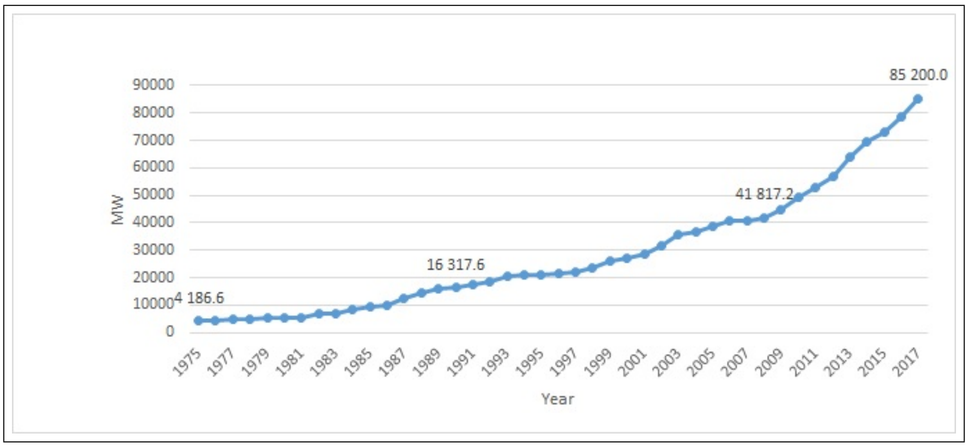


FIGURE 3.1: Total Installed Power Capacity in Turkey (1975-2017)

In Figure 3.2, the proportion of the installed capacity according to the institutions is given. The largest proportion of the installed capacity by the end of 2017 belongs to private sector with 61.4%. Followed by Electricity Generation Company (EÜAŞ), which is a state-owned company with 23.4% [8, 52].

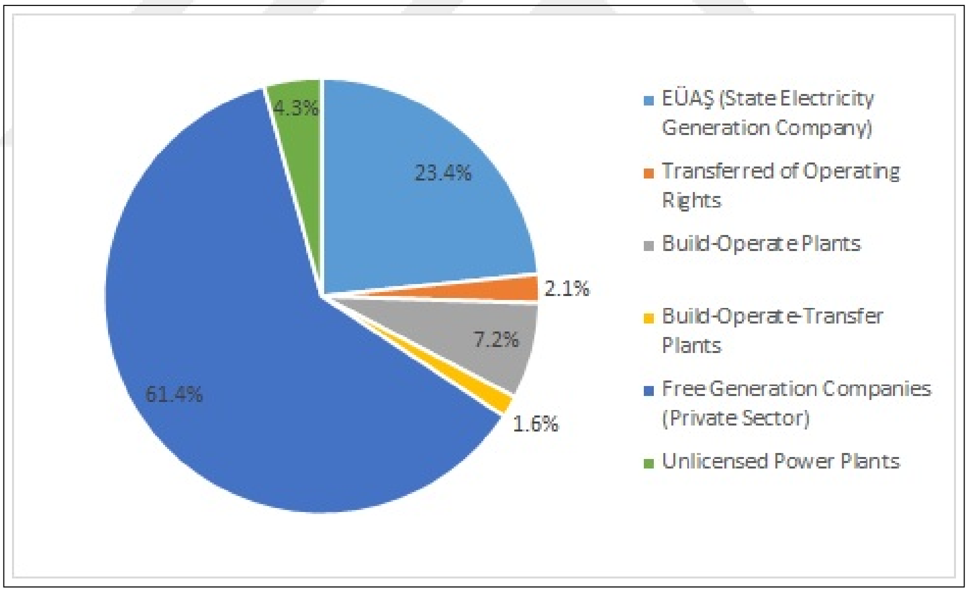


FIGURE 3.2: Installed Power Capacity According to Institution, 2017

Distribution of the installed power capacity according to sources, the largest two proportion is Hydraulic energy sources with 32% and Natural Gas with 31.1%. Proportions of other organizations and resources are also showed in detail in Figure 3.2 and Figure 3.3 [8, 52].

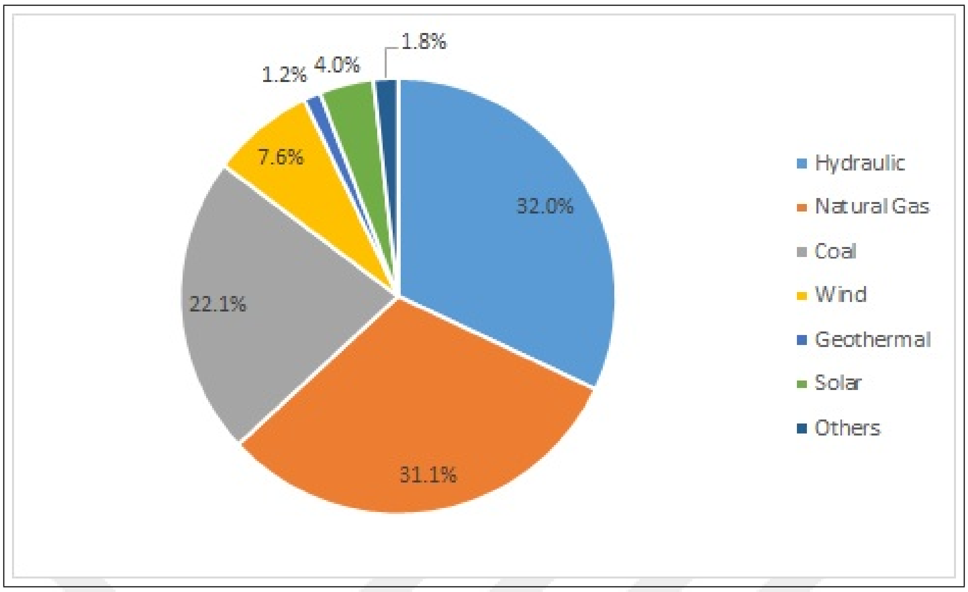


FIGURE 3.3: Installed Power Capacity According to Sources, 2017

3.1.2 Generation and Consumption

As it can be seen in Figure 3.4, according to TEİAŞ data, the electricity production amount has reached 19 times higher from 15,622.8 GWh in 1975 to 290,546.2 GWh in 2017. According to the same sources, the amount of consumption has increased from 13,491.7 GWh to 289,975.2 GWh, which is about 22 times higher.

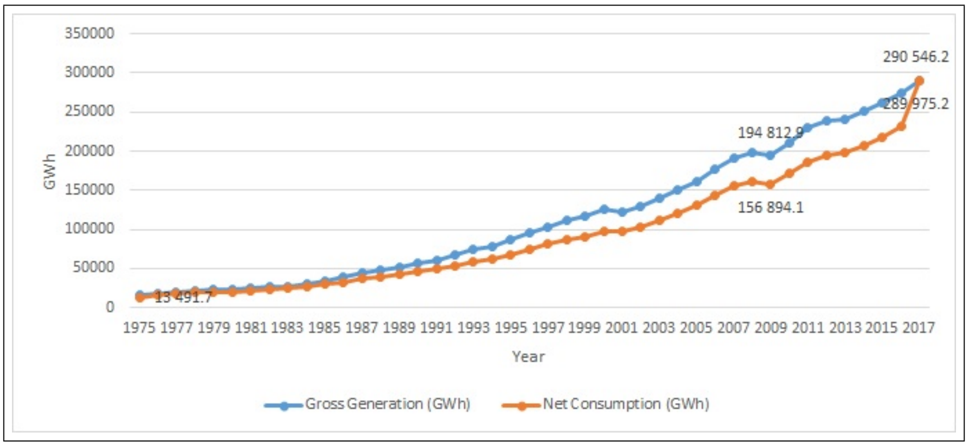


FIGURE 3.4: Amounts of Generation and Consumption (1975-2017)

Monthly electricity generation and consumption amounts for 2017 are shown in Figure 3.5. As can be seen in the figure, in summer (July-August) and winter (December-January) consumption is high.

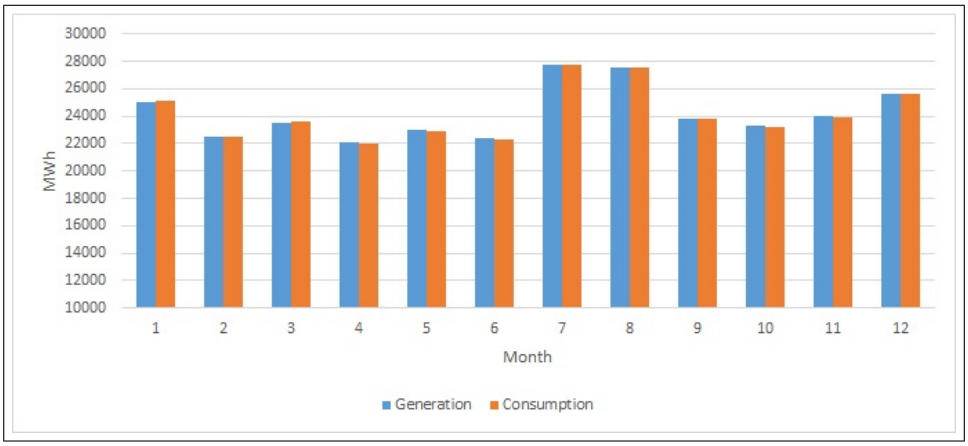


FIGURE 3.5: Monthly Comparison of Generation and Consumption, 2017

Peak loads for each month in 2017 are shown in Figure 3.6. Peak load quantities, as well as generation and consumption, have seen the highest amounts in July and August during the year.

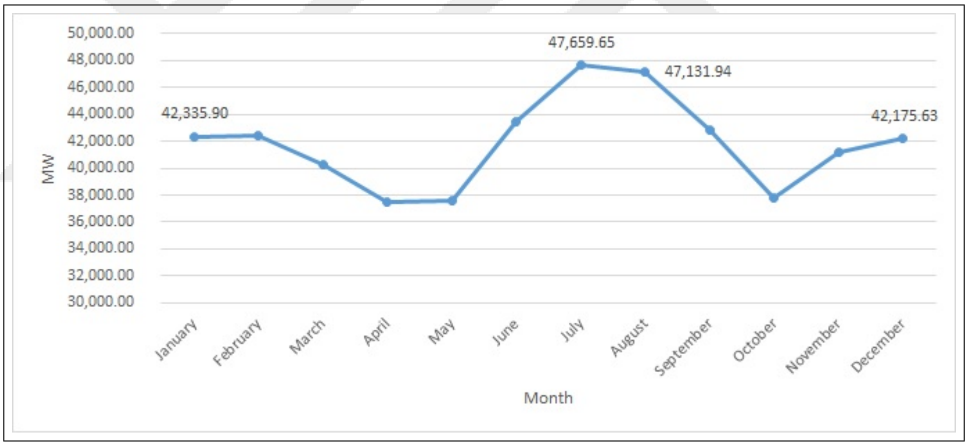


FIGURE 3.6: Instantaneous Peak Load, 2017

The annual development of electricity generation by energy sources between 2006-2016 and generation rates according to sources in 2017 are shown in Figure 3.7 and Figure 3.8, respectively. As it could be seen in detail, Natural gas has the highest share in all years except 2016. The highest generation rate in 2016 is owned by the coal, rising from 2006 onwards [53].

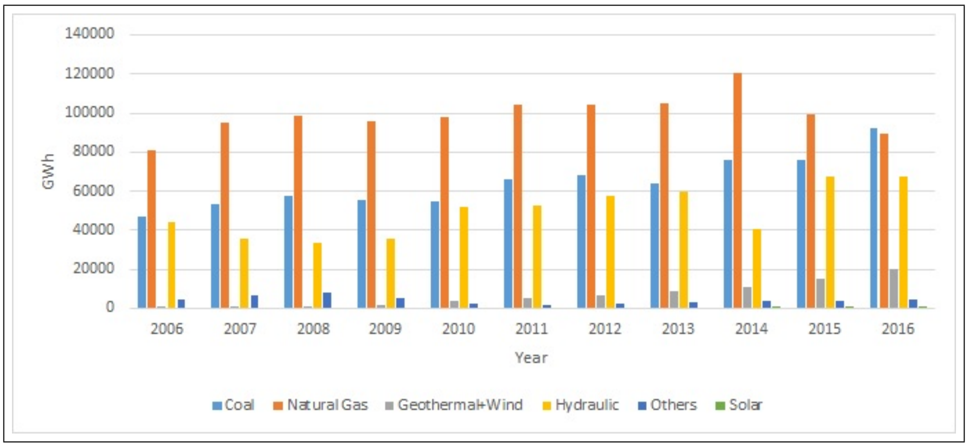


FIGURE 3.7: Annual Development of Electricity Generation by Energy Sources (2006-2016)

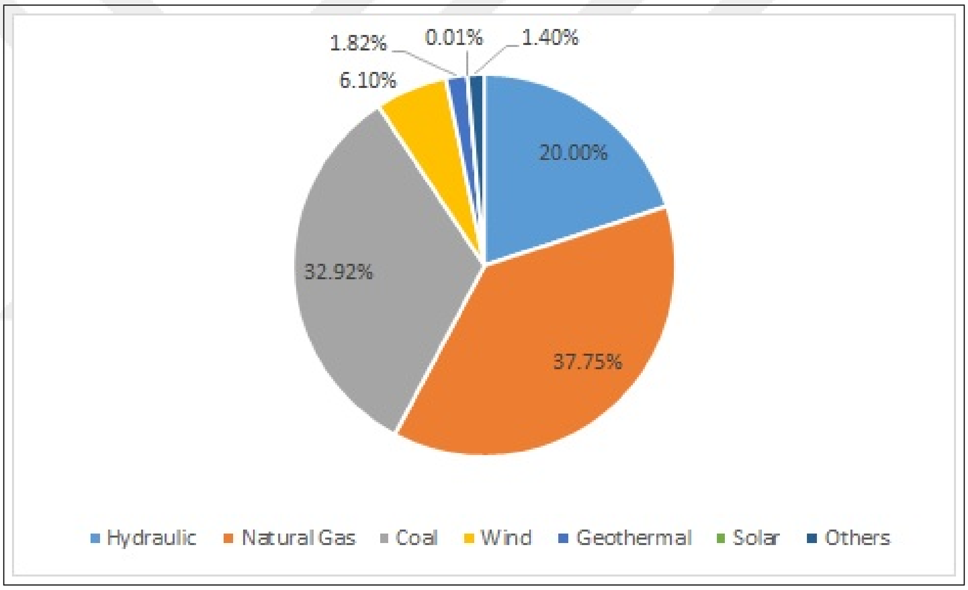


FIGURE 3.8: Generation Rates According to Sources, 2017

According to the base-case scenario in the projections, electricity consumption in 2023 is expected to reach 385 TWh [54].

3.1.3 Transmission System

The transmission system consists of cables, transformers and substations. According to the Energy Market Regulatory Authority (EPDK) data, as of 2016, there are 997 substations and 2038 transformers with 180,485 MVA capacities in the transmission system. The total length of the transmission line is 61,269 kilometers. The number of transformers and their powers between 2002-2015 and development of transmission lines lengths is shown in Table 3.1 and Table 3.2, respectively. The detailed amounts of the substations and lines according to the voltage levels in 2016 can be seen in Table 3.3. As can be seen from the tables, the majority of substations and transmission lines consist of 154 kV voltage level equipment. TEİAŞ has invested 1.9 billion TL in transmission lines in 2016. The loss rate of the transmission system is 2.23% [9, 55].

Table 3.1: Number of Transformers & Power of Transformers[8]

YEARS	400 kV		154 kV		66 kV ve less		TOTAL	
	NUMBER OF TRANS-FORMERS	POWER (MVA)	NUMBER OF TRANS-FORMERS	POWER (MVA)	NUMBER OF TRANS-FORMERS	POWER (MVA)	NUMBER OF TRANS-FORMERS	POWER (MVA)
2002	111	18910.0	882	45446.9	62	776.6	1055	65133.5
2003	116	20110.0	893	46240.4	63	734.3	1072	67084.7
2004	121	21290.0	905	46917.4	63	734.3	1089	68941.7
2005	132	24240.0	899	46979.0	57	678.0	1088	71897.0
2006	151	28015.0	923	49385.0	56	662.0	1130	78062.0
2007	153	28715.0	963	52669.0	57	672.0	1173	82056.0
2008	174	33220.0	1010	55584.0	57	672.0	1241	89476.0
2009	184	35020.0	1034	58015.0	54	637.0	1272	93672.0
2010	197	37870.0	1067	61365.0	53	617.0	1317	99852.0
2011	203	39620.0	1105	64470.0	49	568.0	1357	104658.0
2012	222	43795.0	1153	68458.0	50	593.0	1425	112846.0
2013	245	48540.0	1212	73123.0	48	573.0	1505	122236.0
2014	255	50415.0	1245	76317.0	48	573.0	1550	127705.0
2015	282	56665.0	1302	81365.0	42	521.0	1628	138951.0

Table 3.2: Developments of Transmission Lines Lengths[8]

YEARS	400 kV (km)	220 kV (km)	154 kV (km)	66 kV (km)	TOTAL
2002	13625.5	84.5	28506.0	549.3	42765.3
2003	13958.1	84.5	30961.7	718.9	45723.2
2004	13970.4	84.5	31005.7	718.9	45779.5
2005	13976.9	84.5	31030.0	718.9	45810.3
2006	14307.3	84.5	31163.4	477.4	46032.6
2007	14338.4	84.5	31383.0	477.4	46283.3
2008	14420.4	84.5	31653.9	508.5	46667.3
2009	14622.9	84.5	31931.7	508.5	47147.6
2010	15559.2	84.5	32607.8	508.5	48760.0
2011	15978.4	84.5	32878.4	509.4	49450.7
2012	16343.7	84.5	33480.8	509.4	50418.4
2013	16808.3	84.5	33942.5	509.4	51344.7
2014	17682.8	84.5	35132.0	509.4	53408.5
2015	19070.9	84.5	37500.5	139.7	56795.6

Table 3.3: Numbers and Power Amounts of Substations and Length of Power Lines According to Voltage [9]

Voltage (kV)	TEIAS Ownership			Private Ownership			Lines	
	Number of Sub-stations	Number of Trans-formers	Total Trans-formers Power (MVA)	Number of Sub-stations	Number of Trans-formers	Total Trans-formers Power (MVA)	Number of Lines	Length (KM)
380	98	298	61060	20	39	5785	245	20250
220	1	2	400	0	0	0	1	16
154	653	1342	91915	215	330	20923	1483	40883
66	9	26	392	1	1	10	17	121
Total	761	1668	153767	236	370	26718	1746	61269

3.1.4 Distribution System

Turkey Electricity distribution and retail business is carried out by 21 private companies in 21 separate regions under the supervision of Turkey Electricity Distribution Corporation (TEDAŞ). The distribution network consists of cables, transformers and substations. There are 41,055,915 consumers in Turkey electricity distribution system in 2016 according to EPDK data. The number of consumers according to distribution companies is given in Table 3.4 in the descending order in terms of the number of subscribers.

TABLE 3.4: Number of Consumer According to Distribution Company [9]

Distribution Company	Number of Consumer	Distribution Company	Number of Consumer	Distribution Company	Number of Consumer
BOĞAZİÇİ	4,872,387	MERAM	1,964,377	TRAKYA	991,026
BAŞKENT	4,099,788	YEŞİLIRMAK	1,938,042	ARAS	935,816
TOROSLAR	3,669,912	ADM	1,787,566	ÇAMLIBEL	917,913
GDZ	3,061,100	DİCLE	1,675,698	FIRAT	888,483
ULUDAĞ	2,983,810	OSMANGAZİ	1,661,395	KAYSERİ VE CİVARI	673,432
İ.ANADOLU	2,751,857	SAKARYA	1,654,546	AKEDAŞ	635,620
AKDENİZ	2,000,386	ÇORUH	1,269,278	VANGÖLÜ	623,483
		TOTAL	41,055,915		

There are 426,299 transformers with 148,368 MVA power in the distribution network. The length of the distribution lines is 1,102,508 km. While the overhead lines constitute the majority with 933,158 km, the underground lines are 169,369 km. Loss rates in the distribution network vary widely depending on the region. The highest loss and leak rate is in Dicle distribution area with 67.63% while the lowest rates are in Trakya distribution area with 5.46% and Uludağ distribution area with 5.57%. Detailed loss rates by distribution companies are given in Figure 3.9. A total of 4.28 billion TL was invested in the distribution network in 2016.

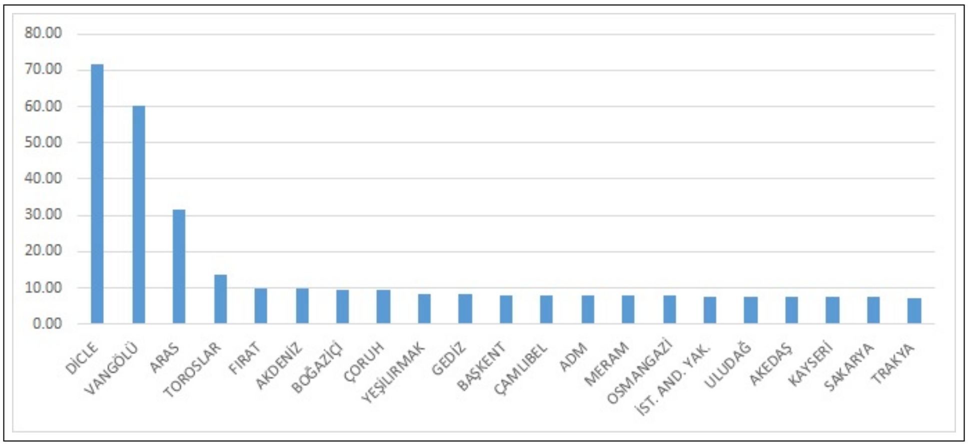


FIGURE 3.9: Loss Rates According to Distribution Companies in 2016

3.2 Overview of Smart Grid Studies in Turkey

There are various studies related to Smart Grid in Turkey. In the past years, those are studied under the concepts of "New Generation Network" and "Intelligent Grid" were carried out to make the grid better. However, it is not known exactly when the smart grid concept first emerged in Turkey. The first known general comprehensive study is the 2012-2023 Energy Efficiency Strategy Document which is prepared by the supervision of Ministry of Energy and Natural Resources in 2011. Public institutions, the private sector, and non-governmental organizations participated in the preparation of this document. Subjects of the work which has the number SA-04/SH-02/E-01 are the tariff scaled according to the amount of energy and power, the implementation of multi-stage meters and smart grid applications. The basis of studies related to smart grids in Turkey is replacing existing meters with smart meters and remote metering these meters with an automated metering system [56].

In addition, according to the Electricity Distribution and Retail Sale Quality of Service Regulations of Energy Market Regulatory Authority (EMRA) electricity market legislation, information and communication systems such as automatic monitoring systems and geographic information systems, remote monitoring and control, distribution system management and smart meter infrastructure are emphasized and investments are made in these areas [57].

At the meeting held with the participation of representatives of EMRA and Electricity Distribution Companies on 01.06.2012, the "Smart Grid" was discussed and the topics involves the improvement of the electricity distribution network, the provision of the network with communication infrastructure, the integration of distributed generation facilities into the system and electric vehicles etc. [58]. After the meeting, "Smart Grid Platform" was established with the participation of electricity distribution companies.

Studies are also being carried out on the real-time examination of energy in a wide range subject in our country. The "National Power Quality Project" has been carried out since 2006 in order to monitor the power quality components, power, and energy flow as uninterruptedly. In this project, real-time monitoring of all electrical size and power quality parameters of the power transmission system has been carried out nationwide [59].

The 2015-2019 Strategic Plan [60], published by the Ministry of Energy and Natural Resources, consists of 8 main themes and a total of 16 objectives under these themes. Within these objectives, 62 detailed targets related to these objectives are included. The themes are as follows:

1. Energy Supply Security
2. Energy Efficiency and Energy Saving
3. Good Governance and Stakeholder Interaction
4. Regional and International Activity
5. Technology, R&D and Innovation
6. Improvement of Investment Environment
7. Raw Material Procurement Security
8. Productive and Efficient Use of Raw Material

Within these themes, there are some aims planned to achieve. Ensuring that the energy infrastructure is robust and reliable, achieving the optimum levels of resource diversity, and pursuing the demand management is actively are some of these aims. In addition, it is aimed to be a country that uses energy efficiently, makes advanced capacity building to achieve this efficiency, and has a ministry that effectively uses information technologies. At the same time, it is desired to become a strong country in the regional arena by integrating into the regional energy market. It is aimed to be more result oriented in R&D studies and to use domestic technology in energy and natural resource studies.

Among the steps taken towards the purpose of transition to the Smart Grid are the following: Energy Investments, Renewable Energy Investments, Environmental Investments, Transmission and Distribution network Investments and Efficiency.

3.2.1 General Energy Investments

According to the Ministry of Energy and Natural Resources data, it can be seen in the Table 3.5 when the Energy Investment reports of the last 10 years are examined, it seems that the most investment is to thermal power plants to meet the demand. Although has remained behind investments made in Wind Energy in recent years the second area which investment is made in hydraulic power plants in general terms. There is some investment in solar energy only in the recent years [10].

Percentages of total investments for last 10 years, calculated from the data in Table 3.5, are shown in the Figure 3.10:

TABLE 3.5: Amount of Investments According to Fuel Types, Between 2008-2017[10]

Fuel Type	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**TOTAL (MW)**
Thermal	403.704	1835.392	3150.084	1666.021	1011.299	3647.178	3899.960	958.436	3531.139	3295.402	23398.615
Hydraulic	432.693	725.168	1299.449	1305.624	2534.645	2613.359	1368.755	2229.462	809.720	525.174	13844.049
Wind	217.100	439.100	528.600	408.550	531.850	498.100	882.290	830.750	1245.678	711.965	6293.983
Geothermal	6.850	47.400	17.000	20.000	48.000	148.620	94.100	218.957	196.980	198.870	996.777
Waste, Biomass, Waste Heat, Stack Gas	16.960	21.673	17.092	18.532	118.721	79.078	60.069	49.966	122.681	77.627	582.399
Solar	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	12.900	1.000	13.900
TOTAL	1077.307	3068.733	5012.225	3418.727	4244.515	6986.335	6305.174	4287.571	5919	4810	45129.723

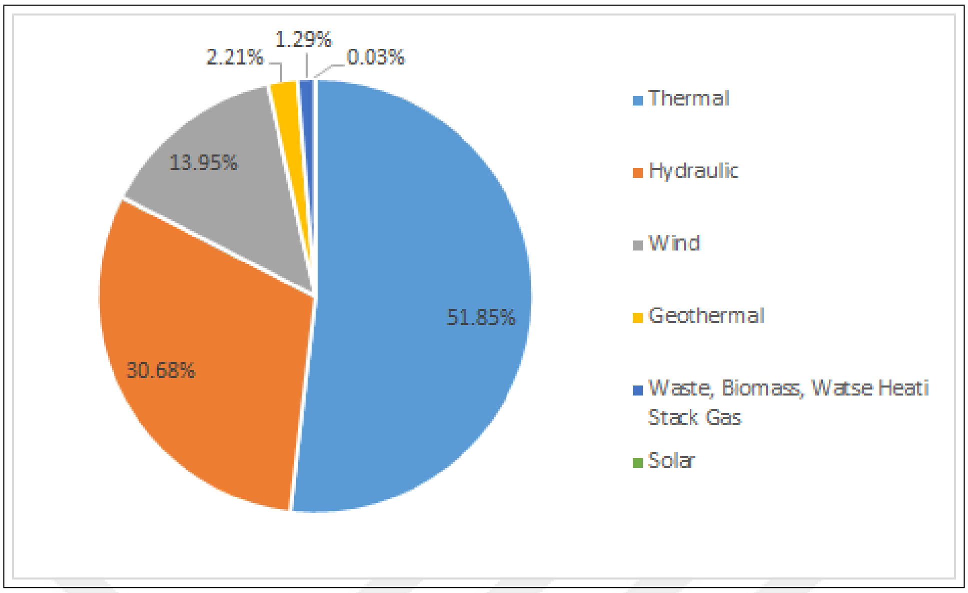


FIGURE 3.10: Rates of Total Investments According to Source Type Between 2008-2017

3.2.2 Renewable Energy Investments

Diversification of Renewable Energy Sources and increasing their share are might be the most important steps for the transition to Smart Grid. Important projects carried out in Turkey in this area. The largest PV solar power plant of Turkey will be established in the region of Konya Karapınar in 2018. A total investment of $1 billion was made for this facility and an additional investment of $300 million was selected the same facility to set up a production facility with solar panels. The plant will have 500 MW energy generation capacity annually and will have a potential to meet the daily energy needs of more than 600,000 households.

In addition, the capacities of LNG (Liquid Natural Gas) plants, which allow natural gas to be stored as the liquid and served in gas form if needed, are also increased. Besides, "The Project of Tracking Electrical Power which is produced by wind and Forecasting System Development in Turkey (RITM)", the Large-Scale Wind Power Plants (RES) is intended to ensure the integration of Turkey Electrical Systems [61].

3.2.3 Environment

In the last 20 years, various studies have been carried out on environment, which is one of the key areas of Smart Grids. The stack gas treatment plant projects have been carried out in order to reduce the emission values of the resulting sulfur dioxide to below the limit values specified in the Regulation on the Protection of Air Quality. Within this context, stack gas treatment facilities were integrated into Çayırhan (1st and 2nd units) in 1991, Orhaneli in 1998, Kemerköy in 2002, Yatağan in 2007, Yeniköy Power Plant in 2008 and then activated. In 2000, Çayırhan (3 and 4 Units) and Kangal (3rd Unit) and in 2005, Afşin Elbistan-B Thermal Power Plants, Stack Gas Sulfur Treatment Plant was made with the power plants and taken over.

3.2.4 Energy Efficiency

There are various studies about energy efficiency in the whole world. In recent years, cost reductions have been realized in large quantities with the more efficient use of the available electric power. There are many ongoing projects about energy efficiency in Turkey. The realization of energy efficiency in Turkish Industry "Improving Energy Efficiency in Industry Project", dissemination the using of energy efficient electrical appliances and accelerating the market transformation "Energy Efficient Electrical Household Market Transformation Project" are among the ongoing projects. Within the scope of support for the monitoring and evaluation "Tracking Energy Efficiency in Turkey and Developing Assessment Project (Netherlands / Turkey cooperation)" and related to increasing energy efficiency in the building sector project" are also among the ongoing projects. Various statements on energy efficiency are existing in Ninth Development Plan accepted in Turkey and the Medium Term Program. Some of these statements are the efficient use of energy in every phase from generation to consuming, demand-side management and the reduction of the loss-to-leak rates [62][1]. The efficiency of Consuming Energy should be increased by 20% until 2023 in Turkey by Energy Efficiency Law [2] .

3.2.5 Distribution Companies Studies

ELDER (Association of Distribution System Operators) is a non-governmental and umbrella organization for Turkey Distribution Company. It is also helping to coordinate companies by bringing them together. According to the distribution companies' authorities, some of the distribution companies have invested and implemented Smart grid applications. For instance, according to the manager of two joint distribution company, approximately 3 thousand 350 km of distribution lines, 546 distribution transformers and 743 thousand customers were invested in 2 distribution areas served by 2015. Implementations and investments in Geographic Information Systems (GIS), SCADA (Supervisory Control and Data Acquisition), DMS, Outage Management Systems (OMS), and Automatic Meter Reading System (AMRS) are ongoing. Thanks to these systems the power

[1]T.C Resmi Gazete, Dokuzunca Kalkınma Planı Stratejisi (10399), 13.05.2006
[2]T.C Resmi Gazete, 5627 Sayılı Enerji Verimliliği Kanunu (26510), 02.05.2007

system can be monitored remotely, and it is possible to detect and take precautions before failures occur. As a result, the opportunity to provide better quality service to consumers in the region is emerging.

Some of the Distribution Companies using SCADA and DMS that are able to monitor and manage the electricity network. They are aiming to increase the continuity and quality of supply. At the same time, they are continuing the Smart Grid Feasibility Study. And some other companies from the different region in Turkey using also GIS, AMRS and Integrated Information Systems. One of these companies which is serving electricity to middle part of the Turkey, using Customer Relationship Management.

3.3 Comparison of Turkey with Some Countries

Each country could approach the Smart Grid differently and could focus on different areas of the smart grid. Therefore, it is not possible to say that one grid is better than the others. Since the Smart Grid does not have a single definition there are no fixed metrics to measure smartness of the grid. However, it is possible to compare the countries how many project they carried out in some different domains about smart grid and also how well they adapt their grid in different areas of the smart grid by means of some defined performance indicators. In this section, Turkey will be compared with other countries through performance indicators presented in the study of Dupont et al. [4]. Dupont et al. [4] determined six characteristics for Smart Electricity Grid benchmarking. These are "Enabled informed participation by customers, Accommodate all generation and storage options, Sell more than kWhs, Provide power quality for the 21st Century, Optimize assets and operate efficiently, Operate resiliently to disturbances, attacks and natural disasters". They evaluated these characteristics by dividing 24 categories can be found in Appendix A A.1. In addition we expand this characteristics to eight with adding renewable energy sources and projects supported by the European Commission. Analyses of projects are carried out using data which are updated by the end of 2017 obtained from the report by Joint Research Centre [63].

3.3.1 Smart Grid Projects Supported by European Union

Turkey will be compared with some countries on the basis of involving or performed projects supoorted by European Union according to the results of analyses. In a nutshell, there are 950 projects totally participated by 49 countries. 540 of these projects are R&D projects, 410 of them are demonstration projects. 626 projects are national and 324 projects are multinational. The projects are classified into six separate main application headings. These are Smart Network Management (SNM), Demand Side Management (DSM), Integration of Distributed Generation and Storage (IofDGS), Integration of Large-Scale Renewable Energy Sources (IofLSRES), E-Mobility and Others. Others domain includes some headings which are not included in previous five identified headings, such as market and regulation, cybersecurity and developments of energy infrastructure roadmaps.

The first project supported by the European Commission in the database of the Joint Research Centre is a Research & Development project and it is a multinational project, which started in 1994 in partnership with Spain, Portugal and Belgium. The three most up-to-date projects in the database are started in 2016. These three projects are demonstration projects. One is a national project of Romania and is planned to be completed in 2018. The others are multinational projects and participated by Norway, Sweden, Portugal and Turkey and one of them is planned to be completed in 2018 and the second one is in 2019. Project numbers of all countries between 1994-2016 are shown in Figure 3.11:

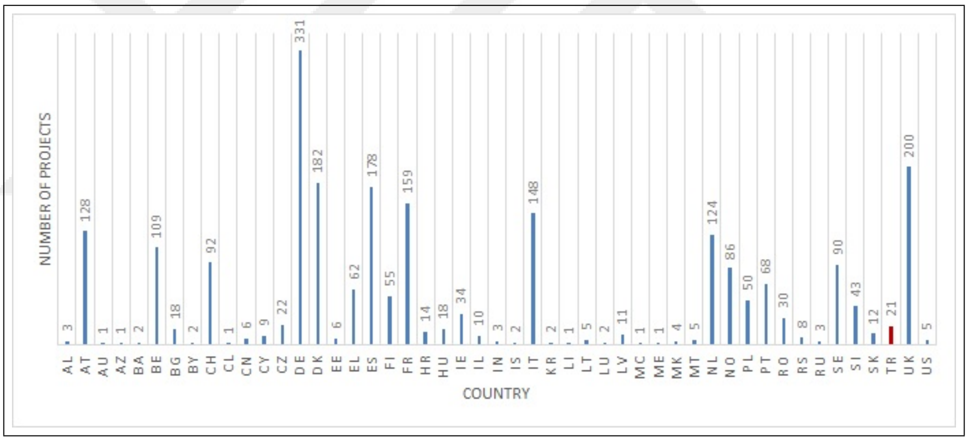


Figure 3.11: The Number of Projects per Country (1994-2016)

As shown in Figure 3.11, Germany is the first country in terms of the number of projects. Germany participates in 140 national, 191 multinational projects and amount of 178 of these projects are R&D and 153 are demonstration projects. Germany has studied mostly in SNM, DSM and Int. of DG&S areas. The second is the United Kingdom with 200 projects. The United Kingdom took part in 73 national, 127 multinational projects. Of these projects, 96 are R&D projects and 104 are demonstration projects. Other countries in more than 100 projects are Denmark (182), Spain (178), France (159), Italy (148), Austria (128), Netherlands (124) and Belgium (109). The number of projects started in each year in Europe is shown in Figure 3.12. The distributions of R&D and demonstration numbers of the projects are shown in Figure 3.13:

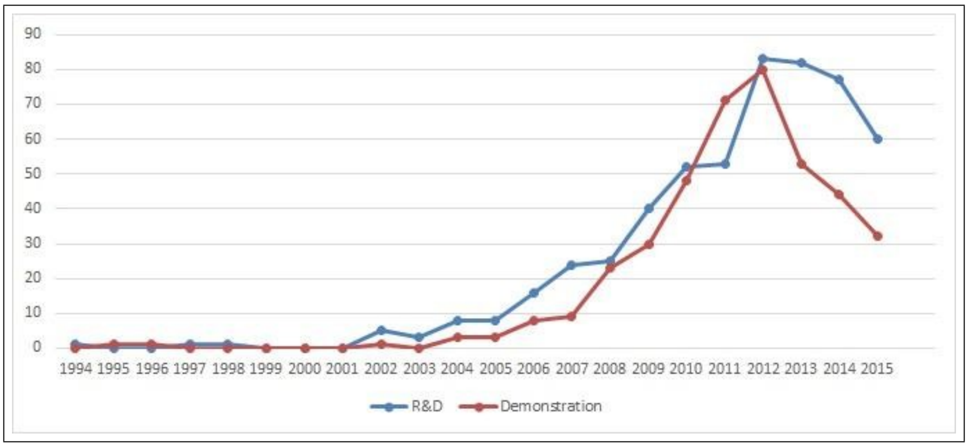


FIGURE 3.12: The Number of Projects Started in Each Year in Europe (1994-2015)

Over the years, there has been a radical increase in the number of projects as a result of countries' increased interest and inclination towards the Smart Grid.

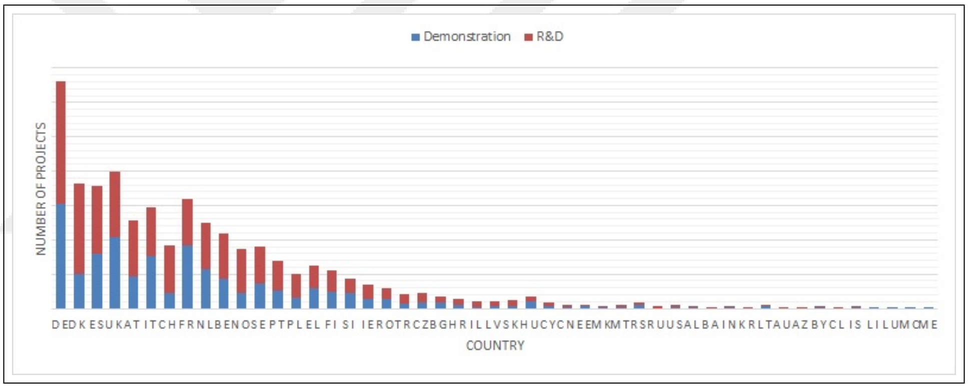


FIGURE 3.13: The Number of R&D and Demonstration Projects per Country (1994-2016)

If we look briefly to Turkey, Turkey has been involved in 21 projects in total. Two of these projects are categorized as national and 19 are multinational. As shown in Figure 3.14, 14 of these projects are R&D projects and seven are demonstration projects. Turkey has been a participant of eight projects (five are R&D, three are demonstration) in SNM domain, seven (four R&D, three demonstration) are in DSM, seven projects (three R&D, four demonstration) in integration of DG & Storage part, one project (R&D) in integration of Large-Scale RES field, one in (demonstration) the area of E-mobility and four projects (three R&D, one demonstration) in the Other domains.

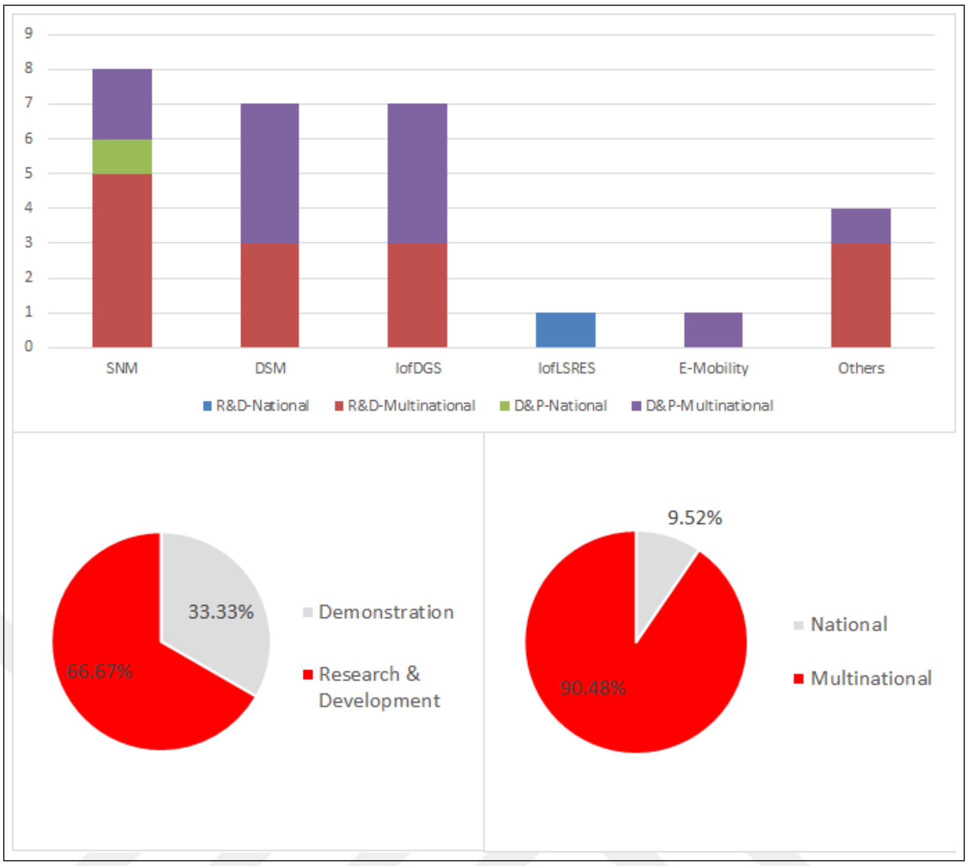


FIGURE 3.14: The Number of Projects in Turkey (1994-2016)

Turkey has been a participant in projects conducted in each area. However, it is clear that national projects are less than multinational projects. The superiority of R&D projects to demonstration projects is shown in the 3.14.

In following sections for each category, we will compare Turkey with different countries in that area and average number of projects are carried out by all countries included in database. We select countries by having most projects in that area. There is not any repetition of the compared countries. Comparison continues with secondary or next country.

There are 410 projects including Smart Network Management. While 237 of these projects are R&D projects, 173 of them are demonstration projects. 270 of these projects are carried out as national and 140 are multinational. Germany has the most projects in this area with 138 projects. Germany implements 81 of these projects as R&D projects and 57 of them as demonstration projects. Germany, which has 331 projects in total, has deployed 107 of these projects in the DSM area (40 R&D, 67 demonstration), 127 in integration of DG&Storage (56 R&D, 71 demonstration), 24 in the integration of Large-Scale

RES (18 R&D, six demonstration), 60 in the field of E-mobility (24 R&D, 36 demonstration) and 24 in the other areas (19 R&D, five demonstration). The comparison of Turkey and Germany which is the pioneer in this area is in Figure 3.15. Germany has the largest number of national projects in this area. Turkey has conducted only one national project. It has generally been a participant of multinational projects. Turkey and Germany are participant in 3 common projects in this area while they have 13 in total. Number of Projects in Turkey vs Average Number of Projects According to Countries in SNM shown in Figure 3.16

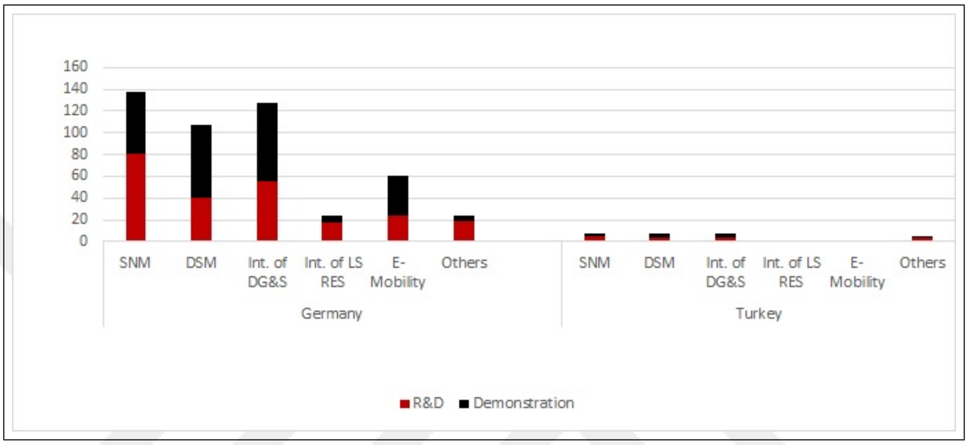


FIGURE 3.15: Comparison of Number of Projects between Germany vs Turkey (1994-2016)

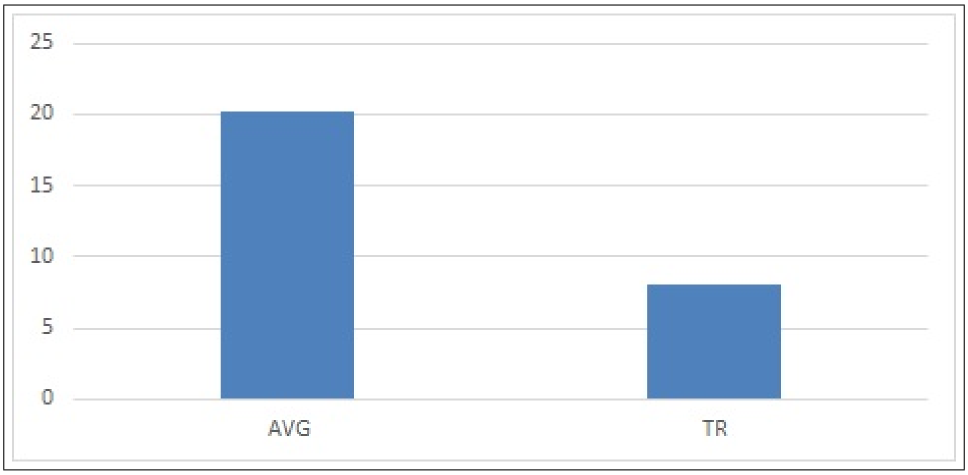


FIGURE 3.16: Number of Projects in Turkey vs Average Number of Projects According to Countries in SNM (1994-2016)

There are 346 projects including Demand Side Management. 143 of these projects are R&D projects and 203 are demonstration projects. 208 of these projects are applied as national and 138 are as multinational. In this area also Germany is the most active country with 107 projects. Spain has come after from Germany with 79 projects. Spain implemented 33 of these projects as R&D projects and 46 of them as demonstration projects. Spain, which has 178 projects in total, 71 of these projects in the SNM area (37 R&D, 34 demonstration), 73 in integration of DG & Storage (33 R&D, 40 demonstration), 11 in the integration of large-scale RES (eight R&D, three demonstration), 24 in the field of E-mobility (12 R&D, 12 demonstration) and 16 in the other areas (13 R&D, three demonstration). Turkey's comparison with Spain, which is one of the pioneers in this field of study is in Figure 3.17. Spain has only seven national DSM projects while Turkey does not have any national projects in this area. Both countries are participants mostly in multinational projects. Turkey and Spain are participant in 4 common projects in this area while they have 15 in total. Number of Projects in Turkey vs Average Number of Projects According to Countries in DSM shown in Figure 3.18

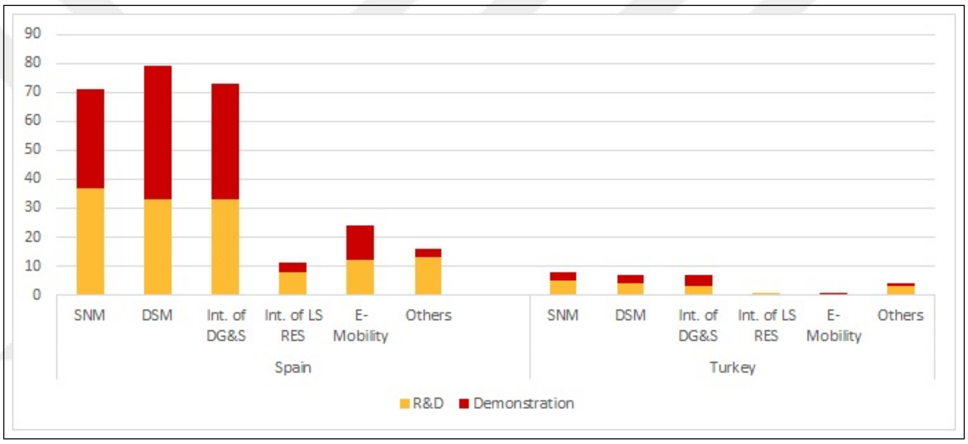


FIGURE 3.17: Comparison of Number of Projects between Spain vs Turkey (1994-2016)

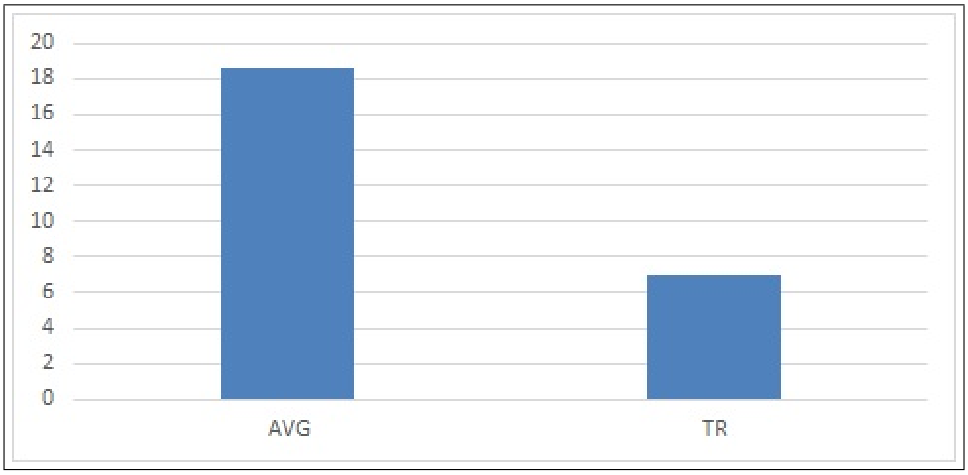


FIGURE 3.18: Number of Projects in Turkey vs Average Number of Projects According to Countries in DSM (1994-2016)

There are 367 projects including Integration of Distributed Generation and Storage. 182 of these projects are R&D projects and 185 are demonstration projects. 247 of these projects are national and 120 are multinational. Germany has the most projects in this area with 127 projects. After Germany, the United Kingdom comes with 82 projects. The United Kingdom implemented 35 of these projects as R&D projects and 47 of them as demonstration projects. The United Kingdom, which has a total of 200 projects, included 101 of these projects in the SNM area (49 R&D, 52 demonstration), 75 in the DSM field (20 R&D, 55 demonstration), 12 in the integration of large-scale RES (eight R&D, four demonstration), 17 in the field of E-mobility (eight R&D, nine demonstration) and 11 in the other areas (eight R&D, three demonstration). Turkey's benchmark with the United Kingdom, one of the pioneering country in this area is in Figure 3.19. While Turkey does not have any national projects in this area, the United Kingdom applied 40% of its projects as national. Turkey and United Kingdom are participant in 2 common projects in this area while they have 11 in total. Number of Projects in Turkey vs Average Number of Projects According to Countries in IoDGS shown in Figure 3.20

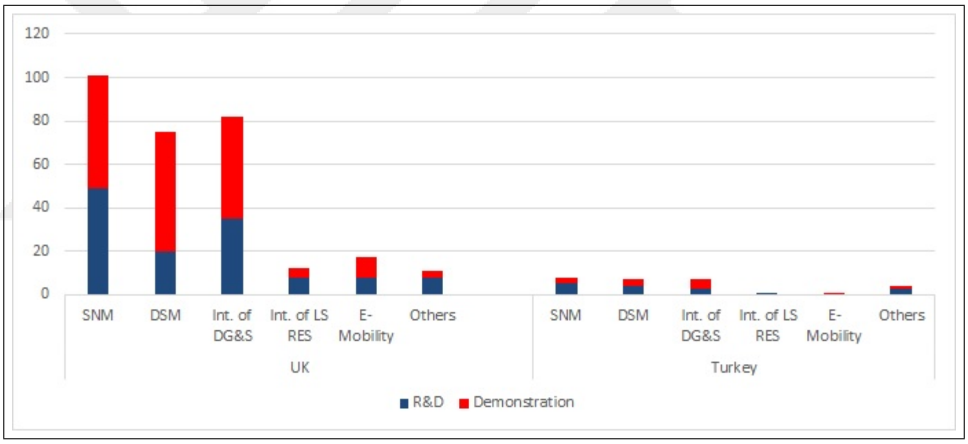


Figure 3.19: Comparison of Number of Projects between the United Kingdom vs Turkey (1994-2016)

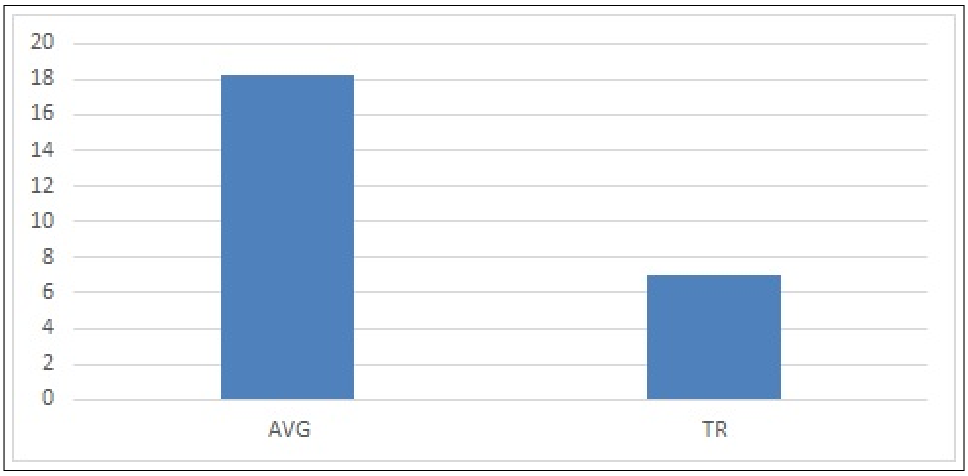


FIGURE 3.20: Number of Projects in Turkey vs Average Number of Projects According to Countries in IoDGS (1994-2016)

There are 39 projects in the area of Integration of Large-Scale Renewable Energy Sources. 30 of these projects are R&D projects and nine of them are demonstration projects. 23 of these projects are carried as national and 16 are multinational. In this area also Germany is the pioneer country with 24 projects. After Germany, Denmark is the second country with 16 projects. Denmark implemented 11 of these projects as R&D projects and five of them as demonstration projects. DK, which is located in 182 projects in total, consists of 62 of these projects in the SNM area (45 R&D, 17 demonstration), 67 in the DSM area (41 R&D, 26 demonstration), 70 in integration of DG & Storage (47 R&D, 23 demonstration), 21 in the field of E-mobility (14 R&D, seven demonstration) and 13 in the other areas (11 R&D, two demonstration). The comparison of Turkey and Denmark is in Figure 3.21. Turkey carried out its one project in this area as national while Denmark has five national and 11 multinational projects. Turkey and Denmark aren't participant in any common projects in this area while they have 8 in total. Number of Projects in Turkey vs Average Number of Projects According to Countries in IoLSRES shown in Figure 3.22

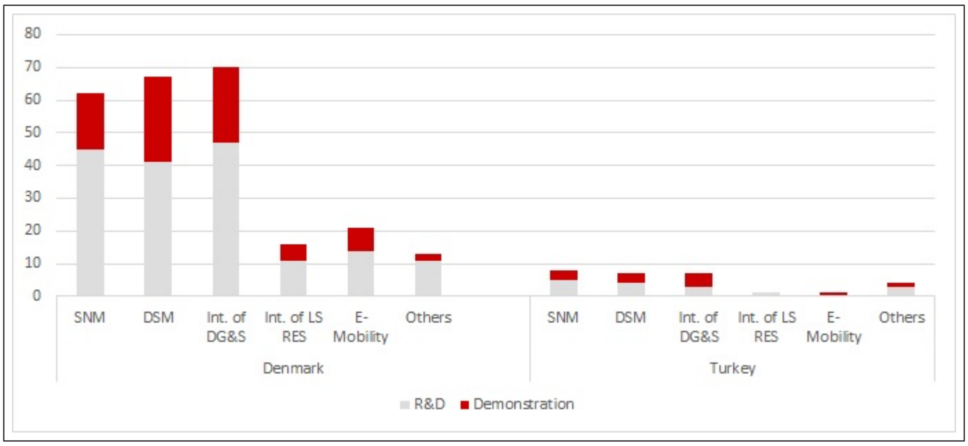


FIGURE 3.21: Comparison of Number of Projects between Denmark vs Turkey (1994-2016)

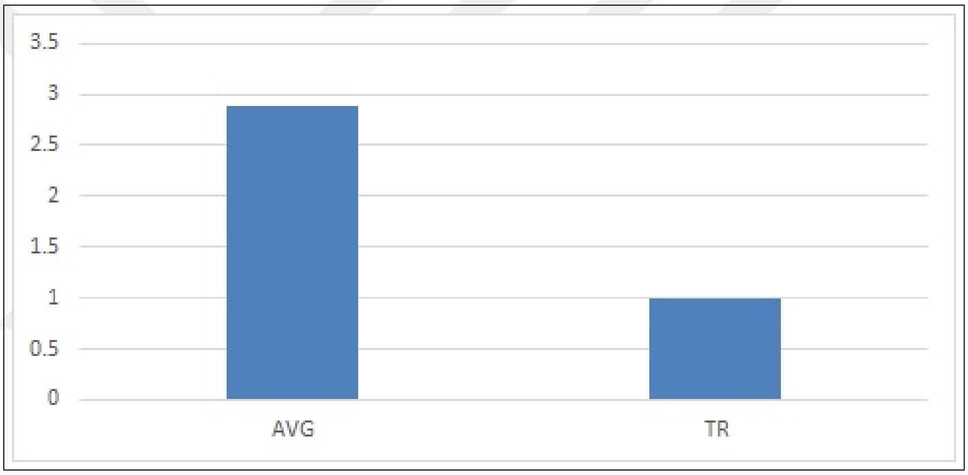


FIGURE 3.22: Number of Projects in Turkey vs Average Number of Projects According to Countries in IoLSRES (1994-2016)

There are 131 projects covering the field of e-mobility. 57 of these projects are R&D projects and 74 of them are demonstration projects. In these projects, 95 of them are applied as national and 36 of them are multinational. In this area, Germany also has the most number of projects with 60 projects. After Germany, Spain is second with 24 projects and France is third with 22 projects. France implemented 8 of these projects as R&D projects and 14 of them as demonstration projects. France has 159 projects in total and 56 of these projects are located in the SNM area (27 R&D, 29 demonstration), 72 in the DSM area (17 R&D, 55 demonstration), 66 integration DG&Storage area (21 R&D, 45 demonstration), eight in the integration of Large-Scale RES (four R&D, four demonstration) and 15 in other areas (13 R&D, two demonstration). Turkey's comparisons with France in this area is in Figure 3.23. Turkey has just one project in this area as a participant. France carried out seven projects as a national and 15 as a multinational. Turkey and France aren't participant in any common projects in this area while they have 9 in total. Number of Projects in Turkey vs Average Number of Projects According to Countries in E-mobility shown in Figure 3.24

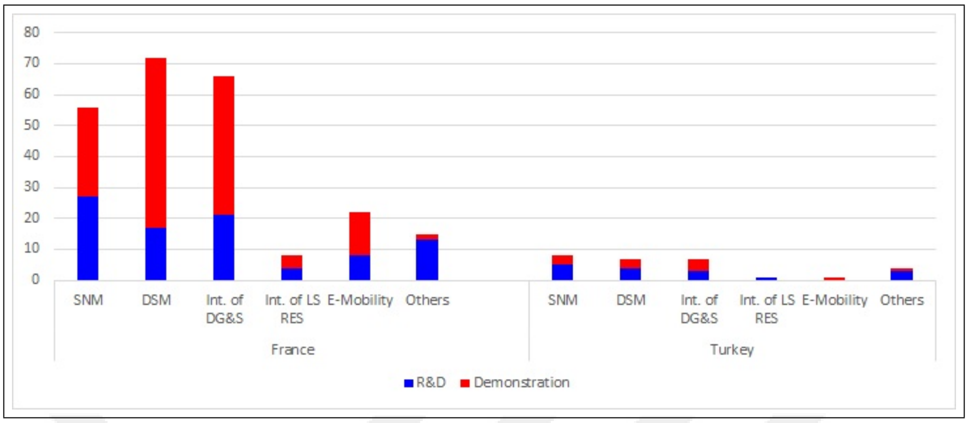


Figure 3.23: Comparison of Number of Projects between France vs Turkey (1994-2016)

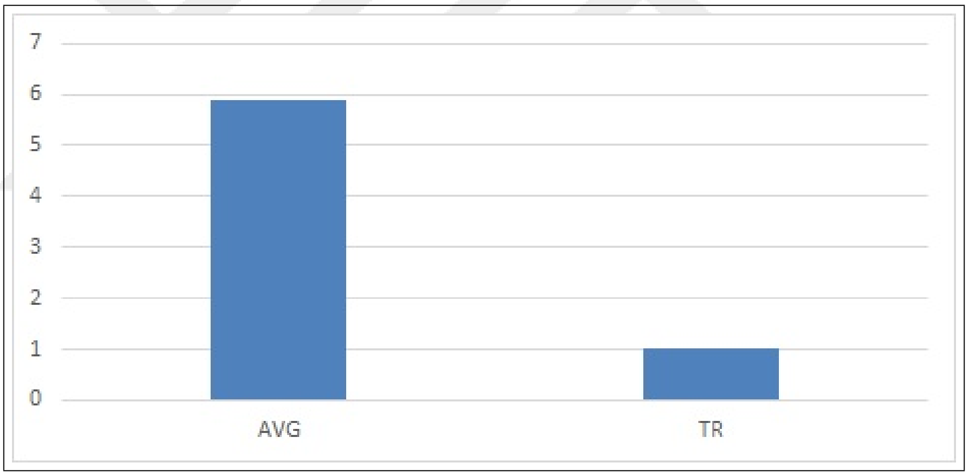


Figure 3.24: Number of Projects in Turkey vs Average Number of Projects According to Countries in E-Mobility (1994-2016)

There are a total of 61 projects in the domain called others, which are not included in these areas. 52 of these projects are R&D projects and nine are demonstration projects. 26 of these projects are national and 35 are multinational. Germany is also the first country in this area. After Germany, Austria comes with 20 projects. Austria implemented 17 of these projects as R&D projects and three of them as demonstration projects. Austria, which has a total of 128 projects, has 52 of these projects in the SNM area (36 R&D, 16 demonstration), 46 in the DSM area (21 R&D, 25 demonstration), 48 in the integration of DG & Storage (26 R&D, 22 demonstration), five in the integration of Large-Scale RES (four R&D, one demonstration) and 18 in the field of E-mobility (nine

R&D, nine demonstration). The comparison of Turkey and Austria which is one of the pioneer countries in this area is in Figure 3.25. Turkey has not any national projects also in this area while Austria has 20% national projects. Turkey and Auistria are participant in 4 common projects in others area while they have 6 in total. Number of Projects in Turkey vs Average Number of Projects According to Countries in Others Domain shown in Figure 3.26

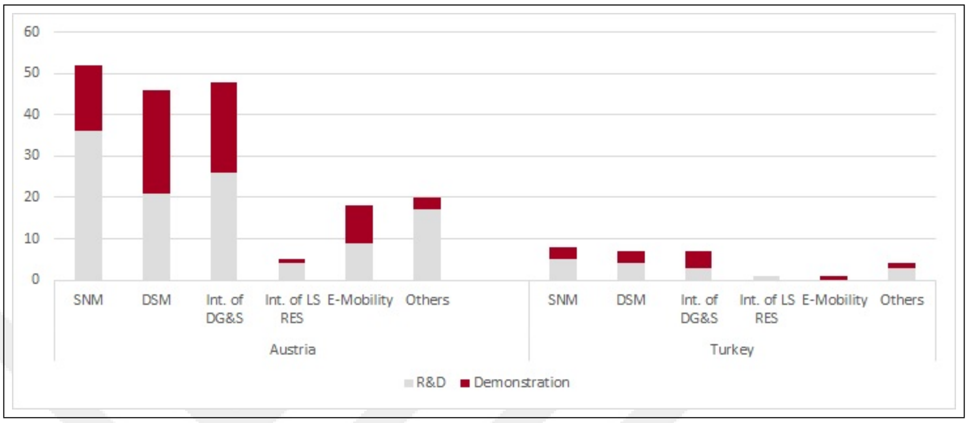


FIGURE 3.25: Comparison of Number of Projects between Austria vs Turkey (1994-2016)

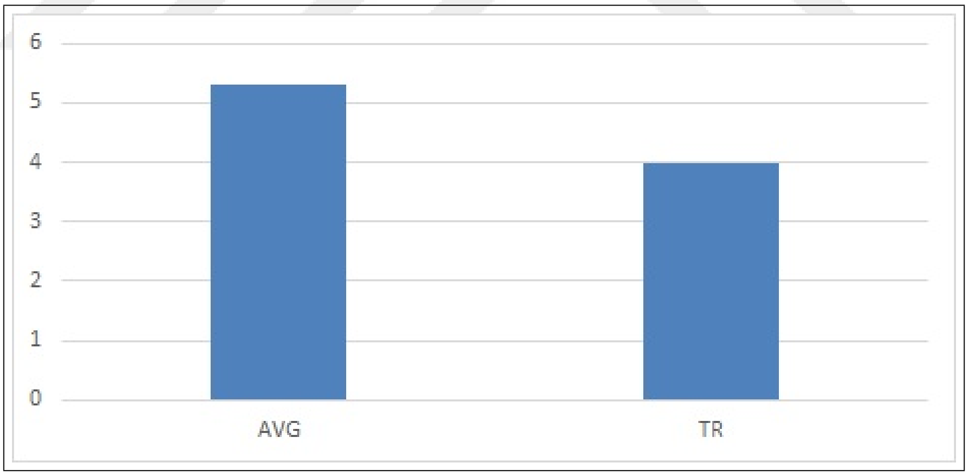


FIGURE 3.26: Number of Projects in Turkey vs Average Number of Projects According to Countries in Others Domain (1994-2016)

As can be understood from comparison with pioneering countries in all areas, projects in Turkey is very few. In particular, there is almost no project in the area of Integration of Large-Scale RES and E-mobility. Germany is the country with the most projects in each area. 22 countries have implemented 10 or fewer projects. In addition, Australia, Azerbaijan, Liechtenstein, Monaco, and Montenegro participated in only one multinational project. When we look at projects in general, Smart Network Management is the leader area with 410 projects. Second, Integration of Distributed Generation and Storage area comes with 367 projects. They are followed by Demand Side Management area with 346 projects, E-mobility with 131, and Integration of Large-Scale RES area with 39 projects. Finally, there 61 projects in other domain.

3.3.2 Enable Informed Participation by Customers

Advanced meters which are called smart meters, instantaneous notification of consumption price information to customers, various smart appliances, efficient management of demand side and customer side, information about prosumers called also professional consumers who are able to supply electricity back to the grid when needed are the criteria of the first characteristics, Enable informed participation by customers. Among these criteria, we could only find smart meter quantities in the network and their percentages in the total meters for Turkey and UK. Also the percentage of smart meters in total meters in Canada is given. In addition, number of tariffs including real time pricing are mentioned in this part.

Smart meters can have the ability to measure consumption instantaneously according to their types. This feature provides varied payment options through measurements in different time slots. Thus, the demand could be shaped according to the grid. In the ideal case, the smart meters is expected to provide bi-directional communication and information flow between the consumer and the grid. Thus, consumers and their smart appliances could have the ability to manage their own usage behaviors thanks to real-time price information. The number of smart meters and total meters are obtained for the UK and Turkey in this study. The distribution in Turkish Electricity Grid is provided by 21 private companies. The number of smart meters used by each company is collected from these companies. As a result of the acquired data, it is found that there are approximately one million smart meters in Turkey Electricity Distribution Grid and 4,720,000 smart meters in the United Kingdom [64, 65]. For an additional information, Canada has the rate of 65% smart meters in total meters [66]. The number of smart meters and the total meters of Turkey and the United Kingdom are shown in Figure 3.27. The ratio of smart meters to total meters can also be seen in Figure 3.28. The percentage of total demand served by the advanced meters is also an indicator of this characteristic. The ratio of the electricity demanded by the smart meter helps to understand how much of the demand in the grid can be diverted if necessary. However, no data is available for this indicator.

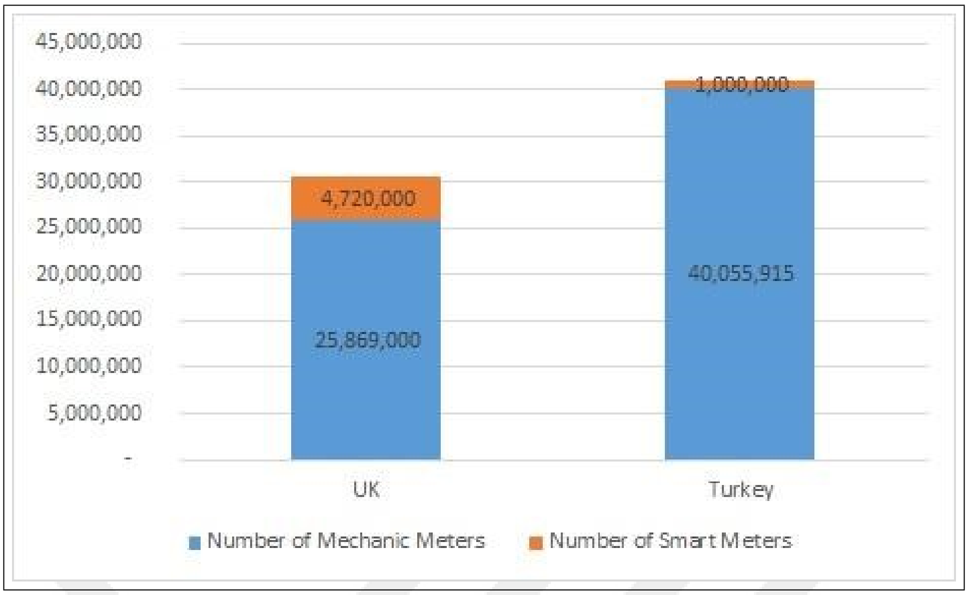


FIGURE 3.27: Number of Meters in UK and Turkey (2017)

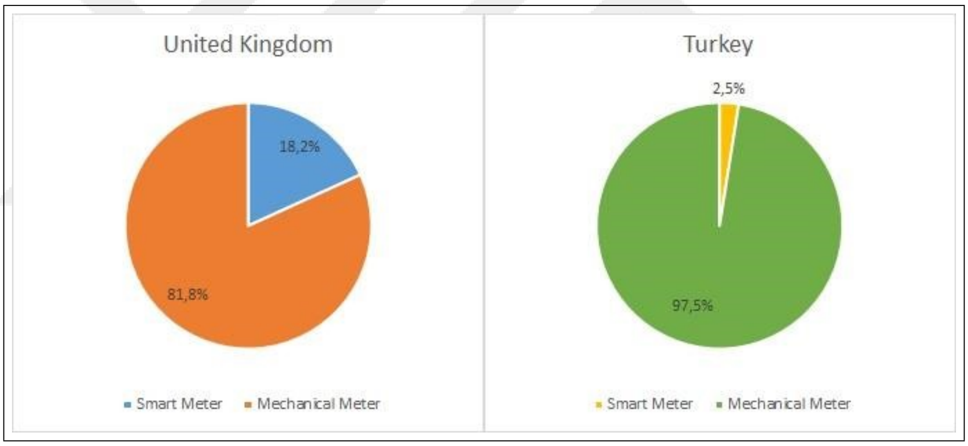


FIGURE 3.28: Percentages of Smart Meters in UK and Turkey (2017)

Turkey has more total meters but the UK has more smart meters. As a result, the percentage for UK is better than approximately 8 times than Turkey. In United Kingdom, with the use of smart meters, peak consumption is shifted around 2.1%, and 2.2% saving is provided on total consumption [67].

The number of tariffs applied, the existence of Real-Time pricing tariffs in the system and the load that the users of these tariffs requested are three of the indicators in this characteristic that show the customers are well informed. Unfortunately, the data of loads that RTP tariff customers requested are not available. RTP tariffs are one of the advantages that smart meter usage provides. Customers know when and how much they are going to pay for their electricity usage thanks to these tariffs and they can avoid using electricity on peak hours where the prices increase due to intense usage in a network. This can help taking peak hours under control. Also, having different types of RTP tariffs can provide control on demand distribution by giving customers a variety of options.

There are 5 different tariffs in the UK and the member states of the European Union. These are namely, "fixed, flat, time of use, event-driven including critical peak pricing and dynamic including real-time" tariffs. On the other hand, there are 2 types of tariffs in Turkey. One of them is single time tariff, which is subject to the same pricing for every hour of the day while the other is multi-time tariff (three-times) which offers three different payment options for three different periods of time, day, night and peak, of the day. The fixed tariff, one of the five options, works on the same principles as the single time tariff used in Turkey. The advantage of this tariff is that the customers whose electricity consumption during peak hours is intense pay the relatively lower fee than other tariffs. Time of Use (ToU), on the other hand, can show different pricing options during different time slots of the day or seasons, similar to the three-time tariff that is used in Turkey. The advantage of this tariff is that the consumer can plan his/her consumption hours and save money by using electricity on cheaper hours. Critical peak pricing is similar to the ToU. The most distinct difference is that the peak periods in ToU is determined well in advance while they are determined 1-2 days in advance in critical peak price, and notified to consumer. Dynamic pricing is the tariff where the consumer is charged based on the intensity of the instant usage in the network [68].

The quantities of smart appliances used at the end-consumer point and their load-modifying capacities are undoubtedly the important indicators in this characteristic. These tools consume less electrical energy thanks to their technology and also have the ability to exchange information with the network, thus helping to balance load intensity in the network by proposing to delay the use of the network at peak hours or when unit charges are high. In many parts of the world, including in Turkey, smart appliances are available with their certain features, though we do not have the data on their sales quantities and capacity to modify the load. However, if we look at the features of them which produced by the some private companies in Turkey, providing energy savings, could be used in different modes such as holiday, economy etc., to provide remote control from mobile devices, can communicate with other smart appliances, and hosting various detection sensors etc.

The ratio of the generation of local facilities to the total grid consumption, the minimum and maximum generation capacities of these facilities, and the generation and consumption rates of both producers and consumers, called prosumers, are also indicators in this area. These points are useful at the point of organizing the demands in the grid, but there is no data on these items.

3.3.3 Accommodate All Generation and Storage Options

The existence, capacities and status of distributed generation and storage units apart from central generation and PHEV's are the criteria in the second characteristic, accommodate all storage options. Interconnection points of these distribution systems are also another criterion. In this study, PHEV's number, the ratio of PHEV's in total vehicles, and the number of charging points required to charge them are analyzed for Turkey and several countries and presented in this section.

By being decentralized, electricity does not take long distances, which leads to less transmission and distribution losses. Distributed generation points established with renewable energy sources are important components in terms of positive effects on the environment as well as relaxation of the demands of the network. However, there isn't any data for the number, capacity of these generation units or the number of the grid attachment points of these generation units for Turkey.

As mentioned before, Environment is one of the six key areas of the Smart Grid. Plug-in and hybrid electric vehicle (PHEV) numbers and their share in all vehicles, their charge and storage capacities and the number of charging stations for these vehicles can be evaluated as distributed generation and storage. PHEV's help on reaching the target point on GHG emission amounts. Also, the consumption of fossil fuels is reduced with the use of PHEVs. Although we could not reach the data of charge and storage capacities, the change in the number of electric vehicles according to years in different parts of the world is shown in Figure 3.29, and their ratio in total vehicle number is shown in Figure 3.30 in detail [69].

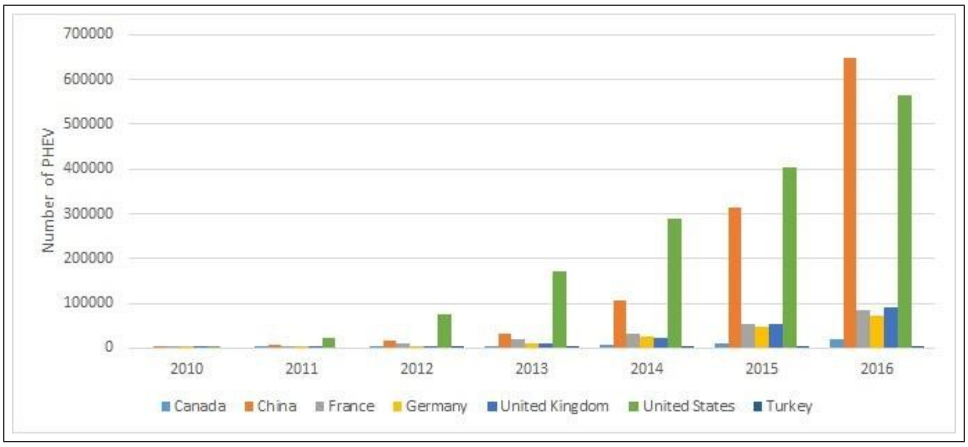


Figure 3.29: Number of PHEV's According to Countries (2010-2016)

According to the Global EV Outlook 2017 Report, which was prepared considering the end-2016 data, the country with the highest number of electric vehicles in the world is China. In this rank, China followed by USA [70].

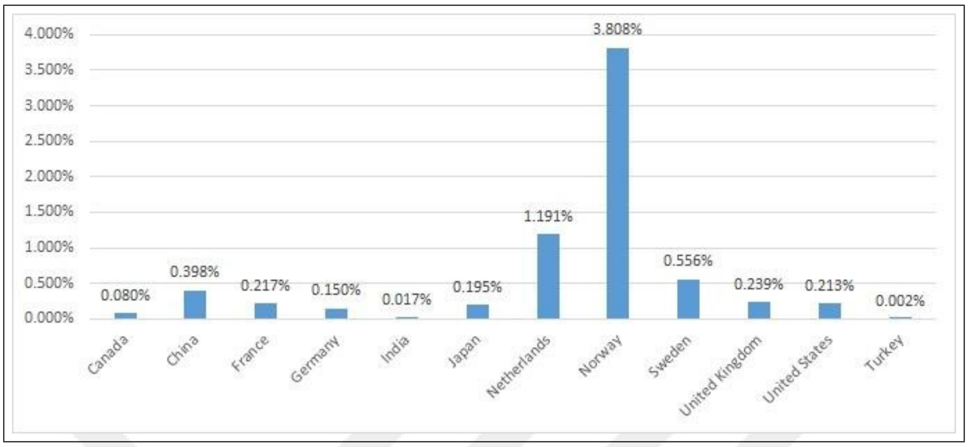


Figure 3.30: Percentage of PHEV's in Total Vehicles in 2016

Norway has the highest rate of PHEV in the number of all vehicles [71]. Although China is the leading country in the number of electric vehicles, it is in the middle rank of percentage because of the huge number of total vehicles. It is clear that this is influenced by China's population. Besides number of PHEV's, the number of charging stations is also an important metric. The comparison of the number of charging stations in different countries is shown in Figure 3.31. In this regard, United States of America (USA) is the leading country in the world and Germany is the second. Turkey is far behind in both also areas [72, 73].

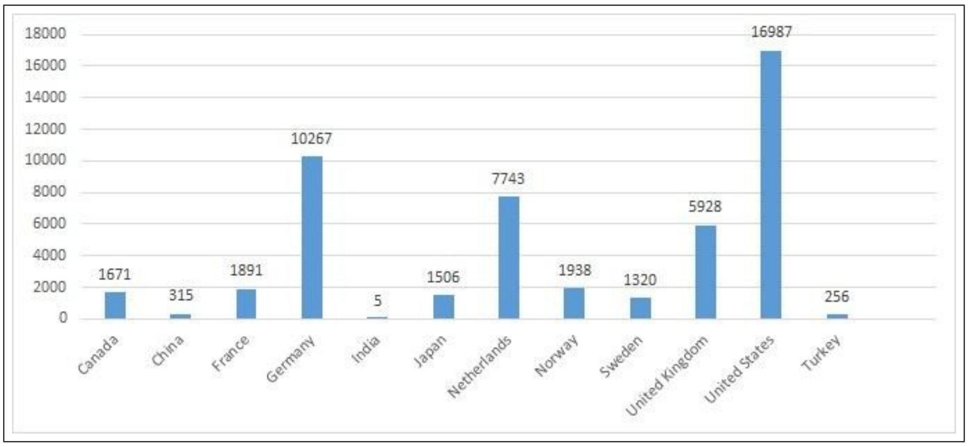


Figure 3.31: Number PHEV's Charge Stations According to Countries in 2017

3.3.4 Sell More Than kWhs

The number of customers serviced by ESCOs and the services offered to these customers, the flexibility between aggregators and customers, the number and variety of tariffs offered to customers that customers have right to make choices, the support type provided for investments and the interoperability between the stakeholders of the electricity system are criteria for this characteristic. In this section, we deal with the number of customers receiving service, and investment developments in smart grid. Since the tariff diversification is mentioned in 3.3.2, it isn't repeated here.

The services offered to the customers ensure that they are smart consumers. On this count, they can consume more conscious electricity and save money, alleviating both their budgets and the total costs and burdens on the network. The number of consumers who are served by distribution companies and the change of these numbers according to years are available in Table 3.6 [11].

Table 3.6: Number of Consumers According to Distribution Company per Years[11]

	2013	2014	2015	2016
BOĞAZİÇİ	4,464,471	4,615,621	4,732,112	4,872,387
BAŞKENT	3,321,058	3,847,029	3,969,789	4,099,788
TOROSLAR	3,088,099	3,432,049	3,505,182	3,669,912
GDZ	2,757,843	2,888,610	2,971,756	3,061,100
ULUDAĞ	2,729,178	2,812,446	2,893,903	2,983,810
İ.ANADOLU	2,304,789	2,613,603	2,676,318	2,751,857
AKDENİZ	1,803,081	1,876,289	1,941,193	2,000,386
MERAM	1,788,887	1,839,153	1,889,687	1,964,377
YEŞİLIRMAK	1,766,936	1,833,851	1,884,597	1,938,042
ADM	1,668,748	1,728,496	1,778,773	1,787,566
DİCLE	1,385,082	1,417,236	1,588,562	1,675,698
OSMANGAZİ	1,515,857	1,565,042	1,611,585	1,661,395
SAKARYA	1,501,482	1,528,503	1,578,224	1,654,546
ÇORUH	1,165,271	1,205,566	1,237,935	1,269,278
TRAKYA	928,483	944,039	968,459	991,026
ARAS	841,694	880,302	906,537	935,816
ÇAMLIBEL	857,697	877,003	898,618	917,913
FIRAT	796,569	828,301	858,178	888,483
KAYSERİ VE CİVARI	609,878	636,296	654,578	673,432
AKEDAŞ	598,180	610,127	631,557	635,620
VANGÖLÜ	533,473	573,184	599,921	623,483
TOTAL	36,426,756	38,552,746	39,777,464	41,055,915

Additional services from distribution companies are provided by private companies that carry out the distribution. Invoice comparison with previous months, energy saving hints applications, mobile applications to control consumption informations are can be shown as examples [74]. In addition to these, consumers who have exceeded a certain amount of consumption are entitled to be eligible consumer. In this way, the consumer can choose their own ESCO and can pay with lower unit price. This is an important issue for the Smart Grid in terms of competition among energy distribution companies and therefore quality enhancement. Change of eligible consumer limit and the increase the number of eligible consumers by years in Turkey are shown in Figure 3.32:

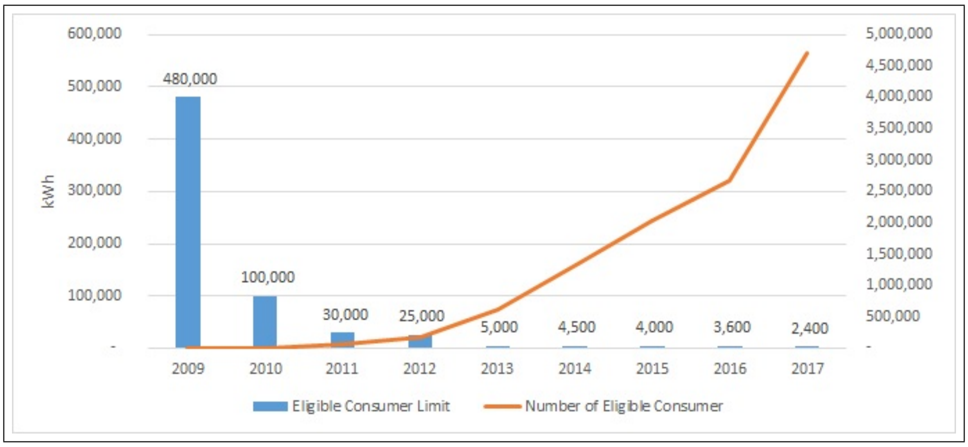


Figure 3.32: Amount of Being Eligible Consumer Limits and Number of Eligible Consumer According to Years (2009-2017)

Reducing the limit of being a eligible consumer enables the market liberalization and competition between distribution companies to increase. As a result, an increase in the number of eligible consumers is also observed. By 2009, the limit of eligible consumers, which was 480,000 kWh and above, was dramatically reduced to 100,000 kWh by 2010. In Turkey, being the eligible consumer limit is set at 2000 kWh for 2018 [75].

Investments in the Smart Grid and their funding type, such as rates, subsidies or external are also indicative of this area. There are various investments of transmission and distribution companies. In 2015 and 2016, approximately four million Turkish Lira worth of investments were made in the transmission network. The vast majority of these investments were made for new transformers and new lines, while others were made for operations and machines. In addition, there are the investments made in 2015 and 2016 by 21 private distribution companies operating in Turkey. Approximately 3.56 million TL were invested in 2015, with an increase of 20% in 2016, reaching 4.3 million Turkish liras. Although these investments are mostly made in the grid, they are also built into meters, environmental and security measures [76]. Investments in renewable energy sources is one of the significant component of Smart Grid in Turkey are given in Figure 3.33 and 3.34 according to the years [77]. There are no data available for sources of investments, such as rates, subsidies or external financing. With a detailed research about these informations, the positive/negative effects on economy of the separated budget can be observed.

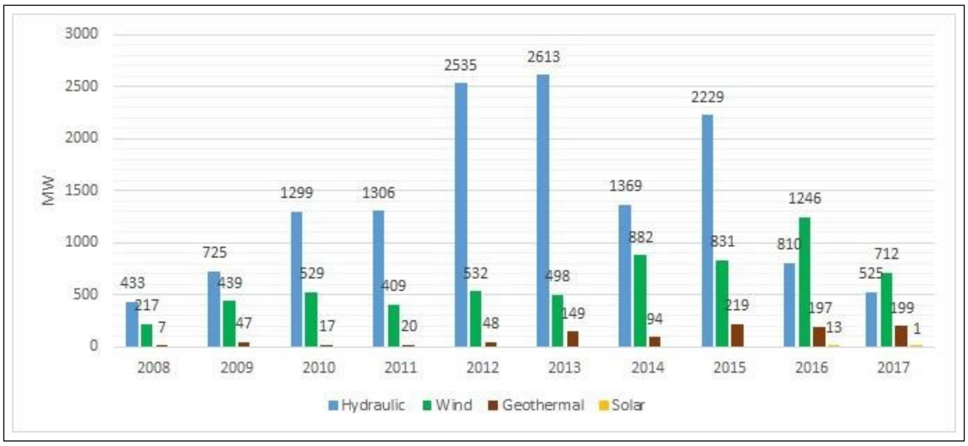


FIGURE 3.33: Amounts of RES Investments According to Resources for Turkey (2008-2017)

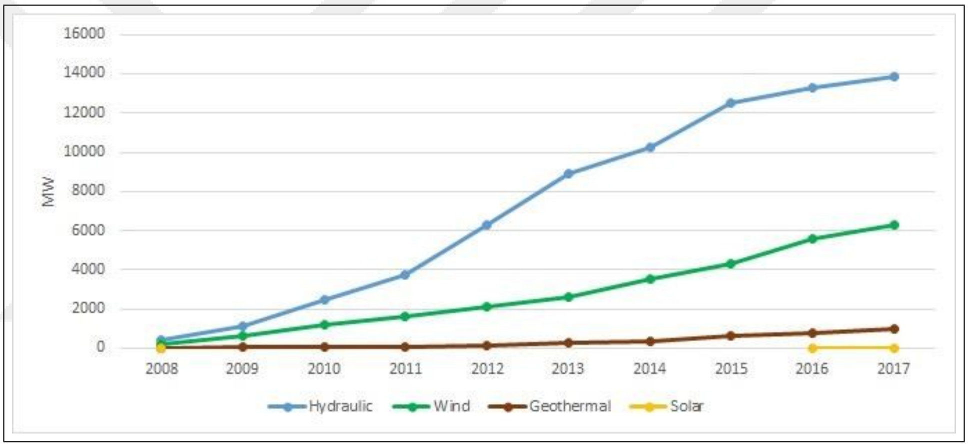


FIGURE 3.34: Cumulative Amounts of RES Investments According to Sources for Turkey (2008-2017)

Investments are mostly made to Hydraulic Energy sources. Wind Energy investments have increased in the last 5 years and have exceeded hydraulic energy investments in the last 2 years. Solar energy source investments have just started in recent years.

Finally, one of the indicators in this field is the maturity level of the interoperability of the electricity system stakeholders. There is no information obtained on this issue, but yet there is no interoperability situation in Turkey. At the point of generation, transmission, distribution and consumption, stakeholders are all concerned with their own responsibilities.

3.3.5 Provide Power Quality for the 21st Century

This characteristic evaluation is based on the available power quality, the required power quality and the microgrids and the ratio of their capacities to the total capacity of the grid. Only frequency and voltage values of some countries are mentioned in this section.

Increasing the presence and proportions of the microgrids is a factor that will increase the quality of the grid. Failures or interruptions in the main grids can be healed by influencing fewer users via microgrids. The changes in the voltage and their frequency are the parameters that can be displayed as a problem in terms of the quality of the network. Turkish grid is connected to European Union system and frequency is controlled by Union for the Coordination of the Transmission of Electricity (UCTE). Thus, changes in voltages and their frequency cannot be compared. Besides these, the frequency range and the voltage range are also among the indicators in this field. Frequency and voltage ranges specified in Turkey are as follows: 220V/50 Hz. It is 240V/50 Hz for UK, 120V/60 Hz for USA, 230&400V/50 Hz for Germany [78].

3.3.6 Optimise Assets and Operate Efficiently

This characteristic is evaluated by criteria as automation of transmission and distribution systems, technologies used in this area such as Dynamic Line Rating, analysis of demands and installed power capacities, and efficiency in terms of losses and fuels. In this section we compared the Turkey and UK in terms of the ratio of the maximum peak demand to the installed power. We also give the UK's fuel-efficiency information and make a small comparison of the UK and Turkey in terms of losses.

The fact that the transformer stations are subject to automation and the use of Dynamic Line Rating technology in lines allows monitoring of instant transmission capacities of transmission and distribution lines. However, this information related to transmission substations and distribution lines in Turkey could not be obtained. Fortunately, the Figure 3.35 shows the maximum peak loads according to years, as well as their ratios to the installed power capacity for both Turkey and UK. In addition, two-year distribution loss rates for again Turkey and the UK are given in the Figure 3.36 [12, 65, 79].

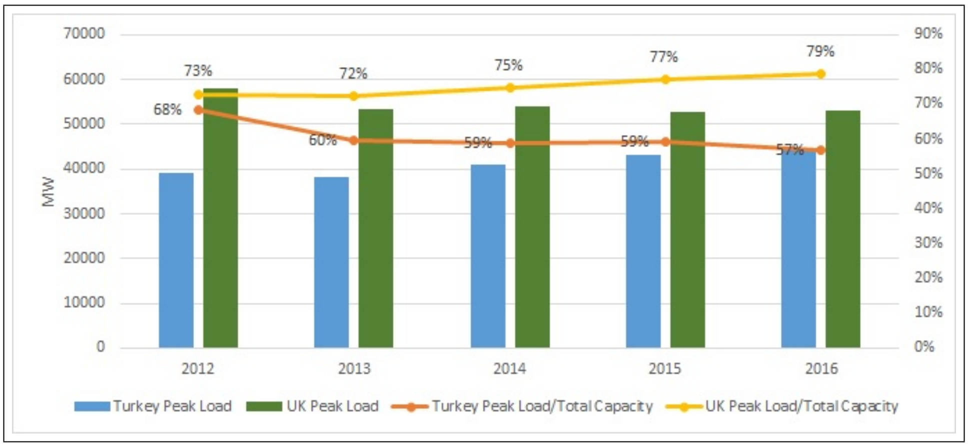


FIGURE 3.35: Comparison of Peak Loads and Averages in Total Capacity between Turkey and UK (2012-2016)

Peak Load in Electricity Grid of United Kingdom is more than Turkey. Similarly, peak load/total installed capacity ratio is higher than Turkey. It can be understood that this higher demand can meet with the lower capacity. This is an important indicator of the efficiency of the network.

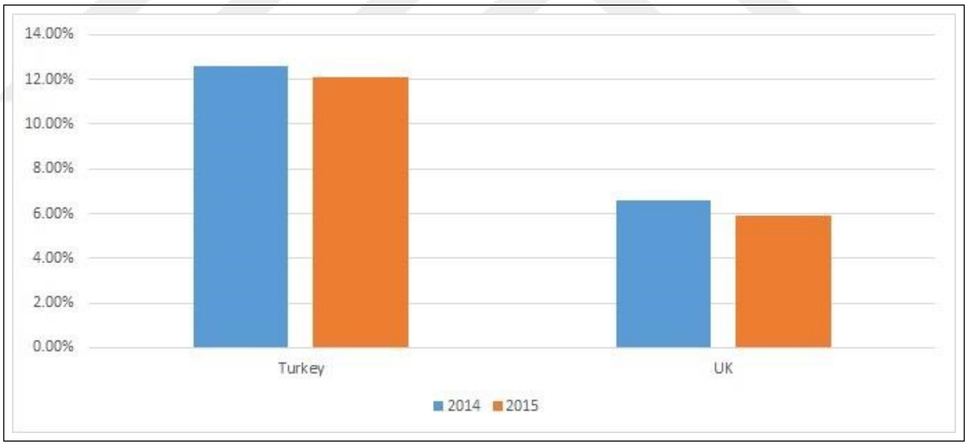


FIGURE 3.36: Comparison of Distribution Losses Between Turkey and United Kingdom (2014-2015)

Each loss ratio for the two countries also decreased compared to the previous year. Indeed, the rate of losses in Turkey Electricity Distribution Grid is about 2 times the United Kingdom's rate. This can be interpreted as the fact that United Kingdom has the more efficient distribution system.

Finally, another indicator of efficiency is the efficiency of generation facilities. The input/output ratio of the fuel that is used for electricity generation determines the efficiency of these facilities. Such data cannot be found for Turkey, but for the UK, the change in this rate over the years is given in the Figure 3.37 [65].

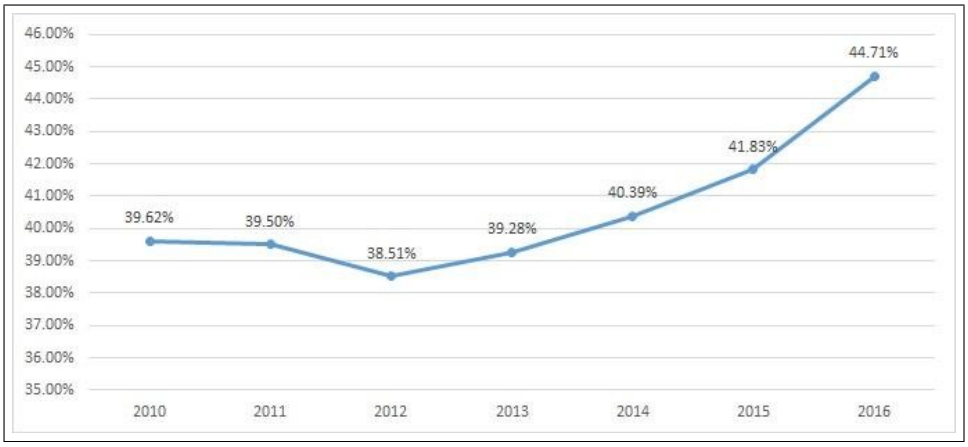


FIGURE 3.37: Rate of UK Energy Efficiency Based on Fuel Output-Input (2010-2016)

Energy Efficiency of United Kingdom has increased in recent years. The demanded energy was able to meet with less fuel input thanks to increasing efficiency. This not only reduces the depletion of sources but also reduces GHG emissions due to less using fossil fuels.

3.3.7 Operate Resiliently to Disturbances, Attacks and Natural Disasters

In the last characteristic determined by the reference study, the sensors in the grid and the technologies supporting them, the intra-grid information flow, the reliability evaluation of the transmission and distribution system in terms of interruption and outage, and finally compliance with the standards applied globally in telecommunication sector are used as criteria. In this section, we are providing information about the power outage that occurred in Turkey and Turkey's compliance with international standards in telecommunication sector.

Real-time monitorability amounts of grid elements, transformer centers equipped with advanced measurement technologies and application amounts supported by these technologies are important. Faults or problems that may occur at any point of the grid can be detected and intervened quickly thanks to these technologies. In addition, grid elements that can be controlled remotely can reduce network operating costs and increase work safety. However we do not have these data for Turkey.

Number of minutes customers are interrupted each year, total number of customer interruptions per customer, average outage duration etc. can be included in the reliability of the grid. Increases in these values indicate increased problems in the grid. Average interruption times are given Table 3.7, according to the distribution companies for Turkey [12].

Table 3.7: Amount of Average Interruption Times According to Distribution Company[12]

	2015			2016			
Distribution Company	**P**[a]	**W**[b]	**T**[c]	**P**	**W**	**T**	**Change(%)**
VANGÖLÜ	619.0	7,175.0	7,794.0	323.6	3,587.8	3,911.4	-49.82
ULUDAĞ	1,187.7	1,185.8	2,373.4	2,274.0	803.7	3,077.7	29.67
ARAS	79.1	1,620.5	1,699.6	229.0	2,793.5	3,022.5	77.84
TRAKYA	277.3	2,276.4	2,553.8	534.2	1,493.3	2,027.6	-20.60
YEŞİLIRMAK	683.7	2,214.5	2,898.3	610.0	1,303.9	1,913.9	-33.97
ÇORUH	70.9	1,613.5	1,684.5	188.2	1,646.3	1,834.4	8.90
MERAM	1,237.4	1,318.0	2,555.4	788.3	1,007.0	1,795.3	-29.74
TOROSLAR	731.2	852.1	1,583.3	878.6	906.2	1,784.8	12.73
SAKARYA	475.3	1,326.4	1,801.7	425.6	1,145.1	1,570.6	-12.82
BOĞAZİÇİ	153.1	1,380.4	1,533.5	198.0	1,334.5	1,532.4	-0.07
GDZ	302.1	1,595.0	1,897.1	360.5	1,052.5	1,413.0	-25.52
FIRAT	5.9	133.3	139.2	69.5	1,089.5	1,158.9	732.35
AKEDAŞ	69.5	431.4	500.9	506.6	610.5	1,117.1	123.00
ADM	228.5	729.7	958.2	378.4	627.9	1,006.3	5.02
AKDENİZ	179.2	760.1	939.2	226.5	779.2	1,005.7	7.07
ÇAMLIBEL	55.2	241.9	297.1	350.4	553.0	903.4	204.07
OSMANGAZİ	265.7	1,047.0	1,312.8	262.5	398.0	660.5	-49.68
İSTANBUL AN. YK.	219.4	289.9	509.3	291.0	328.4	619.4	21.63
BAŞKENT	138.6	691.9	830.5	225.2	372.6	597.9	-28.01
KAYSERİ VECİVARI	190.6	658.8	849.4	180.3	212.6	392.9	-53.74
DİCLE[d]	325.3	2,011.3	2,336.6	0	0	0	-

[a]PreNotified AVGTIME (min)
[b]Without Noticed AVGTIME (min)
[c]Total AVGTIME (min)
[d]In 2016, in the Dicle distribution area was not evaluated, because of the loss ratio is over 40% in all the provinces in 2015.

The total average interruption time in the Fırat distribution area in 2015 was quite small compared to other distribution areas, but it has lost huge ranking in efficiency caused by more than increasing 700% increasing in interruption time. Although the Vangölü distribution area showed a good decline in interruption time between the two years, it became has the highest total average distribution area in both years. It can be interpreted as the effect of the winter season, which is hard at this area, on distribution lines.

Finally, conformity with established European and international protocols and standards is also an important indicator of infrastructure as mentioned above. Turkey is well adapted in this official necessities.

3.3.8 Renewable Energy Sources

Renewable Energy Sources (RES) is an important component of Smart Grid that is not considered as an indicator in our reference study. Variety of RES, Percentages of RES in Total Installed Power Capacity, and Percentages of RES in Total Electricity Generations are very important indicators in this area. Foreign source dependency is diminishing while the diversity and proportion of the renewable sources are increasing in generation and installed power capacity. This also contributes to the economic development of the countries. Moreover, reduction of the fossil fuel use rates are not only affects the decreasing politically dependency but also helps reduce the carbon emissions. Percentages of Renewable Energy Sources in total installed power capacity and total electricity generation for Turkey can be seen in Figure 3.38 and Figure 3.39.

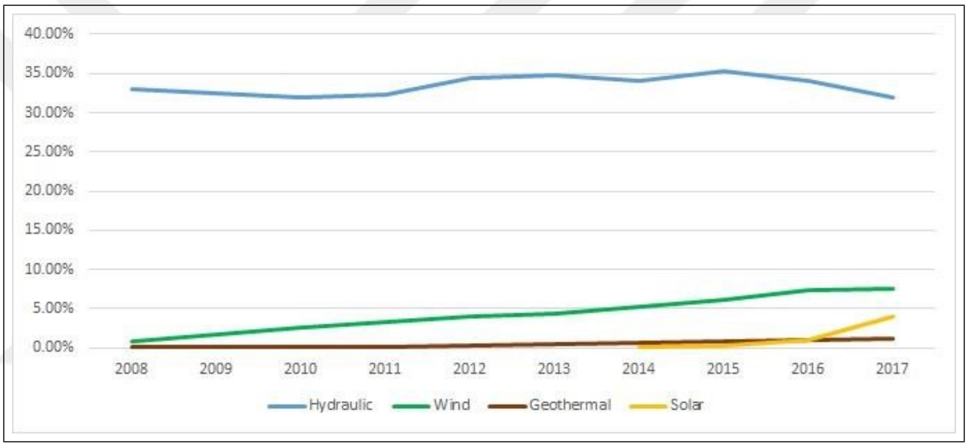


FIGURE 3.38: Percentages of Renewable Energy Sources in Total Installed Power Capacity According to Sources (2008-2017)

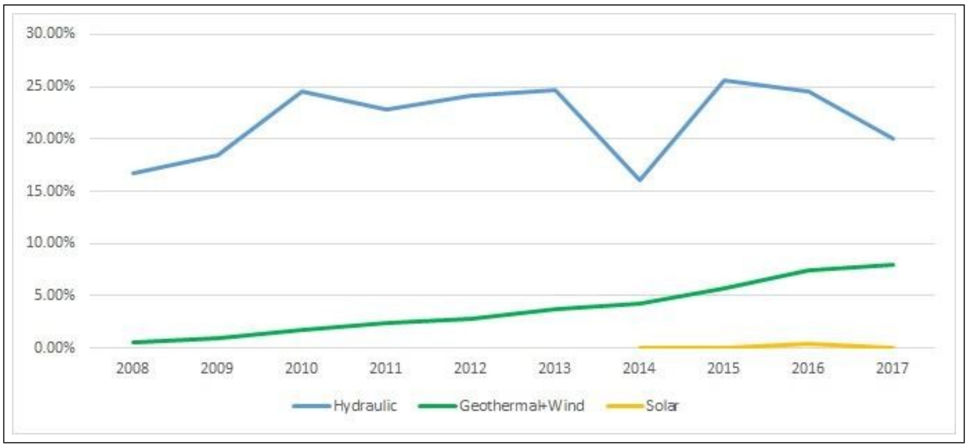


FIGURE 3.39: Percentages of Renewable Energy Sources in Total Electricity Generations According to Sources (2008-2017)

According to years, renewable energy sources have increased in installed capacity and production. Hydraulic energy has the largest share of renewable resources. Although the share of hydraulic energy in total electricity production has generally increased, the decline in 2014 is striking. This can be interpreted as the drought that occurred that year [80].

According to data by the end of 2015 from the report prepared by the European Commission, comparison of the renewable energy sources in total installed capacity and total electricity generation between Turkey and various countries in Figure 3.40 [81].

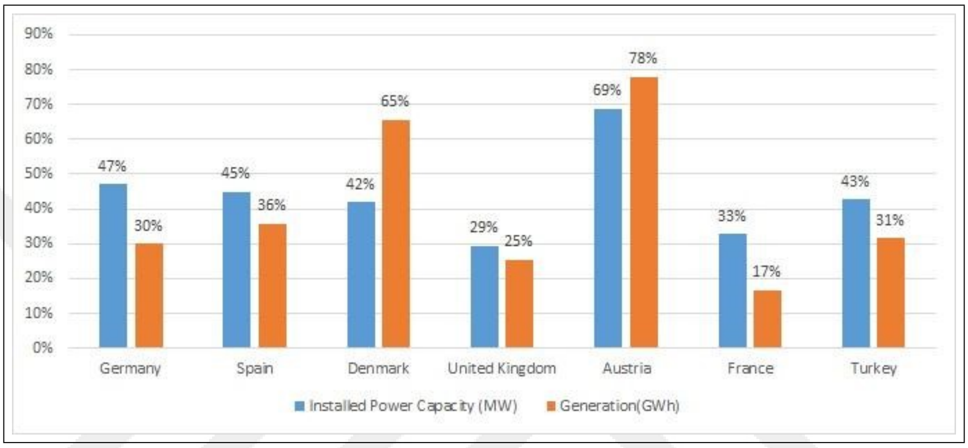


FIGURE 3.40: Comparison of Percentages of RES in Total Installed Power Capacities & RES in Electricity Generations According to Countries in 2015

Austria is the leading country in both areas. Unlike other countries, Austria and Denmark's Generation percentages are higher than Installed Power Capacity, which can be interpreted as efficiency in the use of renewable resources. Nearly half of Turkey's Capacity was created by RES, but it did not provide the same productivity in generation. However, it is still close to the targeted values.

Chapter 4

Conclusion and Future Works

In this study, Turkey's electricity grid was explained and its place in the world on smart grid was tried to be understood. First of all, it is important to note that there are serious problems about the announcement, availability and accessibility of the studies that have been carried out. There is not much informative work on the benefits that the smart grid can provide. Besides, there are serious difficulties in reaching the information about grid system, its members and some numerical values. For example, despite the fact that all distribution companies and information centers (BIMER) have been referred to, the official numbers for the total number of smart meters in the country and their features have not been reached. Instead, the number specified in a different study has been referenced by communicating with the author. Two different state-affiliated institutions gave inconsistent information at various points. In addition, platforms and institutions that are established in this area cannot demonstrate sufficient activity.

When we look at the results of comparisons made with countries that are pioneering in specific areas of smart grid, we can see that we are far behind those countries in many characteristics. When we look at the projects, it is observed that our national project number is very low and that sufficient level of PHEV use cannot be reached adequate maturity while vehicle use is very extensive in our country.

However, it can be said that we are in a better place on providing production and installed power from renewable sources and renewable energy potential compared to other fields. Adequate and general information about smart meters, which have a great importance in terms of bi-directional communication and information flow, which are important features and needs of the smart grid system, could not be obtained. However, according to the data of some regional distribution companies, there are meters with good features, for instance, remote reading and data storage capacity.

As a possible work to be done in this area in the future, a study on expert opinion research about smart grids can be conducted. Other than that, contrary to general assessments, more detailed studies can be done in some specific areas. The smart grid subject is, as already mentioned, a very comprehensive topic. Therefore, this topic can be dissected into smaller parts. Detailed studies can be carried out on each part and individual proposals can be made with the help of detailed observations.

Appendix A

Indicators Table

Characteristics, Categories, and Key Performance Indicators of a Smart Electricity Grid [4] table is below.

Enable informed participation by customers	
Advanced Meters	1A: Number of advanced meters installed
	1B: Percentage of total demand served by advanced meters
Dynamic Pricing Signals	2A: The fraction of customers served by RTP tariffs
	2B: The fraction of load served by RTP tariffs
Smart Appliances	3A: Total yearly retail sales volume for purchases of smart appliances [€]
	3B: Total load capacity in each consumer category that is actually or potentially modified by behaviours of smart appliances [MW]
Demand Side Management	4A: Fraction of consumers contributing in DSM [%]
	4B: Percentage of consumer load capacity participating in DSM [MW/MW]
	4C: Potential for time shift (before start-up and during operation) [h]
Prosumer	5A: Total electrical energy locally (decentralised) produced versus total electrical energy consumed [MWh/MWh]
	5B: Minimal demand from grid (maximal own production) versus maximal demand from the grid (own production is zero) [MW/MW]
	5C: Fraction of time prosumer is net producer and consumer [h/h]
Accommodate all generation and storage options	
Distributed Generation and Storage	6A: Amount of production generated by local, distributed generation (MW/MW)
	6B: Potential for direct electrical energy storage relative to daily demand for electrical energy [MWhel/MWhel]
	6C: Indirect electrical energy storage through the use of heat pumps: time shift allowed for heating/cooling [h]
PHEVs	7A: The total number and percentage shares of on-road light-duty vehicles, comprising PHEVs
	7B: Percentage of the charging capacity of the vehicles that can be controlled (versus the charging capacity of the vehicles or the total power capacity of the grid) [MW/MW]
	7C: Percentage of the stored energy in vehicles that can be controlled (versus the available energy in the vehicles or the total energy consumption in the grid) [MWh/MWh]
	7D: Number of charging points that are provided to charge the vehicles
DER Interconnection	8A: The percentage of grid operators with standard distributed resource interconnection policies
Sell more than kWhs	
New Energy Services	9A: Number of customers served by ESCO's
	9B: Number of additional energy services offered to the consumer
	9C: Number of kWh that the consumer saves in comparison to the consumption before the energy service
Flexibility	10A: The number of customers offering flexibility to aggregators
	10B: The flexibility that aggregators can offer to other market players [MWh]
	10C: The time that aggregators can offer a certain flexibility [h]
	10D: To what extent are storage and DG able to provide ancillary services as a percentage of the total offered ancillary services
	10E: Percentage of storage and DG that can be modified vs. total storage and DG [MW/MW]
Customer Choice	11A: Number of tariff plans available to end consumers
Support Mechanisms	12A: The average percentage of smart grid investment that can be recovered through rates or subsidies
	12B: The percentage of smart grid investment covered by external financing
Interoperability Maturity Level	13A: The weighted average maturity level of interoperability realised among electricity system stakeholders
Provide power quality for the 21st Century	
Power Quality	14A: Amount of voltage variations in the grid [RMS]
	14B: Time of a certain voltage variation [h]
	14C: The percentage of customer complaints related to power quality problems (excluding outages)
Required Power Quality	15A: Range of frequencies [Hz] contracted and range of voltages [V] contracted
Microgrids	16A: The number of microgrids in operation.
	16B: The capacity of microgrids [MW]
	16C: The total grid capacity of microgrids to the capacity of the entire grid [MW/MW]
Optimise assets and operate efficiently	
T&D Automation	17A: Percentage of substations applying automation technologies
Dynamic Line Rating	18A: Number of lines operated under dynamic line ratings
	18B: Percentage of kilometers of transmission circuits operated under dynamic line ratings [km]
	18C: Yearly average transmission transfer capacity expansion due to the use of dynamic (versus fixed) line ratings [MW-km]
Capacity Factors	19A: Yearly average and peak generation capacity factor (%)
	19B: Yearly average and average peak capacity factor for a typical kilometer of transmission line (%-km per km)
	19C: Yearly average and average peak distribution transformer capacity factor (%)
Efficiencies	20A: Efficiency of generation facilities [energy output (MWh) / energy input (MWh)]
	20B: Energy losses in transmission and distribution [MWh/year]
Operate resiliently to disturbances, attacks and natural disasters	
Advanced Sensors	21A: Number (or percentage) of grid elements (substations, switches, …) that can be remotely monitored and controlled in real-time
	21B: The percentage of substations possessing advanced measurement technology
	21C: The number of applications supported by these various measurement technologies
Information Exchange	22A: Total SCADA points shared per substation (ratio)
	22B: Fraction of transmission-level synchrophasor measurement points shared multilaterally (%)
	22C: Performance (bandwidth, response speed, availability, adaptability, …) of the communication channels towards grid elements
T&D Reliability	23A: SAIDI represents the average number of minutes customers are interrupted each year [Minutes]
	23B: SAIFI represents the total number of customer interruptions per customer for a particular electric supply system [Interruptions]
	23C: CAIDI represents the average outage duration that a customer experiences [Minutes]
	23D: MAIFI represents the total number of customer interruptions per customer lasting less than five minutes for a particular electric supply system [Interruptions]
Standards in telecommunication infrastructure	24A: The compliance of electric power industries with European and international telecommunication standards and protocols.

FIGURE A.1: Characteristics, Categories, and Key Performance Indicators of a Smart Electricity Grid [4]

Bibliography

[1] Chisholm Institute. Design overhead distribution systems, 2010.

[2] A.J. Expósito, A.G. Conejo and C. Canizares. *Electric energy systems: analysis and operation*. CRC press, 2016.

[3] International Energy Agency. Technology roadmap smart grids. http://www.iea.org/publications/freepublications/publication/smartgrids_roadmap.pdf, 2018.

[4] B. Dupont, L. Meeus, and R. Belmans. Measuring the 'smartness' of the electricity grid. In *Energy Market (EEM), 2010 7th International Conference on the European*, pages 1–6. IEEE, 2010.

[5] H. Rehman. The pathway to smart grid: Policy predevelopment and opportunities for entrepreneurs. Master's thesis, Universitat Politècnica de Catalunya, 2013.

[6] H. Zhang. *Smart Grid Technologies and Implementations*. PhD thesis, City University London, 2014.

[7] MA. Akcanca and S. Taşkın. Akıllı şebeke uygulanabilirliği açısından türkiye elektrik enerji sisteminin incelenmesi. *Akıllı Şebekeler ve Türkiye Elektrik Şebekesinin Geleceği Sempozyumu*, pages 26–27, 2011.

[8] TEİAŞ Genel Müdürlüğü Planlama ve Yatırım Yönetimi Dairesi Başkanlığı. Türkiye Elektrik Enerjisi 5 Yıllık Üretim Kapasite Projeksiyonu (2017-2021), 2017.

[9] Republic of Turkey Energy Market Regulatory Authority-Strategy Development Department. Electricity Market Development Report 2016, 2017.

[10] Enerji ve Tabii Kaynaklar Bakanlığı. Enerji İşleri Genel Müdürlüğü raporları. http://www.enerji.gov.tr/tr-TR/EIGM-Raporlari#, 2018.

[11] EPDK. Elektrik piyasası yıllara göre piyasa gelişim raporları. http://www.epdk.org.tr/TR/Dokumanlar/Elektrik/YayinlarRaporlar/ElektrikPiyasasiGelisimRaporu.

[12] Elektrik piyasası gelişim raporları. `http://www.epdk.org.tr/TR/Dokumanlar/Elektrik/YayinlarRaporlar/ElektrikPiyasasiGelisimRaporu`, .

[13] M. KOZAK and Ş. KOZAK. Enerji depolama yöntemleri. *SDU International Journal of Technological Science*, 4(2), 2012.

[14] Virginia Techs' Consortium on Energy Restructuring. Distributed generation educational module. `http://www.dg.history.vt.edu/ch1/introduction.html`, 2017.

[15] R.A. Huggins. *Energy Storage: Fundamentals, Materials and Applications*. Springer, 2010.

[16] M.H. Dickson and M. Fanelli. *Geothermal energy: utilization and technology*. Routledge, 2013.

[17] E. Hau and H. von Renouard. *Wind turbines: fundamentals, technologies, application, economics*. Springer, 2003.

[18] A. Fahrenbruch and R. Bube. *Fundamentals of solar cells: photovoltaic solar energy conversion*. Elsevier, 2012.

[19] M. Hosenuzzaman, N.A. Rahim, J. Selvaraj, M. Hasanuzzaman, A.B.M.A. Malek, and A. Nahar. Global prospects, progress, policies, and environmental impact of solar photovoltaic power generation. *Renewable and Sustainable Energy Reviews*, 41:284–297, 2015.

[20] M. Hoogwijk, A. Faaij, R. Van Den Broek, G. Berndes, D. Gielen, and W. Turkenburg. Exploration of the ranges of the global potential of biomass for energy. *Biomass and bioenergy*, 25(2):119–133, 2003.

[21] Z. Melhem. *Electricity transmission, distribution and storage systems*. Elsevier, 2013.

[22] L.L. Grigsby. *Electric power generation, transmission, and distribution*. CRC press, 2016.

[23] TC Enerji and Tabii Kaynaklar Bakanlığı. Dünya ve ülkemiz enerji ve tabii kaynaklar görünümü. *Strateji Geliştirme Başkanlığı*, (11):01, 2016.

[24] S. Paul, M.S. Rabbani, R.K. Kundu, and S.M.R. Zaman. A review of smart technology (smart grid) and its features. In *Non Conventional Energy (ICONCE), 2014 1st International Conference on*, pages 200–203. IEEE, 2014.

[25] M.R. Hossain, A.M.T. Oo, and A.B.M.S. Ali. Smart grid. In *Smart Grids*, pages 23–44. Springer, 2013.

[26] Y. Bamberger, J. Baptista, R. Belmans, B.M. Buchholz, M. Chebbo, J.L.D.V. Doblado, V. Efthymiou, L. Gallo, E. Handschin, N. Hatziargyriou, et al. Vision and strategy for europe's electricity networks of the future: European technology platform. 2006.

[27] Department of Energy U.S. Smart grid system report. 2009.

[28] B.A. Hamilton, J. Miller, and B. Renz. Understanding the benefits of the smart grid-smart grid implementation strategy. *United States: United States Department of Energy's National Energy Technology Laboratory*, 2010.

[29] C. Cecati, G. Mokryani, A. Piccolo, and P. Siano. An overview on the smart grid concept. In *IECON 2010-36th Annual Conference on IEEE Industrial Electronics Society*, pages 3322–3327. IEEE, 2010.

[30] K.G. Di Santo, E. Kanashiro, S.G. Di Santo, and M.A. Saidel. A review on smart grids and experiences in brazil. *Renewable and Sustainable Energy Reviews*, 52: 1072–1082, 2015.

[31] A. Mallett, J.C. Stephens, E.J. Wilson, R. Langheim, R. Reiber, and T.R. Peterson. Electric (dis) connections: Comparative review of smart grid news coverage in the united states and canada. *Renewable and Sustainable Energy Reviews*, 2017.

[32] C. Brandstätt, N. Friedrichsen, R. Meyer, and M. Palovic. Roles and responsibilities in smart grids: A country comparison. In *European Energy Market (EEM), 2012 9th International Conference on the*, pages 1–8. IEEE, 2012.

[33] M.G. Simões, R. Roche, E. Kyriakides, A. Miraoui, B. Blunier, K. McBee, S. Suryanarayanan, P. Nguyen, and P. Ribeiro. Smart-grid technologies and progress in europe and the usa. In *Energy Conversion Congress and Exposition (ECCE), 2011 IEEE*, pages 383–390. IEEE, 2011.

[34] P. Acharjee. Strategy and implementation of smart grids in india. *Energy Strategy Reviews*, 1(3):193–204, 2013.

[35] N. Karali, J. Yu, S. Vitiello, C. Marnay, G. Flego, and D. Zhang. Uncertainty in benefit-cost analysis of smart grid demonstration projects in the us, china and italy. In *Energy: Expectations and Uncertainty, 39th IAEE International Conference, Jun 19-22, 2016*. International Association for Energy Economics, 2016.

[36] Litos Strategic Communication. What smart grid means to americans. `https://energy.gov/oe/downloads/what-smart-grid-means-americans`, 2009.

[37] F. Gangale, A. Mengolini, and I. Onyeji. Consumer engagement: An insight from smart grid projects in europe. *Energy Policy*, 60:621–628, 2013.

[38] S. Kaufmann, K. Künzel, and M. Loock. Customer value of smart metering: Explorative evidence from a choice-based conjoint study in switzerland. *Energy Policy*, 53:229–239, 2013.

[39] C.C. Lin, C.H. Yang, and J.Z. Shyua. A comparison of innovation policy in the smart grid industry across the pacific: China and the usa. *Energy Policy*, 57:119–132, 2013.

[40] R. Rothwell and W. Zegveld. *Industrial Innovation and Public Policy: Preparing for the 1980s and the 1990s.* Number 42. Greenwood Pub Group, 1981.

[41] M. Fadaeenejad, A.M. Saberian, M. Fadaee, M.A.M. Radzi, H. Hizam, and M.Z.A. AbKadir. The present and future of smart power grid in developing countries. *Renewable and Sustainable Energy Reviews*, 29:828–834, 2014.

[42] M.H.S.M.K. Hashmi, S. Hänninen, and K. Mäki. Survey of smart grid concepts, architectures, and technological demonstrations worldwide. In *Innovative Smart Grid Technologies (ISGT Latin America), 2011 IEEE PES Conference on*, pages 1–7. IEEE, 2011.

[43] T.S. Attar, S.S. Mahdavi, J. Saebi, and M.H. Javidi. Implementations of smart transmission grid in iran (case study: Khorasan regional electricity company). In *Electrical Engineering (ICEE), 2012 20th Iranian Conference on*, pages 422–426. IEEE, 2012.

[44] S. Suryanarayanan, P.F. Ribeiro, and M.G. Simões. Grid modernization efforts in the usa and brazil-some common lessons based on the smart grid initiative. In *Power and Energy Society General Meeting, 2010 IEEE*, pages 1–5. IEEE, 2010.

[45] MA. Akcanca and S. Taşkın. Akıllı şebeke uygulanabilirliği açısından türkiye elektrik enerji sisteminin incelenmesi. *Akıllı Şebekeler ve Türkiye Elektrik Şebekesinin Geleceği Sempozyumu*, pages 26–27, 2011.

[46] I. Colak, G. Fulli, S. Vitiello, I. Tekin, R. Bayindir, and K. Demirtas. Developments of turkish grid system infrastructure for integration with europe. In *Power Engineering, Energy and Electrical Drives (POWERENG), 2013 Fourth International Conference on*, pages 1765–1770. IEEE, 2013.

[47] I. Colak, G. Fulli, S. Sagiroglu, M. Yesilbudak, and C.F. Covrig. Smart grid projects in europe: Current status, maturity and future scenarios. *Applied Energy*, 152:58–70, 2015.

[48] I. Colak, R. Bayindir, G. Fulli, I. Tekin, K. Demirtas, and C.F. Covrig. Smart grid opportunities and applications in turkey. *Renewable and Sustainable Energy Reviews*, 33:344–352, 2014.

[49] B. Şanlı and A. Hınç. Smart grid (akıllı sebekeler): Türkiye'de neler yapılabilir? *2010*.

[50] E. Kırmızıoğlu. Ülkemizin 2023 stratejik vizyonu doğrultusunda akıllı şebekeye geçilmesi için öneriler. 2014.

[51] E. Kırmızıoğlu. Akıllı şebeke stratejileri ve örnek projeler. `www.emo.org.tr/ekler/b790c8dde17d8bf_ek.pdf`.

[52] Teíaş sektör raporları kurulu güç 2017. `http://www.teias.gov.tr/sites/default/files/2018-01/Kguc2017.pdf`, 2017.

[53] TEİAŞ. Elektrik İstatistikleri. `http://www.teias.gov.tr/sites/default/files/2017-12/AylikElektrikİstatistikleri.xlxs`, 2017.

[54] `http://www.enerji.gov.tr/tr-TR/Sayfalar/Elektrik`, .

[55] Turkey Electricity Distribution Corporation. Annual report 2016, 2017.

[56] TEİAŞ - faaliyet raporları. `http://www.teias.gov.tr/FaaliyetRaporlari.aspx`, .

[57] ETKB. Enerji verimliliği strateji belgesi, 2012.

[58] T.C Kalkınma Bakanlığı. Bilgi ve İletişim teknolojileri destekli yenilikçi çözümler ekseni mevcut durum raporu. `www.bilgitoplumu.gov.tr`.

[59] Güç Kalitesi Milli Projesi. Güç kalitesi. `http://www.guckalitesi.gen.tr/tr/about/mission.php`.

[60] Enerji ve Tabii Kaynaklar Bakanlığı. 2015-2019 strateji planı, 2014.

[61] Rith Project. Power monitoring and forecasting. `http://www.ritm.gov.tr/aboutUs/ritm.php`.

[62] Bütçe ve Mali Kontrol Genel Müdürlüğü BUMKO. Orta vadeli program. `http://www.bumko.gov.tr/TR,42/orta-vadeli-program.html`.

[63] F. Gangale, J. Vasiljevska, C.F. Covrig, A. Mengolini, and G. Fulli. Smart grid projects outlook 2017. *Joint Research Centre of the European Commission: Petten, The Netherlands*, 2017.

[64] Arkenus. `http://www.3eelectrotech.com.tr/arsiv/yazi/179-akilli-sebeke-donusumunde-sayaclarin-rolu`.

[65] Energy Department for Business and Industrial Strategy. Smart meters quarterly report. `https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/662089/2017-Q3-smart-meters-quarterly-report.pdf`, 2017.

[66] International Smart Grid Action Network. Country Report Canada. http://www.iea-isgan.org/bbs/content.php?co_id=sub4_5.

[67] European Commission. Benchmarking smart metering deployment in the eu-27 with a focus on electricity. http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52014SC0188&from=EN, .

[68] European Commission. Impact assessment support study on: 'policies for dsos, distribution tariffs and data handling'. https://ec.europa.eu/energy/sites/ener/files/documents/ce_vva_dso_final_report_vf.pdf, .

[69] Otomotiv Distribütörleri Derneği. Sektörel değerlendirme aralık 2017 raporu. http://www.osd.org.tr/sites/1/upload/files/2017-12_OSD_RAPOR_SB_1-3300.pdf.

[70] International Energy Agency. Global ev outlook 2017 report. https://www.iea.org/publications/freepublications/publication/GlobalEVOutlook2017.pdf, 2017.

[71] Vehicles in use. http://www.oica.net/category/vehicles-in-use/, 2018.

[72] https://openchargemap.org/site/, 2018.

[73] http://www.sarjet.com/, 2018.

[74] Müşteri İlişkileri. Pozitif Çözümler. https://www.enerjisa.com.tr/tr/musteri-islemleri/pozitif-cozumler, 2018.

[75] TEDAŞ. Faaliyet raporları, 2017.

[76] EPDK. Elektrik piyasası 2016 yılı piyasa gelişim raporu. http://www.epdk.org.tr/TR/Dokuman/7952, 2017.

[77] Ministry of Energy and Natural Sources. Energy investment reports, 2017.

[78] Chamber of Electric Engineering. Reports, 2018.

[79] Yük tevzi bilgi merkezi. https://ytbs.teias.gov.tr/ytbs/frm_login.jsf, 2018.

[80] Eigm raporları. http://www.enerji.gov.tr/tr-TR/EIGM-Raporlari#, 2017.

[81] International Energy Agency. Country data sheets. https://ec.europa.eu/energy/sites/ener/files/documents/countrydatasheets_august2017.xlsx, 2017.