



## A Supply and Demand Analysis for the Turkish Electricity Market: Supply Adequacy and Resource Utilization

Selim Önay, Ahmet Yücekaya, Ayşe Bilge, Esra Ağca Aktunç\*

Department of Industrial Engineering, Kadir Has University, Istanbul, Turkey. \*Email: [esra.agca@khas.edu.tr](mailto:esra.agca@khas.edu.tr)

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### ABSTRACT

Electricity is a critical commodity for which the demand should be met using reliable, cost-effective, and sustainable resources. The characteristics of supply and demand should be comparatively analyzed for efficient electric power system planning. This study examines Turkey's current electricity supply and demand and their characteristics for future balance. Turkey's installed capacity and electricity consumption per capita are analyzed using historical data, and trends for future electricity demand are estimated. Electricity supply based on generation sources is reviewed, and the historical contribution of each source to total generation is shown. Statistical distribution of electricity generation by generation types and their relationships are also investigated. As the supply adequacy should be carefully reviewed for sustainability, finally, the characteristics of supply are analyzed using capacity factors, reserve margins, capacity margins, load duration curves, and peak-to-average demand ratios. It is shown that although the margins are above comfortable levels after 2017, they still need to be increased as the increased use of renewables might require extra availability. The load duration curves and peak-to-average demand ratios have shown that the density of demand is increasing, and capacity needs to be expanded and utilized carefully in the future for the reliability of the power system.

**Keywords:** Electricity Supply-Demand, Electricity Generation Sources, Consumption Trends, Capacity Factor, Reserve Margin, Load Duration Curve  
**JEL Classifications:** Q41, O13, L94

### 1. INTRODUCTION

Electricity is a unique commodity in the sense that its supply and demand both have stochastic characteristics, and storage is not economically viable and hence limited. The investment for new power plants and distribution lines requires significant capital costs, which prevent many investors from entering the market. Projections for electricity demand have always been a crucial issue for infrastructure planning. In addition to meeting the demand reliably, there should also be room for flexible competition needs in free power markets. In fact, the liberalization of the energy markets has necessitated more detailed and accurate analyses towards reliable forecasts at various horizons.

Reliability requires a reserve to satisfy demand when supply and demand uncertainty would otherwise lead to a shortage. It is thus

necessary to have a surplus in overall generation capacity, not only for meeting the demand but also for regulating power markets. For example, electricity system operators such as Independent System Operator (ISO) New England and PJM (Pennsylvania-New Jersey-Maryland) Interconnection provide incentives to power companies to support capacity investments and encourage long-term availability of required capacity. It is also possible in some markets to have a capacity market in which investments, market design, and retirements of old power plants are observed to assure that adequate resources are available to meet the load reliably (Cramton, 2017).

Electrical power generation over a given period is analyzed through installed capacity, capacity factors, reserve margin, capacity margin, and load duration curves. "Capacity Factor" is defined as the ratio of the actual output to the potential output of

a generation unit; hence it is a measure of the efficiency of the generation unit and the reliability of the system with respect to long-term variations in the demand. “Reserve Margin” is defined as the ratio of the difference between the available capacity and the peak demand to the peak demand. Reserve margin measures the level of available reserved capacity to secure the supply, and it is related to the reliability of the system with respect to short-term stochastic variations (Laleman and Albrecht, 2016). “Capacity Margin” can also be used as an alternative to Reserve Margin. These margins act as insurance against unexpected losses of power or surges of demand; hence, they are crucial for a reliable operation of the system. The smaller the margins are, the greater the risk of failure to meet the high demand is. Although the reserve and capacity margins are calculated based on the peak demand, the distribution of demand over time also plays an important role in the system. The load duration curve shows the distribution of the loads and the percentages of each load level in total.

The difference between the available supply and the demand provides flexibility for scheduling generation sources as well as options for a competitive market. If the supply and demand are too close, there will be a high risk of being short in cases of critical failures or fuel shortages and less room for competition in the liberalized market. Hence, the margins should be wide enough to ensure a smooth market operation.

It should also be noted that the majority of capacity additions in recent years are renewables such as solar and wind which are intermittent. They contribute to supply whenever the sources are present, and the remaining demand needs to be covered with other available sources. This should be taken into account in the determination of margins and capacity planning.

Although there are studies about the Turkish power system and other electricity markets in the literature, supply adequacy and reliability issues are not addressed within the scope of the set of measures used in this study, namely capacity factor, reserve margin, load factor, load duration curve, and peak-to-average ratio. The main research questions of this study are, whether the current trends in the power generation of Turkey would lead to sufficient supply to meet the future demand, which power generation sources would be more important for maintaining the supply-demand balance in the future, and what types of policies can be implemented to incentivize investment into power generation expansion plans. The specific objectives of this work can be further described as:

- To evaluate the evolution of electricity generation sources from past to present, paying special attention to resource utilization and renewables,
- To analyze utilization of generation resources using capacity factors and seasonality effects on electricity production by different sources,
- To evaluate the supply adequacy to meet the peak demand in the Turkish power market using margins,
- To evaluate the structure of the demand using load duration curve and peak-to-average ratio in an effort to identify a trend for the demand, and

- To identify possible implications for future market design and energy transition pathways.

To achieve the aforementioned objectives, in this work, an extensive supply and demand analysis for the Turkish electricity market is presented. The historical and current structure of the installed capacities and the contribution of each generation source as well as interdependencies of generation sources are presented to display the trend in supply sources. The utilization of generation sources is analyzed using capacity factors, reserve margins, capacity margins, load duration curves, and peak-to-average ratios. The capability of meeting the peak demand with available and average capacity is also analyzed. The proposed methods to analyze the supply adequacy of the electricity system beginning from generation sources to demand characteristics are novel and have not been applied before within this scope. Policy implications for future market design to ensure a smooth market operation and a sustainable power system are discussed.

The remainder of this paper is organized as follows. In Section 2, the background of the Turkish power market is outlined and an overview of the related literature is presented. In Section 3, the statistics of Turkey’s electricity supply and demand over the years are examined. In Section 4, the methodological approach is described. In Section 5, contribution and correlations of electricity generation sources are discussed, electricity supply analysis is performed using the capacity factor, reserve margin, load factor, load duration curve, and peak-to-average ratio computations, and changes in recent years are interpreted. In Section 6, a detailed discussion of the results is provided, and in Section 7, the paper is concluded with policy implications drawn from the analyses.

## 2. BACKGROUND AND LITERATURE REVIEW

The Turkish power market has experienced a significant development on both the demand and supply side and no significant shortage has occurred in the last decades. The liberalization process started in the early 2000s and privatization led to new capacity investments in the market. Coal, natural gas, and hydro have been and still are the dominant electricity generation resources while the majority of coal and hydro plants are old and state-owned. The generation from other sources depends highly on the hydro resources, which have been the essential baseload plants for the country, followed by coal plants.

Since 2000, Turkey’s electricity demand increased from 128 TWh to 303.3 TWh in 2019, while the total installed capacity increased from 27 GW to 91.3 GW (TEIAS, 2019a). According to Vision 2023 energy targets, it is expected to reach 120 GW in 2023 (Melikoglu, 2018). Although the electricity demand has been met without any major problems, as the economic growth of the country, rising population, and electrification increased the demand, the use of generation sources needs to be analyzed to ensure that the available capacity is well utilized and the planned capacity will meet future demand.

There are several studies in the literature focusing on Turkey's total electricity demand using econometric tools, showing that the demand will increase, and analyzing the rate of increase using different parameters (Akan and Tak, 2003). Melikoglu (2018) uses a forecasting model based on population and electricity demand per capita to predict Turkey's electricity demand to be between 327 TWh and 429 TWh depending on different demand growth rates and total installed capacity to exceed 110 GW in 2023. It is also noted that if all Vision 2023 energy targets are realized, about half of Turkey's installed capacity would be supplied from renewable energy sources, 30% by hydropower and 23% by other renewable energy sources. The potential of clean and sustainable renewable energy resources in Turkey, including biomass, wind power, hydropower, solar energy, geothermal energy, and nuclear energy, is investigated in (Benli, 2013). Suggestions include utilizing hydropower more as it can meet 25–35% of Turkey's electrical energy demand in 2020, investing in wind energy, constructing large solar power plants, utilizing the geothermal potential more as it can meet 14% of Turkey's total energy demand, and using thorium reserves for nuclear power generation provided that necessary technological steps are taken.

The long-term capacity expansion plans for electricity include a target reserve margin (LEAP, 2021). The required capacity is estimated for each year and a reserve margin is also considered for the system reliability. Reimers et al. (2019) analyze the impact of reserve margin on long-term energy planning in USA. They show that higher reserve margins led to a more flexible electricity system and higher solar investments for USA. Hemmati et al. (2013) propose a reliability constrained generation expansion planning in the presence of uncertainty. The methodology maximizes the expected profit of companies considering reserve margin and loss of load expectation. Ang'u et al. (2020) analyze the role of reserve margin in electricity tariffs in Kenya using a regression model and it is shown that the reserve margin has a role in determining the electricity prices. Diewvilai et al. (2011) propose a probabilistic approach to determine the appropriate reserve margin for an electrical system taking Thailand as the case study. Their main motivation is that too much reserve margin requires over-investment in generation capacity whereas too low a margin might cause generation risk and decreased reliability. The role of the reserve margin for supply adequacy and the public good is well explained in (Rochlin, 2004).

The supply adequacy for the smooth operation and reliability of a power market has been discussed in some studies such as Cepeda and Finon (2011), Wen et al. (2004), Griffin et al. (2013), and Finon and Pignon (2008). The reserve and capacity margins are shown to be important to decrease the cost and increase the reliability of the system; however, the resource utilization and the characteristics of the demand also need to be analyzed to increase the reliability and help a smooth market operation. The capacity is available in the power market, but its utilization should be efficient. The demand, on the other hand, needs to be analyzed using peak demand, average demand, load duration, and trends over time.

Although various studies are focusing on Turkey's electricity demand, to the best of our knowledge, none of the existing studies

consider the evaluation of capacity factors, reserve margins, and load duration curves to address supply adequacy and reliability issues discussed in this study.

### 3. DATA AND TRENDS IN THE TURKISH POWER SYSTEM

Data used for the analyses in this study consist of public information on the websites of the Independent System Operator (EPIAS) and the Authorized Transmission Operator (TEIAS). Generation sources are broadly classified as hydroelectric plants, natural gas-fired plants, thermal plants using various types of coal, generation units using liquid fossil fuels, and renewable energy. On the EPIAS and TEIAS platforms, these basic sources are further detailed.

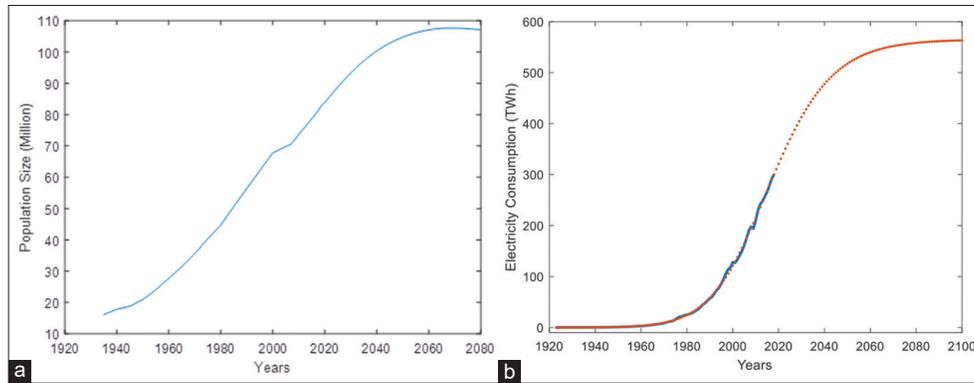
Population projections are crucial for long-term energy demand projections. Population projections published by the Turkish Statistical Institute (TurkStat) predict an increase until 2069, reaching an estimated maximum of 107 million 664 thousand people, corresponding to 29.47% increase from 83 million 155 thousand in 2019, as shown in Figure 1a (TurkStat, 2020). In order to obtain energy projections for a longer horizon, long-term past data (1923–2018) published by the Ministry of Energy and Natural Resources of Turkey is used to obtain a sigmoidal fit to the data shown in Figure 1b, based on the assumption that energy demand will reach a stable asymptotic value in the future. This scenario indicates a stabilization of the energy demand by 2080 and agrees qualitatively with the maximum of the population growth curve in 2069. The demand rises from 310,590 TWh (smoothed value) in 2019 to 551,245 TWh in 2069 and 563,429 TWh (estimated values) in 2100, corresponding to 77.48% and 81.40% increases.

The installed capacity and demand in the near past are studied to analyze the variability. Turkey's installed capacity, which was 16 GW in 1990, increased to 27 GW in 2000, 49 GW in 2010, and 88.5 GW in 2018. Table 1 provides the installed capacities by each source as of October 2020. It is observed that natural gas and coal still have almost 40% of the total installed capacity, showing that the total capacity is still dominated by fossil-based resources. On the other hand, the installed capacity for wind and solar have shown significant growth in recent years due to the strategic governmental decision for renewables and accompanying

**Table 1: Installed capacity by sources as of October 2020 (TEIAS, 2020)**

Source	Capacity (MW)	Share (%)
Hydro (Dams and Rivers)	29,916	31.85
Natural Gas	25,634.3	27.29
Hard Coal (including Imported Coal and Asphaltite)	10,202.7	10.86
Lignite	10,097.3	10.75
Wind	8330.1	8.87
Solar	6454.4	6.87
Geothermal	1579.2	1.68
Biomass and Others	1398	1.49
Fuel Oil	305.9	0.33
Diesel Oil	1	0.00
Total	93,918.9	100

**Figure 1:** (a) TurkStat population data for 1935–2019 and projections for 2020–2080, (b) Turkey’s electricity consumption for 1923–2018 (in blue) and demand projection for 2019–2100 (in red)



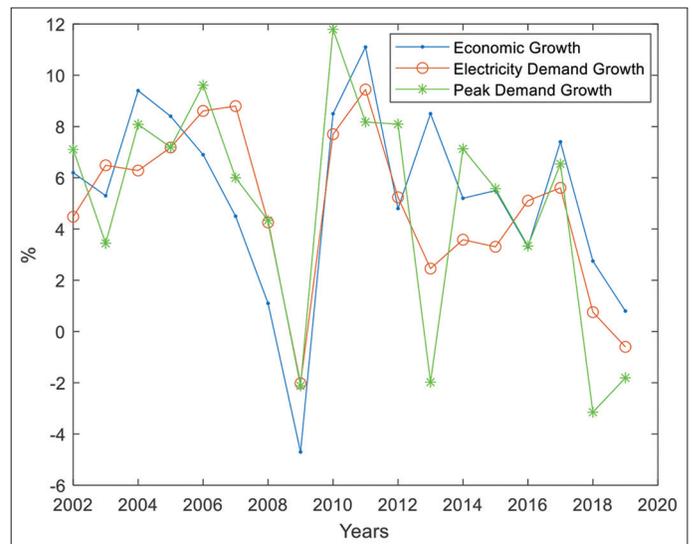
supports. The shares of wind and solar were 5.20% and 0.06% in total installed capacity in 2014 and they are increased to 8.87% and 6.87% in 2020, respectively. Starting in 2014, 46 renewable energy cooperatives have been established in Turkey, all of which rely on solar power due to the cost-effectiveness and scalability of photovoltaics (Özgül et al., 2020).

As population and installed capacity are both increasing, to compare their growth rates, one needs to evaluate changes in the per capita installed capacity. The growth in per capita installed capacity is slightly more pronounced than the growth of the total installed capacity. This agrees with the remarks in Mucuk and Uysal (1997), where attention is drawn to the growth of energy demand in recent years, by the increase of new areas of electricity demand.

As seen in Figure 1, there is a strong trend of increase in both population and consumption, but both are expected to be stabilized. In addition to the total electricity consumption, per capita electricity consumption is also an indicator of development for a country (General Directorate of Energy Affairs, 2015). Turkey’s electricity consumption per capita also increases over time becoming 3149 kWh in 2018. While per capita electricity consumption in the world is around 3144 kWh, it is around 5909 kWh in the European countries, 7985 kWh in the OECD member countries, and 12,973 kWh on average for the United States as of 2014 (World Bank, 2014). The population and demand projections given in Figure 1 predict a per capita electricity consumption of 5120 kWh by 2069. It is thus necessary to plan 75–80% capacity increase to supply a per capita demand at the level of about 5000 kWh, in the long run.

The total electricity demand is growing as the population, economy, industrial activities, and electricity use per consumer grow. Figure 2 shows the growth rates of annual electricity demand, peak electricity demand, and the economy in Turkey between 2002 and 2019. The growth rates are significantly related to and impacted by each other. Correlation analysis shows that the correlation between economic growth and electricity demand growth is 0.74. The relationship is obvious at the time of economic crises in which economic activity and industrial production decrease. Turkey has experienced many crises but the crises in 2009 and 2019 and their impact can be clearly observed from the figure.

**Figure 2:** The relationship between the growth of the economy, electricity demand, and peak demand in Turkey



### 3.1. Evolution of Electricity Generation Sources: 1960–2019

Electricity generation in terms of resources used in Turkey varied considerably over the years. Historically, coal-based plants had been dominant in electricity generation until the 1970s, but later, hydroelectric power became the main source of energy. Currently, hydro, coal, and natural gas have the highest shares. In addition, the shares of solar power and wind-driven plants started to increase significantly in recent years. The shares of the source types over the 1970–2019 period are shown in Figure 3. It can be seen that starting from the 1980s, natural gas appears as a substitute for liquid fuel, whose share is negligible (<1%) at present. Thus, the main energy sources are hydropower, coal, natural gas, and renewables.

Total power generated by these main energy sources is plotted in Figure 4. Comparing Figures 3 and 4, one can see that although total production by hydropower is increasing more or less linearly, its share is decreasing due to the exponential increase in demand. Similarly, although the share of coal-based production is generally distributed between 25 and 35% since the 1970s,

an increasing trend in total production raises serious concerns on environmental impacts. Electricity generation with natural gas has the highest share of more than 40% of total production since 2001 and it has maintained its share of more than 35% until 2016. As natural gas is imported, the decrease of its share would be a positive development for Turkey. Clean electricity generation, as an environmentally conscious alternative, has seen an acceleration in recent years. The use of renewable resources in electricity production had a share of approximately 12.7% in 2018 and such resources are expected to be used more actively in the upcoming years.

### 3.2. Electricity Generation Sources: 2010–2019

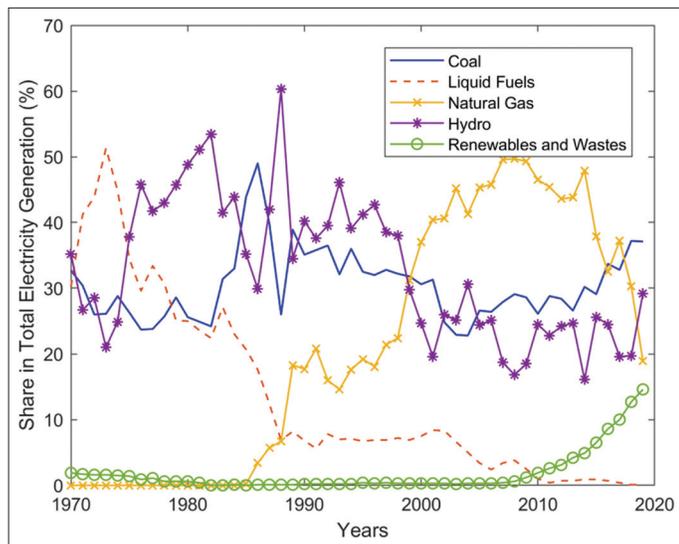
Total daily real-time production for the 2010–2019 period is shown in Figure 5, where an upward trend and a seasonality in the total consumption are clearly observed. The lowest production levels in the total consumption correspond to the religious holidays,

during which almost all industrial plants are shut down and the consumption is practically reduced to household usage. The seasonality in the total consumption is due to the changes in daylight hours and the use of electricity for heating and cooling purposes.

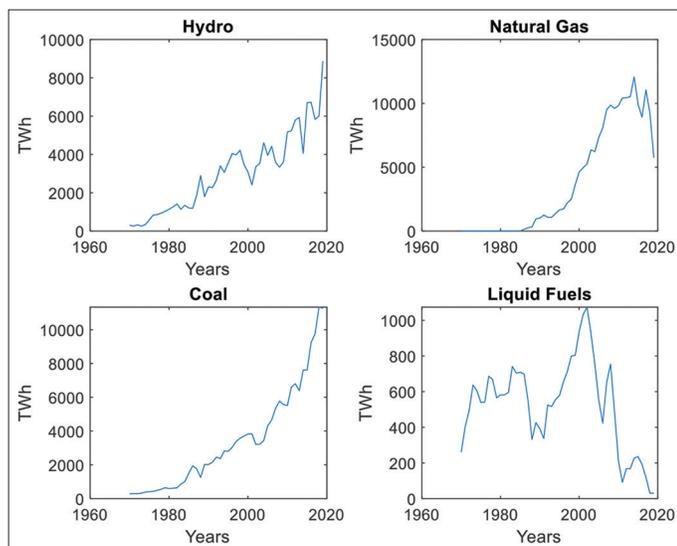
The share of each generation source for the 2010–2019 period is presented in Table 2.

A close-up of the contribution of energy sources is presented in Figures 6 and 7 for the 2010–2019 period. Figure 6 shows the contribution of natural gas plants, coal-based plants, dams, and rivers. The strong seasonality in the production of river-based plants can be observed from the data. It should also be noted that the contribution of run-of-the-river-based plants is increasing. Coal-based plants still have a high share in electricity generation. Figure 7 shows that the contributions of renewable sources such as wind, geothermal, biomass, and solar are low, but increasing. The solar energy data is available starting from early 2017. The contributions of the remaining energy sources, as well as imported energy, are negligible. International energy exchange is also negligible except for an unusual spike in 2015 because of a countrywide blackout on March 31<sup>st</sup>, 2015 due to transmission lines problems preventing electricity transmission to some regions of the country.

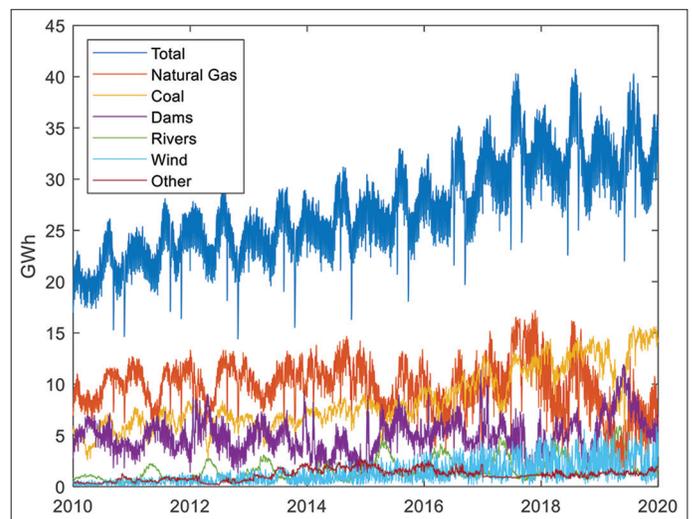
**Figure 3:** Turkey’s electricity generation by energy resource, 1970–2019 (TEIAS, 2019c)



**Figure 4:** Trends in electricity generation by different energy resources (TEIAS, 2019c)



**Figure 5:** Daily electricity production by plant type, 2010–2019 (TEIAS, 2019c)



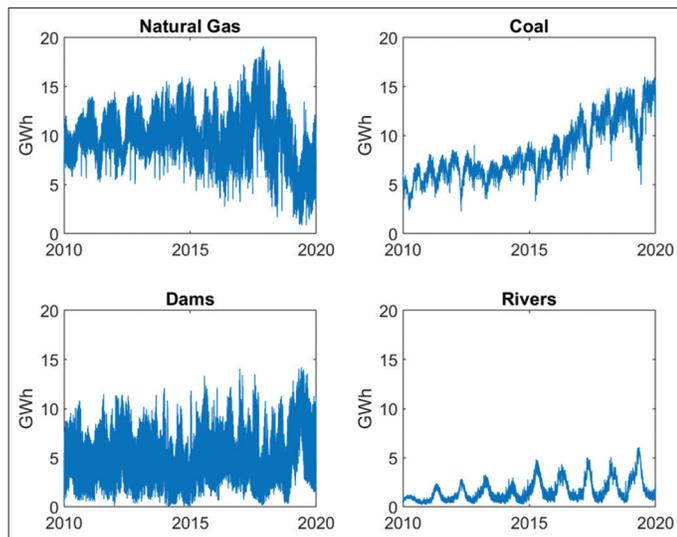
**Table 2: Proportion of total production by sources (TEIAS, 2019b)**

Power Plant Type	Percentage of Production (%)					
	2010	2012	2014	2016	2018	2019
Natural gas	46.5	43.6	47.9	32.5	30.3	18.6
Hard Coal (including imported coal and Asphaltite)	9.1	13.9	15.7	19.6	22.4	21.8
Hydro	24.5	24.2	16.1	24.5	19.7	29.2
Lignite	17.0	14.5	14.5	14.1	14.8	15.4
Geothermal, Wind, Solar	1.7	2.8	4.3	7.8	11.5	13.2
Combustible	0.2	0.3	0.6	0.9	1.2	1.5
Renewables and Wastes						
Fuel and Diesel Oil	1.0	0.7	0.9	0.7	0.1	0.2

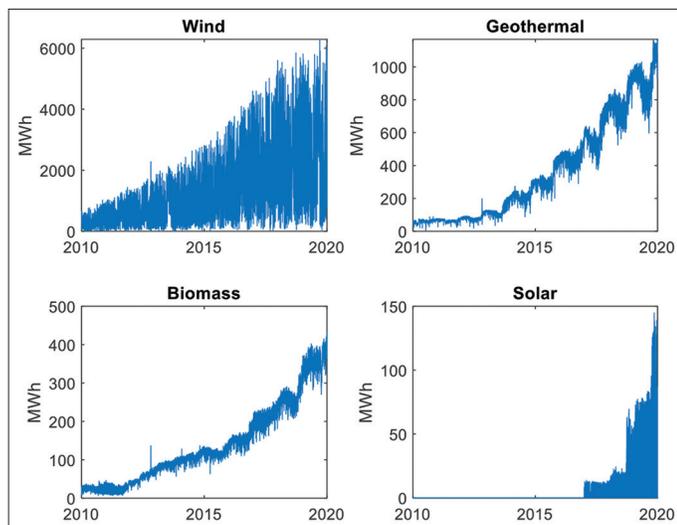
### 3.3. Seasonality Effects on Production

In addition to the seasonality in the consumption, there are seasonality effects specific to certain source types. For example, electricity production from dams reaches its lowest levels in September and starts to rise again in November. On the other hand, the production of rivers increases a little later than the dams, and the decrease in the amount of production comes up earlier than the dams. The reason for this change is that river power plants are more dependent on rainfall conditions than dams. After the dams have reached a sufficient occupancy rate, they can produce for a certain period even if there is no rainfall. In principle, natural gas and coal plants have production levels that do not demonstrate seasonality. If necessary, they can be used, to a large extent, independent of climatic conditions. Nevertheless, as these plants are costly to operate, they may refrain from bidding for generation at times hydropower is available at a lower cost, hence their production also shows a seasonality.

**Figure 6:** Contributions of natural gas and hydroelectric power (TEIAS, 2019c)



**Figure 7:** Contributions of wind, geothermal, biomass, and solar (TEIAS, 2019c)



The relationship between precipitation and electricity production types and their lagged correlations are given below in Figure 8. As seen in Figure 8, rainfall and electricity generated by natural gas plants are completely out of phase. This shows that when more water is available for hydro resources, hydro resources are given priority for generation over natural gas plants as a result of market-based dispatch mechanism. The hydro resources offer lower cost and eventually become the base units and are selected by the market because of merit-based order. On the other hand, there is a time shift between rainfall and electricity production by dam-based plants. Finally, hydropower generation by river-based plants is completely in phase with precipitation.

The lagged correlations between production by dams, rivers, and natural gas plants and rainfall, displayed in Figure 8 show that the delay for which the production from dams has the most significant correlation with precipitation data appears to be 3 months, with a value of 0.47. Similarly, the 3-month lagged correlation of electricity generation from rivers shows a significant correlation with rainfall data.

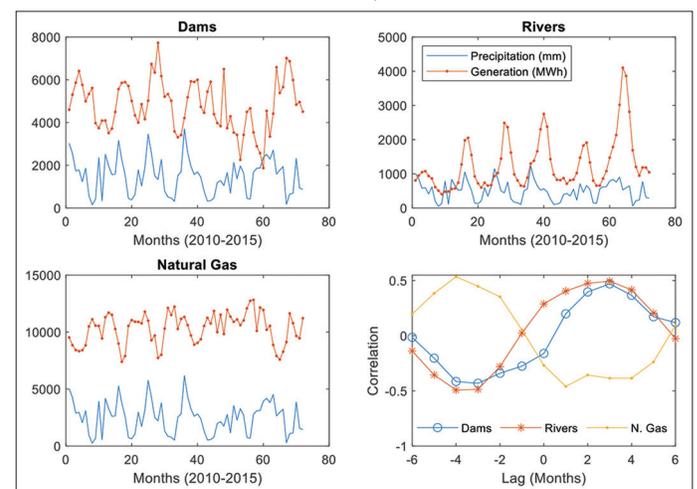
## 4. METHODOLOGY

The objectives of this study are to provide an analysis of the current state of electricity supply and demand in Turkey by examining the installed capacity, consumption, and supply based on power generation sources, and to assess the supply adequacy using capacity factors, reserve margins, capacity margins, load duration curves, and peak-to-average demand ratios. As a result of these analyses, the overarching objective of this study is to provide policy implications for future market design for ensuring a smooth market operation and a sustainable power system. The performance measures used to achieve these objectives are explained below.

### 4.1. Capacity Factor

The generation expansion decisions are made based on demand growth and technological factors. In this study, the historical evolution of supply and demand is analyzed to extract important

**Figure 8:** Precipitation and electricity generation by natural gas, dams, and rivers, and their lagged correlations with precipitation (TEIAS, 2015)



information for the sustainable system operation. The long-term electricity demand is affected by population growth, economic activities, and per capita electricity consumption. Although these measures show a growing trend, installed capacity, on the other hand, does not mean the generation ability, since the capacity includes renewables and other sources limited by their capacity factors. In addition, the utilization of electrical energy generation sources is analyzed using past data to show how the existing capacity is utilized. Also, correlations among electricity generation sources and correlations between sources and precipitation are analyzed.

In the analysis of supply adequacy and reliability against the demand, capacity factors, reserve margins, capacity margins, and load duration curves are used. The capacity factor of a plant  $p$  as a generation source,  $CF_p$ , is the ratio of actual output,  $AO_p$ , to its potential output,  $PO_p$ , over a period of time as represented below.

$$CF_p = AO_p / PO_p \tag{1}$$

$CF_p$  is expected to depend on the plant and fuel characteristics and it is different from efficiency and availability. The potential of the generation capacity of plants is not used fully due to various reasons. The capacity factor includes reduction of power output due to planned maintenance and unexpected failures that require the plant to stop operating or reduce its generation (Naderi et al., 2020). Furthermore, if the price of electricity is too low to cover the cost, the plant would not be dispatched and will not use its capacity. The plants that wait for the peak hours can be considered within this class. The capacity factor is not a sharp indication of whether a plant is operating effectively. However, the capacity factor can be measured to evaluate the resource utilizations and different plants with similar and different technologies can be compared.

### 4.2. Reserve Margin and Capacity Margin

Reserve margin (RM) is the ratio of the difference between available capacity and peak demand to peak demand over a given period. Having a reserve is costly, but required for flexibility and for avoiding imports and extra cost on generation. On the other hand, markets need different requirements based on the nature of renewables, load profiles, and the ability to import required electricity when needed. The maximum available capacity can be used as the available capacity for RM; however, this is not guaranteed to be available at the time of peak demand. The average capacity is more likely to be available to meet the demand. Hence, two types of RM are calculated using average capacity and maximum capacity:  $RM_{ave}$  using the average available capacity,  $AC_{ave}$ ,  $RM_{max}$  using the maximum available capacity,  $AC_{max}$ , as shown below.

$$RM_{ave} = AC_{ave} / PD - 1 \tag{2}$$

$$RM_{max} = AC_{max} / PD - 1 \tag{3}$$

The capacity margin (CM) of a system is the ratio of the difference between available capacity and peak demand to available capacity, over a period of time. Similar to RM,  $CM_{ave}$  is calculated using

average available capacity,  $AC_{ave}$ , and  $CM_{max}$  is calculated using the maximum available capacity,  $AC_{max}$ , as shown below.

$$CM_{ave} = 1 - PD / AC_{ave} \tag{4}$$

$$CM_{max} = 1 - PD / AC_{max} \tag{5}$$

### 4.3. Load Duration Curves

The demand characteristics should also be analyzed in terms of its density, i.e., whether the pattern of the demand throughout the year is stable or has a trend that needs to be identified for operation planning. Not only the peak demand but also the density of the demand over the year is important for the market operation. Load duration curve is a graph of the demand frequency distribution (Poulin et al., 2008). Therefore, the cumulative distribution function of the loads (demand) on the power system over the year is displayed in the descending order of the loads, and the load duration curve is calculated. The distribution is defined in percentages taking values between 0 and 100. Load duration curves provide valuable information on the proportion of time that the load is above a certain level and on the changes in the density of the demand over time.

### 4.4. Peak-to-Average Ratio

A peak-to-average ratio is also used to evaluate the relationship between average and peak demand through years. The ratio is commonly used to assess the load in the transmission system over time and help characterize the nature of the demand. A ratio that is closer to 1 shows a demand set with a lower standard deviation. In other words, the ratio of the demand that is closer to peak demand is increasing and the system operator needs to plan the operations accordingly as the average system load will be higher and closer to peak load (Jordehi, 2019).

The results of the analyses employing the methods described above are presented in the next section.

## 5. RESULTS

In this section, capacity factors, reserve margins, capacity margins, and load duration curves are discussed in detail and compared with presented reference cases. The characteristics of supply and demand are then evaluated to determine the weak points in the current system and the required actions that need to be taken for a more reliable power system.

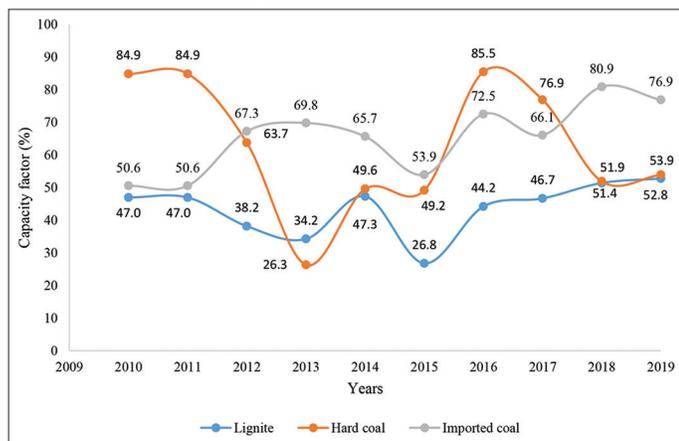
### 5.1. Capacity Factor

The capacity factor is an important indicator of the relative usage of the potential and how effectively the resources are used. Although the capacity factor of each plant is expected to be different, it is still possible to reach an average as plants with similar characteristics tend to have close capacity factors. Figures 9 and 10 present the average capacity factors for power plants in the Turkish power market.

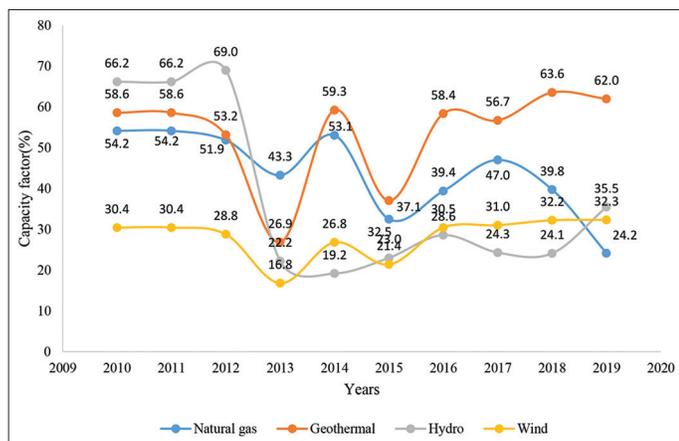
The actual annual output for each resource is calculated using all the real hourly generation provided by the system operator. The average capacity factors for 9 years are calculated in terms of

Geothermal (53.7%), Hydroelectric (37.8%), Biomass (37.8%), Natural gas (44.0%), Hard coal (62.7%), Lignite (43.5%), Imported coal (65.4%), and Wind (28.1%). These capacity factors can be compared with the reference values of the U.S. Energy Information Administration (EIA): Geothermal (76%), Hydroelectric (41.9%), Biomass (61.8%), Natural gas (65.4%), Coal (60%), and Wind (34.6%) (EIA, 2019). The average capacity factors found for Turkish power plants are less than the EIA reference values except for hard coal. The capacity factor for imported coal increases as it is cheaper than hard coal and lignite while having better heat content making this option viable for the market. The capacity factors of the natural gas-fired power plants decrease over time and they are severely affected by the market conditions. The majority of natural gas is imported and expensive, and such plants are operating when the price reaches certain levels. Plants based on renewable resources such as hydro and wind depend on the availability of these resources, hence, it might not be possible to control their capacity factors. Solar power is usually treated differently as it is only available during the daytime and the capacity usage is directly related to solar radiation. As new renewable capacity is added to the portfolio, the generation from natural gas capacity is replaced with renewable capacity which is supported by the government using feed-in tariffs and, therefore, is cheaper.

**Figure 9:** Capacity factors for Lignite, Hard coal, and Imported coal plants, 2010–2019



**Figure 10:** Capacity factors for Natural gas, Geothermal, Hydro, and Wind plants, 2010–2019



### 5.2. Reserve Margin and Capacity Margin

Reserve margin, the ratio of the difference between available capacity and peak demand to peak demand, is regularly reviewed in some markets such as PJM, NYISO, and ERCOT, and usually a level of 16% is targeted (PJM, 2019). The markets in North America usually target reference cases between 15 and 20% while some markets reach 30% reserve margin (NERC, 2019). Using the same data, the reference for capacity margin in the markets in North America is estimated as 13–16%. Henriot and Glachant (2014) analyze RM in some European countries considering 15% as a comfortable threshold. Tzimas et al. (2009) also explain the importance of having 15–20% RM for reliability.

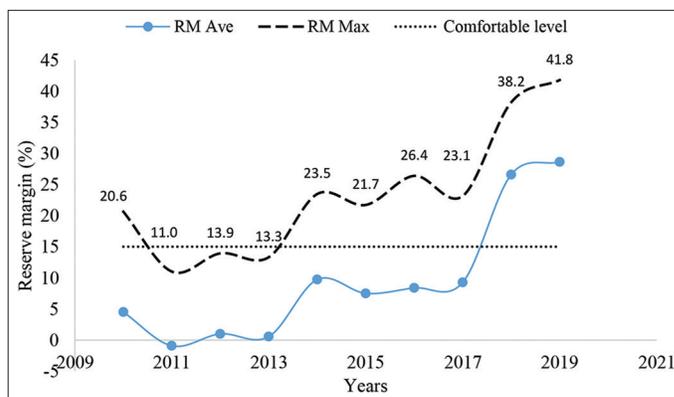
Capacity margin, the ratio of the difference between available capacity and peak demand to available capacity, is also a measure of supply reliability. Capacity expansion decisions for the electricity generation sources can be supported by reserve and capacity margins based on the peak demand. The peak demand usually occurs on hot summer or cold winter days. The intermittency of the renewables and climatic uncertainties require even a higher amount of reliable capacity to be available when needed.

Figures 11 and 12 show the RM and CM values using the capacity and demand data provided by the system operator for the 2010–2019 period.

Although  $RM_{max}$  values show the margins that can be used at peak demand given the maximum available capacity, this capacity is not usually available at the time of peak demand. The capacity includes renewables and capacity lost due to failures in power plants.  $RM_{ave}$  values, on the other hand, show the average margin that can be used during peak hours, as, in this case, the average capacity will mostly be available throughout the year. The same can be told for  $CM_{ave}$  and  $CM_{max}$  values. The reliable average capacity that can be used at peak hours is more practical than the maximum available capacity as the available capacity changes over the year.

Figures 11 and 12 show that  $RM_{ave}$  and  $CM_{ave}$  values have been significantly lower than the comfortable levels until 2017. In

**Figure 11:** The reserve margin in the Turkish power system (2010–2019)



some studies, an RM which is <10% is considered risky (Henriot and Glachant, 2014). It is possible to meet the required demand through imports when needed and the usual way is to import the required amount during these times. However, such levels of  $RM_{ave}$  and  $CM_{ave}$  could not provide enough flexibility, competitiveness, and lower prices to the market. On the other hand,  $RM_{max}$  and  $CM_{max}$  values have been above the comfortable levels since 2013, especially after renewable capacity is added to the portfolio.

RM and CM values increase above comfortable levels in 2018 and 2019. The capacity growth reports show that there has been a significant renewable capacity addition in the last 2 years. The renewable resources show high variability in terms of generation and need to be supported with some other resources. The peak demand which is correlated with economic growth also impacts RM and CM values. The reports show that the economic growth decreased and the country has seen decreasing growth rates in the last 2 years (World Bank, 2020).

### 5.3. Load Duration Curve

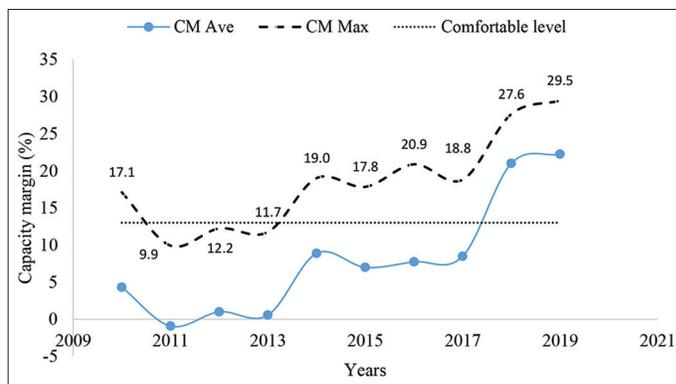
Although the peak demand and reserve margin are important parameters to assess a power system, they do not provide information on the usage rates of the electricity over time. The load duration curve shows the distribution of the loads on the power system over the year showing the loads rearranged from the highest to the lowest and providing information on the rate of time that the load is above a certain level. The region in which the curve is linear, that is, the demand is concentrated, indicates the range where the system generally has average demand. A denser demand also indicates there is higher demand than usual that needs to be met and the need for generation of load following and peak load plants might increase. Such information is needed to observe the density of demand over the year for better utilization of resources.

The load duration curve is not concerned with how the consumption varies over a specified time interval. In other words, it is not possible to extract the seasonal effect by looking at the load duration curve. In general, the power concentration of demand over a certain period can be measured in the graphs.

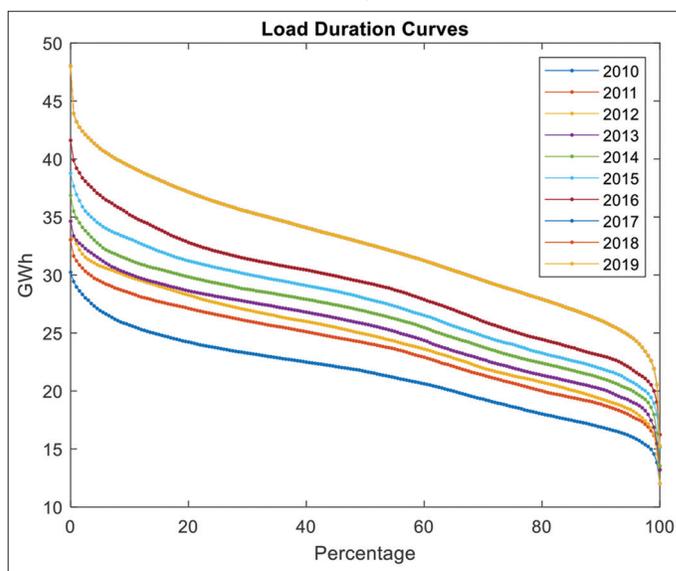
Figure 13 shows the actual load duration curves for 2010–2019 where the ranking was made by starting from the highest consumption amount in a year. The magnitude of the load duration curve increases as the demand increases over the years.

A regression analysis of the data shows that the negative slopes of load duration curves in Figure 13 are decreasing over the years indicating that the density of the load is increasing, i.e., the percentage of the demand that is closer to peak demand is increasing. As shown in Figure 14, the absolute value of the slope is increasing over the years. An increasing slope indicates that the average demand gets closer to peak demand over time, and hence the average system load would increase and available reserve capacity over time should increase. The electrical power system should take action to meet this increasing demand density considering the intermittency and uncertainties of renewables and other power plant conditions.

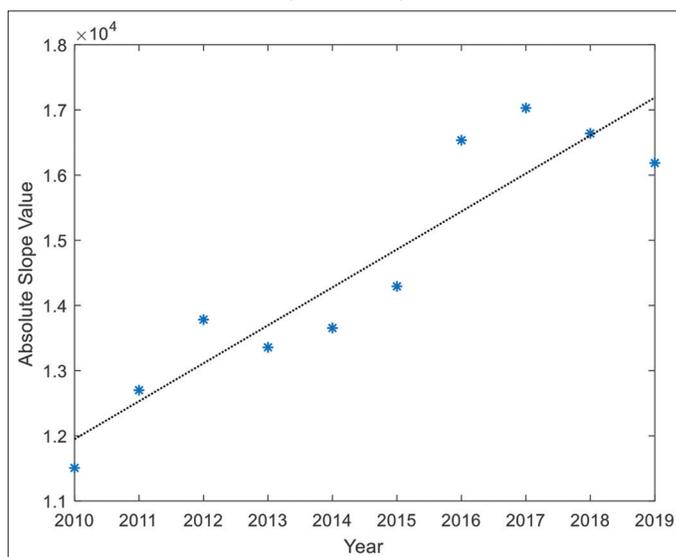
**Figure 12:** The capacity margin in the Turkish power system (2010–2019)



**Figure 13:** Load duration curves in the Turkish power system (2010–2019)



**Figure 14:** The slopes of load duration curves for the total generation (2010–2019)



### 5.4. Peak-to-Average Ratio

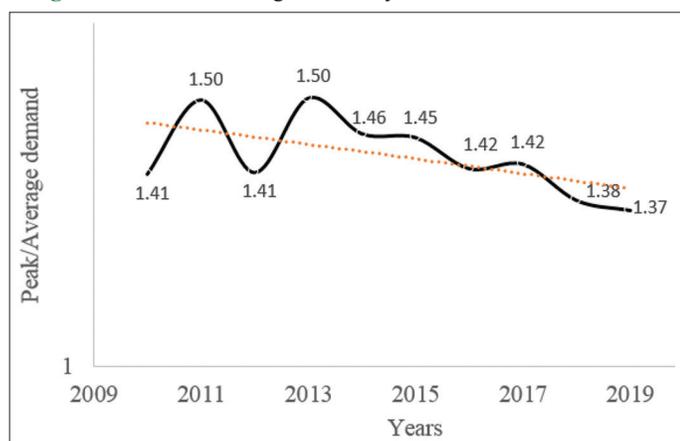
In addition to the load duration curve, the peak-to-average electricity demand ratio is also used for evaluation. A report shows that the peak-to-average electricity demand is rising in the US electricity markets; the ratio was 1.52 in 1993 and 1.89 in 2012 with the average being 1.67 in the New England electricity market (EIA, 2014). Figure 15 shows the peak-to-average electricity demand ratio in the Turkish power market in the 2010–2019 period. A decreasing trend is observed from 1.41 in 2010 to 1.37 in 2019 with an average of 1.43, i.e., the peak demand was, on average, 43% higher than the average demand. The time shift for summer and winter decisions plays an important role in the peak-to-average ratio (Doğan et al., 2016). Durma et al. (2016) analyze the peak demands for different regions and cities and discuss the impact of the time shift on the peak demand. The electric power system needs to maintain a sufficient capacity to meet expected peak loads and reserve margin (Rochlin, 2004). A decreasing peak-to-average electricity demand ratio requires peak load units to be called for operation as the average load is closer to peak through the year. The results show that the load density is increasing in the long term and gets closer to peak as a result of the changes in supply and demand.

## 6. DISCUSSION OF RESULTS

Turkey is not considered an energy-rich country and it has provided much of its electricity from fossil fuels. After the 1990s, natural gas became an imported source for electricity generation due to new pipelines and availability. Hydroelectric resources that have been the main resource until the 1980s have a decreasing share in the total production, but they still act as baseload units. The total share of various coal plants is still significant. The share of wind energy reached an appreciable level; solar energy is increasing at an accelerated rate and it is expected to reach significant proportions.

It is quite interesting to observe that although the production by hydroelectric resources is increasing, its total share is decreasing and this demand is managed by the increasing use of fossil fuels that keep a constant share in the total production. The relationship between precipitation and hydro-based electricity generation confirms this argument. Precipitation and electricity generation from hydro resources have strong lagged correlations, hence

Figure 15: Peak-to-average electricity demand ratio in 2010–2019



hydroelectricity and fossil fuels have negative correlations. Thus, if hydro resources are available, they are used in advance to generate power, then coal and natural gas resources are used to meet the remaining demand.

The capacity factors, reserve margins, capacity margins, load duration curves, and peak-to-average ratios present useful insights for the efficient operation of power markets. In the Turkish power system, capacity factors are less than the reference case except for hard coal which is usually imported. The liberated Turkish power market has a merit-based system and the typical scheduling order in the supply stack is state-owned thermal plants (mostly lignite), wind, solar, biomass, hydroelectric resources with dams, lignite, imported coal, peak hour hydroelectric resources, natural gas, and fuel oil-based generation resources (SHURA Energy Transition Center, 2020). The order is determined based on the net cost that depends on the offer prices.

Performance measures used in this study indicate that there should be improvements in the capacity factor, an increase in capacity to have reliable margins. It is shown that the power plants are not effectively utilized in terms of operational capability. The problem needs to be deeply analyzed to find the root causes as they might be related to technological obsolescence, efficiency, fuel prices, and plant maintenance. If the capacity factors are increased, supply can be increased and the total system cost can be decreased.

The difference between supply and demand is observed in reserve and capacity margins. Average and maximum hourly available capacities are used in two RM and CM measures and the margins are compared with the comfortable levels used in the literature.  $RM_{ave}$  and  $CM_{ave}$  values are significantly lower than comfortable levels until 2017, whereas  $RM_{max}$  and  $CM_{max}$  values are above the comfortable level after 2013. As the peak demand and maximum availability of generation usually do not occur at the same time due to the nature of hydro and renewables,  $RM_{ave}$  and  $CM_{ave}$  values need to be carefully considered and necessary steps should be taken to increase system flexibility and supply sufficiency. Furthermore, the Turkish economy has shown decreasing growth in 2018 and 2019 that impacted the peak electricity demand, i.e., the peak demand was lower than it was supposed to be, and that might lead to a wrong assumption of sufficient supply. If the economy returns to normal, so will the electricity demand, and the margins have the potential to show decreasing trends. The policymakers need to plan generation expansions based on this assumption. Furthermore, Turkey has an estimated 15% transmission loss which is the highest among OECD countries. An effort to decrease the transmission loss would help increase the margins.

The load duration curve analysis indicates that the demand gets steeper and denser over the year. In other words, the average demand gets closer to peak demand over time in a year. Such results are also observed in the peak-to-average ratio that has a decreasing trend as well as the slope of load duration curves. This means that the duration of time that the electricity generation resources run increases in a year. This will leave less time for maintenance activities which need to be planned according to this new trend. The generation expansion plans and investments need

to consider this information as they will conclude that each power plant will run more frequently in this new scheme.

## 7. CONCLUSIONS AND POLICY IMPLICATIONS

The supply adequacy and resource utilization issues are critical for a reliable electric power system and the policy and decision-makers need useful information for their long-term decision-making processes. In this study, it is shown that capacity factors in Turkish power market are less than the reference levels provided in the literature except for hard coal. Reasons such as outages, fuel availability, technology obsolescence, and not being scheduled due to merit-based selection in the market should be analyzed by policymakers to increase capacity readiness. The reserve and capacity margins are above comfortable levels based on the maximum availability, but usually below comfortable levels based on the average availability of resources. The reserves need to be increased considering that the recent capacity additions are mostly renewables that are intermittent and have uncertain generation. It is shown that the electricity demand is increasing and has a significant correlation with economic and population growth. The need for capacity addition should be calculated based on the fact that at least 15% reserve margin is required for comfortable level and the amount that will ensure the reserve will vary based on the availability of the plant type and forecasted demand.

There has been a remarkable capacity addition for renewables in the Turkish electricity system in recent years and its utilization is rising. Research shows that there is still potential and new additions are expected (Bulut and Muratoglu, 2018). Although new capacity is utilized in the system, integration with storage technologies should be evaluated in an effort to use surplus energy. Additionally, biomass has a significant potential that has not been well utilized in Turkey (Toklu, 2017). As the efficiency, cost-effectiveness, and technological capability of renewable technologies increase, investments should be encouraged by the government with possible incentive mechanisms. Such an approach will also increase the ratio of cleaner energy in total generation.

The analyses show that the total and peak demand increase over the years. The load duration curves indicate that the demand density also increases, which means that the average demand approximates peak demand. Decision-makers need to consider this observation for long-term generation and transmission expansion plans considering that the share of intermittent renewable energy is increasing. A better operation of renewables integrated with storage technologies and shifting the demand through demand-side integration are some options that should be supported with incentives. The peak-to-average ratio validates this argument which is a critical development for the power system and it requires even more reserves to be available. The storage technologies that can be integrated with renewables, such as battery storage for wind turbines in Aliasghari et al. (2018) and renewable energy-based micro-grid in Sedighzadeh et al. (2019), should be considered to increase the margins. Also, the investments for renewables can be supported to utilize the renewable potential. The generation

portfolio should be diversified paying special attention to new technologies for both renewables and fossil-based resources. It is not only the capacity but also the demand that is important for margins and especially the peak demand should be shifted and reduced to increase efficiency.

Until recently, demand management and efficiency have not been considered with strict measures in Turkey. A National Energy Efficiency Action Plan is announced in 2018 aiming to reduce primary energy consumption by 14% until 2023 (Bayraktar, 2018). This strategy is a positive sign and more work should be done for public awareness. Initiatives for demand-side involvement and consumer awareness should also be taken into consideration. The demand pattern is indeed as important as the supply adequacy and they both have to be managed in harmony for a successful future market design.

Consumer awareness and demand-side involvement in the process can help smooth the demand and decrease the demand density. The decision- and policymakers need to consider the analyses of past data, evaluate the present conditions and projections based on the trends accurately, and implement pertinent policies for an efficient, flexible, and competitive market environment. Policies to help shifting the demand to different periods, reducing the demand at key times, increasing demand when needed, and awareness for energy consumption can help increase the flexibility in demand. For instance, informing the consumers about the benefits of higher demand response for the integration of renewable energy may increase the acceptability of dynamic electricity pricing schemes (Huuki et al., 2020). Imposing extra costs such as carbon pricing to limit fossil fuels, and supporting renewables and resources with higher flexibility through feed-in tariffs and tax credits can increase the flexibility on the supply side and increase the share of cleaner resources. Also, allowing customers to become prosumers, allocating small- and large-scale storage for customers, offering an option to customers to select green energy, and encouraging big customers to provide flexibility can also help margins and peak-to-average ratios to approach the reference case, and load duration curve to become more uniform.

In recent years, the concept of prosumer and consumer awareness has been rising. The increase in electrification motivates consumers to behave reasonably and, in some cases, produce their demand. Such approaches allow demand-side integration to manage the electricity system. The change in technology, the number of electronic devices per person, demand patterns, and energy-saving efforts such as energy-efficient buildings and machines have a potential impact on the demand. Although energy efficiency is considered in new buildings, the majority of old structures need to be insulated for energy efficiency. The industrial demand characteristics based on the share of service and manufacturing are also important and need to be considered.

The demand for electricity is increasing depending on the factors such as economic growth, population and increasing electrification. The future energy market needs to be built considering the presented issues, emerging trends, and population growth. Turkey, as an associate country of the European Union,

has an interconnection to the European electricity system and, hence, tends to follow the European standards. The efforts to achieve net and absolute zero options force power systems to carefully plan the energy transition to phase out coal and natural gas and become renewable-dominated in the future. The storage and energy conversion technologies such as pumped hydro, adiabatic compressed air, thermal energy storage, the power to gas, and batteries are discussed in the literature with possible integration to electricity generation sources (Child et al., 2019). Carbon capture and utilization technologies are still valid for future energy scenarios as they allow the utilization of fossil fuels. Nuclear power is considered an option for future low carbon energy systems. The technologies for renewables are improving and the costs and efficiencies are increasing and this leads to easier adaptation. However, the intermittency is still an anticipated issue accompanied by fluctuating generation and prices.

Although there is a nuclear power plant being constructed and expected to be operational in a decade, investments in renewables should be given priority for the future energy system. Policymakers should develop strategies based on the renewable energy potential of Turkey and follow the technological trends for planning. The operational natural gas and coal plants are expected to retire in the future and the capacity that will be lost should be replaced either with renewables or new coal or natural gas plants equipped with carbon capture technologies to increase the capacity factors. Market conditions will eventually make such options viable; however, the policymakers need to manage this process for a smooth transition.

The plan for the future market should be developed considering lower capacity factors, reserve and capacity margins, and demand density in the load duration curve for the sustainability of the system.

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