REPUBLIC OF TÜRKİYE
MINISTRY OF ENERGY AND
NATURAL RESOURCES

TÜRKİYE NATIONAL ENERGY PLAN

2022

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EXECUTIVE SUMMARY

Türkiye National Energy Plan study has been developed in accordance with Article 20 of the Electricity Market Law No. 6446 entitled Supply Security, and Supplementary Article 2 of the Natural Gas Market Law No. 4646, and covers the period up to 2035, based on Türkiye's 2053 Net Zero Emission Target.

In developing the report, the sectoral activities that make up the energy demands of the industry, residential, services, agriculture and transport sectors were estimated taking into account such basic indicators as population, economic development and fuel prices.

The report assumes that sectoral transformations will occur in the long term in line with the Development Plans, especially in the manufacturing industry sub-sectors, based on the economic growth projections of the Presidency of Strategy and Budget (SBB).

While there are many alternatives by which countries can achieve their net zero emission targets, each comes with its own challenges. Meeting these targets requires a major transformation in all sectors and a system approach that is different to that of the previous period.

In the scenario developed by our Ministry within the scope of this study, the following developments are expected to occur in the 2020–2035 period:

- an increase in primary energy consumption to 205.3 Mtoe;
- an increase in electricity consumption to 510.5 TWh;
- an increase in the share of electricity in final energy consumption to 24.9%;
- a 35.3% decrease in energy intensity;
- increases in the installed capacity to:

  - **189.7 GW in total;**
  - **52.9 GW in solar power;**
  - **29.6 GW in wind power;**
  - **7.2 GW in nuclear power;**
- **with a projected capacity expected to be put into operation of 96.9 GW;**
- **an increase in the share of renewable energy sources and intermittent renewable energy sources in electricity generation to 54.7% and 34.2%, respectively;**
- **an increase in the share of renewable energy sources and intermittent renewable energy sources in installed capacity to 64.7% and 43.5%, respectively;**
- **In order to meet the need for flexibility:**
  - **an increase in battery capacity to 7.5 GW (2 hours charging time);**
  - **an increase in electrolyzer capacity to 5.0 GW; and**
  - **an increase in demand-side response to 1.7 GW.**

Moreover, additional measures will be taken by taking into account the investment needs of the electricity sector, unexpected developments such as global and regional crises, pandemics and international political crises, and other factors related to such factors as security of supply, the requirements of the electricity grid, etc.

INTRODUCTION

This study of Türkiye National Energy Plan is carried out as per Article 20 of Electricity Market Law No. 6446, entitled Security of Supply, and Supplementary Article 2 of the Natural Gas Market Law No. 4646, which reads as follows:

"A long-term study for Türkiye National Energy Plan shall be carried out and published by the Ministry every five years, the first of which is within one year from the effective date of this article, after seeking the opinion of the Presidency of Strategy and Budget, the Ministry of Treasury and Finance, and the Energy Market Regulatory Authority."

This study is presented in five chapters: Key Indicators, Sectoral Activity, Policy Preferences, Results of the Implementation of Net-Zero Emission Restrictions (Results with Measures) and Forecasts for the 2035–2053 Period. The annexes to the study include Summary Tables and details of the Energy Model used in the development of Türkiye National Energy Plan.

CHAPTER 1: KEY PARAMETERS

1.1. Population

Population data was based on the reference scenario values given in the projection study conducted by the Turkish Statistical Institute (TURKSTAT) for the 2018–2080 period.

1.2. Economy

For economic growth values, the growth data produced by the Presidency of Strategy and Budget (SBB) were used.

The progress of the economic contribution by the manufacturing industry sub-sectors that have a critical importance in Türkiye Energy Model was examined, and detailed analyses were needed considering the potential for a significant change in the distribution of such sectors compared to developed countries. The estimates of the Organization for Economic Cooperation and Development (OECD) for OECD countries and non-OECD countries were used for the growth projections of some sectors, while a benchmark analysis was carried out with a "Multidimensional Scaling Analysis" approach for others. It is assumed that sectoral transformations will follow a logistic curve structure.

1.3. Fuel Prices

The long-term fuel price forecasts are based on the prices used for the current policies scenario in the International Energy Agency’s (IEA) World Energy Outlook (WEO) 2021 report. The prices were compared with the WEO 2022 report published by the IEA, and no significant differences were observed. It is considered that energy prices, which increased rapidly in the last quarter of 2021 and remained at record

levels in the first half of 2022, will affect the price forecasts in the short and medium term (until 2030). In this context, IEA assumptions are used for the period after 2035, while the price forecasts for the closer period up until 2025 are based on the prices of the contracts traded on the international futures market as of May 2022. For 2030, the prices for the years 2025 and 2035 are interpolated.

CHAPTER 2: SECTORAL ACTIVITY

2.1. Industry Sector

Sectoral activity refers to the magnitude of the activity in each sector that creates the energy demand. The industry sub-sectors that consume energy intensively or whose output can be represented by a single magnitude in Türkiye Energy Model are broken down as follows:

- Iron and Steel
- Non-Ferrous Metals
- Paper and Paper Products
- Cement
- Glass and Ceramics

The activity data of the sectors are shown with the product productions in each sector. The output projections of each sub-sector are estimated externally using statistical methods. For this purpose, the gross value added (GVA) data of the industry sub-sectors for the 2000–2018 period was obtained from the OECD-STAN database. Subsequently, a "Cluster Analysis" was conducted to determine the countries in which the shares of iron and steel, non-ferrous metals, paper and paper products, cement, glass and ceramics sectors in the total value-added of the manufacturing industry were similar to those in Türkiye. The direction of causality was determined from a "Granger Causality Analysis" of the output and sectoral GVA shares of the sectors in similar countries. The results of the analysis indicate that the changes in output can be explained by the changes in GVA shares. For the 2000–2018 period, a regression analysis was conducted using the changes in the output of the iron and steel, non-ferrous metals, paper and paper products, cement, and glass and ceramics sectors and the changes in their GVA shares. Regression models were subsequently developed and used to estimate the output of the sectors.

In Türkiye Energy Model, the industry sub-sectors that are not energy-intensive or whose activity must be shown in terms of value-added due to the high variability in their output are as follows:

- Chemical/Petrochemical (Fertilizer and Petrochemical, Pharmaceutical and Cosmetic Products)
- Food, Beverages and Tobacco
- Textiles
- Engineering
- Other Industries (Mining, Wood and Wood Products, Rubber and Plastic, Furniture and Others)

It is assumed that the previously estimated sectoral value-added of the sectors will affect the activities within the range of flexibility between the value-added and output in other industry sub-sectors.

2.2. Residential Sector

2.2.1. Useful Energy for Thermal Purposes in the Residential Sector

According to studies in literature, space heating and cooling, water heating and cooking account for 80–85% of residential energy consumption, with the space heating alone accounting for 50–60% of residential energy consumption. Useful energy, which is the remaining part of the final energy after its conversion for the intended purpose (e.g. the part of the electricity consumed by a lamp that is converted into light is useful energy), is used as the activity of the residential sector in Türkiye Energy Model. The following steps were followed to come up with an estimate of the useful energy that would provide input to the model.

In the base year (2018), the specific energy consumption (SEC) related to final energy consumption in each area of use is used in the allocation of useful energy for thermal purposes.

Useful Energy = Final Energy Consumption ÷ SEC Value

SEC Value = 1 / Efficiency

The average SEC values for the base year are calculated using the Buildings Performance Institute Europe (BPIE) database. A review of literature reveals that consumption per m^2 and m^2 estimates were used to estimate useful energy on the basis of area of use. For the estimation of the total area (m^2) of the households, the total area values for 2020 were used initially, and an increase was achieved in the following years according to the growth of the number of households. For space heating, estimations were made based on the logistic curve, taking into account the average useful energy consumption per m^2 in the Mediterranean countries in Europe, which are considered to be similar to Türkiye in terms of heating degree days (HDD) and cooling degree days (CDD).

2.2.2. Number of Black/White Appliances and Lighting Units

To estimate the number of black/white appliances and lighting units in the base year, the frequency of use, power consumption and total energy consumption of household appliances were used based on the data available in literature. The numbers of black/white appliances and lighting units per household were estimated, assuming a logistic curve for their growth. Estimations of the total number of appliances and lighting units were obtained using the number of households estimates.

2.3. Service Sector

In Türkiye Energy Model, useful energy is used as the activity of the service sector. The following steps were followed to come up with an estimate of the useful energy that would provide input to the model.

For the uses by the service sector in the table below, energy consumption in the 2018 base year is apportioned pro rata to the percentages of the floor areas of nine service sub-sectors.

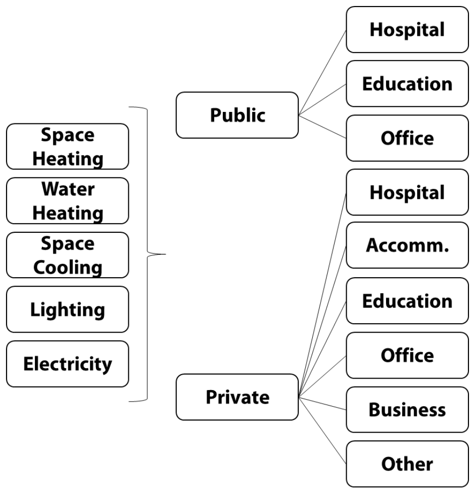


Figure 1. Service Sub-Sectors and End Uses

In the base year, the specific energy consumption (SEC) related to the final energy consumption in each end use is used to distribute the useful energy on the basis of floor area. The SEC values of Mediterranean countries in Europe, which are considered similar to Türkiye in terms of HDD and CDD, were used. The average SEC values for the base year were calculated using the BPIE database. A regression model was developed to estimate floor areas (m^2) of each sub-sector using the floor areas of nine service sub-sectors and the gross domestic product (GDP) according to the 2005–2017 data. Useful energy projections were made based on the area estimates, assuming that useful energy consumption per m^2 calculated for the base year would remain constant throughout the forecast period.

2.4. Agriculture Sector

In Türkiye Energy Model, useful energy is used to reference the activity of the agriculture sector. The following steps were followed to estimate the useful energy to be used as the input to the model.

The relationship between the change in the area of arable agricultural land in Türkiye and GDP growth in the agriculture sector was examined. To identify the relationship between agriculture and livestock based on products and energy consumption, time series data was examined and the necessary procedures were followed to make the product units identical. Based on parameters such as agricultural energy consumption, arable land size and GDP, countries similar to Türkiye were identified and regression analyses were conducted of the relationship between the GVA of the agriculture sector and agricultural energy consumption, and between the total GDP of the agriculture sector and agricultural energy consumption. The change in the useful energy requirement per unit value-added in the service sector on a yearly basis was used also for the agriculture sector.

2.5. Transport Sector

In Türkiye Energy Model, the activities of the transport sector are based primarily on passenger-km data in passenger transport and ton-km data in freight transport.

- Passenger Transport (passenger-km)
  - Private Passenger Transport
    - Private Vehicles (Automobiles)
    - Two-wheeled Vehicles
  - Public Passenger Transport
    - Buses and Minibuses
    - Metro Systems

- Railway Passenger Transport
  - Standard Trains
  - High-Speed Trains
- Passenger Inland Navigation Transport
  - Ships
- Aviation Passenger Transport
  - Airplanes

- Freight Transport (ton-km)
  - Heavy Duty Vehicles
    - Trucks
  - Light Duty Vehicles
    - Light Trucks
  - Railway Freight Transport
    - Trains
  - Freight Inland Navigation Transport
    - Ships

For the transport sector, firstly the passenger-km and ton-km data for the 1990–2020 period published by the Ministry of Transport and Infrastructure, TURKSTAT and the European Statistical Office (EUROSTAT) were analyzed. The occupancy rates of all modes of transport based on passenger-km data, and the capacity factors for all modes of freight transport based on ton-km data were compiled from sectoral reports and literature, and passenger-km and ton-km values were created for the base year.

For the passenger-km and ton-km estimation, the EU Reference Scenario 2020 and Fit for 55 MIX scenario results were reviewed on a country-by-country basis. A "Cluster Analysis" was conducted using the indicators for the transport sector, and regression estimates were calculated using the historical data of both similar countries and developed countries.

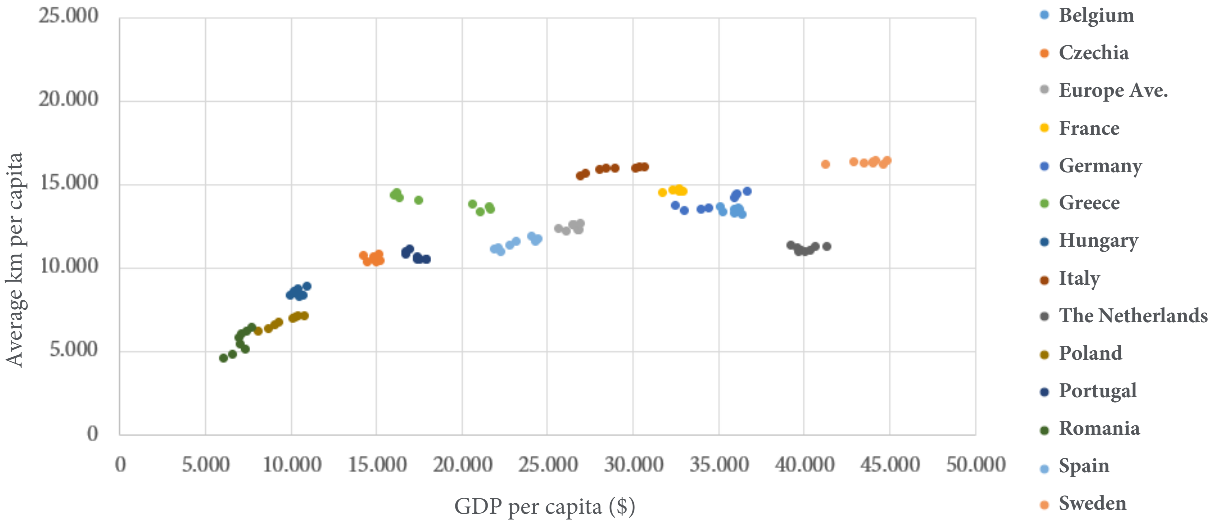


Figure 2. Relationship between Average km per Capita and GDP

GDP, population and country area variables were used for the passenger-km and ton-km estimates. A logistic function, which assumes that the passenger-km and ton-km data will approach saturation point at a given point of economic growth, was selected based on the regression analysis.

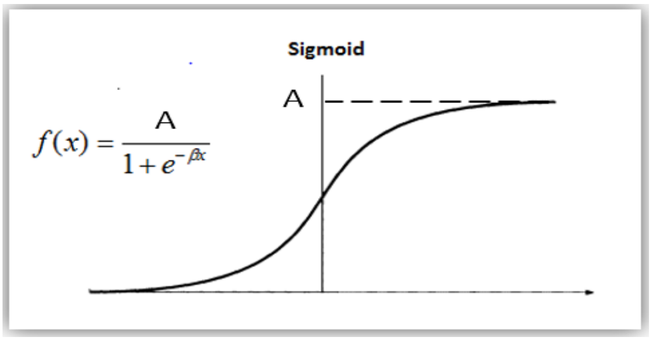


Figure 3. Logistic Function

The activity rates of Private Passenger Transport, Public Passenger Transport, Railway Passenger Transport, Road Freight Transport, Railway Freight Transport, Aviation Passenger Transport and Freight Inland Navigation Transport were determined based on the Ministry of Transport and Infrastructure's Master Plan, EU Reference Scenario 2020 and the Fit for 55 MIX scenario.

CHAPTER 3: POLICY PREFERENCES

3.1. Carbon Prices

In Türkiye Energy Model, the carbon prices needed to reduce emissions were determined on a sectoral basis.

3.2. Carbon Sinks and Carbon Capture Technologies

Taking into account the carbon sink (land use, change in land use and forestry) potential assumed for 2053 in consultation with the Ministry of Environment and Urbanization and Climate Change, and the shares of the sectors in CO_2 emissions, an upper limit was set for emissions originating from the energy sector and the electricity and heat sector in order to reach the net-zero emission target.

Based on the CCS costs, the initial investment cost estimates and the efficiency values of coal and natural gas fired power plants with carbon capture technologies obtained from a review of literature, no decision was made to invest in a new power plant with carbon capture technologies. In the following years, however, it is thought that such power plants may be included in the generation portfolio of thermal power plants with coal and natural gas fueled carbon capture technologies if the initial investment cost decreases further and efficiency increases.

3.3. Transport Sector

The scenarios shared by the Ministry of Industry and Technology regarding the increases in the number of electric vehicles up until 2035 were taken into account.

The biofuel mixture ratio in fossil fuels used by vehicles operating on the highways for the base year is assumed to be constant throughout the study. In aircraft, the share of new generation biofuels in fuel mixtures is increasing based on studies in literature.

3.4. Residential, Service and Agriculture Sectors

In order to reduce emissions, it is foreseen that certain fossil fuels will not be used in boilers used for heating purposes in the residential, service and agriculture sectors from a given date.

3.5. Power Plant Lifetime, Average Availability/Capacity Factor and Investment Costs

For the initial investment costs of power plants, the technology costs determined by the IEA in its current policies scenario were taken into account. The costs have been announced for 2020, 2030 and 2050, and the values for the years in between have been interpolated in Türkiye Energy Model. Costs for different countries/regions are determined by the IEA, and the average values of the costs for China and the European Union were used in the model. Data on the technical life of power plants was drawn from the IEA's Projected Costs of Generating Electricity 2020 study. Economic life is used to annualize the initial investment costs of power plants, and corresponds to approximately 60–75% of the technical life. For the average capacity factor (CF) in renewable energy power plants and the availability factor in other power plants, the actual values from past periods, long-term expectations and values in literature were taken into account.

3.6. Renewable Energy

The share of intermittent renewable energy sources such as wind and solar in total electricity generation is planned to be increased taking into account Türkiye’s current flexibility opportunities and renewable energy potential, and the potential in the future.

In 2035, the installed capacity will increase to:

- 29.6 GW (24.6 GW onshore, 5 GW offshore) in wind power;
- 52.9 GW in solar power.

For other renewable energy sources, the installed capacity will increase to 35.1 GW in hydroelectric power plants and 5.1 GW in geothermal and biomass power plants.

3.7. Coal and Nuclear

3.7.1. Coal-Fired Power Plants

Considering the problems and challenges encountered in the reserve development process of the planned sites, it is predicted that 1.7 GW from domestic coal-fired power plants will be included in the system by 2030. As to imported coal-fired power plants, a new plant with an installed capacity of 1.3 GW was entered into operation in 2022.

3.7.2. Nuclear Power Plants

In Türkiye Energy Model, new investment decisions are taken to minimize the total system cost, and the utilization of resources is determined accordingly. The total installed capacity of nuclear power plants in the system will reach 7.2 GW by 2035.

3.8. Natural Gas

There are currently no large-scale natural gas fired power plants under construction. It is assumed that 2.4 GW installed capacity will be put into operation by 2030. An approximately 10 GW new natural gas combined cycle power plant may be put into operation by 2035 in addition to the abovementioned investments to contribute to the management of the imbalance of intermittent renewable energy plants in the system, and to the sustainability of energy supply security.

The capacity of small-scale natural gas-fired power plants that are mostly used to meet heating requirements in industry, and in which electricity and heat are generated together, will increase by 0.2 GW in the 2021–2025 period and by 0.4 GW in the 2026–2030 period.

3.9. Hydrogen and Synthetic Methane Production

To reduce emissions in Türkiye Energy Model, the natural gas used by end-user sectors needs to be mixed with clean fuels such as hydrogen and synthetic methane. It is possible to make different mixture assumptions for such fuels. Accordingly, the share of hydrogen in the gas mixture for 2035 is set at 3.5%. It is foreseen that hydrogen energy will initially be used for on-site consumption and to meet the needs of the industries.

In line with the policies mentioned above, an electrolyzer capacity of 5.0 GW will be reached by 2035.

Hydrogen obtained using electricity generated from clean sources and carbon obtained using carbon capture technologies are used to produce synthetic methane (CH_4). In Türkiye Energy Model, however, it is considered that synthetic methane can be put into use in the period after 2035.

3.10. Other Sources of Flexibility

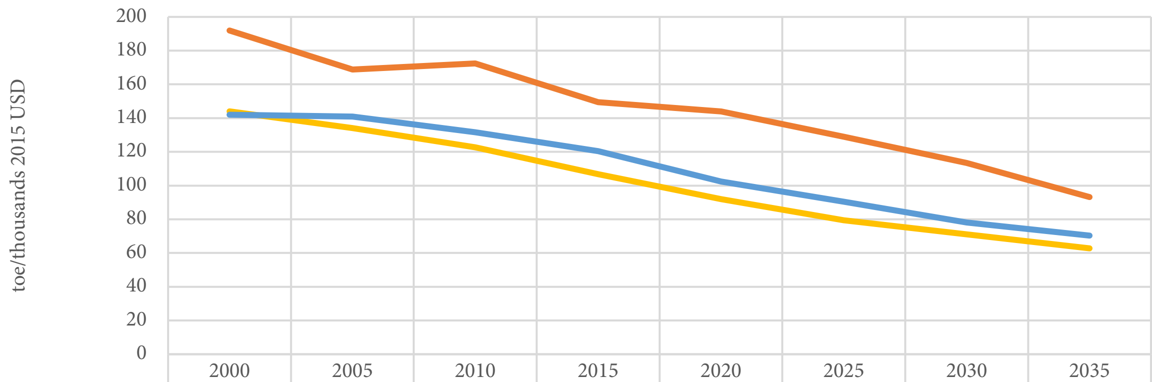
In addition to the flexibility provided by conventional electricity generation technologies, the electrolyzer capacity, battery storage technologies and demand-side response can also contribute to the system. The rapidly growing installed capacity of intermittent renewable power plants also increases system flexibility. Accordingly,

the battery storage capacity in the system (assuming a charge time of two hours) will increase to 7.5 GW by 2035.

The ratio of the theoretical contribution that can be made by the demand-side response to the peak demand, as cited in literature, was taken into account, and the capacity that actively contributes to the system in terms of load reduction and load increase on the demand side rises to 1.7 GW.

3.11. Energy Efficiency

The impact of efficiency, including in the use of high-tech equipment at different levels, was taken into account in the study. In the 2000–2020 period, the energy intensity in Türkiye decreased by 25%. In Germany and France, this figure was 28%–36%. Considering the results obtained for Germany and France in the EU Reference Scenario 2050 study, energy intensity will decrease by 50%–56% in the 2000–2035 period. It is predicted that the improvement in energy intensity in Türkiye will be 51% in the same period. These improvement rates are similar to the levels expected in Germany and France.



	2000	2005	2010	2015	2020	2025	2030	2035
Türkiye	191,9	168,7	172,4	149,4	144,0	129,0	113,3	93,2
Germany	144,0	134,0	122,7	106,7	92,0	79,5	71,1	62,8
France	142,0	141,0	131,5	120,4	102,4	90,4	78,1	70,3

Figure 4. Development of Energy Intensity During Projection Years

CHAPTER 4: RESULTS WITH MEASURES

4.1. Primary Energy Consumption

The primary energy consumption of Türkiye in 2020 was 147.2 Mtoe. The primary energy consumption will increase to 205.3 Mtoe by 2035. Primary energy consumption, which increased by an annual average of 3.1% in the 2000–2020 period, will increase by 2.2% in the 2020–2035 period. Primary energy consumption per capita, which was 1.7 toe per capita in 2020, will increase to 2.1 toe in 2035. The share of renewable energy sources in primary energy consumption, which was 16.7% in 2020, will increase to 23.7% by 2035. Nuclear energy, on the other hand, will reach a share of 5.9% by 2035. The share of fossil resources, which was 83.3% in 2020, will decline to 70.4% by 2035. The share of coal will decrease to 21.4%, and the shares of oil and natural gas will fall to 26.5% and 22.5%, respectively.

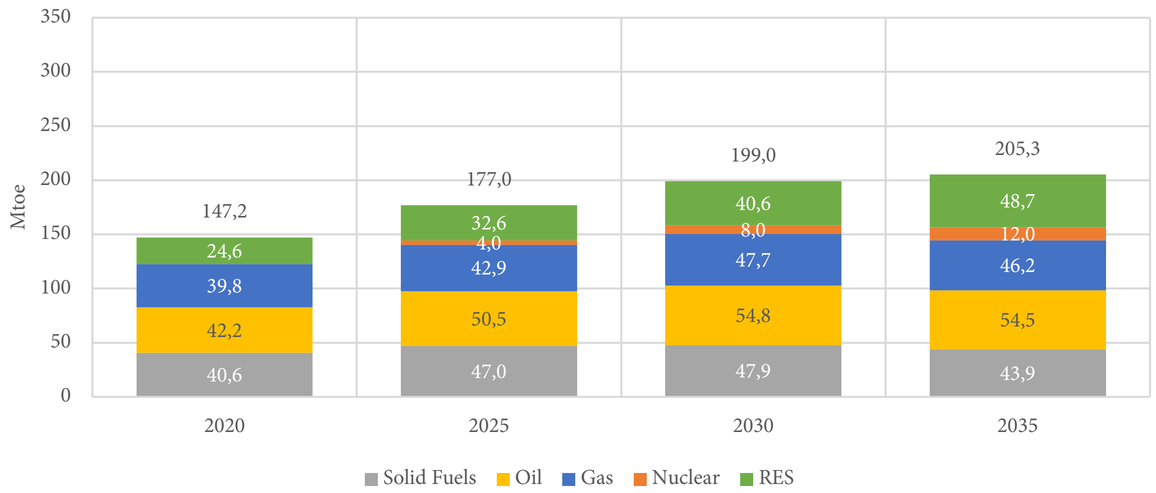


Figure 5. Primary Energy Consumption by Source

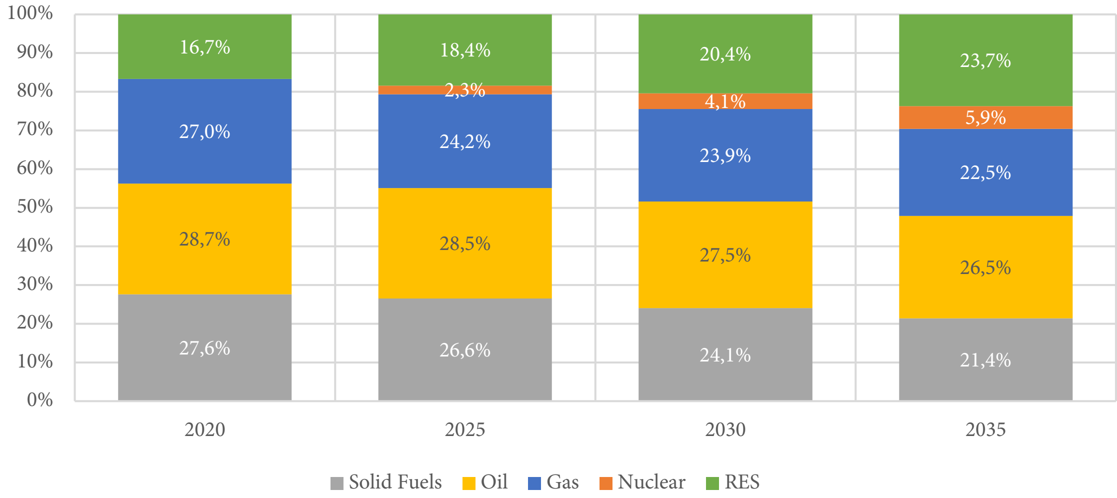


Figure 6. Distribution of Primary Energy Consumption by Source

4.2. Final Energy Consumption

The final energy consumption, which was 105.5 Mtoe in 2020, will increase to 148.5 Mtoe by 2035.

The share of the industry sector, which has the highest share of the final energy consumption in 2020, accounting for 34.4%, will increase to 38.7% by 2035. The share of the residential and service sector in total final energy consumption will decrease from 40.1% to 34.9% by 2035.

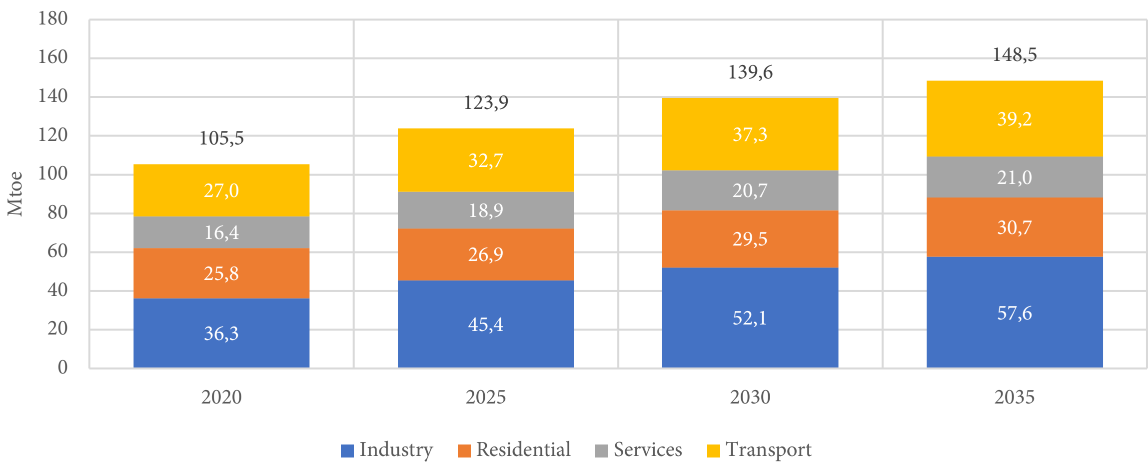


Figure 7. Final Energy Consumption by Sector

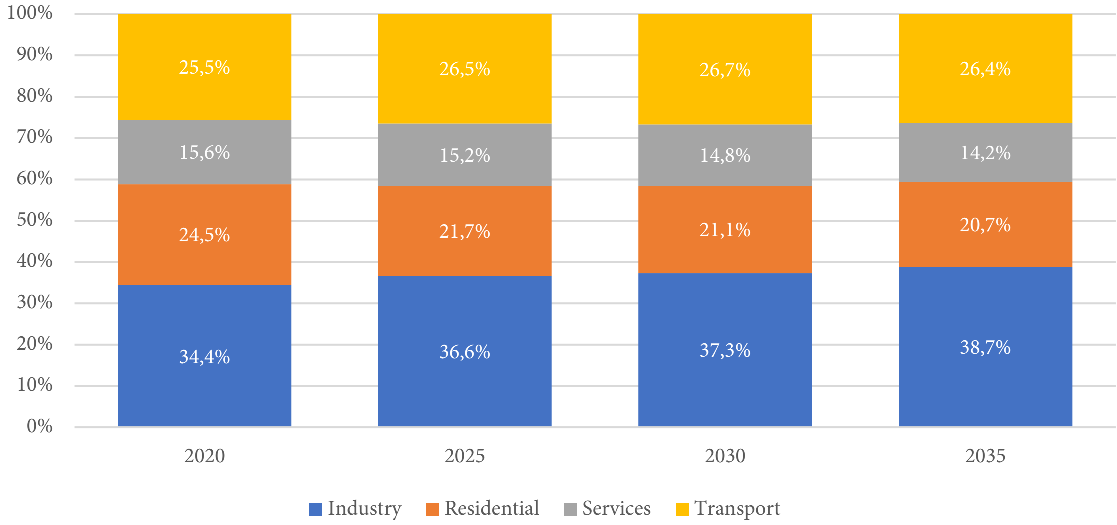


Figure 8. Distribution of Final Energy Consumption by Sector

4.3. Electricity Consumption

Electricity consumption, which rose from 128 TWh to 306.1 TWh, with an annual average increase of 4.4%, in the 2000–2020 period, will reach 510.5 TWh by 2035 with an annual average growth of 3.5%

In the forecast period, annual average electricity consumption is expected to increase by 3.7% in the industry sector, 2.3% in the residential sector and 2.2% in the service sector.

The share of electricity in final energy consumption, which was 21.8% in 2020, will reach 24.9% by 2035.

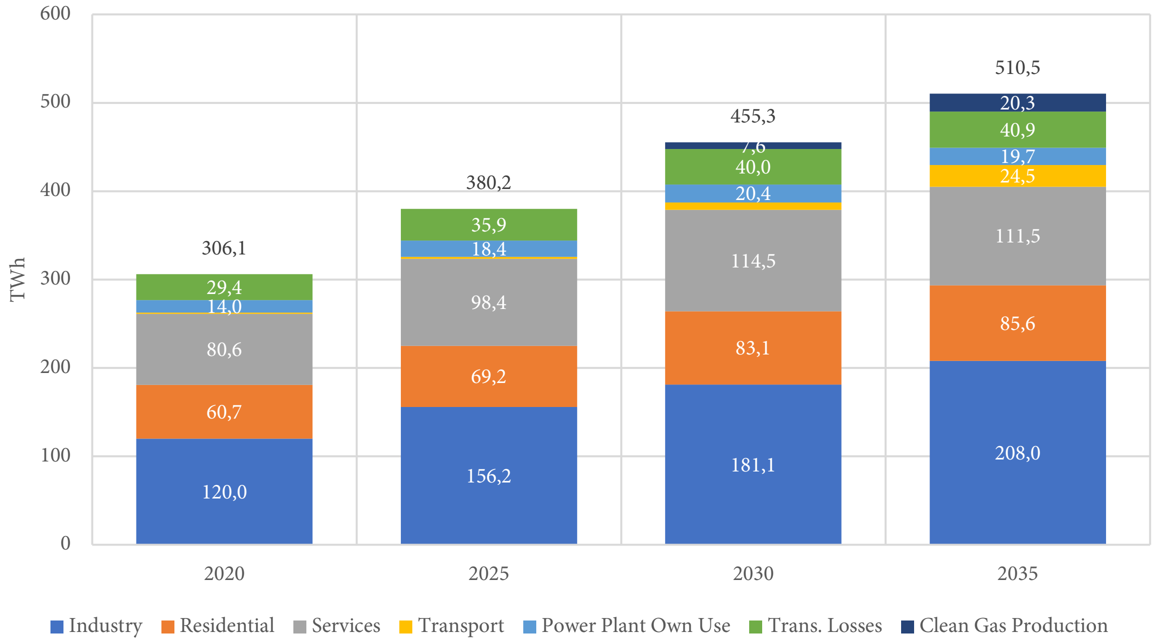


Figure 9. Electricity Consumption by Sector

4.4. Electricity Installed Capacity

The installed capacity, which was 95.9 GW in 2020, will increase to 189.7 GW by 2035. The share of renewable energy sources in installed capacity, which was 52.0% in 2020, will reach 64.7% by 2035. Hydroelectric power plants will reach an installed capacity of 35.1 GW in the medium to long term. Wind power installed capacity will reach 29.6 GW and solar power installed capacity will increase to 52.9 GW. New nuclear power plants are needed in addition to the Akkuyu NPP, which is currently under construction. The installed capacity of geothermal and biomass power plants, which are grouped in the category *Other*, will reach 5.1 GW in total.

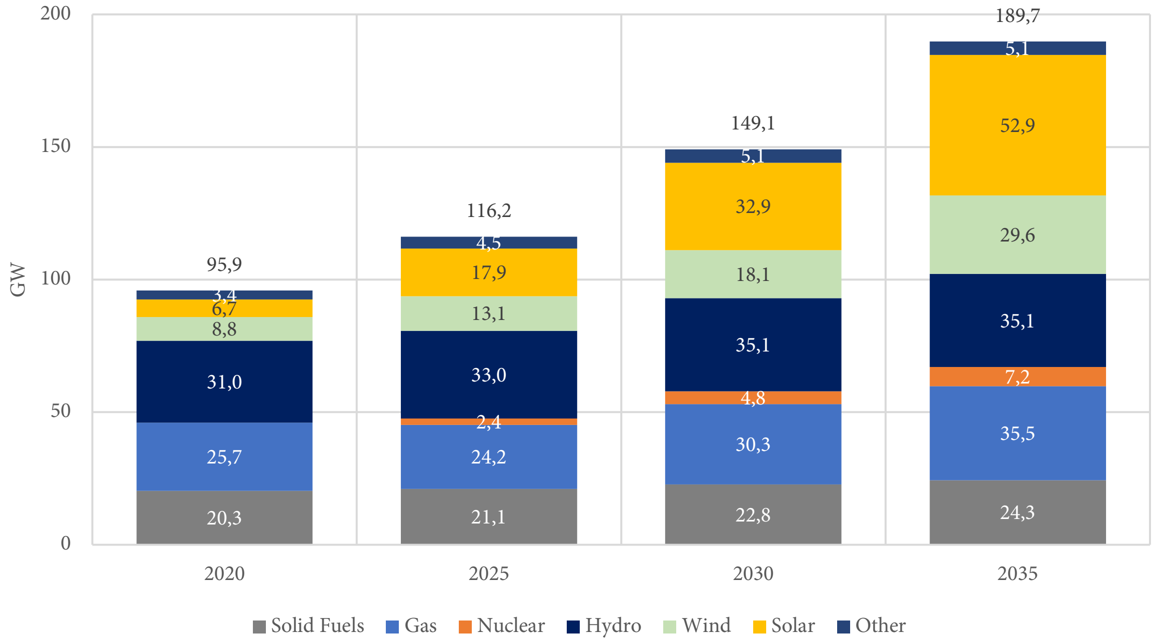


Figure 10. Installed Capacity by Source

4.5. New Installed Capacity Commissioned

The new capacity that needs to be put into operation in the 2021–2035 period is 96.9 GW.

The plan indicates that new capacity amounting to 21.6 GW needs to be put into operation in 2021–2025, 34.3 GW in 2026–2030 and 41.0 GW in 2031–2035.

Of this installed capacity increase, 74.3% should come from renewable energy sources, most notably solar and wind power. The annual new capacity requirement for solar and wind power is 3.1 and 1.4 GW on average, respectively.

As power plants are decommissioned after reaching the end of their lifetime, the total installed capacity will decrease, and the new capacity entered into operation will be reflected in the total installed capacity at a lower level.

In the short and medium term, additional measures may need to be taken, different from the results given by the model, depending on the evaluations by the Ministry.

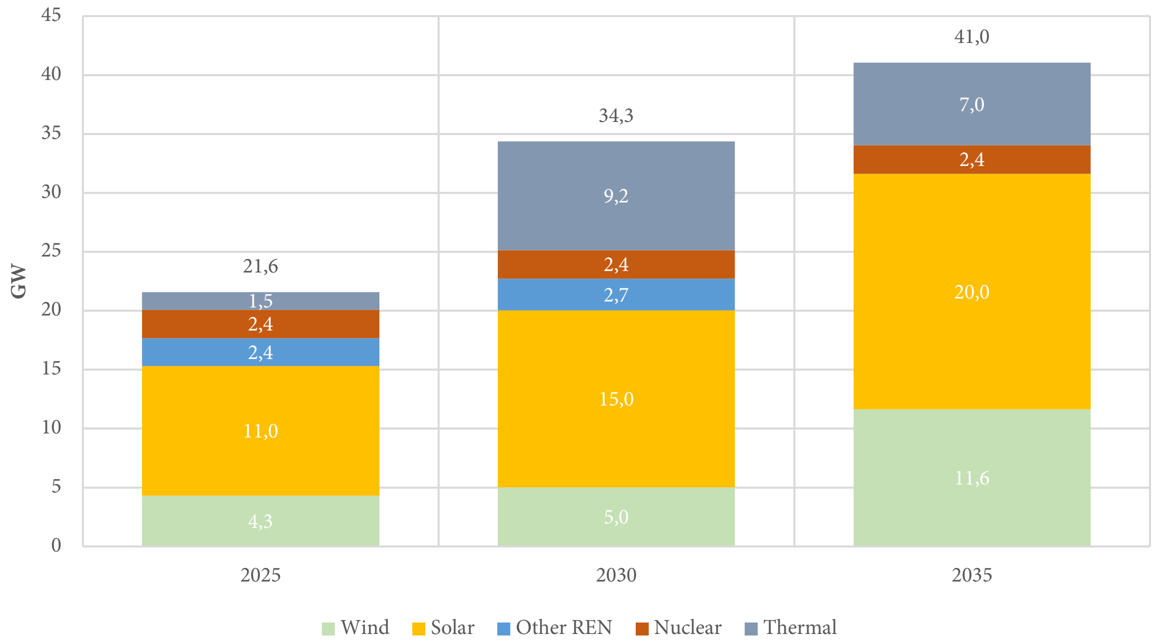


Figure 11. New Installed Capacity Commissioned in Five-Year Periods

4.6. Electricity Generation

The share of intermittent renewable energy sources in electricity generation, which was 11.7% in 2020, will increase gradually to 34.3% by 2035. Similarly, the share of renewable energy sources in electricity generation, which was 42.4% in 2020, will reach 54.8% by 2035.

The share of hydroelectric power plants in total installed capacity, which has currently the highest share in the total installed capacity, will be 17.3% in 2035, as they have approached their maximum installed capacity and generation potential.

Natural gas-fired power plants may contribute higher or lower amounts periodically than those shown in the results, as they offset potential variations in electricity generation from other sources. Electricity generation in coal-fired power plants, which had a share of 34.5% in generation in 2020, will continue to decrease up to 2035. For the electricity and heat generation sector, carbon prices will play a key role in the generation of electricity from coal plants. The capacity support mechanism applied to base/flexible load power plants to ensure the security of electricity supply is expected to continue in the Planning Period.

No investment decision has yet been taken for any new coal or gas-fired power plants featuring carbon capture technologies for the period up to 2035. However, if the decline in prices accelerates due to technological developments and technologies are put into use, coal may take a higher share in electricity generation than that expected, based on the results of this study.

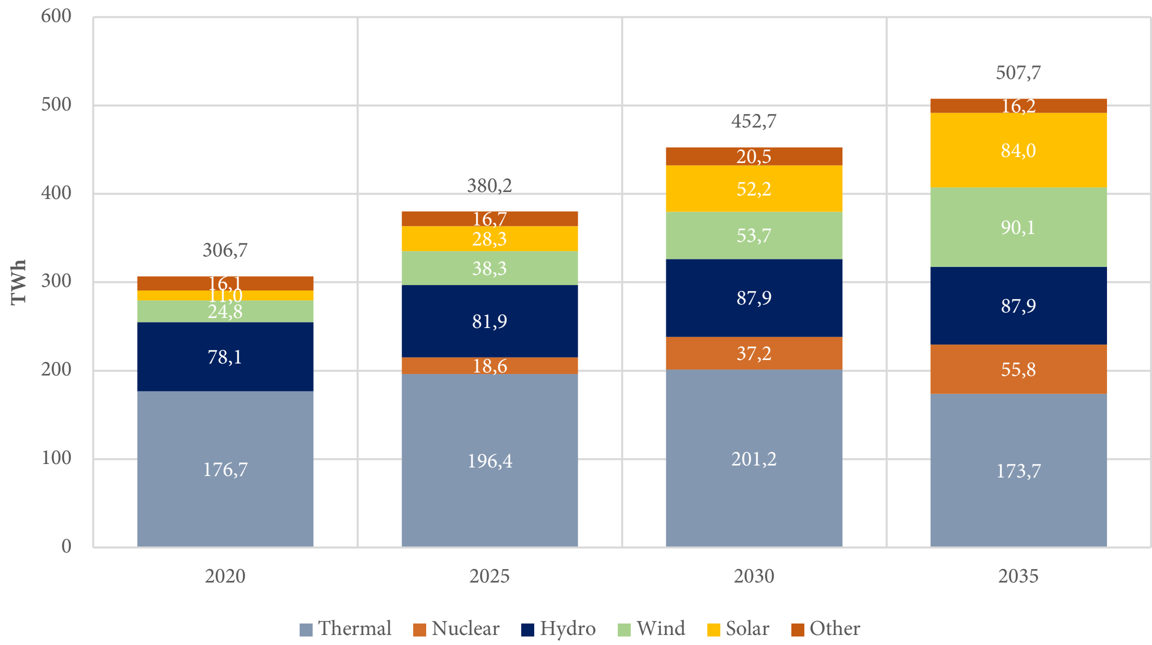


Figure 12. Electricity Generation by Source

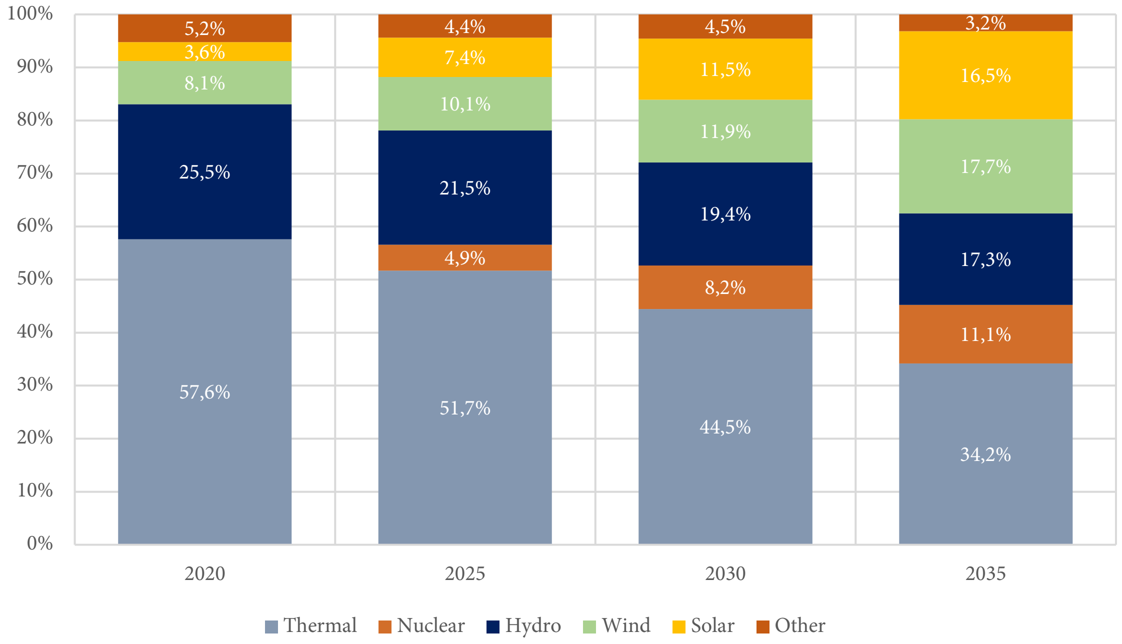


Figure 13. Distribution of Electricity Generation by Source

4.7. Flexibility

With the integration of intermittent renewable energy sources, the need for flexibility in the system is growing.

The need for flexibility can be met by increasing the interconnection capacities between neighboring countries, as well as demand-side response, battery storage, pumped storage hydroelectric power plants, hydrogen production by means of electrolyzers, transition to electric vehicles and highly flexible power plants.

In the model, battery capacity is expected to increase with the intermittent renewable energy sources, and to reach 7.5 GW by 2035.

The electrolyzer capacity will rise depending on the amount of hydrogen and synthetic methane that needs to be mixed with natural gas to meet the emission reduction targets.

As to demand-side response, the contribution of the demand-side to the system in terms of load decreases and load increases should increase, depending on the development of peak demand.

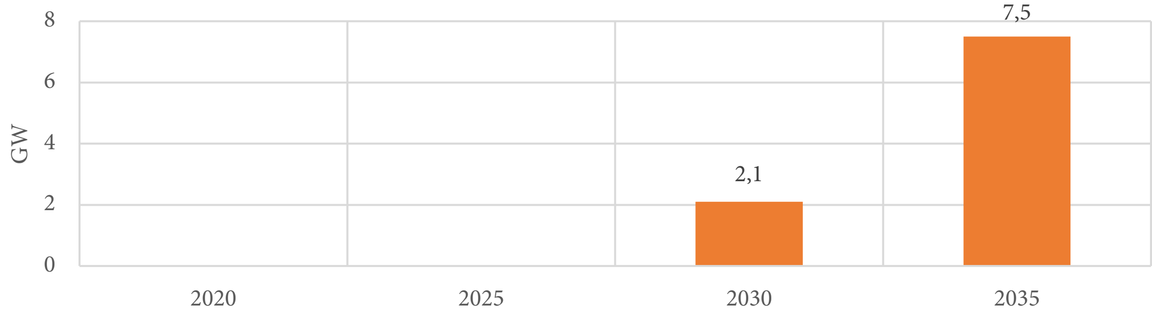


Figure 14. Development of Battery Capacity

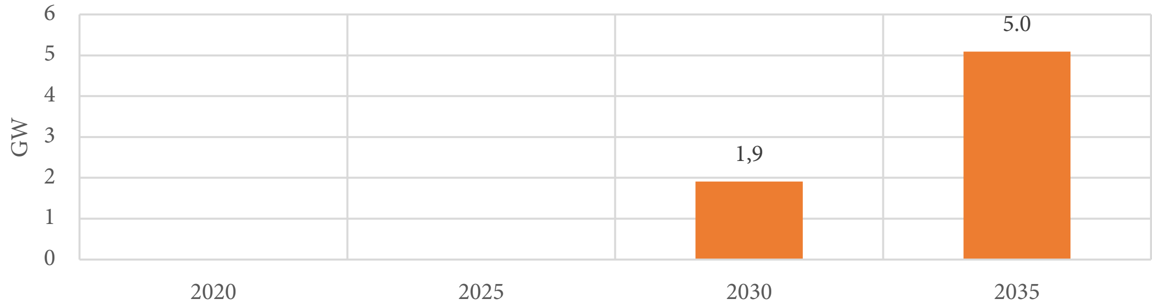


Figure 15. Development of Electrolyzer Capacity

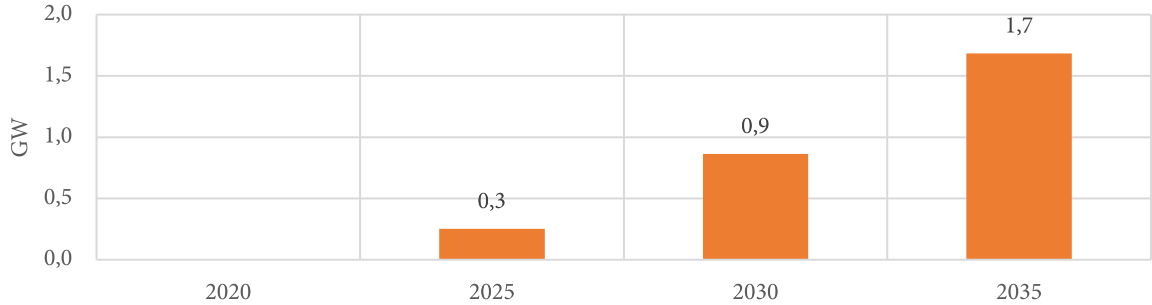


Figure 16. Development of Demand-Side Response

Regardless of the amount of wind and solar power capacity that can be put into operation in the upcoming period, it will be important to be able to manage the supply-demand margin, which may be reduced when the capacity factors of wind and

solar power plants are low. In this framework, factors that can provide additional flexibility to the electricity system, such as battery storage and new base/flexible capacity, will be assessed from the perspective of energy supply security, the requirements of the electricity grid, costs, the growth rate of electricity demand, status of the generation portfolio, etc, and additional measures will be taken as needed.

CHAPTER 5: FORECASTS FOR THE 2035–2053 PERIOD

- **The study is based on the projection data of TURKSTAT for the 2018–2080 period.**
- **The SBB's reference scenario growth data was used for annual average growth values.**
- **The development of electric vehicles is important in the planning study. To reach the 2053 net-zero emission target, the number of electric vehicles needs to be gradually increased. The increase in the number of electric vehicles by 2035 is based on scenarios developed by the Ministry of Industry and Technology, and the forecasts for 2053 were created following the same trend.**
- **Based on the upper emission limit target set for the electricity and heat generation sector and the carbon prices selected accordingly, new investment decisions are taken in a way that minimizes the total system cost in Türkiye Energy Model, and the use of resources is determined accordingly.**
- **The primary energy consumption of Türkiye was 147.2 Mtoe in 2020. Primary energy consumption, which increased by an annual average of 3.1% in the 2000–2020 period, will increase by an average of 1.5% annually in the 2020–2053 period.**
- **The primary energy consumption per capita, which was 1.7 toe in 2020, will rise to 2.4 toe by 2053.**
- **The share of renewable energy sources in primary energy consumption, which was 16.7% in 2020, will rise to 50% by 2053. Nuclear energy will reach a share of 29.3%.**
- **The share of fossil resources, which was 83.3% in 2020, will reach 20.8% by 2053. The share of coal will fall to 3.6%, and the share of oil and natural gas will fall to 5.6% and 11.7%, respectively.**
- **The final energy consumption, which was 105.5 Mtoe in 2020, will see an annual average growth rate of 1.3% up until 2053.**

- **Electricity consumption, which rose from 128.3 TWh to 306.7 TWh, with an annual average growth rate of 4.4% in the 2000–2020 period, will increase with an annual average growth rate of 4.5% until 2053.**
- **The growth rate of electricity consumption, which is expected to be 3.5% in the 2020–2035 period, should be higher after 2035, given the increasing share of electricity in final energy consumption, if the net-zero emission target set for 2053 is to be reached. Thus, the annual average rate of increase in electricity consumption will rise to 5.2% in the 2035–2053 period.**
- **The share of electricity in the final energy consumption, which was 21.8% in 2020, will reach 55.6% by 2053.**
- **The share of renewable energy sources in the installed capacity, which was 42.4% in 2020, will reach 69.1% by 2053. The share of intermittent renewable energy sources in electricity generation, which was 11.7% in 2020, will rise gradually to 61.4% by 2053. This value is in conformity with the projections of such organizations as the IEA and the International Renewable Energy Agency (IRENA), and the share of renewable energy sources noted in the EU's 2050 Reference Scenario study.**
- **Currently, the share of hydroelectric power plants in total installed capacity, which has currently the highest share in the total installed capacity, will fall to below 10% due to the fact that they have approached their maximum installed capacity and generation potential.**
- **The share of natural gas-fired power plants in total electricity generation, which was 23.1% in 2020, will decline in the long term. Natural gas-fired power plants may periodically make higher or lower contributions as they are used to offset variations in electricity generation from other sources.**
- **Electricity generation by coal-fired power plants, which had a share of 34.5% in generation in 2020, will continue to decrease by 2053. This does not mean, however, that the coal-fired power plants in the system will be decommissioned before they have come to the end of their lifetime. All power plants in the system**

will remain active and contribute to the system with reserve capacity and flexibility until the end of their technical lifetime, although their contribution to electricity generation may decrease. For the electricity and heat generation sector, carbon prices will play a key role in the electricity generated by coal-fired plants.

- **The initial investment cost projections for coal and natural gas-fired power plants integrated with carbon capture technologies are $4,113/kW and $2,450/kW, respectively, although it is estimated that these values will decrease by an average of 0.85% annually until 2053. The efficiency of the power plants is considered to be 36.5% for coal-fired plants and 51% for natural gas-fired plants. In addition, no investment decisions have been taken for new coal or gas-fired power plants with carbon capture technologies in the period up to 2053. That said, if the decline in prices of technologies accelerates and technologies are put into use, coal may have a higher share in electricity generation than expected based on the results of this study. In this case, the required nuclear power plant installed capacity may also decrease.**
- **Depending on the need for flexibility in the system, it is considered that tools such as batteries, electrolyzers and demand-side response will contribute increasingly to the system.**
- **Depending on the targeted and actual share of intermittent sources in total generation, the required nuclear power plant capacity will vary depending on the 2053 net-zero emission target, and its share in installed capacity is predicted to reach 8.4%. For the development of the installed capacity of nuclear power plants to take place in accordance with a reasonable investment plan, the upper limit of the capacity that can be put into operation in subsequent five-year periods is increased gradually.**
- **To achieve net-zero emissions by 2053, the natural gas used by end-use sectors needs to be mixed with other clean fuels such as hydrogen and synthetic methane. To this end, the share of hydrogen in the gas mixture in terms of energy equivalent was determined for the period 2030–2035, based on the findings of studies by the**

Turkish Energy, Nuclear and Mineral Research Institute (TENMAK). The generally accepted percentages cited in literature were used for the following periods, with the percentage of natural gas being gradually increased to 12% in the case of hydrogen and 30% in the case of synthetic methane.

- Electricity that will be needed for hydrogen and synthetic methane production will increase rapidly after 2035, as is the case in the transport sector, and the share of electricity to be used for this purpose in the total electricity consumption will reach 17.6%.
- With the integration of variable renewable energy sources, the need for flexibility in the system is growing. The need for flexibility can be met by increasing the interconnection capacities of neighboring countries, as well as demand-side response, battery storage, pumped storage hydroelectric power plants, hydrogen production by means of electrolyzers, transition to electric vehicles and highly flexible power plants. Electrolyzer capacity will increase depending on the amount of hydrogen and synthetic methane that needs to be mixed with natural gas as part of the net-zero emission target. As to demand-side response, the contribution of the demand-side to the system in terms of load decreases and load increases should increase, depending on the development of peak demand.
- In the short and medium term, additional measures may be taken in the event of unexpected developments, such as global and regional economic crises, epidemics, international political crises, etc.

ANNEX 1: SUMMARY TABLES

Primary Energy Consumption by Sources (Mtoe)

	2025	2030	2035
Solid Fuels	47.0	47.9	43.9
Oil	50.5	54.8	54.5
Gas	42.9	47.7	46.2
Nuclear	4.0	8.0	12.0
Renewable	32.6	40.6	48.7
Total	177.0	199.0	205.3

Share of Sources in Primary Energy Consumption

	2025	2030	2035
Solid Fuels	26.6%	24.1%	21.4%
Oil	28.5%	27.5%	26.5%
Gas	24.2%	23.9%	22.5%
Nuclear	2.3%	4.1%	5.9%
Renewable	18.4%	20.4%	23.7%
Total	100.0%	100.0%	100.0%

Final Energy Consumption by Sources (Mtoe)

	2025	2030	2035
Solid Fuels	15.7	16.5	15.4
Liquid Fuels	41.9	45.5	45.3
Gas	29.4	33.7	36.7
Renewable	5.7	7.0	10.4
Heat	3.4	3.9	4.1
Electricity	27.7	33.0	36.6
Total	123.8	139.6	148.5

Share of Sources in Final Energy Consumption

	2025	2030	2035
Solid Fuels	12.6%	11.8%	10.3%
Liquid Fuels	33.8%	32.6%	30.5%
Gas	23.8%	24.2%	24.7%
Renewable	4.6%	5.0%	7.0%
Heat	2.8%	2.8%	2.8%
Electricity	22.4%	23.6%	24.7%
Total	100.0%	100.0%	100.0%

Final Energy Consumption by Sector (Mtoe)

	2025	2030	2035
Industry	45.4	52.1	57.6
Residential	26.9	29.5	30.7
Service	18.9	20.7	21.0
Transport	32.7	37.3	39.2
Sectors in Total	123.9	139.6	148.5

Share of Sectors in Final Energy Consumption

	2025	2030	2035
Industry	36.6%	37.3%	38.7%
Residential	21.7%	21.2%	20.7%
Service	15.2%	14.8%	14.2%
Transport	26.5%	26.7%	26.4%
Sectors in Total	100.0%	100.0%	100.0%

Electricity Consumption by Sector (TWh)

	2025	2030	2035
Industry	156.2	181.1	208.0
Residential	69.2	83.1	85.6
Service	98.4	114.5	111.5
Transport	2.2	8.5	24.5
Sectors in Total	326.0	387.3	429.6
Power Plant Own Use Consumption	18.4	20.4	19.7
Other	35.9	40.0	40.9
Clean Gas Production	-	7.6	20.3
Total	380.2	455.3	510.5

Share of Sectors in Electricity Consumption

	2025	2030	2035
Industry	47.9%	46.8%	48.4%
Residential	21.2%	21.5%	19.9%
Service	30.2%	29.6%	26.0%
Transport	0.7%	2.2%	5.7%
Sectors in Total	100.0%	100.0%	100.0%

Electricity Generation by Source (TWh)

	2025	2030	2035
Thermal	196.4	201.2	173.7
Nuclear	18.6	37.2	55.8
Hydroelectric	81.9	87.9	87.9
Wind	38.3	53.7	90.1
Solar	28.3	52.2	84.0
Other	16.7	20.5	16.2
Total	380.2	452.7	507.7

Share of Sources in Electricity Generation

	2025	2030	2035
Thermal	51.7%	44.5%	34.2%
Nuclear	4.9%	8.2%	11.1%
Hydroelectric	21.5%	19.4%	17.3%
Wind	10.1%	11.9%	17.7%
Solar	7.4%	11.5%	16.5%
Other	4.4%	4.5%	3.2%
Total	100.0%	100.0%	100.0%

Electricity Power Installed Capacity (GW)

	2025	2030	2035
Coal	21.1	22.8	24.3
Gas	24.2	30.3	35.5
Nuclear	2.4	4.8	7.2
Hydroelectric	33.0	35.1	35.1
Wind	13.1	18.1	29.6
Solar	17.9	32.9	52.9
Other	4.5	5.1	5.1
Total	116.2	149.1	189.7

New Installed Capacity Put into Operation (GW)

	2025	2030	2035
Wind	4.3	5.0	11.6
Solar	11.0	15.0	20.0
Other Renewable	2.4	2.7	0.0
Nuclear	2.4	2.4	2.4
Thermal	1.5	9.2	7.0
Total	21.6	34.3	41.0

Other Indicators

	2025	2030	2035
Primary Energy Intensity (toe/thousand $, 2015)	128.9	113.3	93.2
Final Energy Intensity (toe/thousand $, 2015)	90.2	79.5	67.4

ANNEX 2: TÜRKİYE ENERGY MODEL

1. Project Information

The Long-Term Energy Scenarios and Capacity Building Project, financed by the EU under the Instrument for Pre-Accession Assistance (IPA) program for 2013, was launched in October 2018, with the main beneficiary being our Ministry.

The objective of the project is to develop the capacity of our Ministry in the creation of long-term primary energy supply and demand forecasts through basic theoretical and practical training, and to develop and use Türkiye Energy Model in cooperation with the consultant firm.

To ensure continuous use of the model by our Ministry, video and audio recordings were made of all training courses, and submitted to our Ministry with assigned source codes.

2. Project Process

More than 300 hours of training was delivered to meet the needs of the project. The first phase training courses were completed between December 2018 and February 2020, the second phase training courses between June 2020 and December 2020, and the third phase training in May 2021.

- In December 2018 and January 2019, basic one-week training courses on the energy sector were delivered with the participation of approximately 60 personnel from our Ministry and other relevant ministries. The training topics included the following:
    - Basic Macroeconomic Analysis and the Relationship between Energy Supply and Demand

- The Relationship between Economic Growth and Energy Consumption
- Definitions and Basic Concepts of Energy Modeling
- Analysis of Energy Balance Tables
- Energy Planning Practices in EU Countries
- Widely-Used Energy Sector Modeling Tools and Approaches
- Data Requirements
- Basic Concepts in Mathematical Programming

- In March 2019, training was delivered on the GAMS program, which is the mathematical software on which Türkiye Energy Model was built, and on the electricity/heat generation sector. The training topics included the following:
  - Key Features of Türkiye Energy Model
  - Coding and Implementation on GAMS
  - Introduction of Restrictions and Codes for the Electricity/Heat Generation Sectors and Implementation on GAMS
- In June 2019, training was delivered on the part of Türkiye Energy Model concerning energy supply. The training topics included the following:
  - Development of Türkiye Energy Model
  - Supply Module in Türkiye Energy Model: Electricity, Heat and Steam Generation
  - Energy Pricing
  - Biomass Module
  - Applications Related to the Supply Module in Türkiye Energy Model – Scenario Building
- In July 2019, training was delivered on the part of Türkiye Energy Model concerning energy demand. The training topics included the following:
  - Introduction to Energy Demand
  - Relationship of Activity with Energy Demand
  - Discrete Choice Theory

  - **Industry, Residential, Service and Agriculture Sectors in the Demand Module of Türkiye Energy Model**
  - **Applications Related to the Demand Module of Türkiye Energy Model – Scenario Building**
- **In December 2019, changes were made to Türkiye Energy Model based on the identified shortcomings and revisions, and training was delivered covering the changes. The training topics included the following:**
  - **Applications Related to Energy Demand**
  - **New Version of the Electricity Supply Module**
  - **Suggestions for Creating a Reference Scenario**
  - **Long-Term Macroeconomic Forecasts**
- **In February 2020, training was delivered on scenario development and the advanced use of Türkiye Energy Model. The training topics included the following:**
  - **Renewable Energy Scenario**
  - **Energy Efficiency Scenario**
  - **CO_2 Scenario**
  - **Combined Scenario**
  - **Calculation of the Activity Requirement**
- **In June 2020, training was delivered on the calibration of Türkiye Energy Model. The training topics included the following:**
  - **Calibration of the Energy Demand Module**
  - **Calibration of the Energy Supply Module**
  - **Calibration of the Biomass Module**
  - **How to Change the Base Year in the Model and Other Practical Applications**
- **In September 2020, additional improvements were made to Türkiye Energy Model to meet the needs of our Ministry, and training was delivered covering the changes. The training topics included the following:**
  - **Definition of CO_2 and Efficiency Standards**

    - Calculation of Greenhouse Gas Emissions
    - Definitions of Different Day Types Representing a Year
    - Inclusion of Seasonality in Hydroelectric Sources
- In December 2020, additional improvements were made by the consultant to overcome the challenges encountered during the advanced use of Türkiye Energy Model, and training was delivered covering the changes. The training topics included the following:
    - Identification and Correction of Errors in Türkiye Energy Model
    - Running Türkiye Energy Model on an Annual Basis
    - Recommendations for Determining Activities
- In May 2021, indicative studies were carried out by the consultant for advanced decarbonization applications, based on a scenario developed by our Ministry. In addition, improvements were made in the model to represent new technologies related to hydrogen and ammonia. The latest version of the model was delivered in May 2021, and the project was closed.

3. Türkiye Energy Model

Türkiye Energy Model is a mathematical system that has been constructed using the General Algebraic Modeling System (GAMS), which is a widely used mathematical software program for the creation of large-scale models. The program was developed specifically for Türkiye, and all source codes were delivered. The model, for which all input and output reports are generated as Excel files, simultaneously simulates the equilibrium between energy demand and supply for all energy products and finds the lowest cost solution.

Türkiye Energy Model is a market equilibrium model that follows the mathematical form of the PRIMES model on which "EU Reference Scenario 2016" and "EU Reference Scenario 2020" studies were based. Supply and demand equilibrium is achieved through repeated solutions. In addition, the model allows detailed analyses on a sectoral basis.

The model includes energy demand by sector, various energy saving opportunities based on energy efficiency and heat recovery, energy and electricity use, technology capacities, power and steam production, cogeneration, energy resource diversity from the perspective of energy supply technology and end user, fuel price and system costs, investments by sector, energy-related CO_2 emissions as well as key energy and climate indicators. All external assumptions, including fossil fuel prices, price elasticities, technologies or policy constraints, are presented in a transparent manner and can be tested through sensitivity analyses.

4. Main Framework of Türkiye Energy Model

Türkiye Energy Model consists of four modules that operate in turn to reach market equilibrium. The model offers the user the flexibility to specify the number of iterations. The operating principles of the modules are as follows:

- Demand Module: This presents the energy demand required to meet the activities of the industry, residential, transport, agriculture and service sectors. Activity forecasts made externally based on macroeconomic factors serve as inputs for the demand module.
- Power and Heat Module: This reveals how to meet the power and heat/steam demand requirements resulting from the operation of the Demand Module. It contains all the necessary mathematical formulas for the calculation of power, heat/steam and clean gas production. The module includes a separate submodule for commodity pricing. The pricing submodule calculates electricity and heat/steam tariffs, as well as synthetically produced fuel tariffs, by final demand sectors. The updated prices serve as inputs for the Demand Module in the next model iteration.

- Biomass Module: Inputs for this module are provided by the Demand Module and the Power and Heat Module, which clarifies how the demand for bioenergy products (solid biomass, biofuels, biogas, etc.) will be met. This module also includes a specific modeling process for bioenergy pricing. In the model iteration, updated tariffs are calculated for bioenergy products, providing inputs to both the Demand Module and the Power and Heat Module.
- Balancing Module: Türkiye Energy Model achieves annual energy balance based on the results of the Demand, Power and Heat, and Biomass Modules.

Türkiye Energy Model summarizes and presents the results of all models in the form of reports and a database. The main framework of Türkiye Energy Model is shown below.

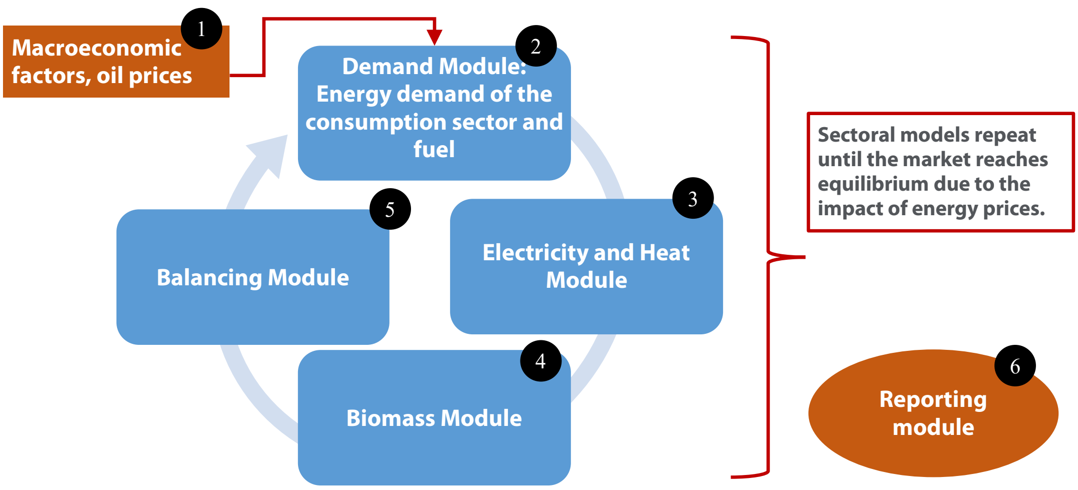


Figure 17. Main Framework of Türkiye Energy Model

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