

TURKEY'S DECARBONIZATION PATHWAY:
TIMELINE AND GEOGRAPHY OF THE TRANSITION (2020-2050)

SAEED TEİMOURZADEH, OSMAN BÜLENT TÖR, BORA KAT, ÜMİT ŞAHİN, KEMAL DEMİRKOL, ARİF KÜNAR, EBRU VOYVODA, ERİNÇ YELDAN

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INTRODUCTION

Turkey, within the framework of the Paris Agreement, submitted its Updated First Nationally Determined Contribution (NDC) to the United Nations Framework Convention on Climate Change (UNFCCC) in April 2023. In this commitment, Turkey pledged to reduce its total greenhouse gas emissions by 41% by 2030 compared to the reference scenario and to reach a peak in 2038 before subsequently reducing emissions.

According to this, Turkey's greenhouse gas emissions, which were 524 million tons in 2020, will increase by 32% to reach 693 million tons by 2030.

According to the Paris Agreement, national contributions need to be updated every five years with increased targets. Accordingly, Turkey is obligated to submit its second Nationally Determined Contribution (NDC) by the end of 2025, with the target year set for 2035. This submission is required to take place before COP30, which will be held in Brazil. Given that the current updated Nationally Determined Contribution (NDC) specifies that total greenhouse gas emissions will peak after 2035 and then begin to decrease, it can be inferred that Turkey is likely to plan a reduction target in its next NDC, rather than an increase over the reference scenario.

Turkey's greenhouse gas emissions increased by 157% in 2021 compared to 1990, reaching 564 million tons. According to the greenhouse gas inventory published in 2023, Turkey's carbon dioxide (CO_2) emissions have approximately doubled from the 1990 level and reached 452 million tons. With this rapid increase, Turkey has risen to the 13th place among 195 countries worldwide in terms of carbon dioxide emissions from fossil fuels and industry in 2021. Turkey's per capita CO_2 emissions, at 5.4 tons, exceed the global average, ranking 64th in per capita CO_2 emissions. In terms of cumulative emissions, which are crucial for historical responsibility, Turkey is ranked 26th. As 80% of greenhouse gas emissions are attributed to CO_2, it can be expected that the projected CO_2 emissions for 2030 in the current updated Nationally Determined Contribution (NDC) will increase to 555 million tons. In this case, Turkey's per capita CO_2 emissions calculated during 2030, recorded in the main scenario of TÜİK, will reach 6 tons and will exceed the EU average in 2030 (which is currently 6.2 tons, but will decrease if the 55% reduction target is achieved). Therefore, Türkiye should set an absolute emission reduction target in the second NDC.

In light of these developments, the importance of scientific research for a long-term decarbonization roadmap in line with Turkey's declared net-zero emissions target by 2053 under the Paris Agreement has increased. Under the leadership of Sabancı University's Istanbul Policy Center (İPM), a series of modeling studies and reports were initiated in 2019, even before Turkey became a party to the Paris Agreement and declared its net-zero target. These studies aimed to provide an exemplary roadmap on how Turkey should decarbonize by 2050, and they were conducted under the assumption of a 2050 target year for net-zero emissions, as the net-zero target for 2053 had not yet been announced when the studies commenced.

The first phase of the studies, conducted in 2021, resulted in the publication of the report titled "Turkey's Decarbonization Roadmap: Net Zero by 2050." This report outlined a net-zero scenario based on baseline scenarios and realistic assumptions for reducing carbon emissions in the energy, transportation, buildings, industry, and other production sectors. According to the net-zero

scenario in this report, Turkey could reduce its emissions by 32% by 2030 compared to the 2018 level and achieve a 68% reduction by 2050. In 2050, there would be approximately 132 million tons of residual emissions, two-thirds of which would originate from industrial and other production sectors. According to this report, all coal-fired thermal power plants would be closed between 2035 and 2040. Additionally, emissions from the electricity sector could be reduced by 50% by 2030 and by 90% by 2050, as outlined in the net-zero scenario.

In the second phase, in 2022, the study titled "Turkey's Decarbonization Roadmap: Sectoral Benefit Cost Analysis (2020-2030)" was published. According to this report, the total cost of the transformation outlined in the net-zero scenario, including investment, operation, maintenance, and other costs, amounts to $171 billion between 2020 and 2030. The majority of the total benefit, around $70 billion, stems from the decrease in fuel usage. The net cost is estimated to be $101 billion, or roughly around $10 billion annually.

The third phase, completed in 2023 and presented in this report, prioritizes the trajectory of decarbonization over five-year intervals, focusing on the electricity sector's transformation schedule, geographical distribution, and its impact on the grid. The report provides insights into when and in what sequence existing coal-fired thermal power plants in the electricity sector could be phased out, completing the transition away from coal. It also outlines the necessity of establishing new natural gas and renewable energy power plants, along with suitable storage facilities, in specific regions, indicating when and at what scale these installations should be implemented. The report further explores the effects on the electricity grid, including the investment requirements for the grid during this transformation.

In this study, evaluations conducted in the transportation, buildings, industry, and other production sectors have also been reviewed and completed at five-year intervals. As a result of the study, an exemplary net-zero scenario for Turkey's Decarbonization Roadmap has been outlined, accompanied by a detailed schedule and geographical maps. The report begins with the results for the electricity sector, followed by assessments of transportation, buildings, and industry, along with other production sectors.

1. ELECTRICITY SECTOR

In this section, the transformation of Turkey's electricity sector towards the net-zero emissions target in 2050, as outlined in the previously published report "Turkey's Decarbonization Roadmap: Net Zero by 2050" (İPM, 2021), has been examined. In this study, the analysis conducted for 10-year intervals in the 2021 report has been refined to be presented in 5-year intervals. The elements particularly scrutinized in this transformation include:

1 | When and in what order the existing coal-fired thermal power plants can be decommissioned to complete the transition from coal in the electricity sector;

2 | In which systems, when and in what dimensions the new natural gas and power plants and storage facilities to be commissioned will be required to be installed and

3 | How the grid will be affected during this transformation, including investment requirements.

The assumptions, methodology, and scenarios used in the study are briefly discussed in this section, and for details, reference can be made to the mentioned report.

1.1. ELECTRICITY SECTOR MODEL AND ASSUMPTIONS

The Base Scenario for the electricity sector model was created based on current projections carried out by TEIAS (Turkish Electricity Transmission Corporation) for total electricity consumption until 2030. For the period beyond 2030, macroeconomic model results were utilized (Table 1). In the study's Base Scenario, the total production requirement for the year 2030 was assumed to be 460 TWh. The electricity demand projection for 2050 was calculated using a macroeconomic model and amounted to 769 TWh.

The production capacity expansion model used in the study is an enhanced version of the TR-Power optimization model[1]. (For methodology, see IPC 2021.)

The carbon dioxide (CO_2) emission factors for fossil fuel sources are provided in Table 2 in terms of $MtCO_2$ per TWh.

1 Kat, B. (2021). Renewable energy transition in the Turkish power sector: A technoeconomic analysis with a high-resolution power expansion model. TR-Power. MIT Joint Program on the Science and Policy of Global Change Report Series, Report 346.

Table 1 Projections of TEIAŞ and electricity demand and generation projections (TWh) used in the report

Year	TEİAŞ Load Projection (2021-2030)			TEİAŞ Generation Projection (2020-2024)			Decarbonization Report Base Scenario			
	TEİAŞ Low Scenario	TEİAŞ Base Scenario	TEİAŞ High Scenario	TEİAŞ Low Scenario	TEİAŞ Base Scenario	TEİAŞ High Scenario	Base Load	Electric Vehicle Household	Other Electrification	Total
2029				441	467	497				
2030	359	396	454				440	4	16	460

Table 2 Emission coefficients

	Local Coal	Imported Coal	Lignite	Natural Gas
Emission Coefficient ($MtCO_2$/TWh)	1.02	0.95	1.19	0.39

In the Net Zero Scenario, the net efficiency and electrification loads calculated from other sector models have been added to the electricity load in the Base Scenario. For error margins in assumptions made in other sectors, a total additional load of 10% has been added to the annual electricity load, a critical input for the energy sector, which is the dominant sector in CO_2 emissions, in the year of the Net Zero target.

Electricity sector models consider the increase in the share of renewable sources in production to be dependent on the flexibility of the grid (Shura, 2018). The grid flexibility solutions considered in the model are as follows (For details, see İPM, 2021):

1 | Natural gas power plants and hydro dams
2 | Storage systems
3 | International interconnection lines

1.2. MARKET AND NETWORK SIMULATIONS

The main outlines of the proposed methodology for calculating the cost elements implemented by the transmission system are shown in Figure 1.

According to Figure 1, the first step involves market simulations. The market simulation engine, whose key inputs, assumptions, and outputs are provided in Figure 2, simulates the day-ahead electricity market by taking the following inputs:

- Total load profile of the system at hourly resolution
- Generation capacity of convection power plants (coal, lignite, gas, nuclear)
- Merit order of different generation technologies

Figure 1 Flow chart of the proposed methodology

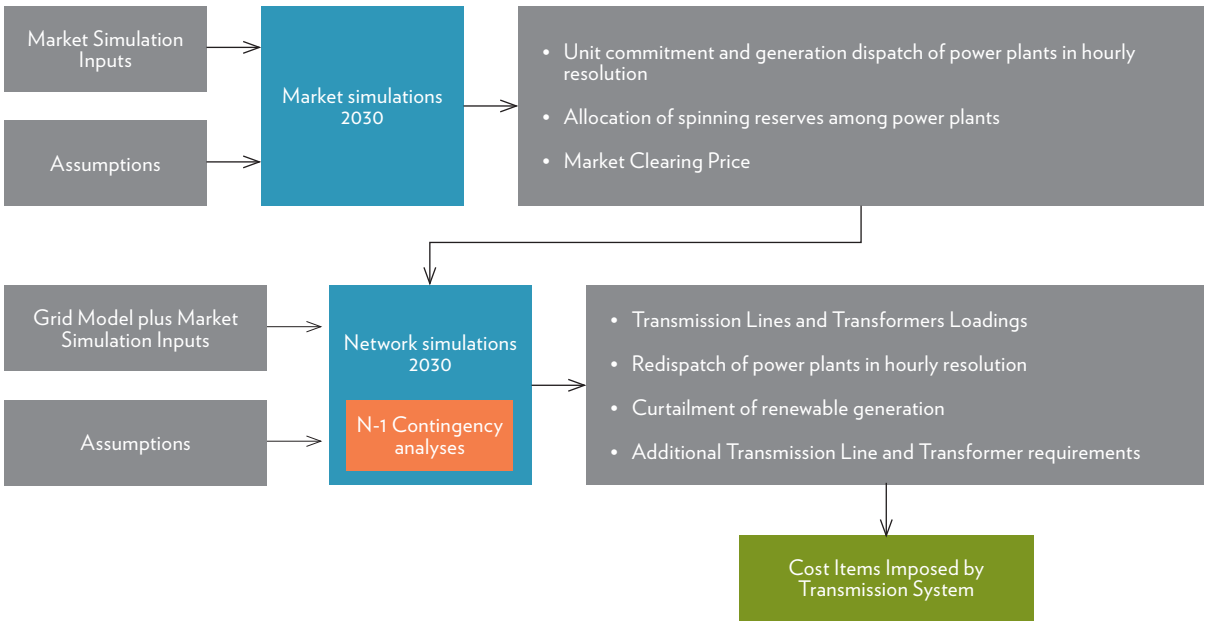
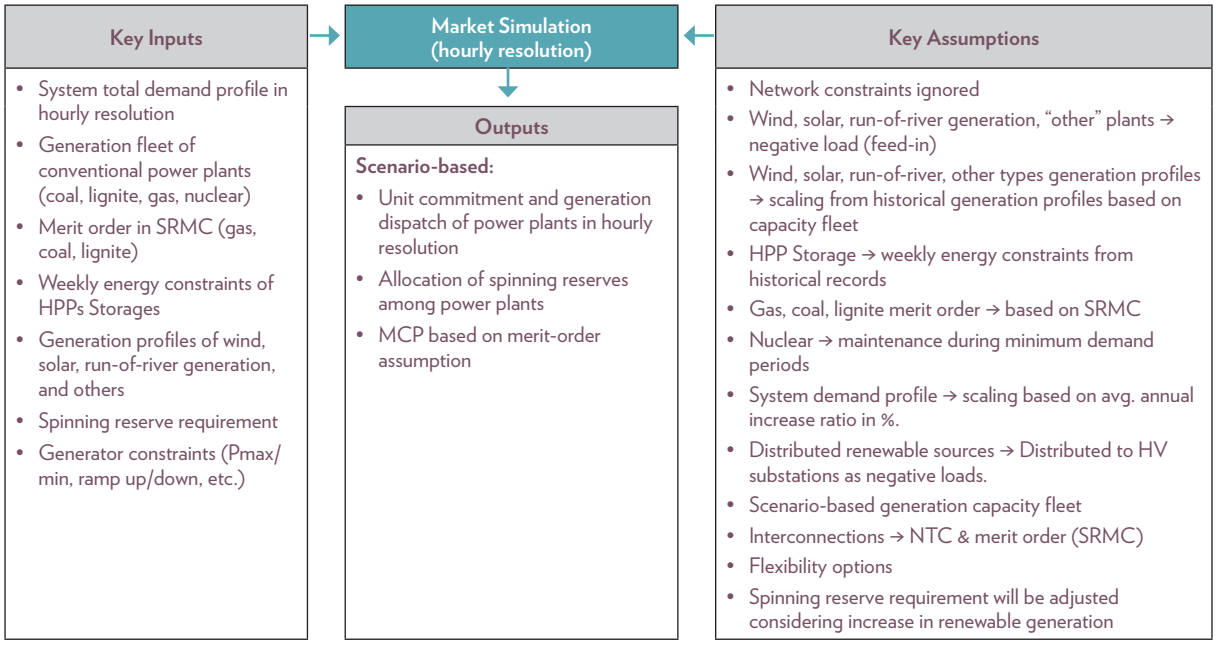


Figure 2 Market simulation model: Key inputs, assumptions, and outputs



- Weekly energy restrictions of hydroelectric power plants
- Generation profiles of wind, solar, run-of-river (RoR) hydro and others
- Spinning reserve requirement
- Generator restrictions (Pmax/min, ramp up/down etc.)

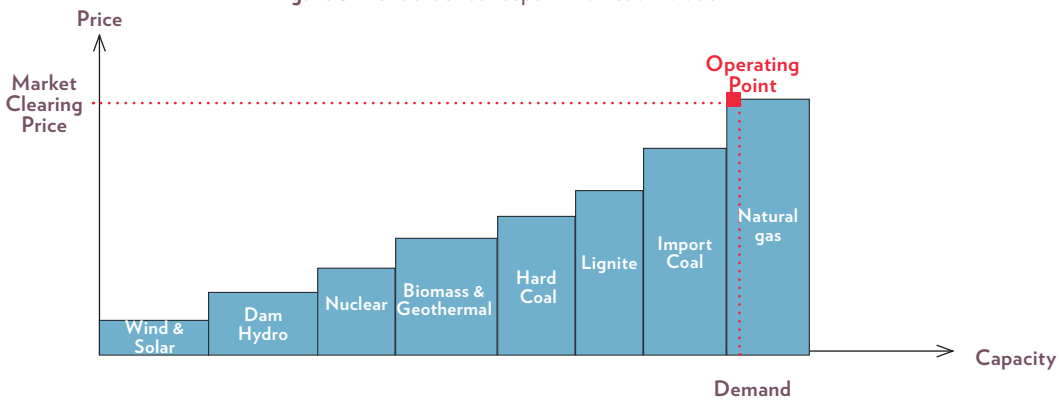
Merit order is a way of ranking available electricity generation technologies based on ascending order of cost (which may reflect the order of short-run marginal generation costs) and sometimes pollution and the resulting amount of energy to be produced (Figure 3). In the market simulation, the ordering is such that those with the lowest marginal cost are put into service first to meet demand, and the facilities with the highest marginal cost are used last. Distributing generation in this way (Economic Power Distribution) minimizes the cost of electricity generation.

The input data provided in Figure 3 is incorporated into an optimization model where the objective is to minimize the total operational cost of a system subject to a series of technical constraints. Key constraints in this context could include the ramp requirements of different energy plants, minimum operating and stopping times for generators, allowed operating intervals for generators, maintenance requirements, and weekly energy constraints for hydroelectric power plants. Outputs of the market simulations are:

- Hourly generation distributions of different generation technologies,
- Power generation of different generators,
- Marginal generator per hour and
- Renewable restriction per hour.

Various assumptions are made in market simulations:

Figure 3 Merit order concept in market simulation

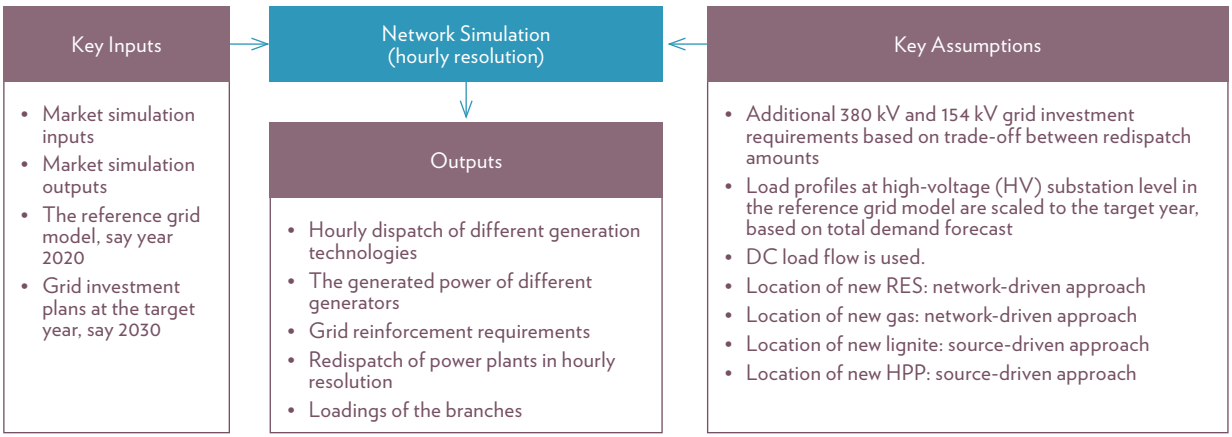


- Network restrictions are ignored.
- Wind, solar and river type hydroelectric power plants are modeled as negative load (feed-in).
- Historical records were taken into account in the weekly energy restrictions of dam-type hydroelectric power plants.
- Maintenance in nuclear power plants takes place during minimum demand periods.
- The system demand profile is created by scaling the average annual increase rate as a percentage.
- Distributed renewable resources are concentrated in high voltage substations.
- The spinning reserve requirement has been adjusted taking into account the increase in renewable generation.

Once the market simulation is performed, the relevant outputs are added to the network simulation to investigate the impact of the transmission grid on the electricity generation of different technologies. Inputs, outputs, and basic assumptions for network simulation are given in Figure 4.

In the models, when determining the coal power plants to be decommissioned, priority was given to lignite power plants that are old and far from the main

Figure 4 Inputs, outputs, and basic assumptions of network simulation



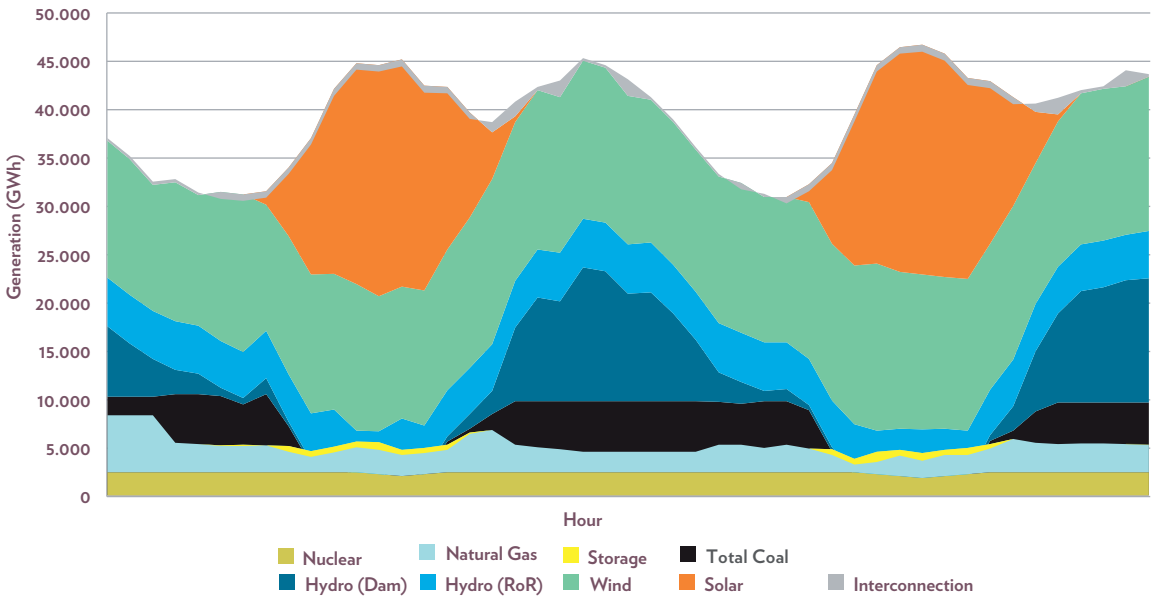
load centers. In addition, it is assumed that the new natural gas and renewable energy power plants to be added to the power system will be located close to the main load centers. As a matter of fact, the YEKA mechanism aims to locate new renewable power plants at suitable points in terms of the network.

It is also assumed that storage systems will be located by giving priority to the main load centers and will be centrally controlled according to the flexibility needs of the network. The infrastructure and market mechanisms required for this central control are beyond the scope of the study.

It is assumed that the net transfer capacities of the interconnection lines will be used according to the flexibility needs of the network, thanks to market integration mechanisms. These market mechanisms are also outside the scope of the study.

Network simulation is a simulation engine that solves congestions of the network by regulating the generation distribution obtained through market simulations, taking into account the network constraints and giving redispatch Up/Down instructions to thermal power plants. With these simulations, additional investment requirements in the target year are determined. An example of the outputs of the network simulation engine (distribution of generation) is shared in Figure 1.2.5.

Figure 5 An example of network simulation model outputs (48 hours)



1.3. BASE SYSTEM

Based on the 2020 network model for the electricity sector, market and network simulations were carried out for the scenarios mentioned in the following section of the report, starting from 2025 and at 5-year intervals until 2050. Since network simulations depend on the network topology, modeling data and analysis results are presented both in the countrywide total and TEİAŞ Regional Dispatching Management Directories shared in Figure 6.

For the 2020 grid model, information regarding the 400 kV transmission system lines in TEIAS Regional Dispatching Centers and the corridors connecting these centers has been shared in Table 3 and Figure 7, respectively. The necessary transmission grid investments for 2025 were calculated based on this model for the analyses. Additionally, TEIAS has a network investment plan targeting the year 2030 (Table 4 and Figure 8). Investment requirements were calculated considering this investment plan from the year 2030 onwards.

Table 3 In the year 2020, the 400 kV transmission lines in the regions

Zone ID	Zone Name	Capacity (GW)	Line Number
1	Thrace	44.21	26
2	West Anatolia	61.95	33
3	North West Anatolia	70.14	44
4	Middle Black Sea	34.85	18
5	Eastern Anatolia	28.28	14
6	Middle Anatolia	50.24	27
7	West Mediterranean	21.15	10
8	East Mediterranean	30.15	16
9	Southeastern Anatolia	81.96	46

Figure 6 TEİAŞ Regional Dispatching Management Directories and International Interconnections

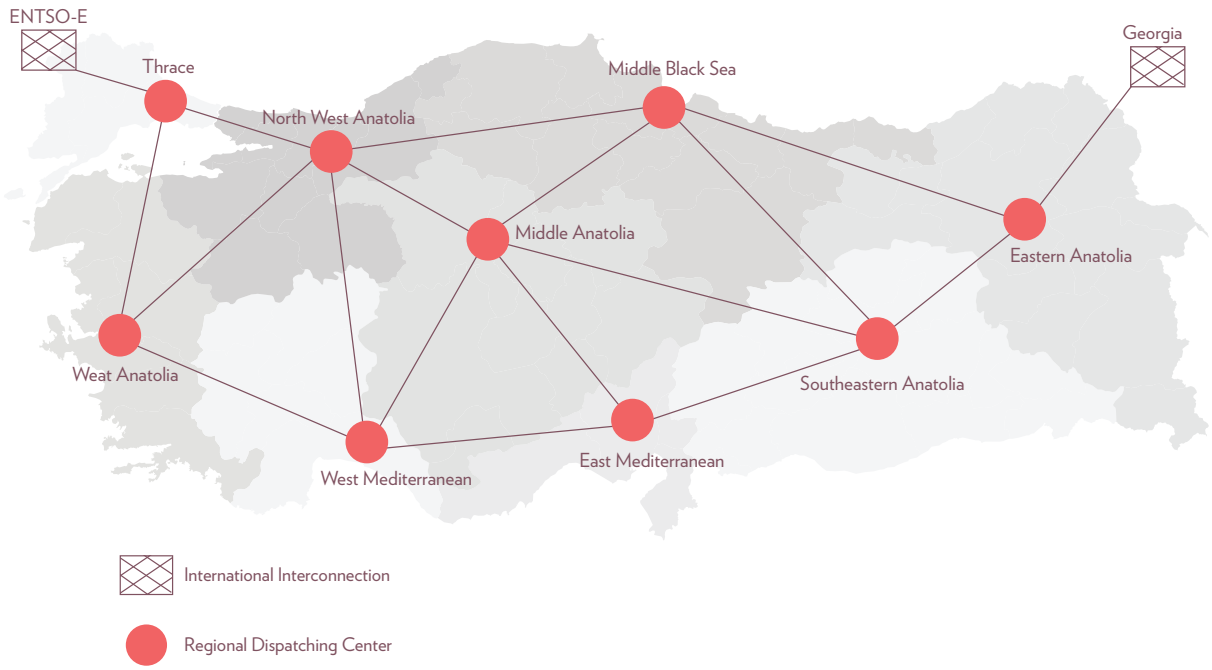


Figure 7 400 kV transmission lines in the corridors in 2020

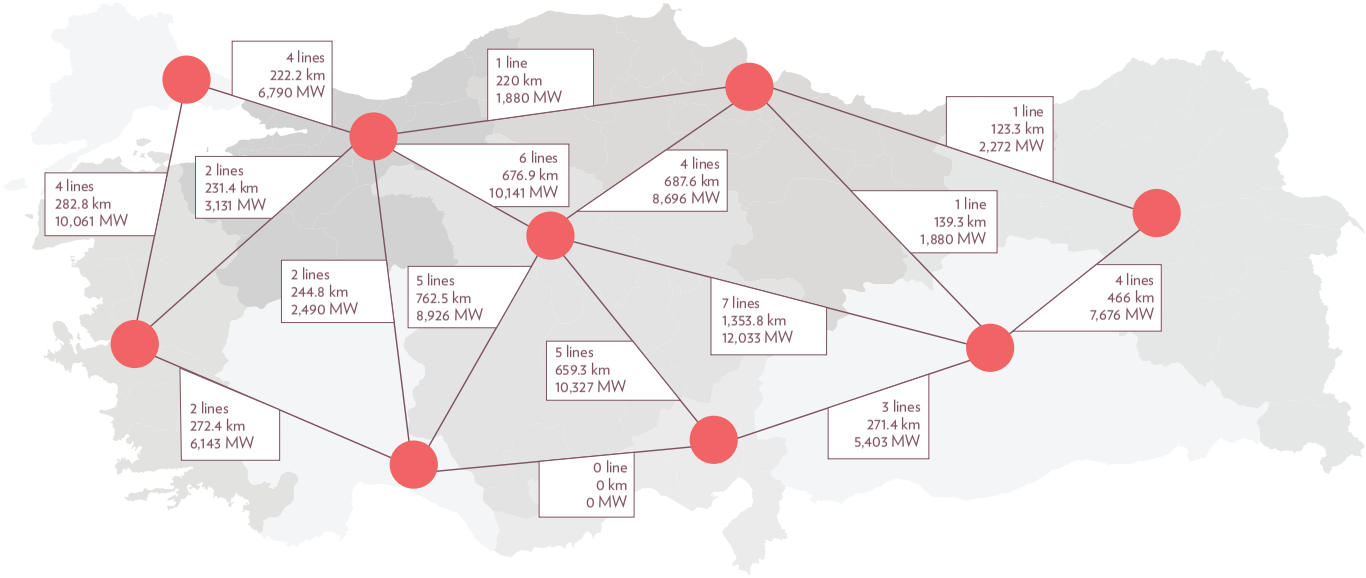


Figure 8 The 400 kV transmission lines in the corridors according to the TEIAS investment plan for the year 2030

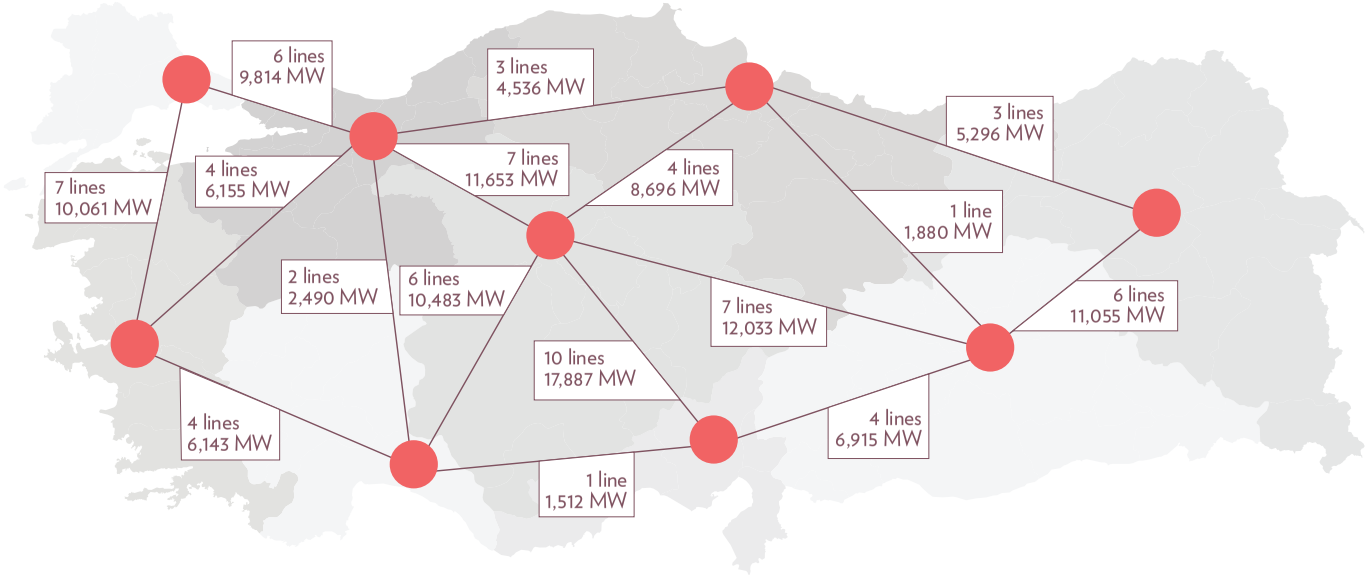


Table 4 The 400 kV transmission lines in the regions according to the TEIAS investment plan for the year 2030

Zone ID	Capacity (GW)	Line Number
1	66.89	41
2	83.78	47
3	96.16	61
4	39.76	21
5	37.54	20
6	65.95	37
7	22.66	11
8	45.49	26
9	91.4	52

1.4. BASE CASE

The Base Scenario is the projected trajectory that Turkey's economy and relevant sectors are expected to follow by 2050 if actions consistent with the Net Zero target for 1.5°C are not taken, aligning with the current trends in the global economy.

For the electricity sector, the elements of the transformation that will occur in the Base Scenario have been considered from 2025 to 2050 at 5-year intervals. Various assumptions have been made for grid flexibility in this scenario:

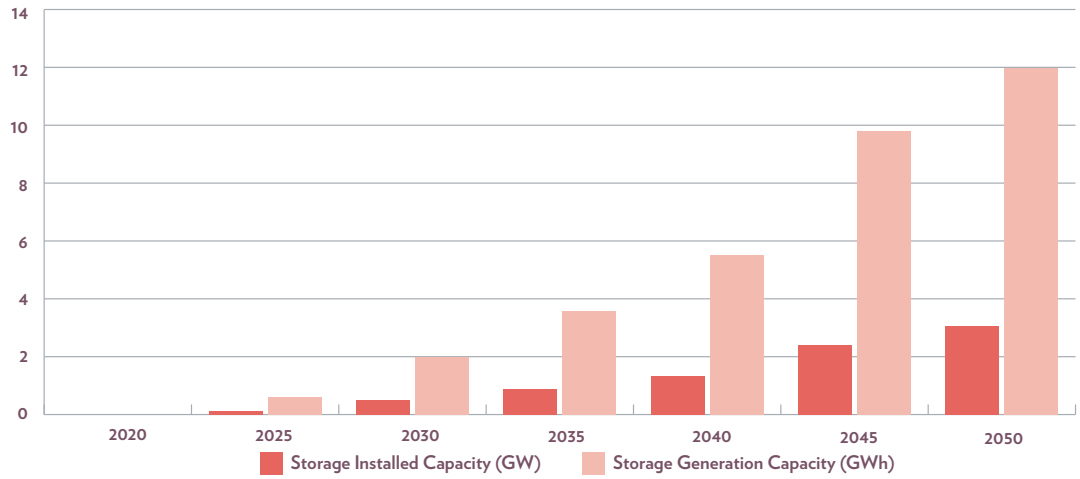
Storage Systems

In the Base Scenario, it is anticipated that storage systems (pumped hydroelectric storage and battery storage) not currently present in the existing system will begin to be deployed on a small scale from 2025. They are expected to remain at a small scale, around 260 MW, until 2030 but will then start to increase, reaching 3 GW by 2050. The development of storage systems in terms of installed capacity and production capacity is shown in Table 5 and Figure 9.

Table 5 Development of storage as installed power and generation capacity in base scenario

	Storage Installed Capacity (GW)	Storage Generation Capacity (GWh)
2020	-	-
2025	0.1	0.63
2030	0.26	1.04
2035	0.91	3.65
2040	1.41	5.63
2045	2.48	9.91
2050	3	12

Figure 9 Development of storage as installed power and generation capacity in the base scenario



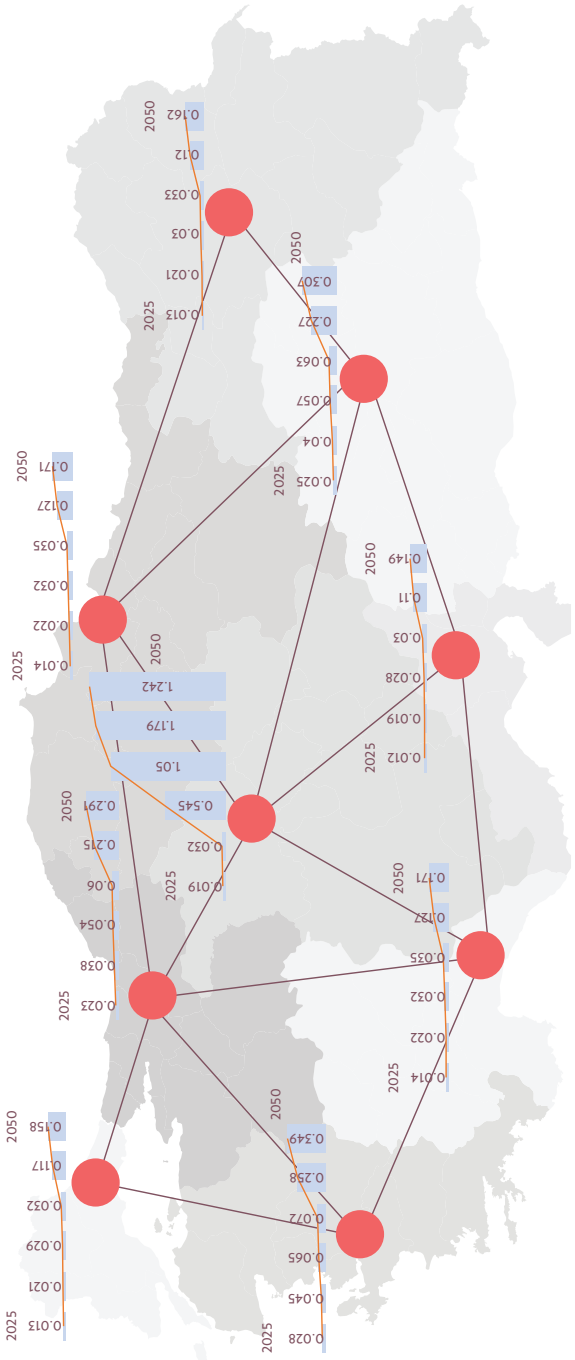


Figure 10 Distribution and development of storage system installed capacity by region in the Base Scenario

The distribution of storage systems according to TEIAS Regional Dispatching Centers and the development of their installed capacities are presented in Figure 10. The installed capacity of renewable energy has played a significant role in the distribution of storage systems among Regional Dispatching Centers. Middle Anatolia Regional Dispatching Center, with its high solar energy potential and the planned Gokcekaya pumped storage hydroelectric power plant in this region, has led to a greater increase in storage systems in this area

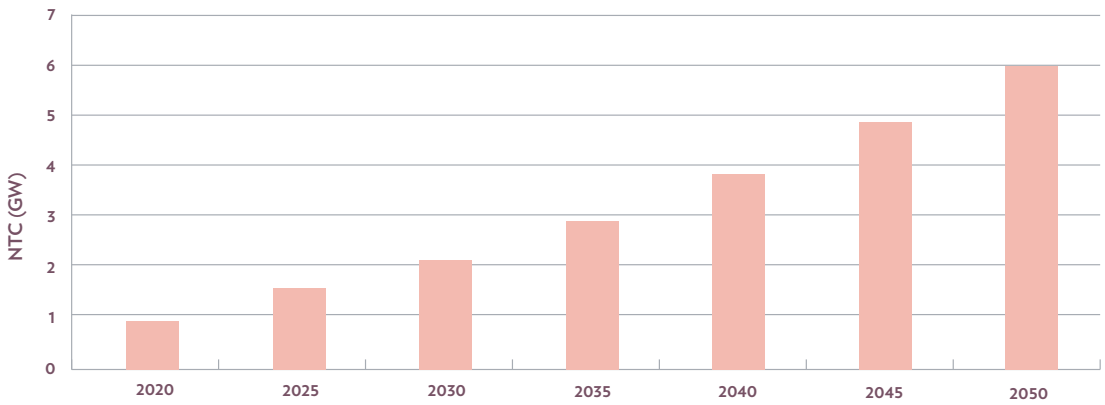
Net Transfer Capacity (NTC)

The Net Transfer Capacity (NTC) of international interconnection lines (ENTSO-E and Georgia), which can be used as a flexibility mechanism, is projected to increase from 0.96 GW in 2020 to 2.18 GW in 2030 and further to 6.05 GW in 2050 (Table 6 and Figure 11). The development of the Net Transfer Capacity for ENTSO-E and Georgia interconnections is presented in Figure 12.

Table 6 Development of hourly Net Transfer Capacity (NTK) of international interconnection lines in base scenarioi

Year	Net Transfer Capacity (GW)
2020	0.96
2025	1.63
2030	2.18
2035	2.97
2040	3.9
2045	4.94
2050	6.05

Figure 11 Development of hourly Net Transfer Capacity (NTC) of international interconnection lines in base scenario



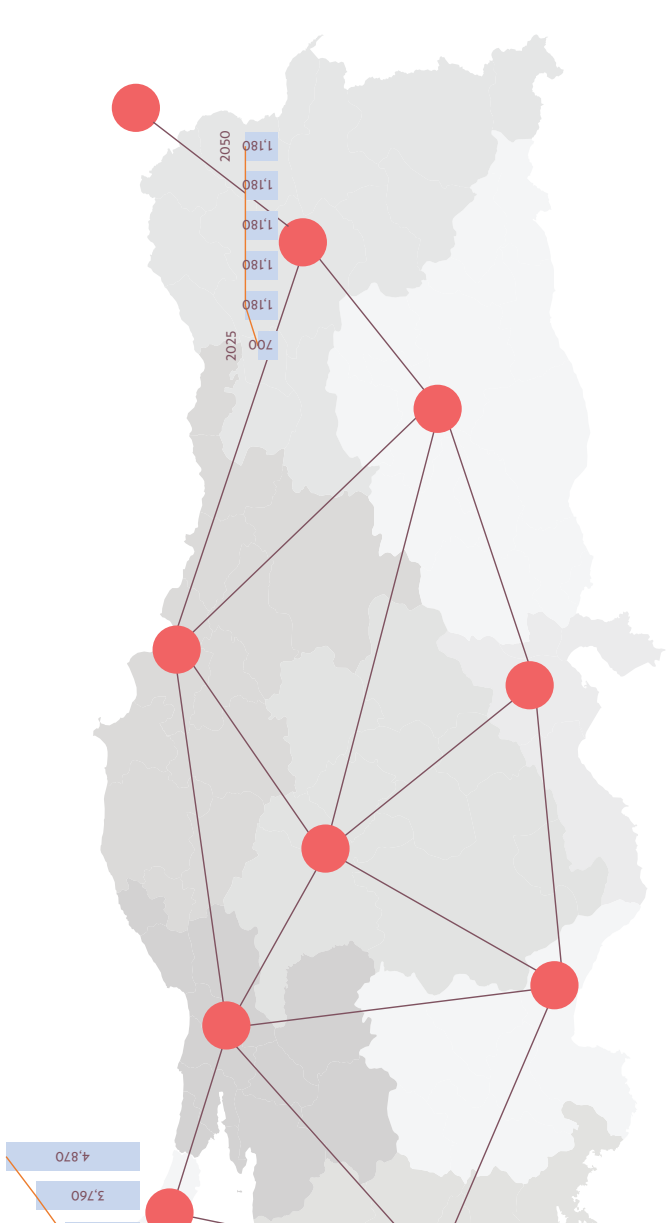


Figure 12 Development of Net Transfer Capacity of ENTSO-E and Georgia interconnections in base scenario

1.4.1. Installed Capacity

In the Base Scenario, without additional policies to achieve the net-zero target, the projected installed capacity capacities in the electricity sector by energy sources, including fossil fuels (hard coal, imported coal, lignite, natural gas, and other fossil fuel sources), nuclear energy, hydroelectric power plants (reservoir and run-of-river types), and modern renewable sources (solar, wind, geothermal, and biomass) are shown in Table 7 and Figure 13, indicating the changes in target years.

According to the Base Scenario, the installed capacity in the electricity sector, which was approximately 96 GW in 2020, is expected to increase to 137 GW in 2030 and reach around 232 GW by 2050, almost 2.4 times higher. In the Base Scenario, the share of fossil fuels in the installed capacity decreases over the years, but it remains above one-third until 2050, while modern renewable sources increase. Their share in installed capacity rises from 19% in 2020 to 31% in 2030 and further to 43% in 2050.

Table 7 Development of installed capacity (GW) by resources in the electricity sector in base scenario

Year	Local Coal	Import Coal	Lignite	Natural Gas	Other	Nuclear	Hydro (Dam)	Hydro (RoR)	Solar	Wind	Geothermal	Biomass	Total
2020	0.7	8.9	9.5	25.6	1.6		23	8.2	6.9	8.6	1.5	1.1	95.6
2025	0.8	11.7	12.8	26.6	2.8		23.5	8.2	13.6	14.1	2	2.2	118.5
2030	**0.9**	**11.7**	**14.9**	**27.1**	**3.6**	**4.8**	**23.5**	**8.2**	**18.9**	**18.2**	**2.4**	**3**	**137.3**
2035	1	11.5	17.1	29.8	4.1	4.8	25.5	8.2	28.1	28.9	3	4.5	166.5
2040	1	11.5	21.3	32.3	4.7	4.8	27.5	8.2	30.4	42.2	3	5	191.9
2045	1	12.9	21.2	37.3	4.9	4.8	29.5	8.2	38.8	48	2.8	4.9	214.4
2050	**1**	**16.7**	**21.2**	**43.2**	**5**	**4.8**	**31.5**	**8.2**	**44.6**	**48**	**2.8**	**4.8**	**231.8**

Figure 13 Development of installed power (GW) by resources in the electricity sector in base scenario

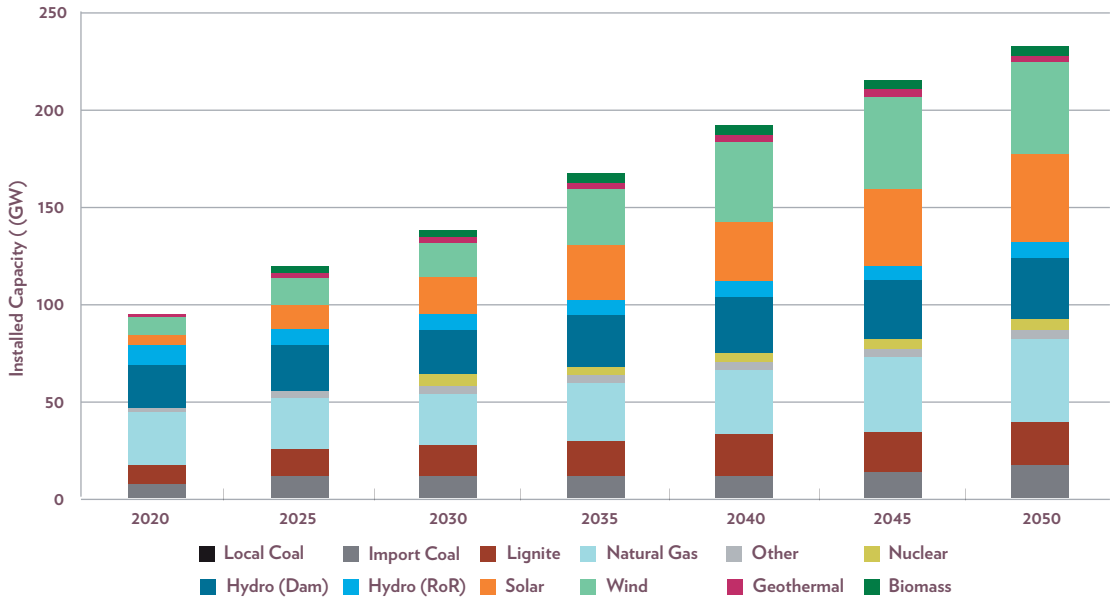
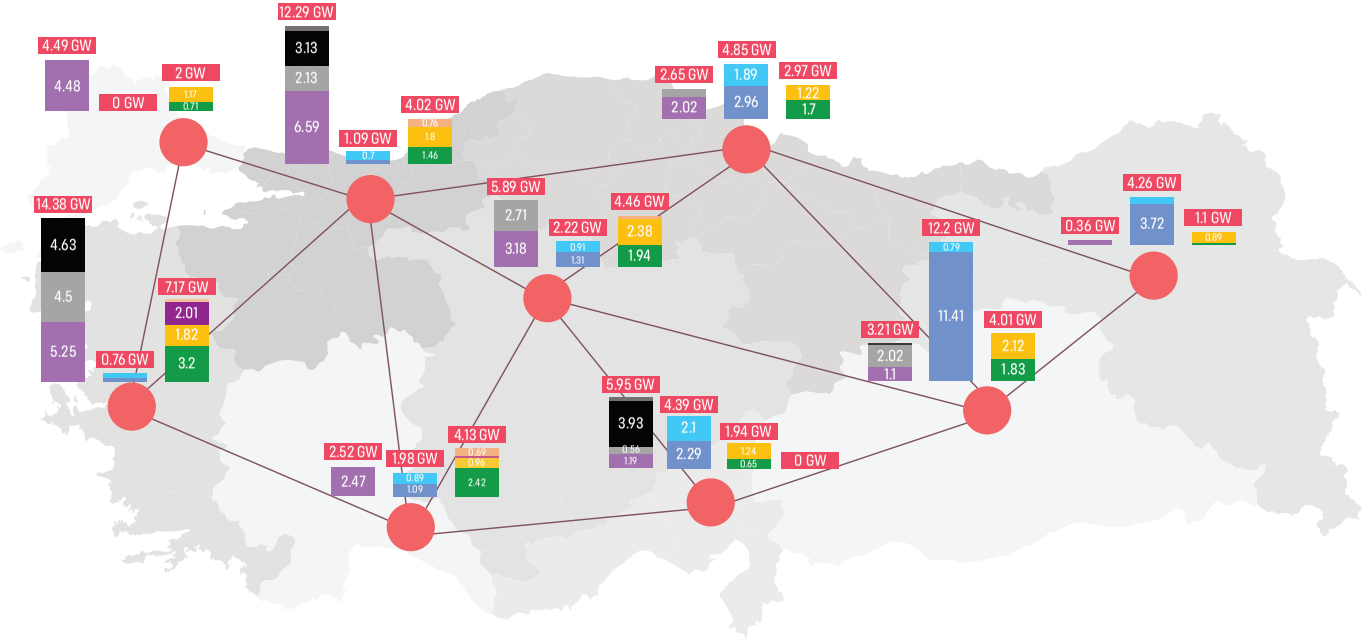


Figure 14 Distribution of installed capacity in the TEİAŞ Regional Dispatching Centers in 2025 in Base Scenario



1st Column / Conventional

Natural Gas (GW) | Lignite (GW) | Import Coal (GW) | Local Coal (GW)

2nd Column / Hydro

Hydro (Dam) (GW) | Hydro (RoR) (GW)

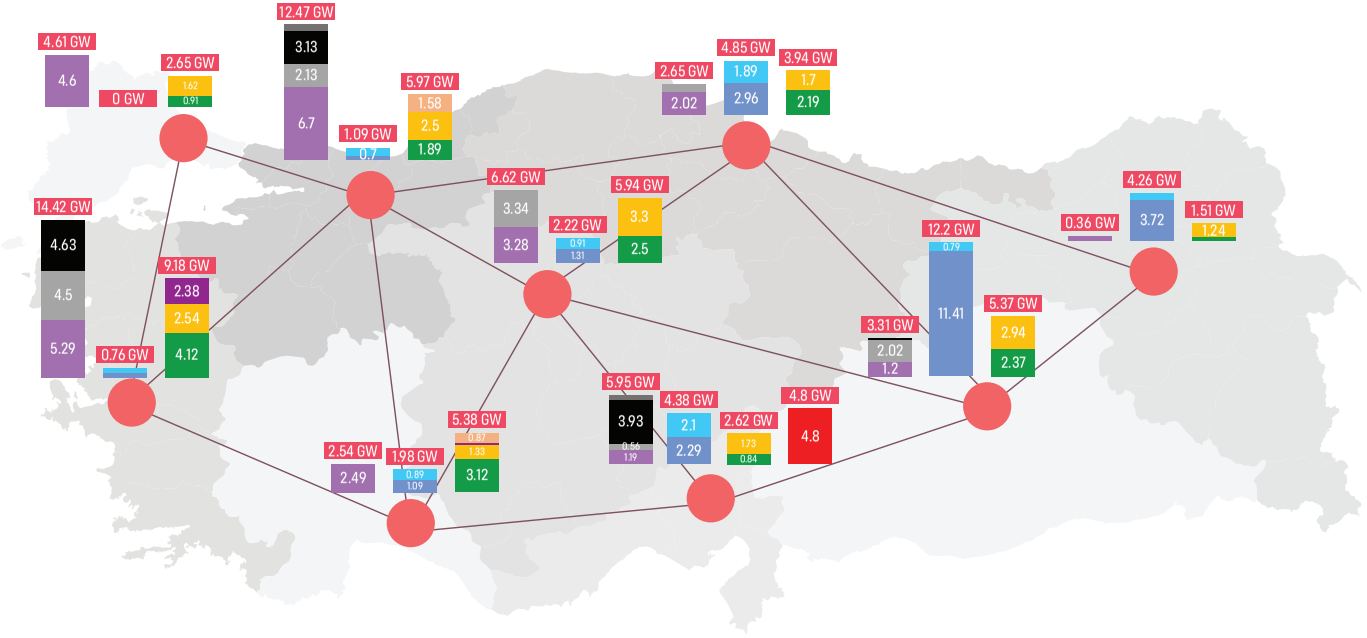
Wind (GW) | Solar (GW) | Geothermal (GW) | Biomass (GW)

3rd Column / Renewables

Nuclear (GW)

4th Column / Nuclear

Figure 15 Distribution of installed capacity in the TEİAŞ Regional Dispatching Centers in 2030 in Base Scenario



1st Column / Conventional

Natural Gas (GW) | Lignite (GW) | Import Coal (GW) | Local Coal (GW)

2nd Column / Hydro

Hydro (Dam) (GW) | Hydro (RoR) (GW)

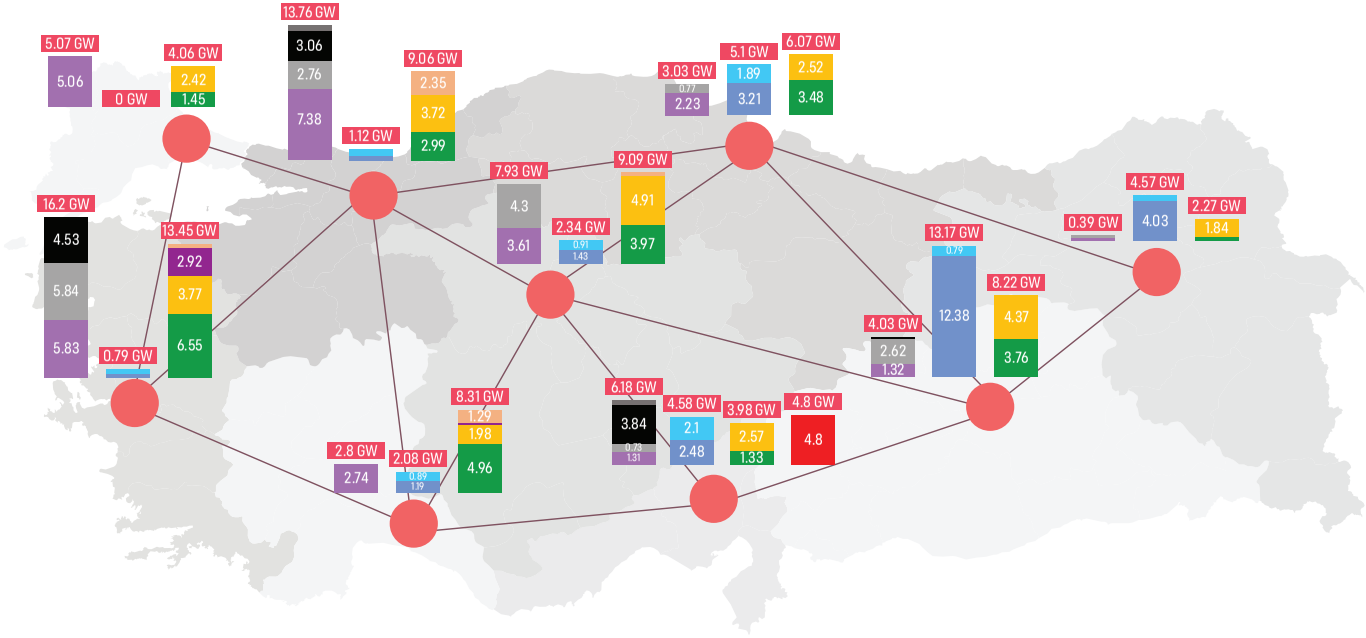
Wind (GW) | Solar (GW) | Geothermal (GW) | Biomass (GW)

3rd Column / Renewables

Nuclear (GW)

4th Column / Nuclear

Figure 16 Distribution of installed capacity in the TEİAŞ Regional Dispatching Centers in 2035 in Base Scenario



1st Column / Conventional

Natural Gas (GW) | Lignite (GW) | Import Coal (GW) | Local Coal (GW)

2nd Column / Hydro

Hydro (Dam) (GW) | Hydro (RoR) (GW)

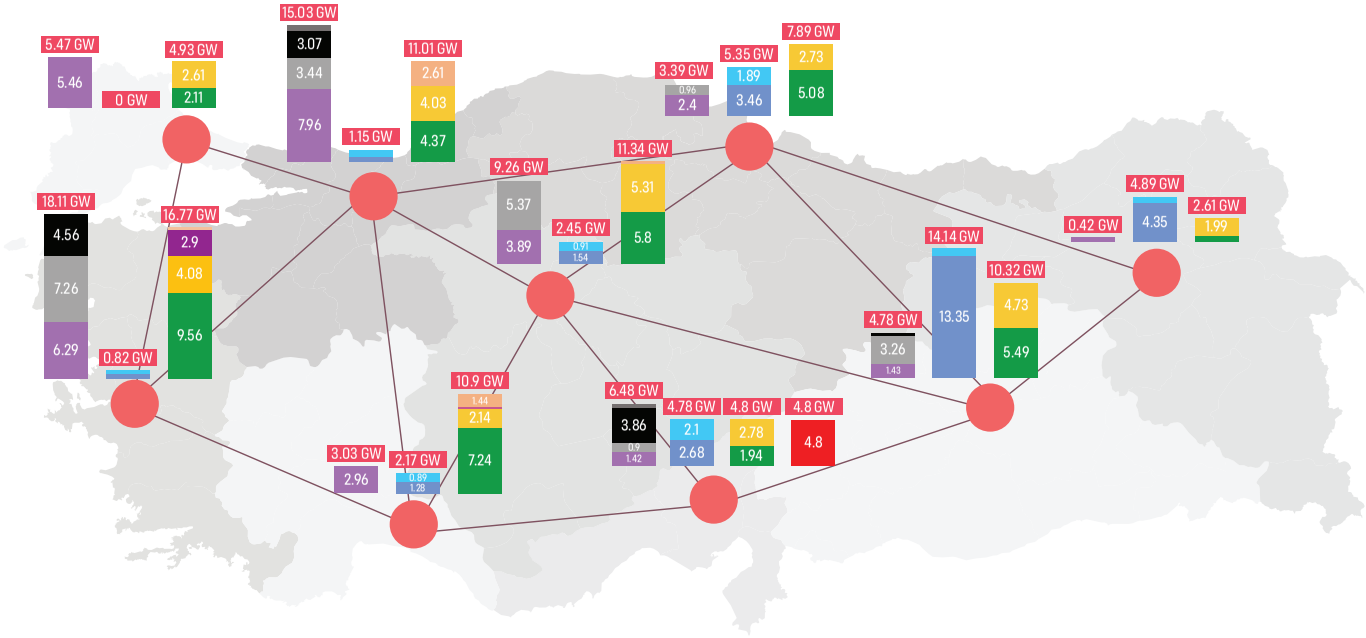
Wind (GW) | Solar (GW) | Geothermal (GW) | Biomass (GW)

3rd Column / Renewables

Nuclear (GW)

4th Column / Nuclear

Figure 17 Distribution of installed capacity in the TEİAŞ Regional Dispatching Centers in 2040 in Base Scenario



1st Column / Conventional

Natural Gas (GW) | Lignite (GW) | Import Coal (GW) | Local Coal (GW)

2nd Column / Hydro

Hydro (Dam) (GW) | Hydro (RoR) (GW)

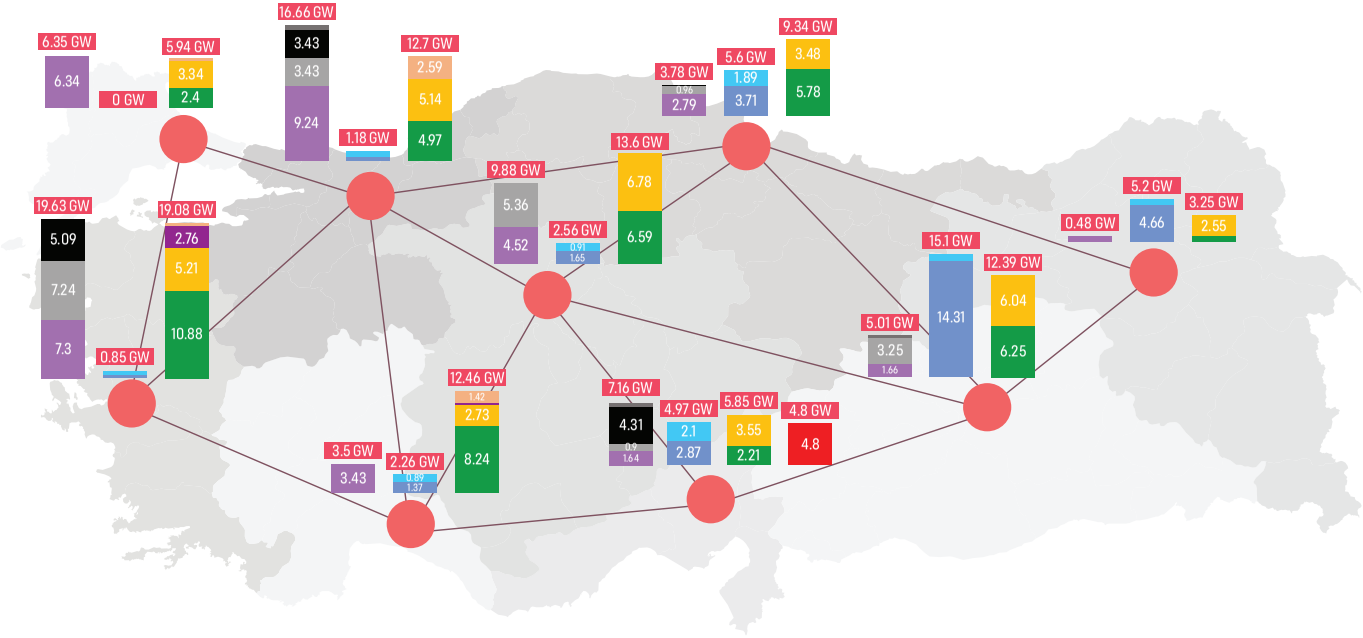
Wind (GW) | Solar (GW) | Geothermal (GW) | Biomass (GW)

3rd Column / Renewables

Nuclear (GW)

4th Column / Nuclear

Figure 18 Distribution of installed capacity in the TEİAŞ Regional Dispatching Centers in 2045 in Base Scenario



1st Column / Conventional

Natural Gas (GW) | Lignite (GW) | Import Coal (GW) | Local Coal (GW)

2nd Column / Hydro

Hydro (Dam) (GW) | Hydro (RoR) (GW)

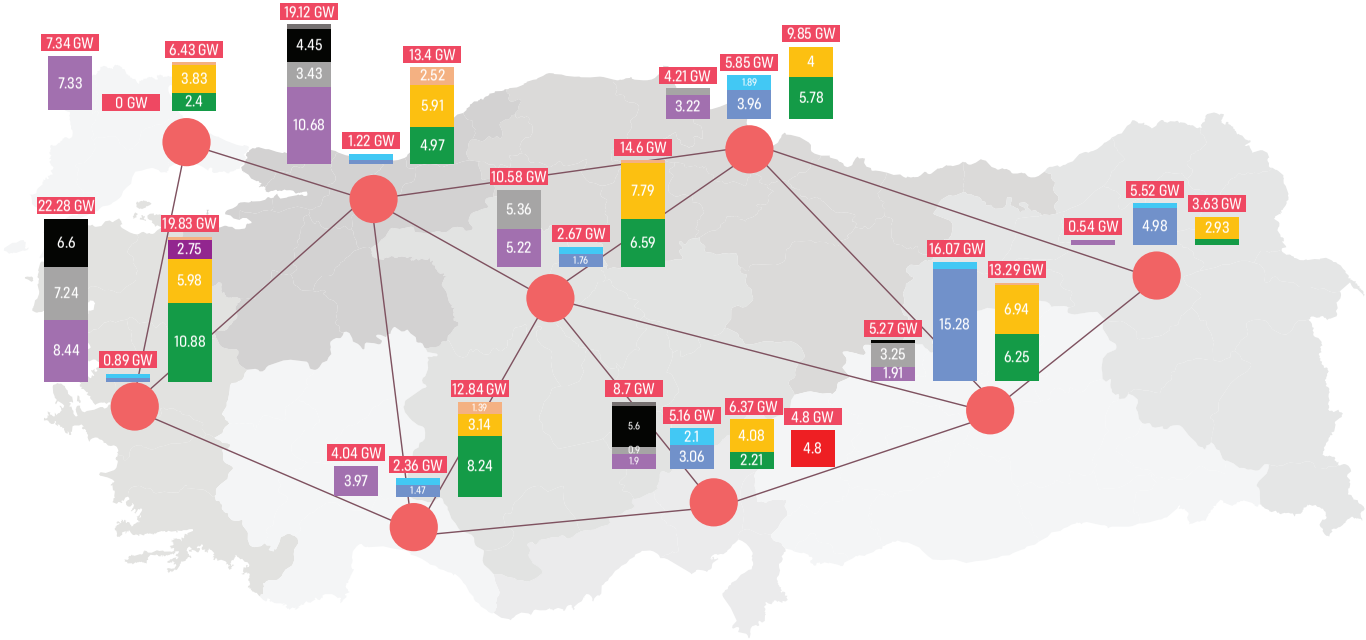
Wind (GW) | Solar (GW) | Geothermal (GW) | Biomass (GW)

3rd Column / Renewables

Nuclear (GW)

4th Column / Nuclear

Figure 19 Distribution of installed capacity in the TEİAŞ Regional Dispatching Centers in 2050 in Base Scenario



1st Column / Conventional

Natural Gas (GW) | Lignite (GW) | Import Coal (GW) | Local Coal (GW)

Wind (GW) | Solar (GW) | Geothermal (GW) | Biomass (GW)

3rd Column / Renewables

2nd Column / Hydro

Hydro (Dam) (GW) | Hydro (RoR) (GW)

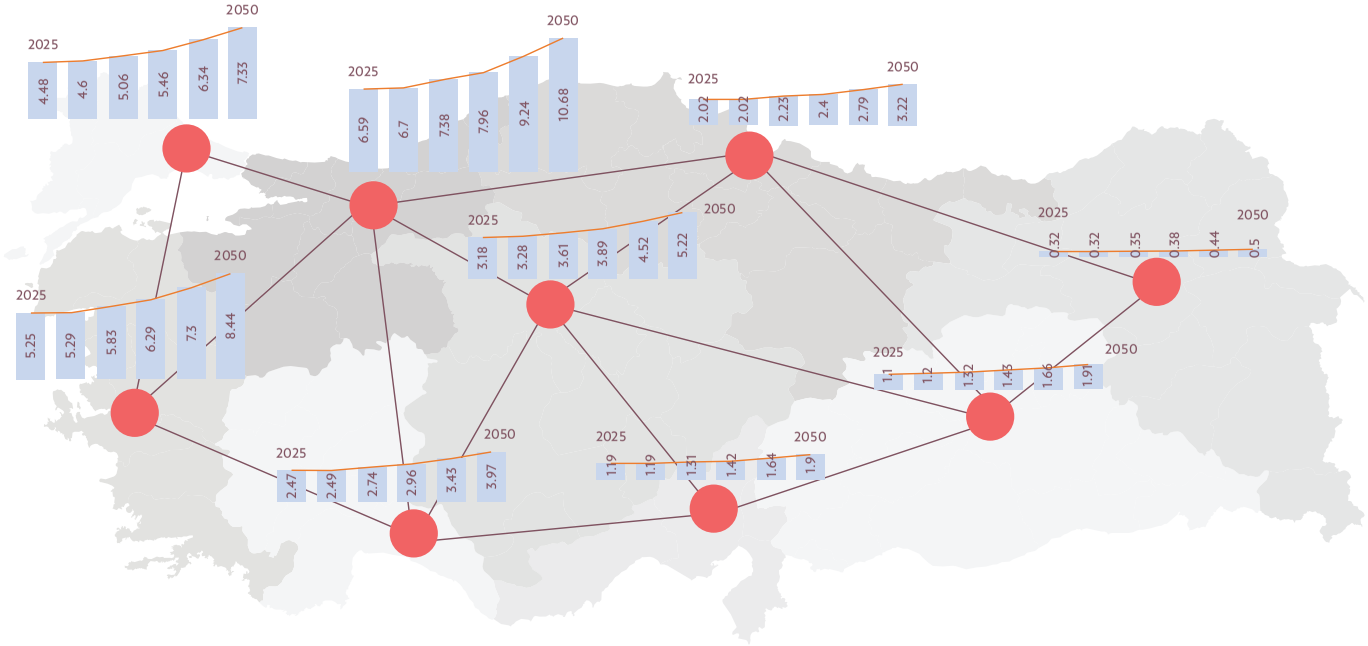
Nuclear (GW)

4th Column / Nuclear

While the installed capacity of hydroelectric power plants (HES) shows a slight increase, their share in the installed capacity, which was 33% in 2020, decreases over the years to reach 17% in 2050. Nuclear energy is introduced into the system towards the 2030s, and its share in installed capacity decreases from 3.5% initially to 2.1% in 2050 and further to 1.6% in 2070. The fundamental approach for changes in the installed capacities of production technologies is a network-oriented approach for natural gas and renewable energy sources, while it is a resource-oriented approach for lignite and hydroelectric units. The distribution of installed capacity among TEİAŞ regional dispatching centers in various years is provided in Figures 14 to 19.

In the Base Scenario, the changes in installed capacities for natural gas, total coal (hard coal, imported coal, and lignite), and total renewable (wind, solar, biomass, and geothermal) power by year are shown in Figures 20, 21, and 22, respectively. The location and installed capacities of renewable power plants in various years in the Base Scenario are illustrated in Figures 23 to 28.

Figure 20 Change in natural gas installed capacity over years at TEİAŞ Regional Dispatching Centers in Base Scenario



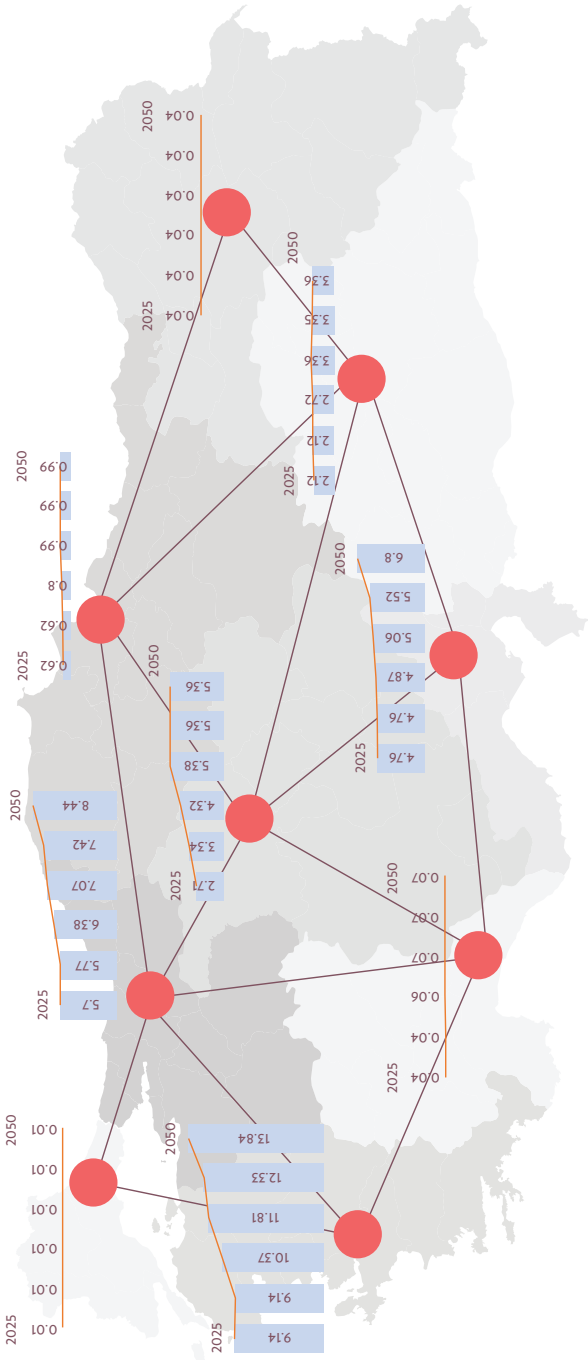


Figure 21 Change in total coal installed capacity over years at TEİAŞ Regional Dispatching Centers in Base Scenario

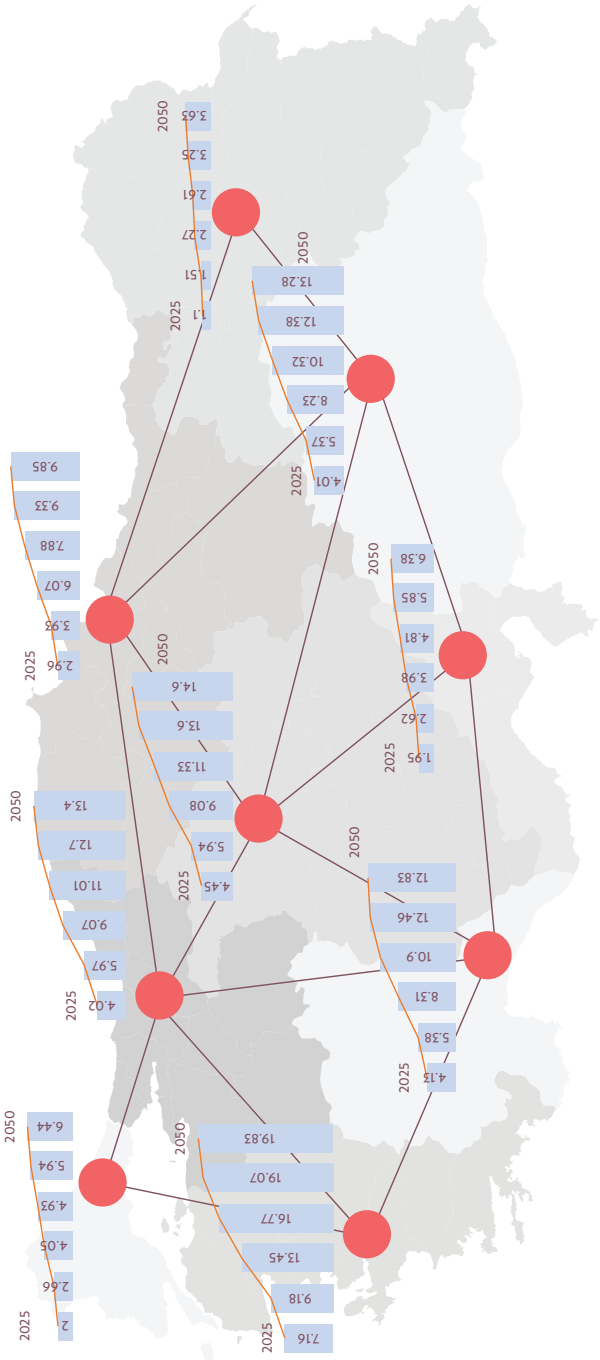
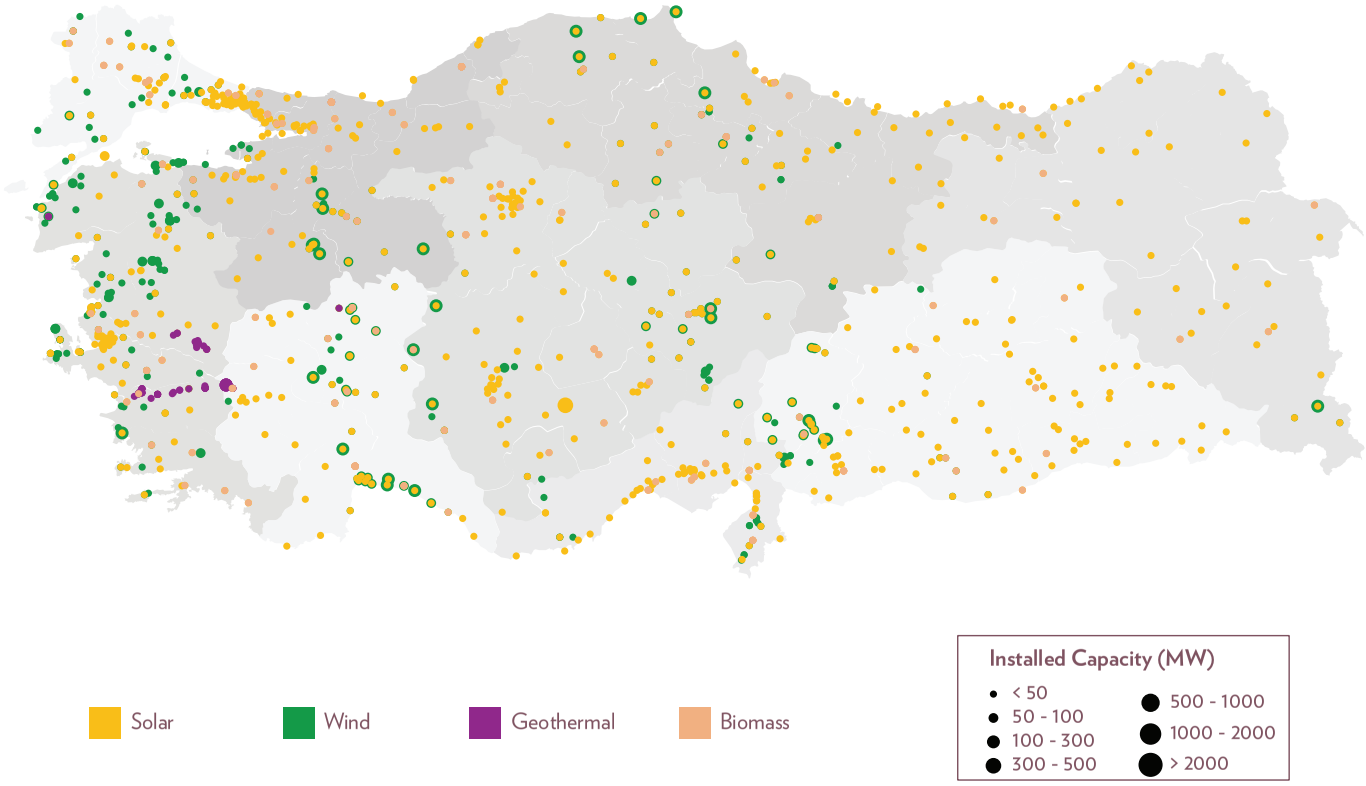


Figure 22 Change in total renewable installed capacity over years at TEİAŞ Regional Dispatching Centers in Base Scenario

Figure 23 Location and installed capacity of renewable power plants in 2025 in Base Scenario



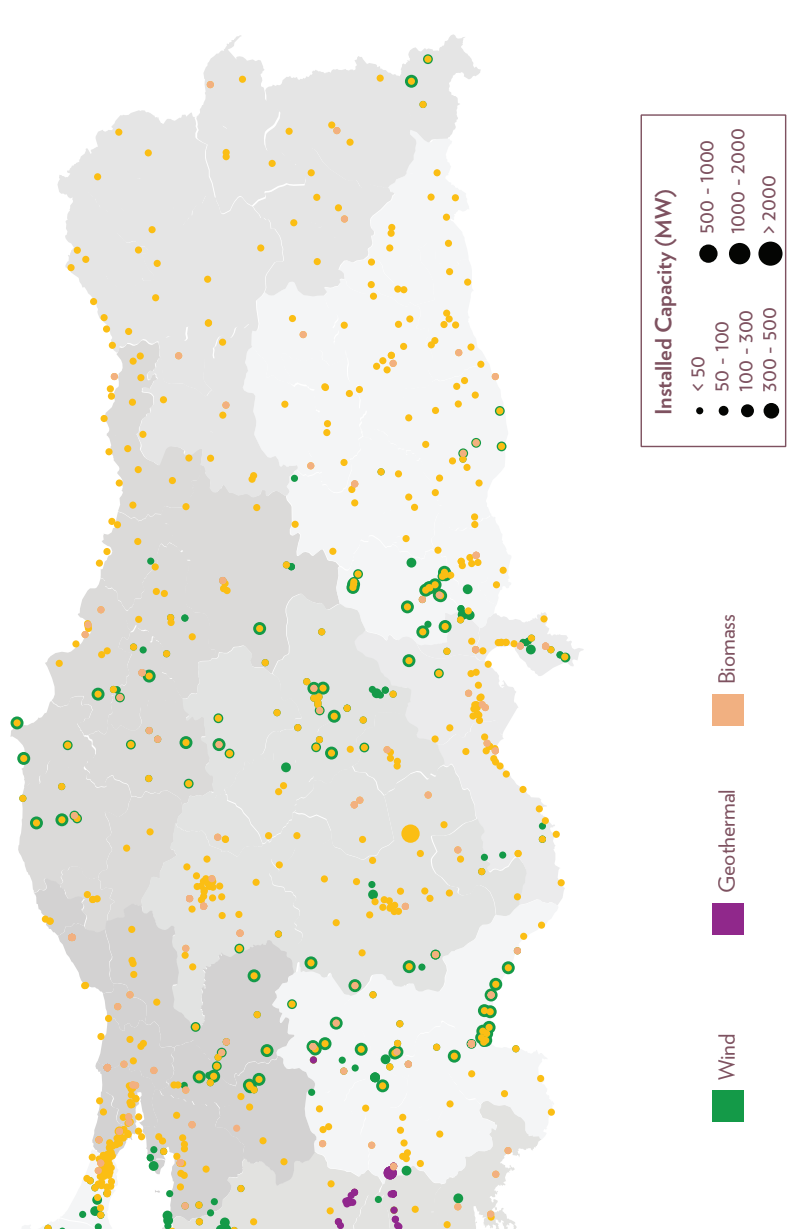
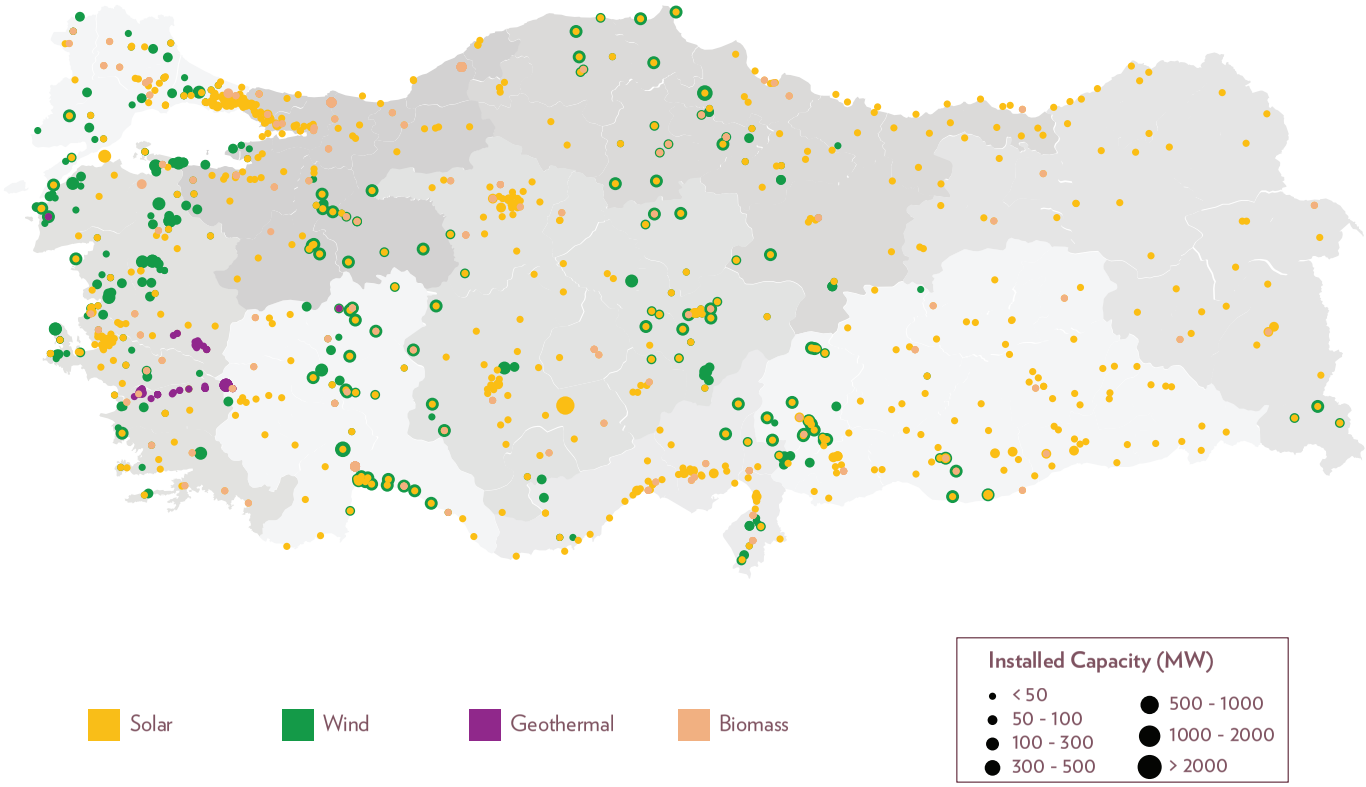


Figure 24 Location and installed capacity of renewable power plants in 2030 in Base Scenario

Figure 25. Location and installed capacity of renewable power plants in 2035 in Base Scenario



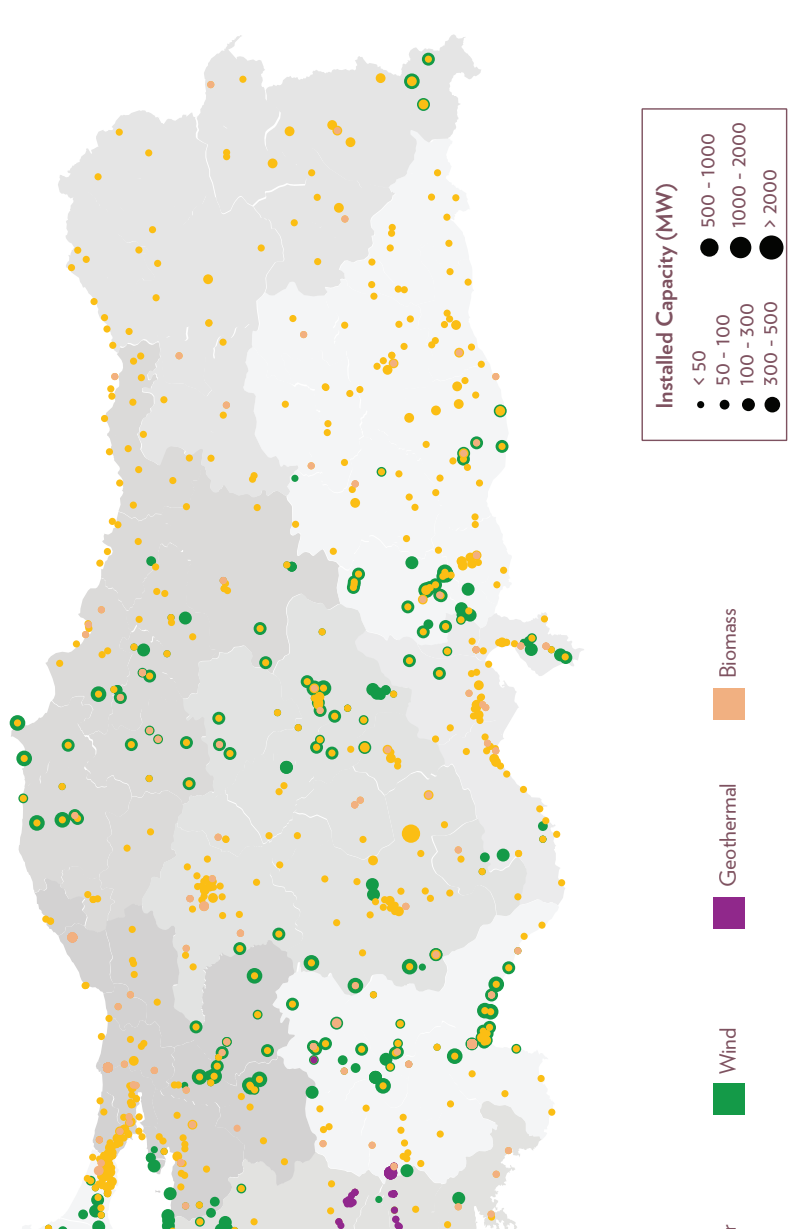
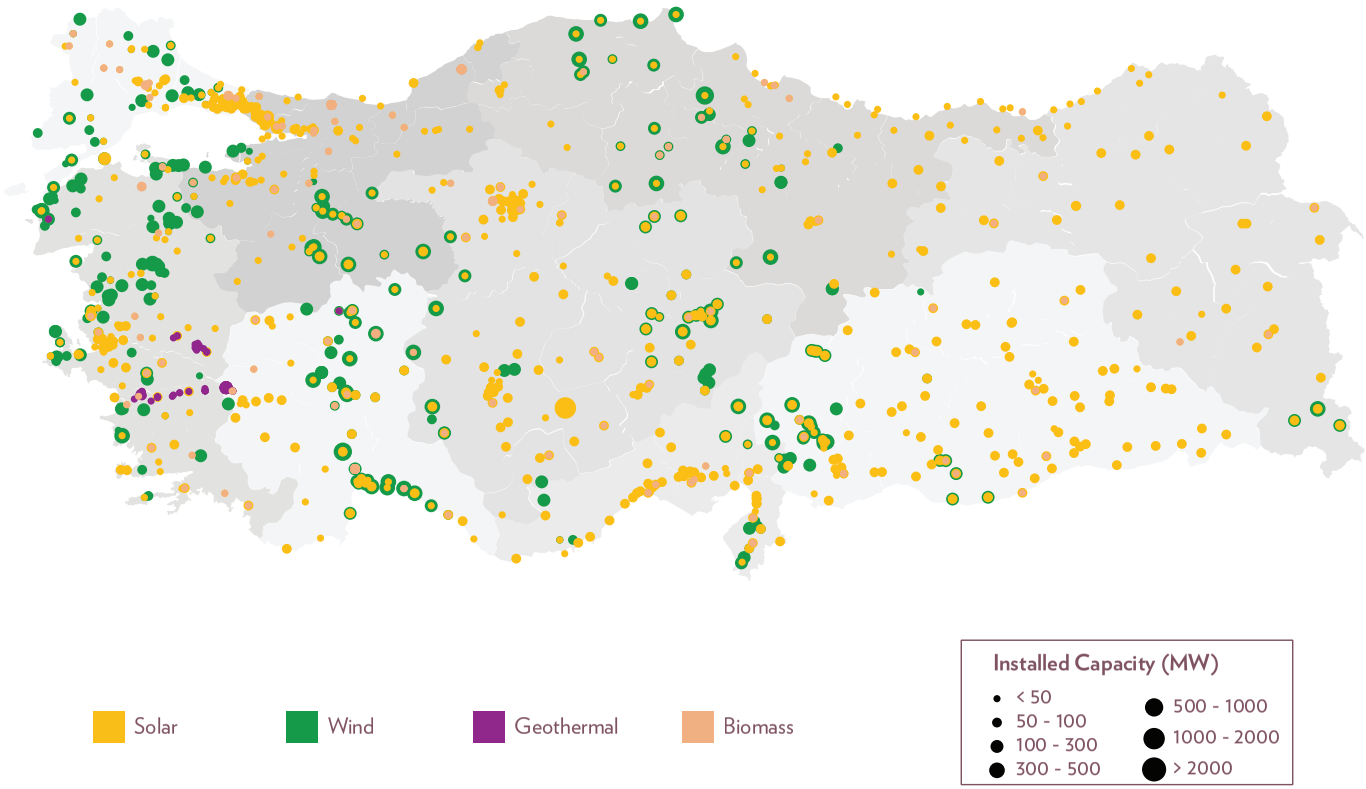


Figure 26 Location and installed capacity of renewable power plants in 2040 in Base Scenario

Figure 27 Location and installed capacity of renewable power plants in 2045 in Base Scenario



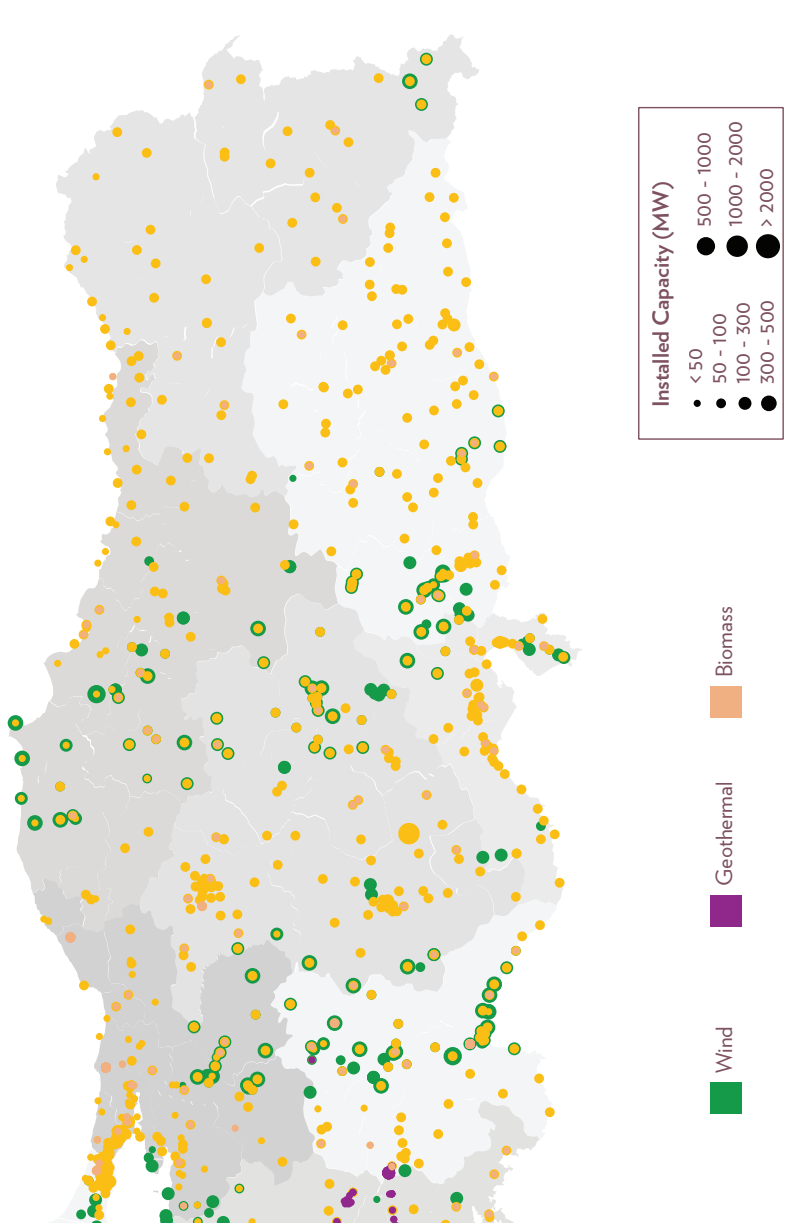


Figure 28 Location and installed capacity of renewable power plants in 2050 in Base Scenario

For each year, market and grid simulations were conducted using the determined installed capacity and network model. The results of these simulations were used to determine the distribution of production by energy sources in target years, redispatch up/down instruction quantities, the amount of curtailments in renewable energy production, and grid investment requirements. With the obtained results and the emission coefficients provided above, the total carbon dioxide emission quantities were calculated, as detailed in the continuation of the report.

1.4.2. Energy Generation by Resources

In the Base Scenario, the distribution of production by energy sources in various years is presented in Table 8 and Figure 29. These results reflect the outcome of grid simulations, where Redispatch Up / Redispatch Down (Up/Down) instructions were issued to alleviate network constraints, taking into account the results of the conducted market simulations. Therefore, the distribution of production by energy sources in grid simulations, where network constraints are considered, may vary compared to market simulations.

Table 8 Distribution of generation by resources in the electricity sector in the base scenario (GWh)

Year	Local Coal	Imported Coal	Lignite	Natural Gas	Other	Nuclear	HPP	HPP	Solar	Wind	Geothermal	Biomass	Total
2020	4,110	60,090	39,850	68,400	2,463	0	55,810	21,010	11,530	23,790	10,690	4,279	302,022
2025	3,530	70,630	63,510	62,180	20,600	0	59,330	21,680	24,700	39,930	16,090	15,290	397,470
2030	**3,550**	**68,960**	**65,560**	**58,290**	**26,240**	**37,920**	**61,400**	**20,500**	**34,330**	**51,540**	**17,620**	**14,690**	**460,600**
2035	3,480	63,810	80,630	58,160	30,390	37,470	66,480	21,680	50,960	81,810	21,530	22,700	539,100
2040	3,320	62,900	105,530	60,280	34,800	37,500	71,670	21,680	55,130	119,460	21,270	25,360	618,900
2045	3,700	72,800	112,620	84,010	35,880	37,510	76,720	21,680	70,330	135,850	20,270	25,310	696,680
2050	**3,980**	**96,920**	**121,070**	**106,820**	**36,690**	**37,540**	**81,770**	**21,680**	**80,790**	**135,790**	**20,390**	**25,040**	**768,480**

Figure 29 Distribution of generation by resources in the electricity sector in the base scenario (TWh)

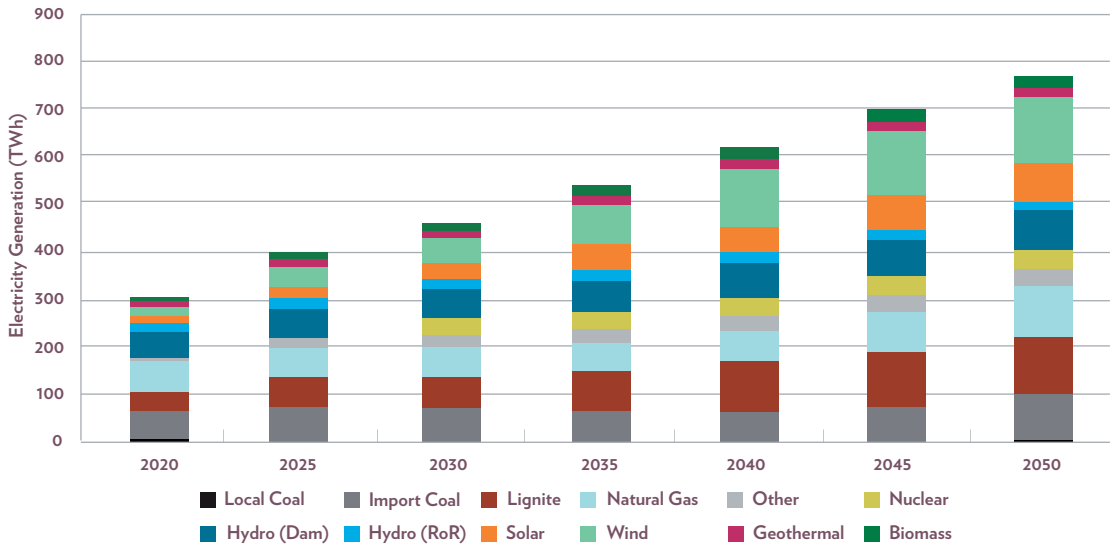


Figure 30 Distribution of energy generation by technology in TEİAŞ regions in 2025 in Base Scenario

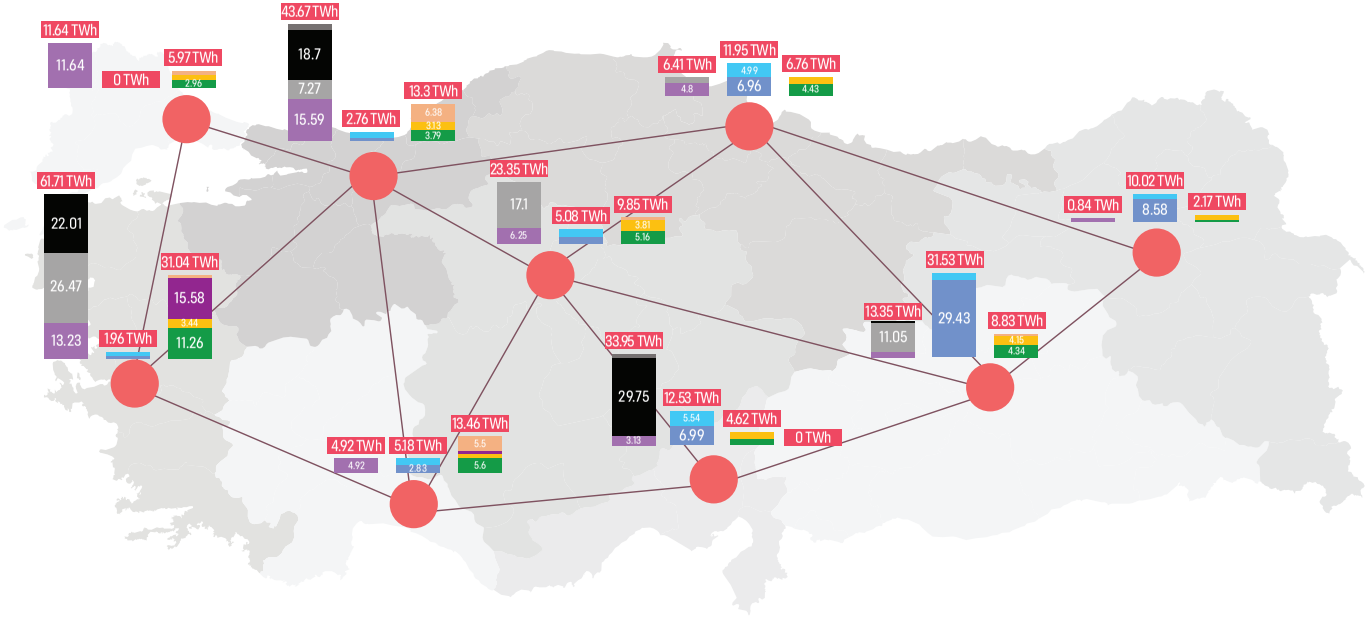


Figure 31 Distribution of energy generation by technology in TEİAŞ regions in 2030 in Base Scenario

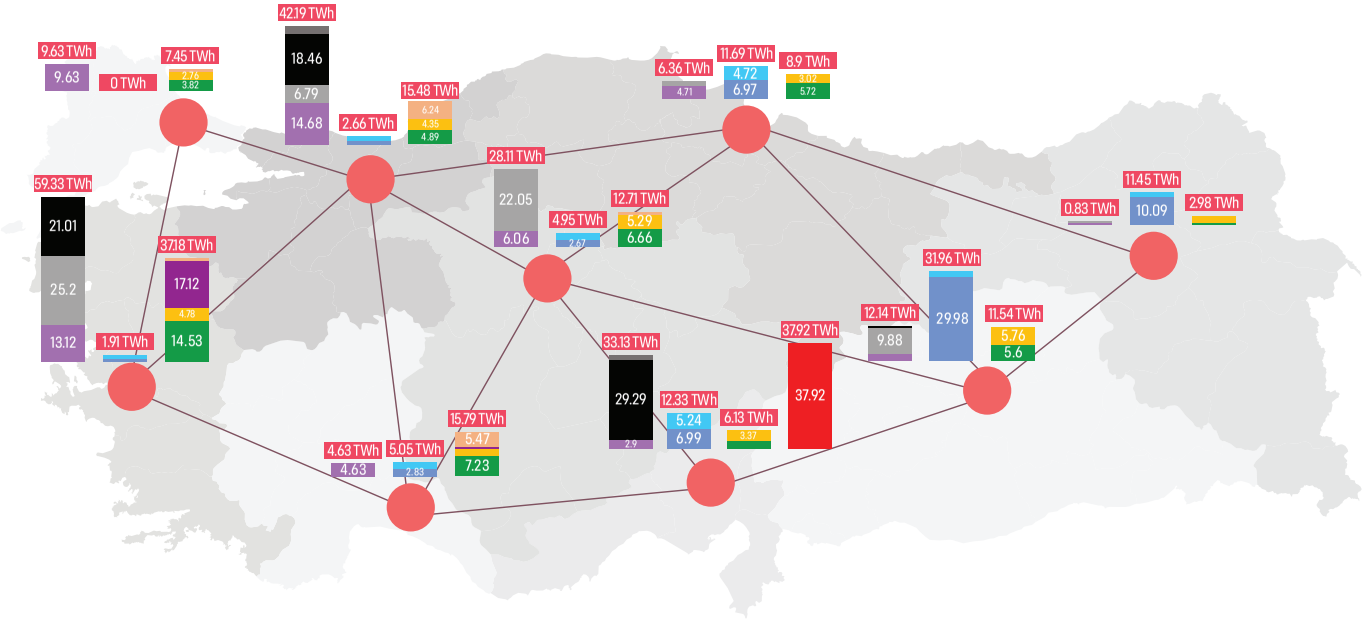
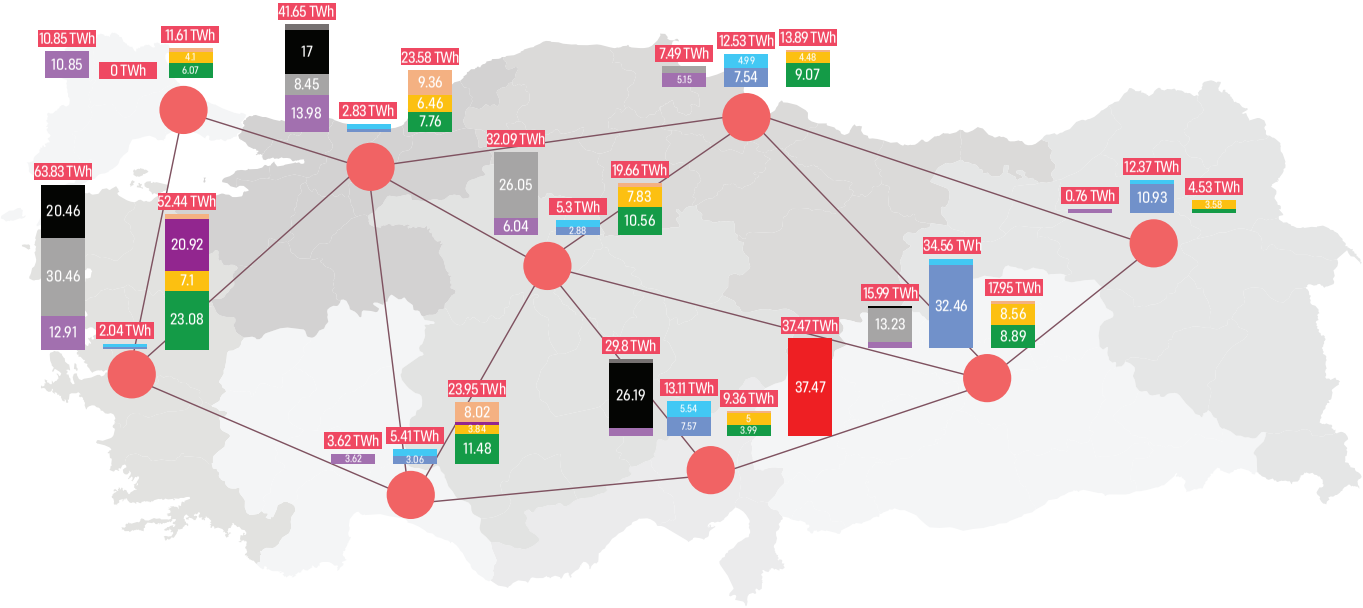


Figure 32 Distribution of energy generation by technology in TEİAŞ regions in 2035 in Base Scenario



1st Column / Conventional

Natural Gas (TWh) | Lignite (TWh) | Import Coal (TWh) | Local Coal (TWh)

2nd Column / Hydro

Hydro (Dam) (TWh) | Hydro (RoR) (TWh)

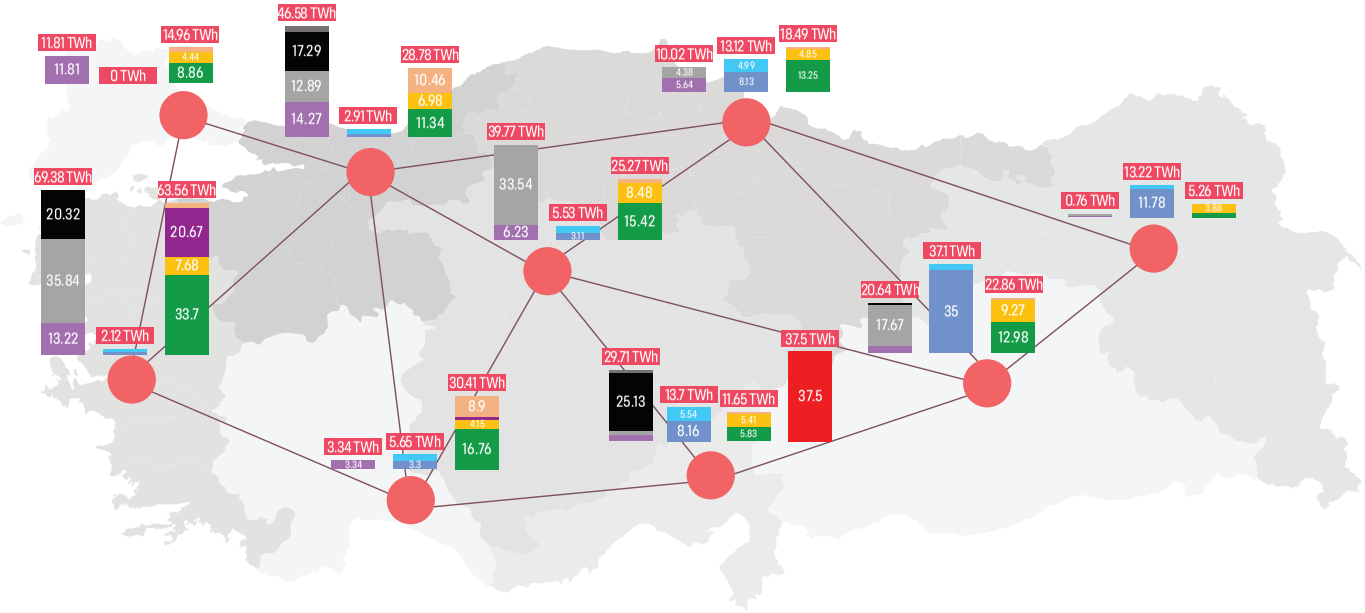
Wind (TWh) | Solar (TWh) | Geothermal (TWh) | Biomass (TWh)

3rd Column / Renewables

Nuclear (TWh)

4th Column / Nuclear

Figure 33 Distribution of energy generation by technology in TEİAŞ regions in 2040 in Base Scenario



1st Column / Conventional

Natural Gas (TWh) | Lignite (TWh) | Import Coal (TWh) | Local Coal (TWh)

2nd Column / Hydro

Hydro (Dam) (TWh) | Hydro (RoR) (TWh)

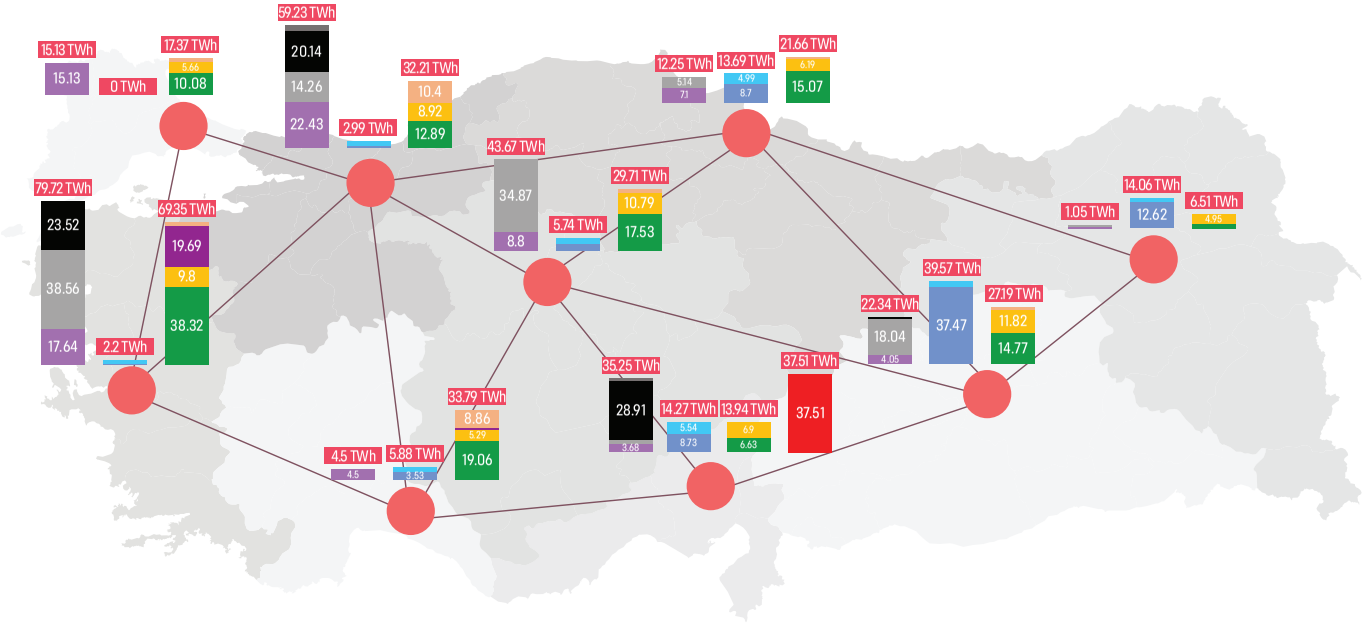
Wind (TWh) | Solar (TWh) | Geothermal (TWh) | Biomass (TWh)

3rd Column / Renewables

Nuclear (TWh)

4th Column / Nuclear

Figure 34 Distribution of energy generation by technology in TEİAŞ regions in 2045 in Base Scenario



1st Column / Conventional

Natural Gas (TWh) | Lignite (TWh) | Import Coal (TWh) | Local Coal (TWh)

Wind (TWh) | Solar (TWh) | Geothermal (TWh) | Biomass (TWh)

3rd Column / Renewables

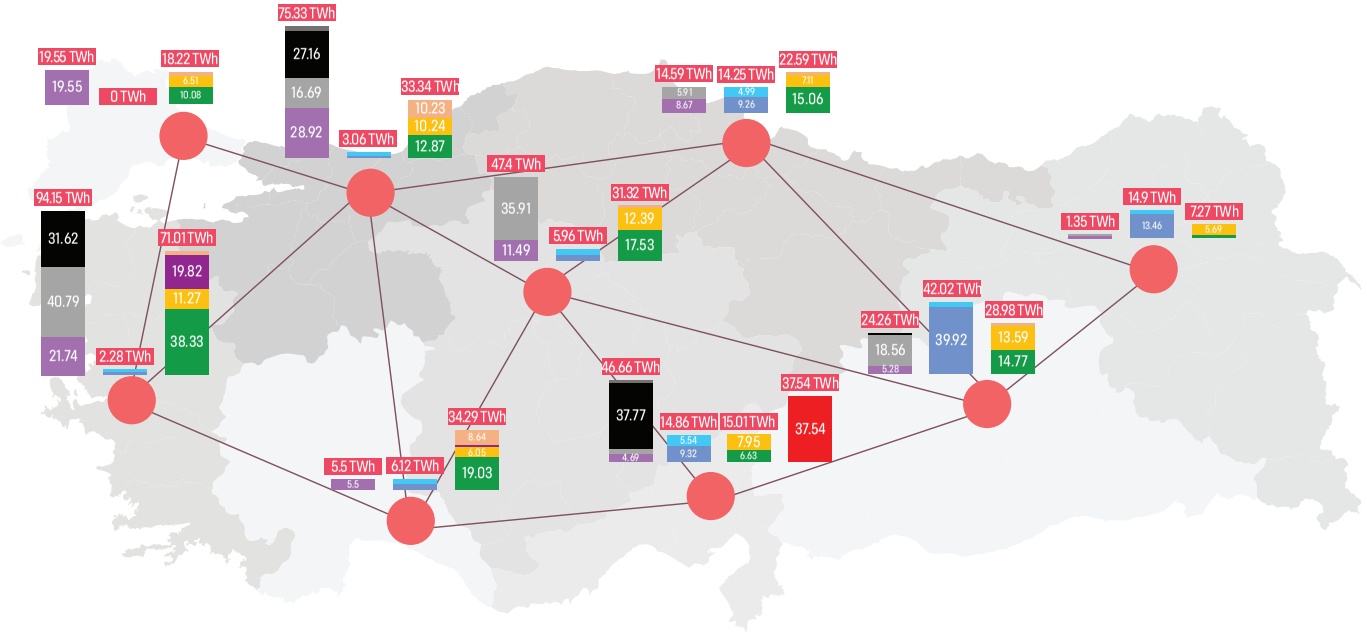
2nd Column / Hydro

Hydro (Dam) (TWh) | Hydro (RoR) (TWh)

Nuclear (TWh)

4th Column / Nuclear

Figure 35 Distribution of energy generation by technology in TEİAŞ regions in 2050 in Base Scenario



1st Column / Conventional

Natural Gas (TWh) | Lignite (TWh) | Import Coal (TWh) | Local Coal (TWh)

2nd Column / Hydro

Hydro (Dam) (TWh) | Hydro (RoR) (TWh)

Wind (TWh) | Solar (TWh) | Geothermal (TWh) | Biomass (TWh)

3rd Column / Renewables

Nuclear (TWh)

4th Column / Nuclear

The electricity production, which was 302 TWh in 2020, increases by 1.5 times to reach 460.6 TWh in 2030 and grows by 2.5 times to reach 768.5 TWh in 2050. The share of fossil fuels in production, which was 57% in 2020, decreases to 43% in 2050. The share of hydroelectric power plants, which was 25% in 2020, decreases over the years to reach 13.5% in 2050. The share of modern renewable sources increases more modestly, and its share in production, which was 17% in 2020, increases to 24% in 2025, 26% in 2030, 33% in 2035, 35.7% in 2040, and 36% in 2045, before slightly decreasing to 34% in 2050. The share of the Akkuyu Nuclear Power Plant, which starts operating in 2030, begins at 8.2% and decreases over the years to 5% in 2050.

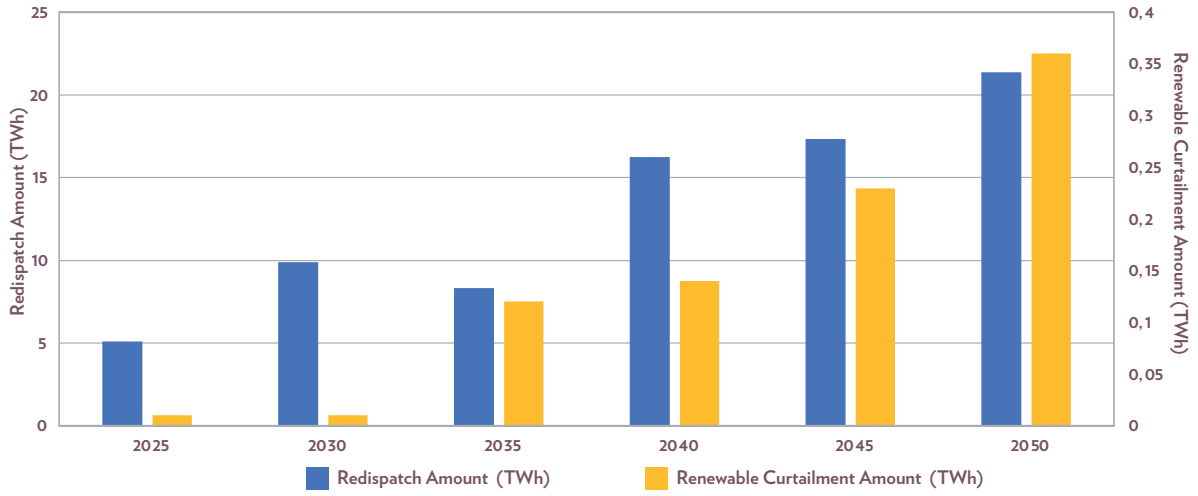
In the Base Scenario, the technology-based distribution of electricity production in TEIAS regions for various years is shown in Figures 30 to 35.

1.4.3. Redispatch Up/Down and Renewable Curtailment Amount

Market simulations aim to achieve minimum cost without considering network topology and constraints, focusing on balancing energy consumption and production. On the other hand, network simulations involve giving instructions for load shedding or adding based on the need, considering network constraints, and responding quickly to plants in the market simulation. This ensures the reliable and stable operation of the energy system, resolving imbalances between energy consumption and production.

In the Base Scenario, Figures 36 and Table 9 illustrate the total Redispatch Up / Redispatch Down (Up/Down) and renewable curtailment amounts for various years.

Figure 36 Redispatch Up/Down and renewable curtailment amounts in Base Scenario



ŞAs grid energy consumption increases, the quantity of Up/Down and, as renewable production increases, the curtailment amount in renewable production also rises. The ratio of Up/Down quantity to total consumption and the ratio of curtailment in renewable production to total renewable production are illustrated in Figure 37 and Table 10.

Total redispatch and curtailment in renewable generation amounts in TEİAŞ regions are shown in Figure 38-43.

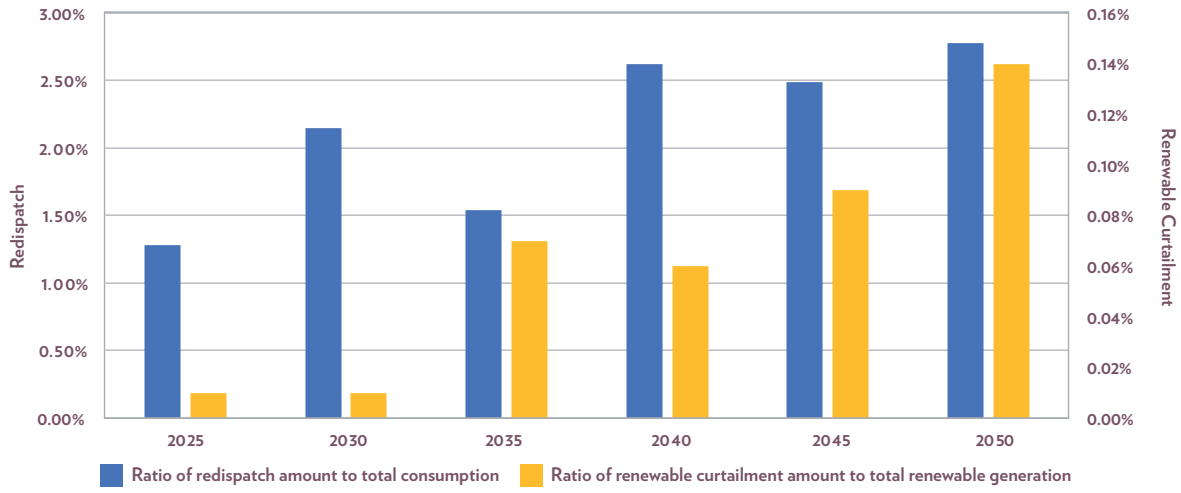
Table 9 Redispatch Up/Down and renewable curtailment amounts in Base Scenario

	Redispatch amount (TWh)	Renewable curtailment amount (TWh)
2025	5.08	0.01
2030	9.89	0.01
2035	8.32	0.12
2040	16.24	0.14
2045	17.34	0.23
2050	21.37	0.36

Table 10 Redispatch and curtailment ratios in Base Scenario

	Ratio of redispatch amount to total consumption	Ratio of renewable curtailment amount to total renewable generation
2025	1.28%	0.01%
2030	2.15%	0.01%
2035	1.54%	0.07%
2040	2.62%	0.06%
2045	2.49%	0.09%
2050	2.78%	0.14%

Figure 37 Redispatch and curtailment ratios in Base Scenario



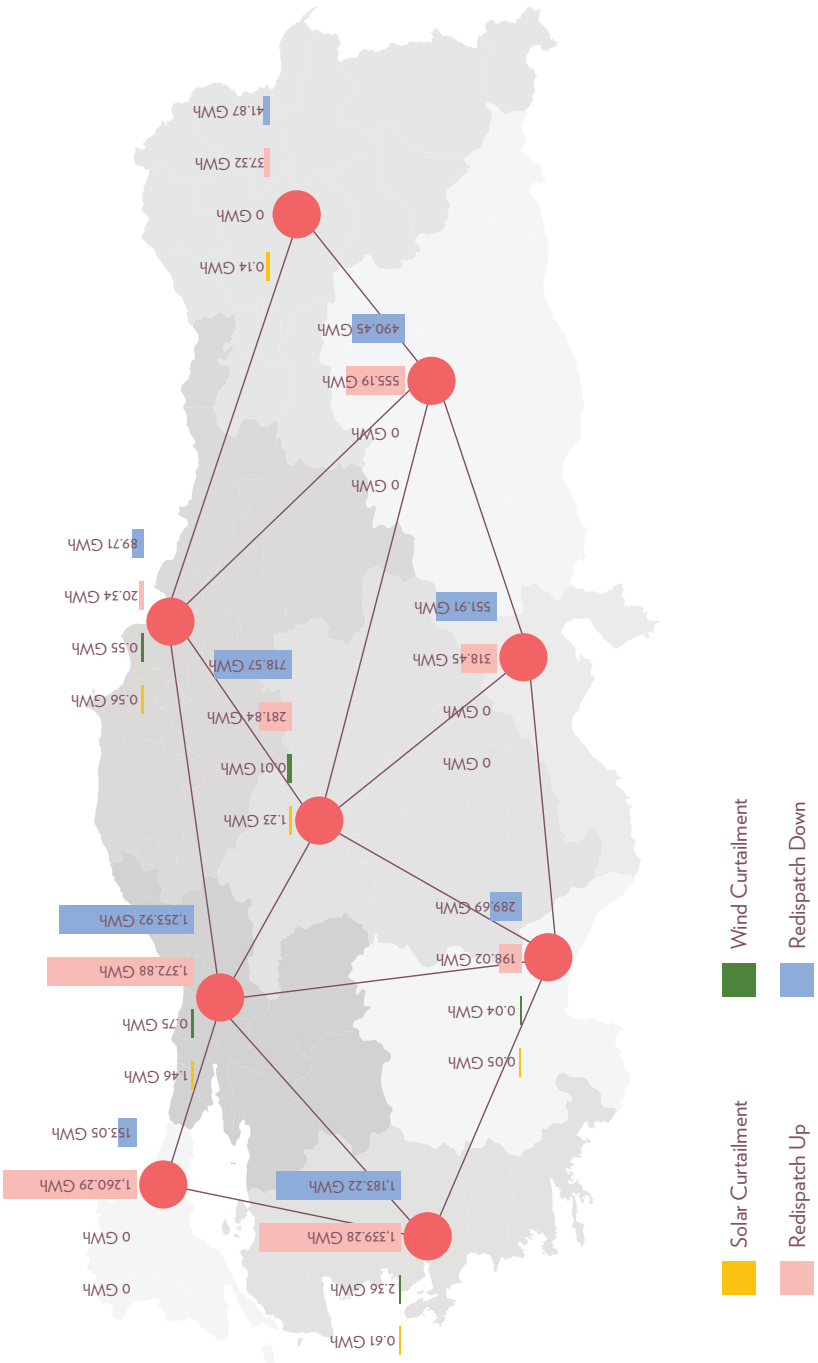
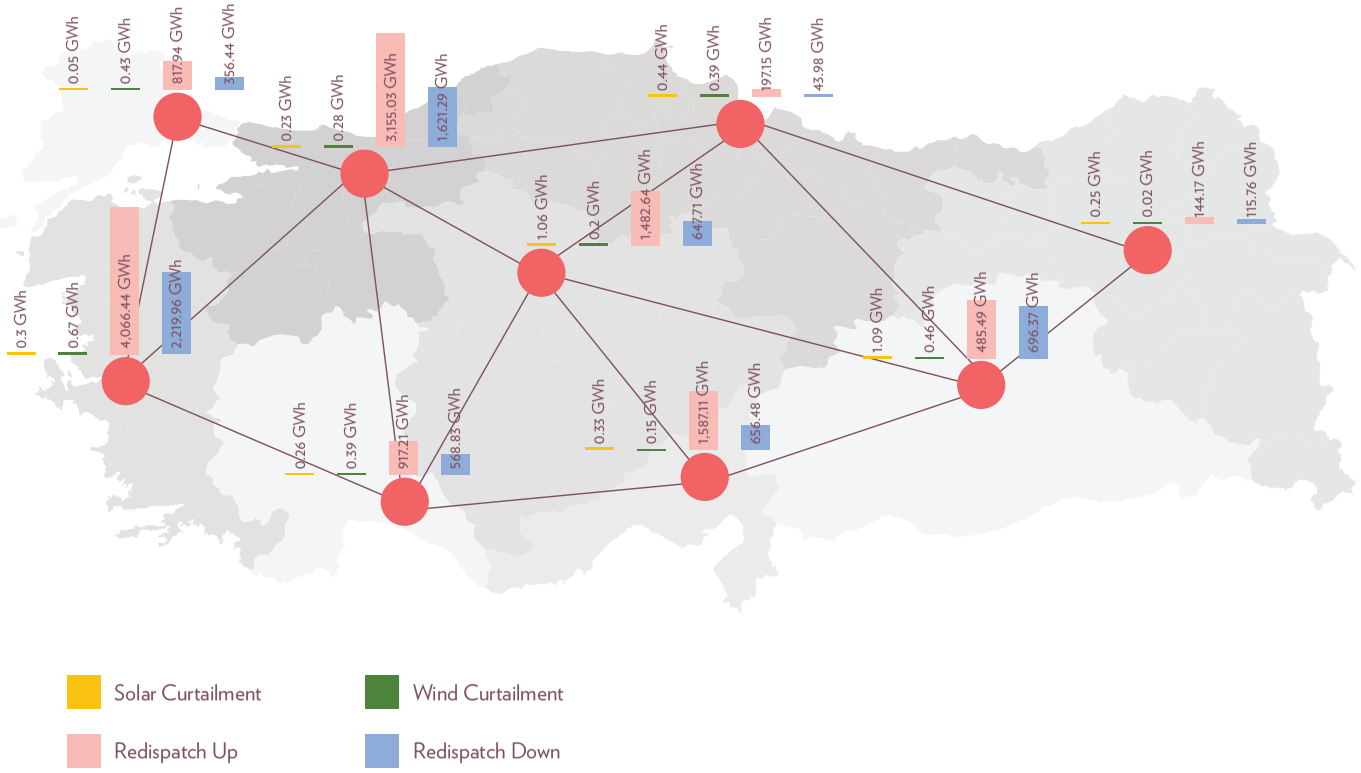


Figure 38 Distribution of redispatch and renewable curtailment amounts based on regions in 2025 in Base Scenario

Figure 39 Distribution of redispatch and renewable curtailment amounts based on regions in 2030 in Base Scenario



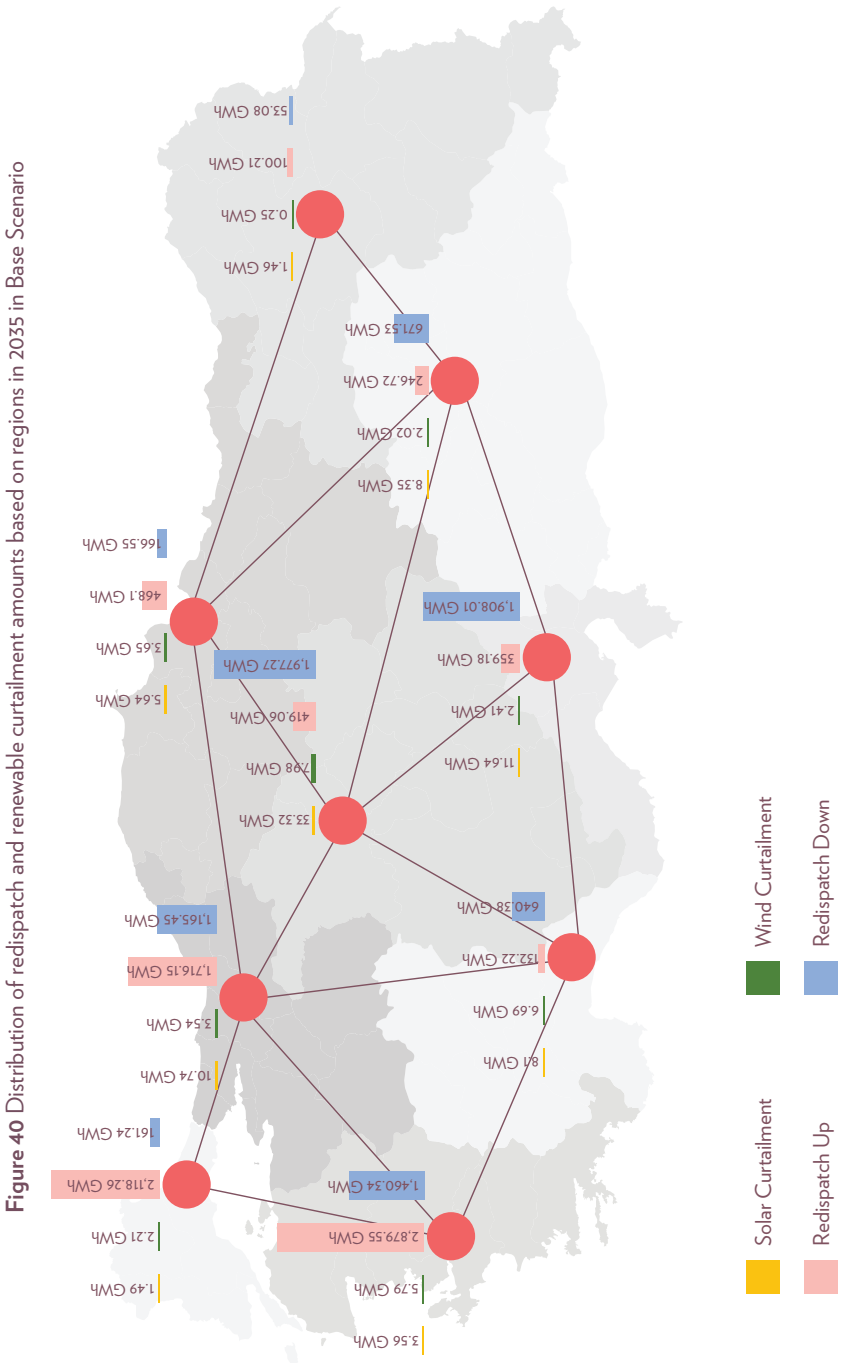
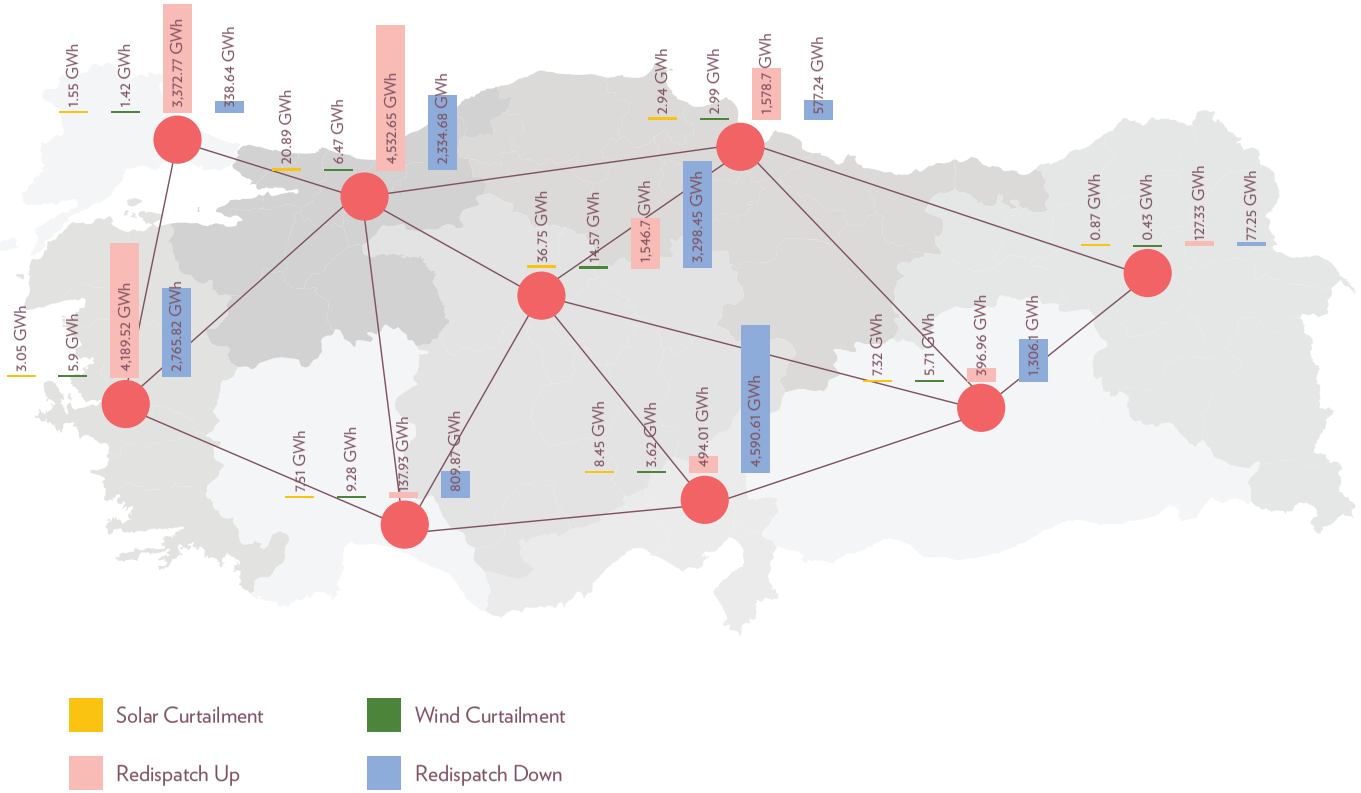


Figure 40 Distribution of redispatch and renewable curtailment amounts based on regions in 2035 in Base Scenario

Figure 41 Distribution of redispatch and renewable curtailment amounts based on regions in 2040 in Base Scenario



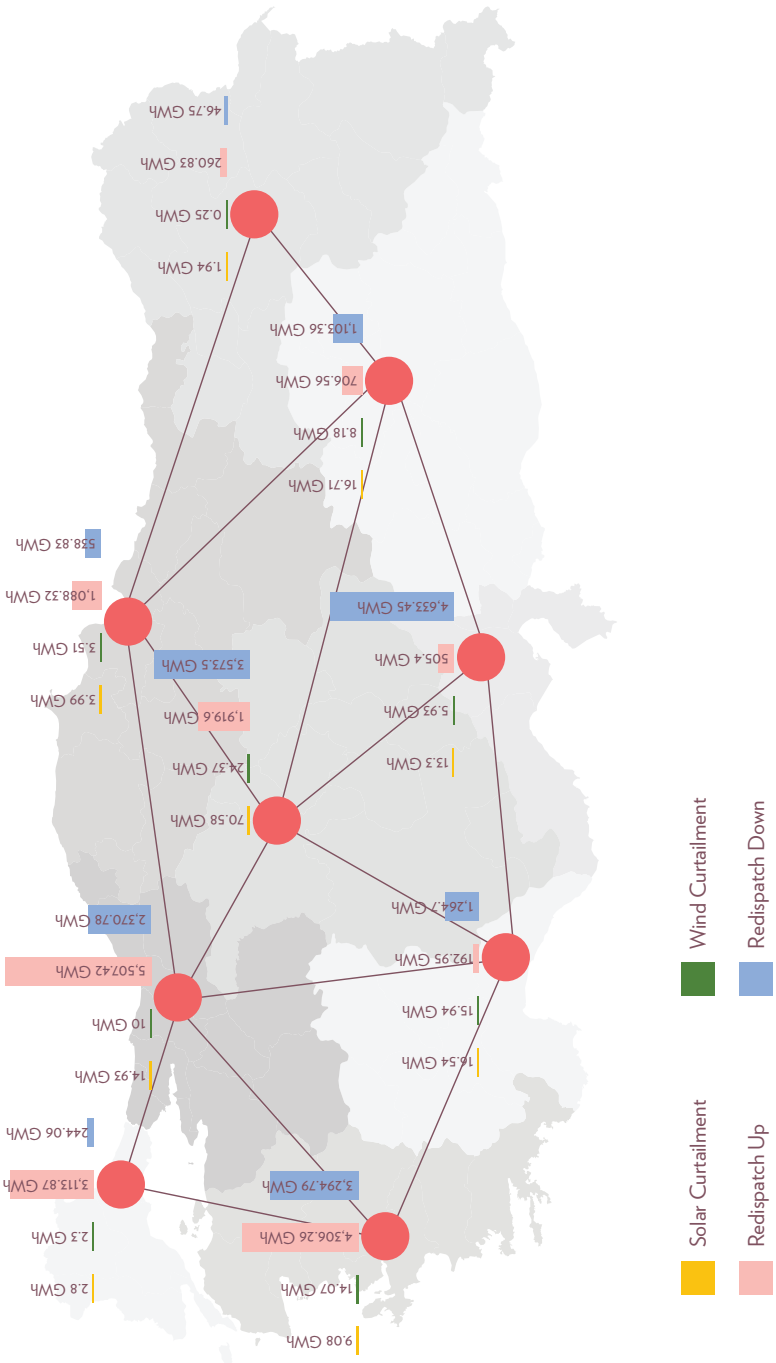
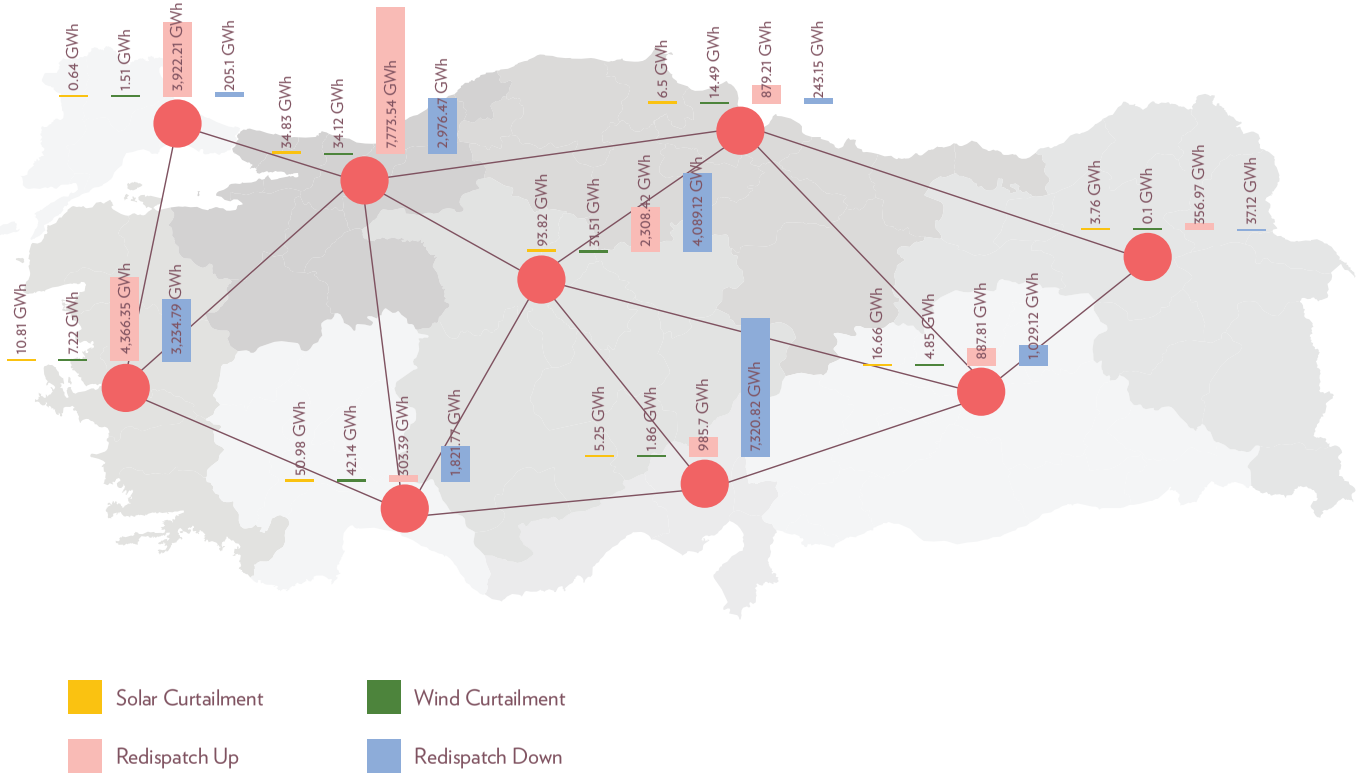


Figure 42 Distribution of redispatch and renewable curtailment amounts based on regions in 2045 in Base Scenario

Figure 43 Distribution of redispatch and renewable curtailment amounts based on regions in 2050 in Base Scenario



1.4.4. Network Investment Requirement

The network investment requirements for the target years have been determined through the conducted grid simulations. As mentioned in Section 1.3, the 2020 grid model was used to determine the 2025 network investment requirements, while the 2030 TEIAS network investment model was employed for the post-2030 investment needs. The development of the total length of 400 kV transmission lines in TEIAS regional dispatching centers with the implemented investments is illustrated in Figure 44.

In the Base Scenario, the investments required for corridors in 2025, based on the 2020 grid model, are presented in Figure 45.

Based on the 2030 TEİAŞ grid investment plan, the additional investment requirements for corridors over the previous 5-year target year for 2035, 2045, and 2050 grids are provided in Figure 46, Figure 47, and Figure 48. In 2040, there is no additional investment requirement for corridors beyond the 2035 corridors.

Figure 44 Development of total line lengths in TEİAŞ regional dispatching centers in Base Scenario (km)

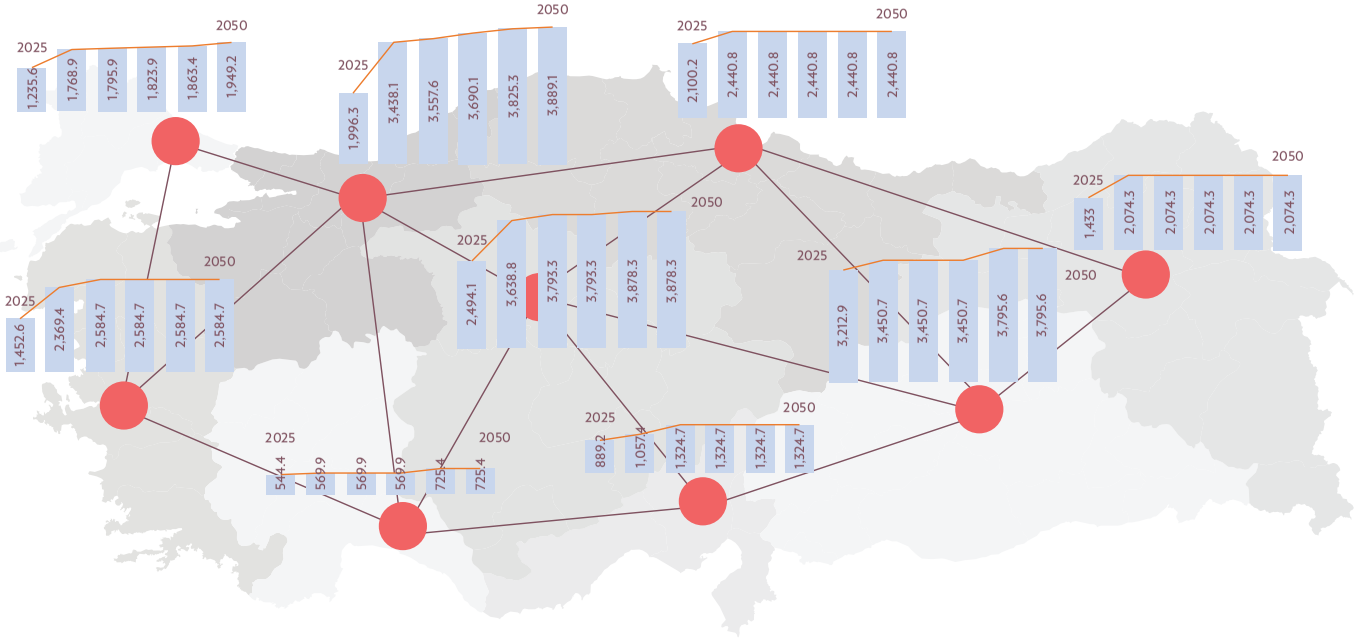


Figure 45 Additional investment requirement of 2025 Base Scenario corridors on top of 2020 network model

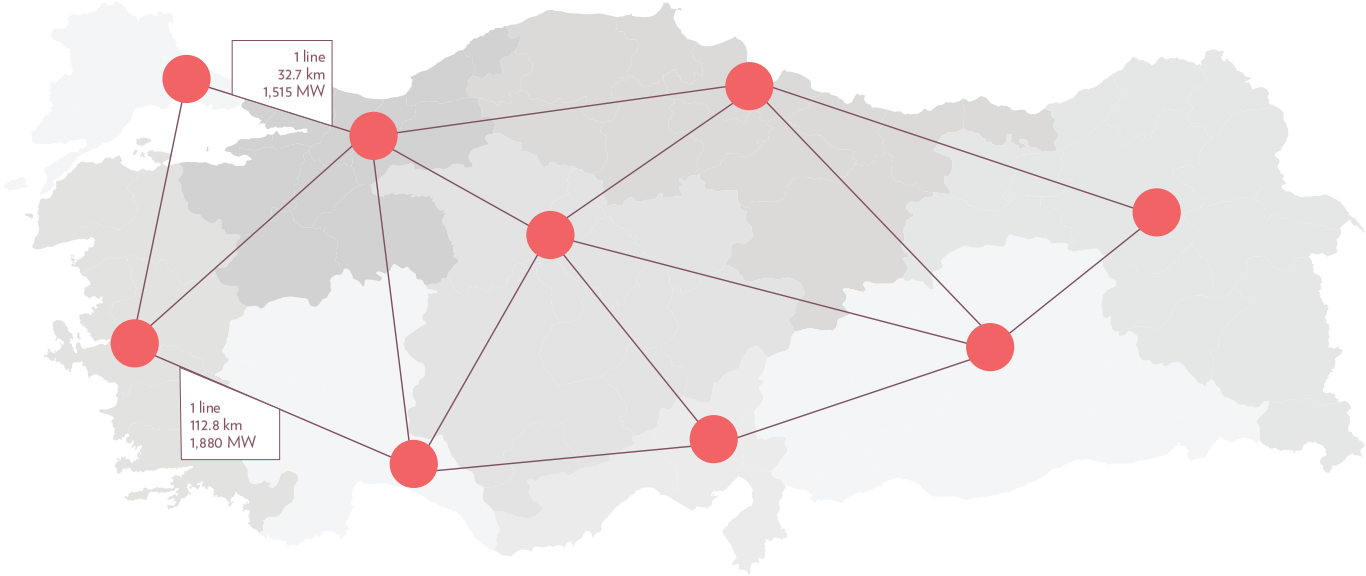


Figure 46 Additional investment requirement for Base Scenario 2035 corridors on top of 2030 TEİAŞ investment plan

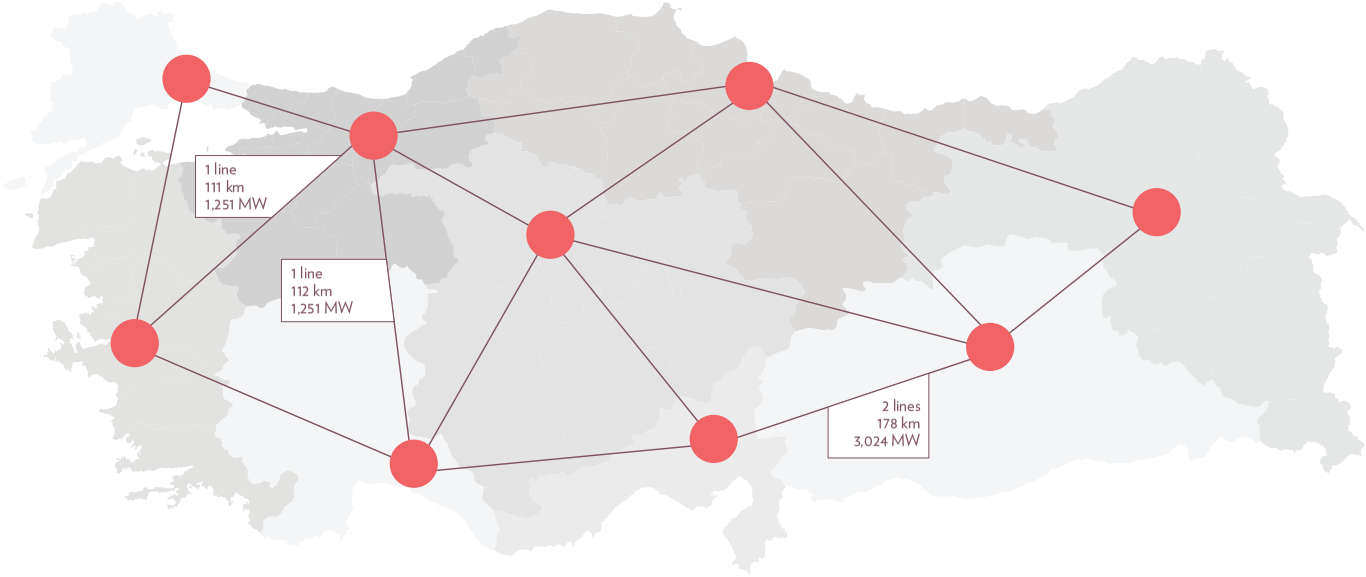


Figure 47 Additional investment requirement for Base Scenario 2045 corridors on top of 2035 corridors

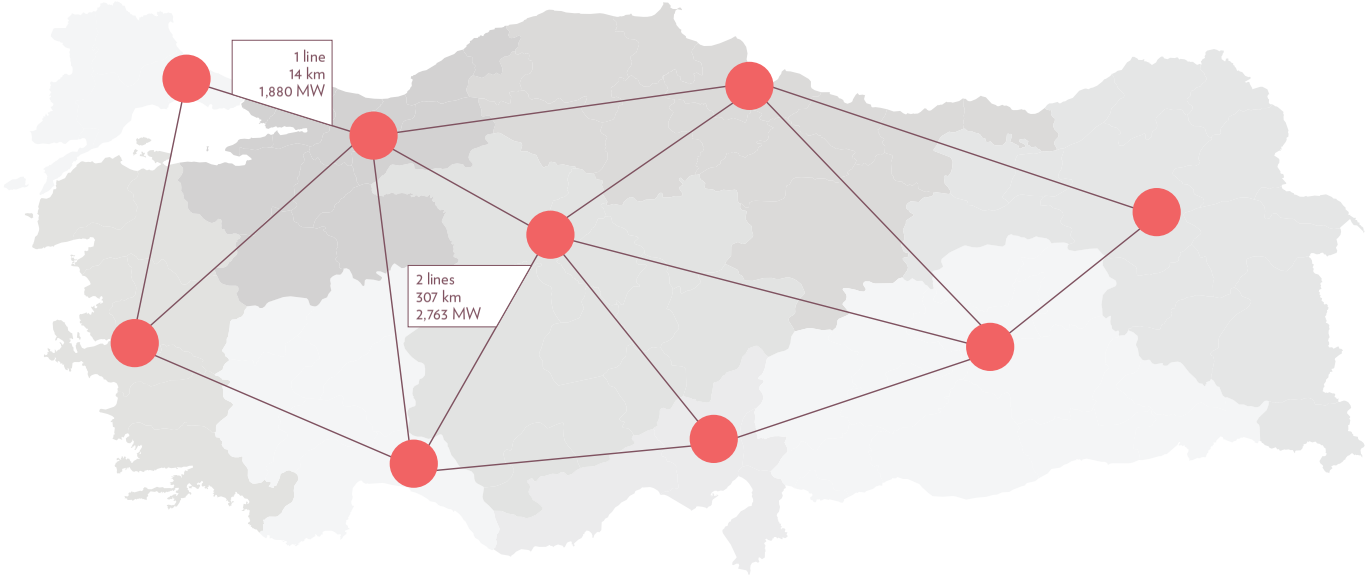


Figure 48 Additional investment requirement for Base Scenario 2050 corridors on top of 2045 corridors



1.4.5. Carbon Dioxide Emissions

CO_2 emissions from the electricity sector in the Base Scenario increase over the years, rising from 135 $MtCO_2$ in 2020 to 170 $MtCO_2$ in 2030 and more than doubling from the 2020 level to reach 282 $MtCO_2$ in 2050.

The formation of CO_2 emissions from the electricity sector shows that the share of lignite, which was 35% in 2020, increases until 2040, reaching 59%. Subsequently, it gradually decreases and reaches 51% in 2050. In contrast, the share of import coal, which was 42% in 2020, decreases until 2040, reaching 28%. However, it increases after 2040 and reaches 33% in 2050. Natural gas follows a similar pattern to import coal, with its share decreasing from 20% in 2020 to 11% by 2040, then increasing to 15% by 2050.

In the Base Scenario, the distribution of CO_2 emissions from the electricity sector based on production technology in TEIAS regional dispatching centers is provided in Figures 50 to 55. It is observed that CO_2 emissions are significantly higher in the regional dispatching centers of Western Anatolia, Northwestern Anatolia, Central Anatolia, and Eastern Mediterranean, where thermal power plants are more concentrated, compared to other regions.

Figure 49 CO_2 emissions of the electricity sector by fossil fuel sources in the base scenario ($MtCO_2$)

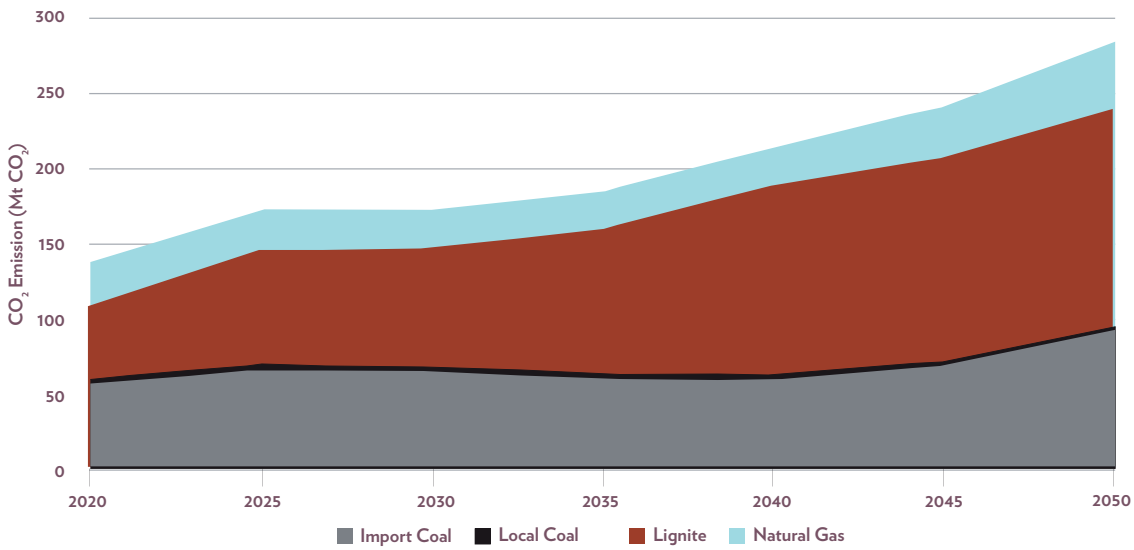
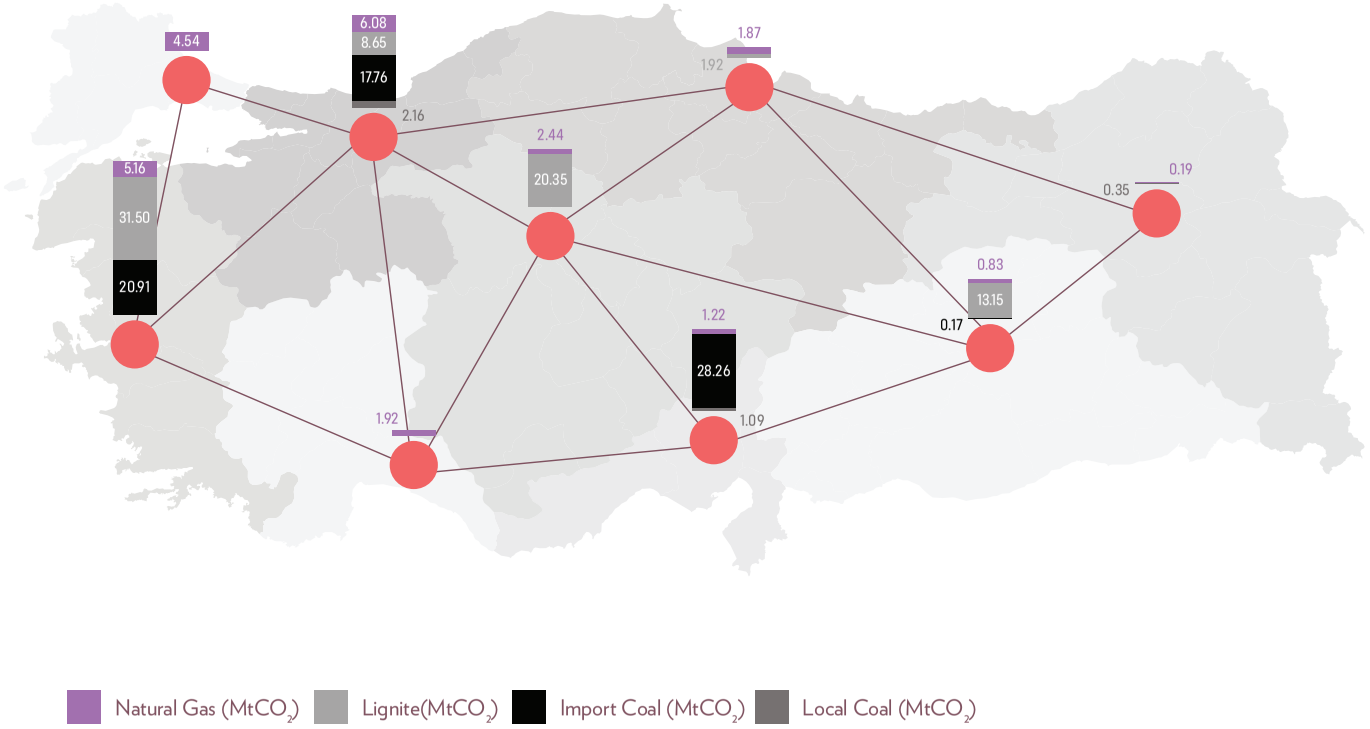


Figure 50 Distribution of CO_2 emissions from the electricity sector in 2025 by regions in base scenario



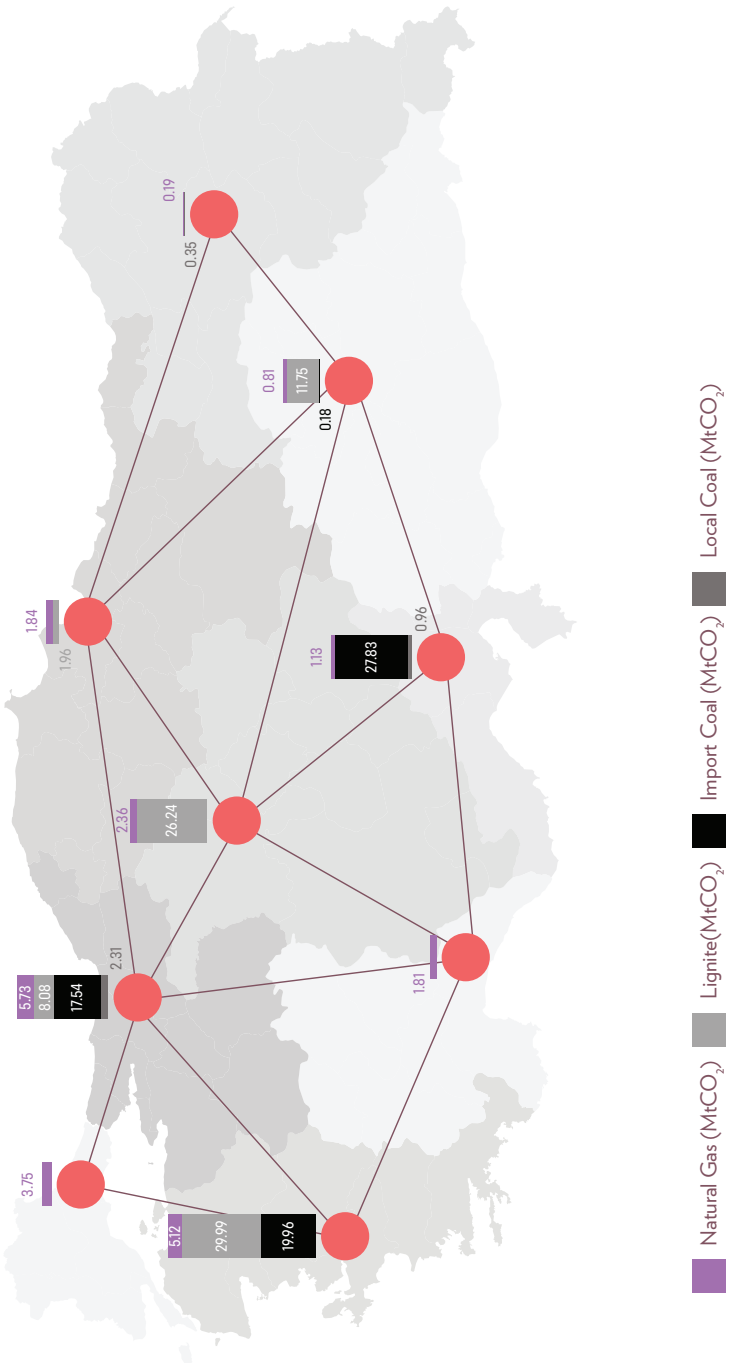
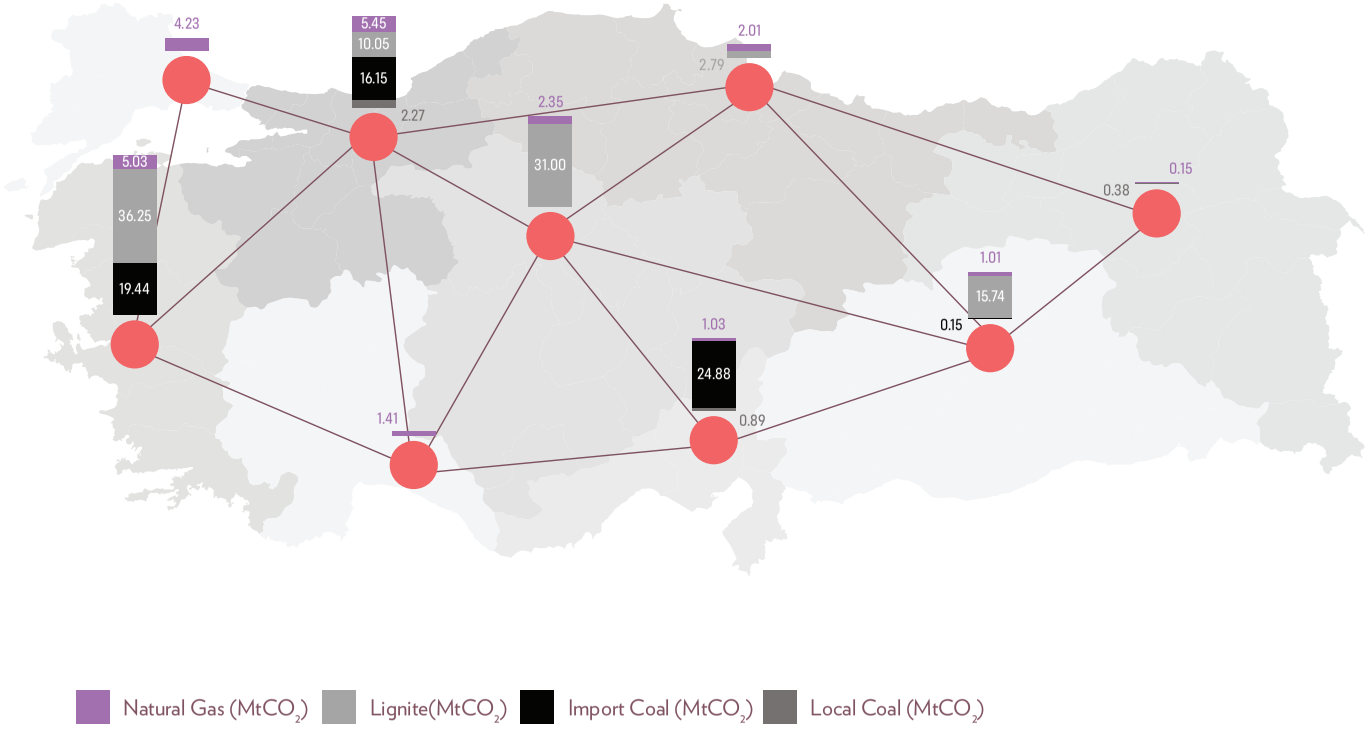


Figure 51 Distribution of CO_2 emissions from the electricity sector in 2030 by regions in base scenario

Figure 52 Distribution of CO_2 emissions from the electricity sector in 2035 by regions in base scenario



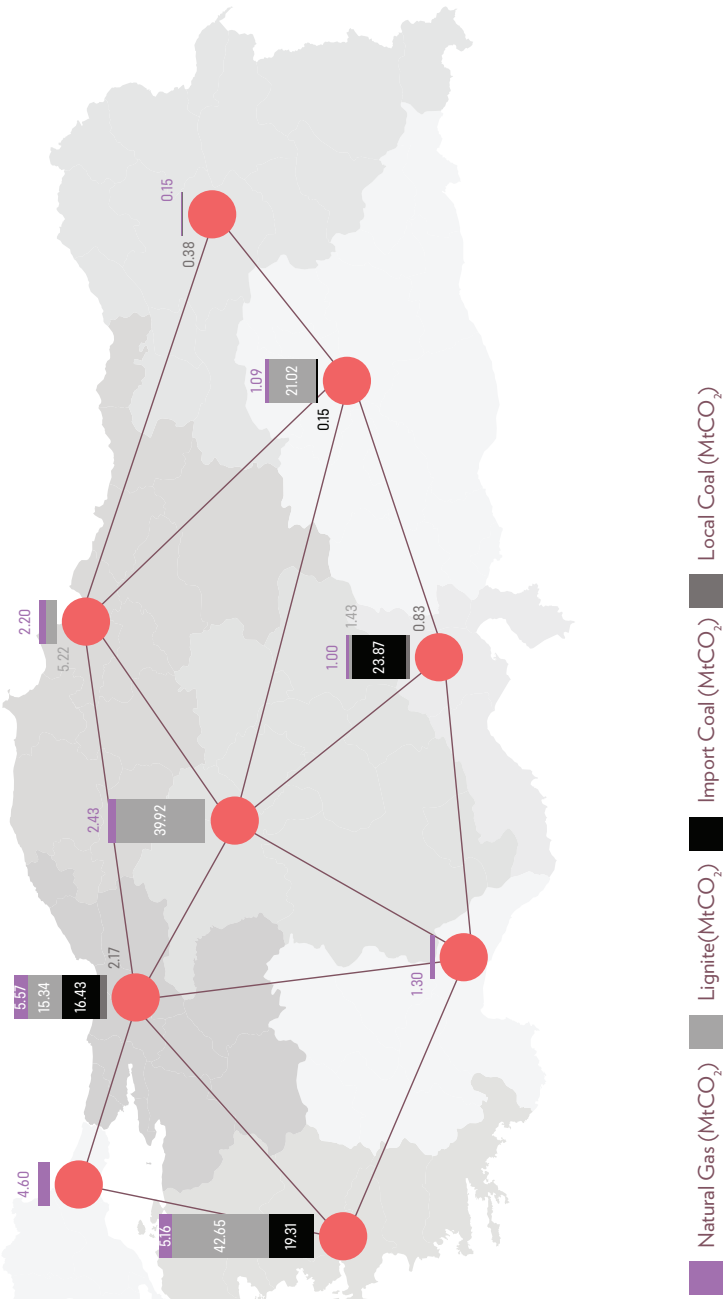
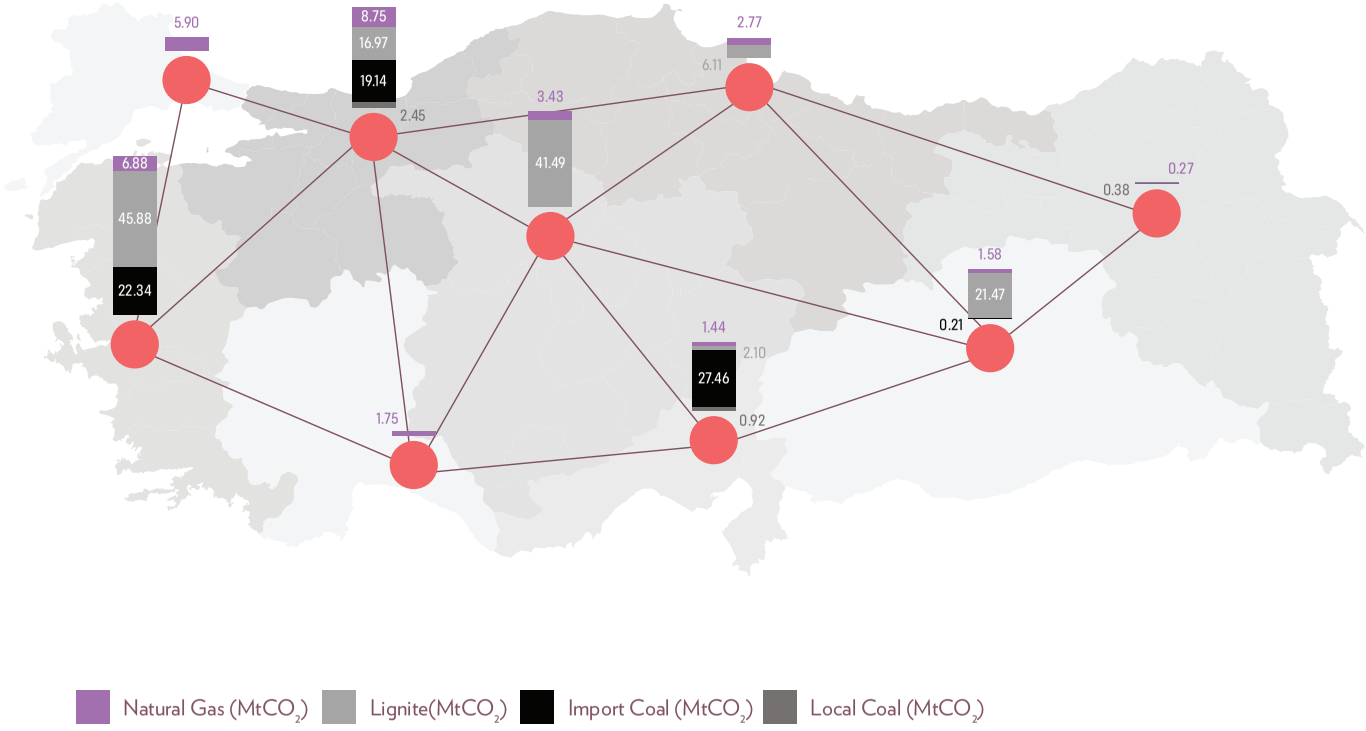


Figure 53 Distribution of CO_2 emissions from the electricity sector in 2040 by regions in base scenario

Figure 54 Distribution of CO_2 emissions from the electricity sector in 2045 by regions in base scenario



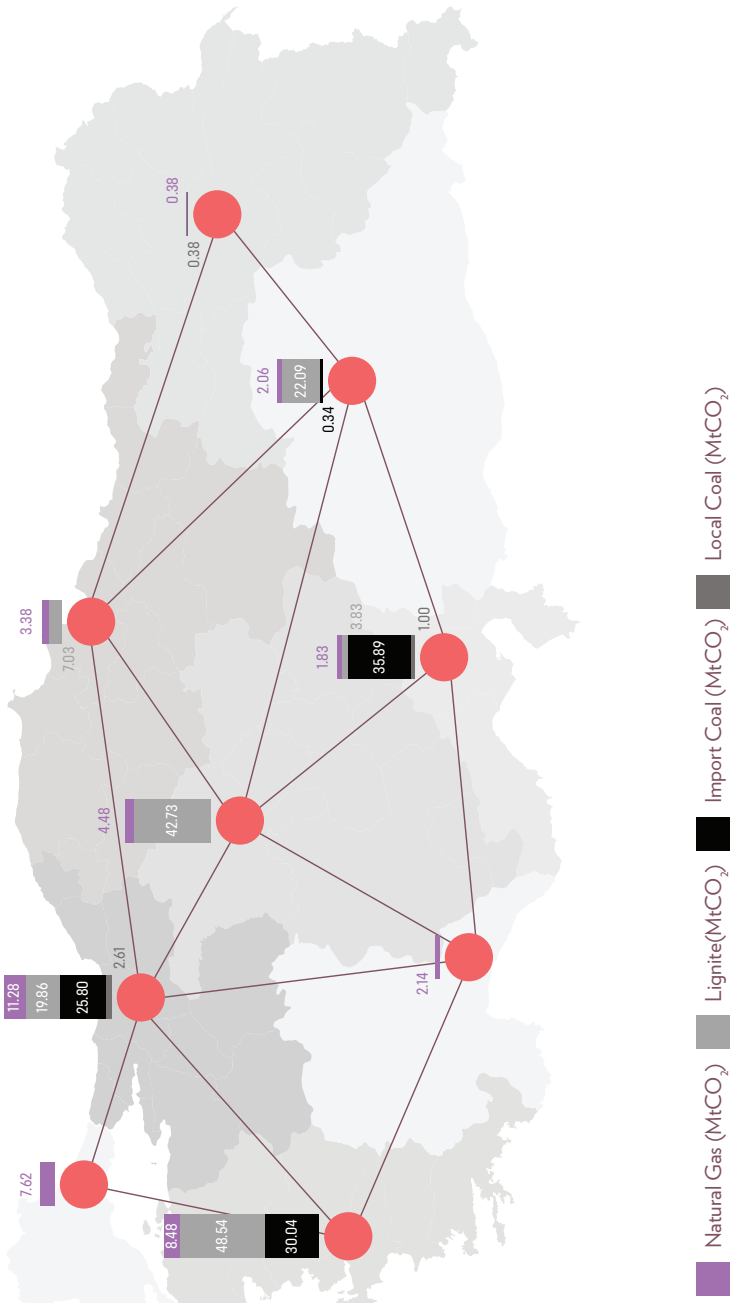


Figure 55 Distribution of CO_2 emissions from the electricity sector in 2050 by regions in base scenario

Table 11 CO_2 emissions of the electricity sector by fossil fuel sources in the base scenario ($MtCO_2$)

	Local Coal	Import Coal	Lignite	Natural Gas	Total
2020	4.2	57.1	47.4	26.7	135.4
2025	3.6	67.1	75.6	24.3	170.6
2030	**3.6**	**65.5**	**78.0**	**22.7**	**169.8**
2035	3.5	60.6	95.9	22.7	182.7
2040	3.4	59.8	125.6	23.5	212.3
2050	4.1	92.1	144.1	41.7	239.7
2050	**4,1**	**92,1**	**144,1**	**41,7**	**282**

1.5. NET ZERO SCENARIO

Net Zero Scenario is the trajectory that the Turkish economy and relevant sectors will follow until 2050, aiming to decarbonize the economy in line with the 1.5°C target of the Paris Agreement through climate actions and in harmony with the current trajectory of the world economy, gradually reducing CO_2 emissions.

Similar to the Base Scenario, simulations have been conducted for the electricity sector in the Net Zero Scenario from 2025 to 2050 at five-year intervals. In this scenario, relatively high assumptions have been made for grid flexibility compared to the Base Scenario. This includes:

Storage Systems

The Net Zero Scenario assumes that storage systems, including pumped hydroelectric power plants and battery storage, will rapidly come online, reaching 5.67 GW by 2030 (compared to 0.26 GW in the Base Scenario) and approximately 40 GW by 2050. This is around 13 times higher than the assumption in the Base Scenario (3 GW). The development of storage systems in terms of installed capacity and production capacity is illustrated in Figure 56 and Table 12.

Table 12 Development of installed capacity and generation capacity of storage in the Net Zero Scenario

	Storage Installed Capacity (GW)	Storage Generation Capacity (GWh)
2020	-	-
2025	3.23	12.92
2030	5.67	22.66
2035	10.71	42.83
2040	16.61	66.43
2045	29.39	117.56
2050	39.57	158.26

The distribution of storage systems among TEİAŞ Regional Dispatching Centers and the development of their installed capacities are presented in Figure 57. Renewable energy capacity has played a significant role in the distribution of storage systems among Regional Dispatching Centers. The high solar energy potential of the Middle Anatolia regional dispatching center and the presence of the Gökçekaya pumped storage hydroelectric plant planned to come online in this region have contributed to a higher increase in storage systems in this region.

Figure 56 Development of installed capacity and generation capacity of storage in the Net Zero Scenario

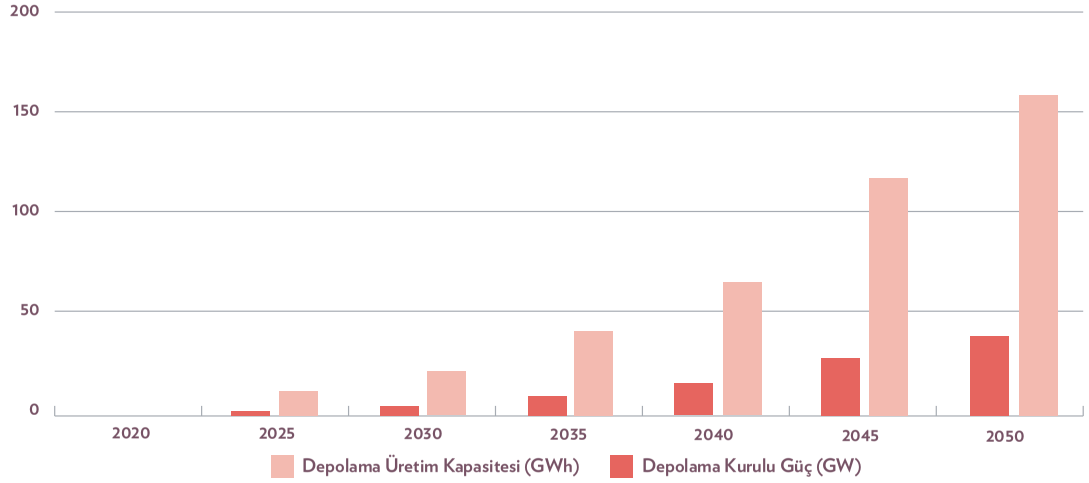


Figure 57 Distribution and development of storage system installed capacity by region in the Net Zero Scenario

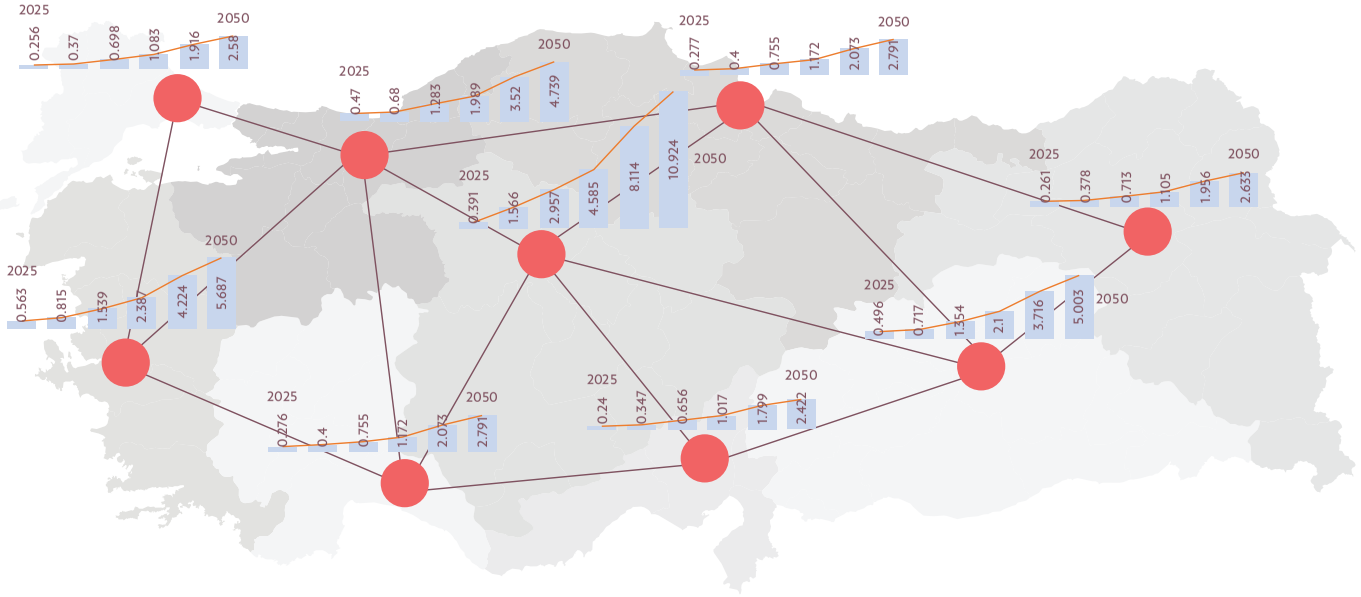
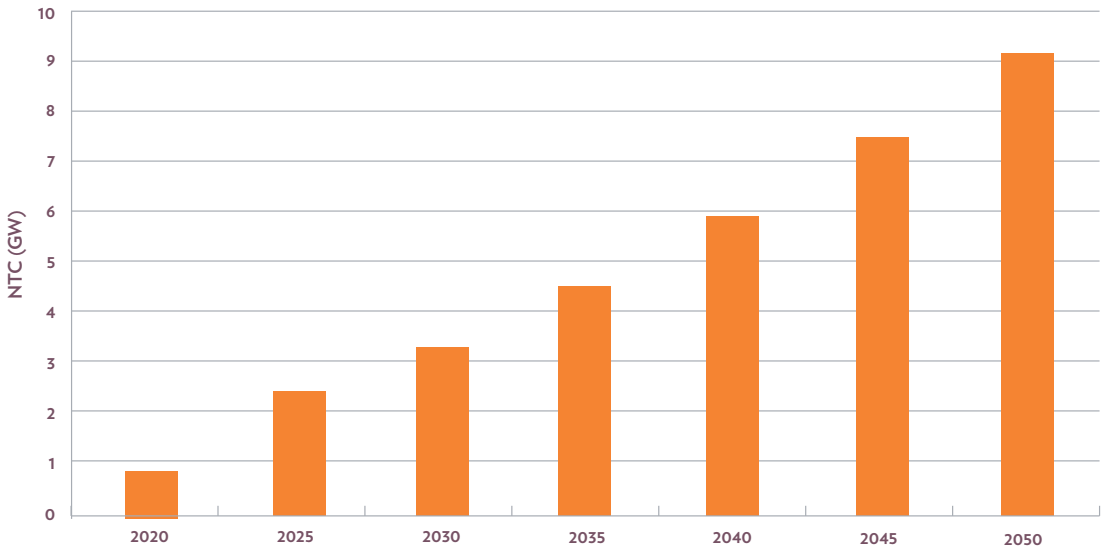


Figure 58 Development of hourly Net Transfer Capacity (NTC) of international interconnection lines in the Net Zero Scenario



Net Transfer Capacity (NTC)

It is anticipated that the Net Transfer Capacity (NTC) of international interconnection lines that can be used as a flexibility mechanism (ENTSO-E and Georgia) will increase from 0.96 GW in 2020 to 3.35 GW in 2030 and further to 9.22 GW in 2050 (Figure 58 and Table 13). The development of Net Transfer Capacity for ENTSO-E and Georgia interconnections is illustrated in Figure 59. The projected Net Transfer Capacity in the Net Zero Scenario is slightly higher than 1.5 times the projected capacity in the Base Scenario.

Table 13 Development of hourly Net Transfer Capacity (NTC) of international interconnection lines in the Net Zero Scenario

Year	Net Transfer Capacity (GW)
2020	0.96
2025	2.48
2030	3.35
2035	4.56
2040	5.97
2045	7.54
2050	9.22

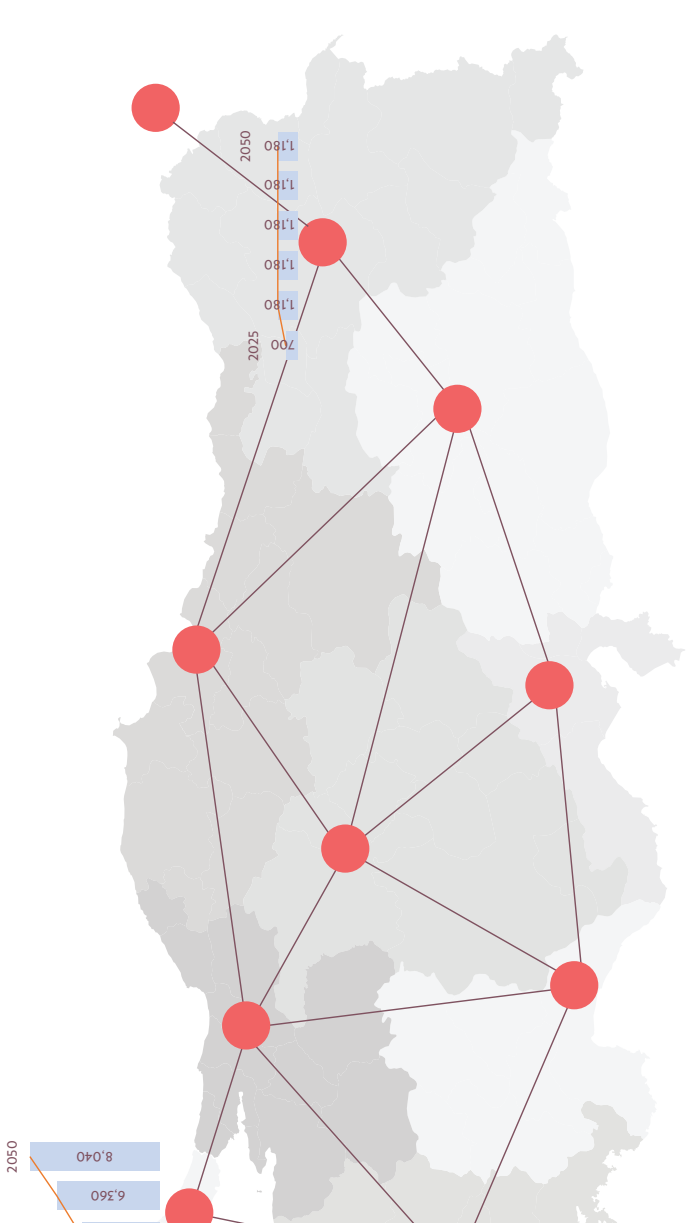
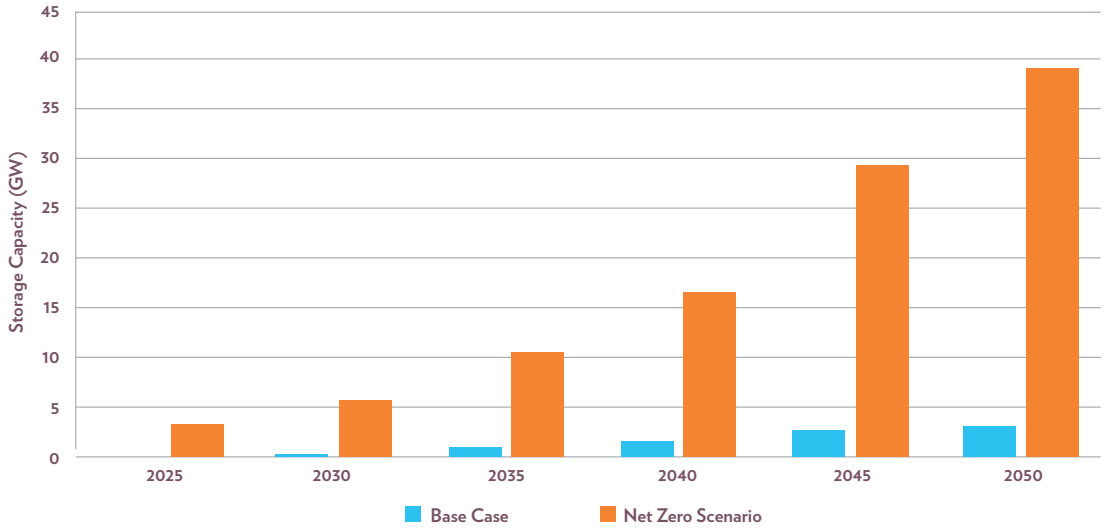


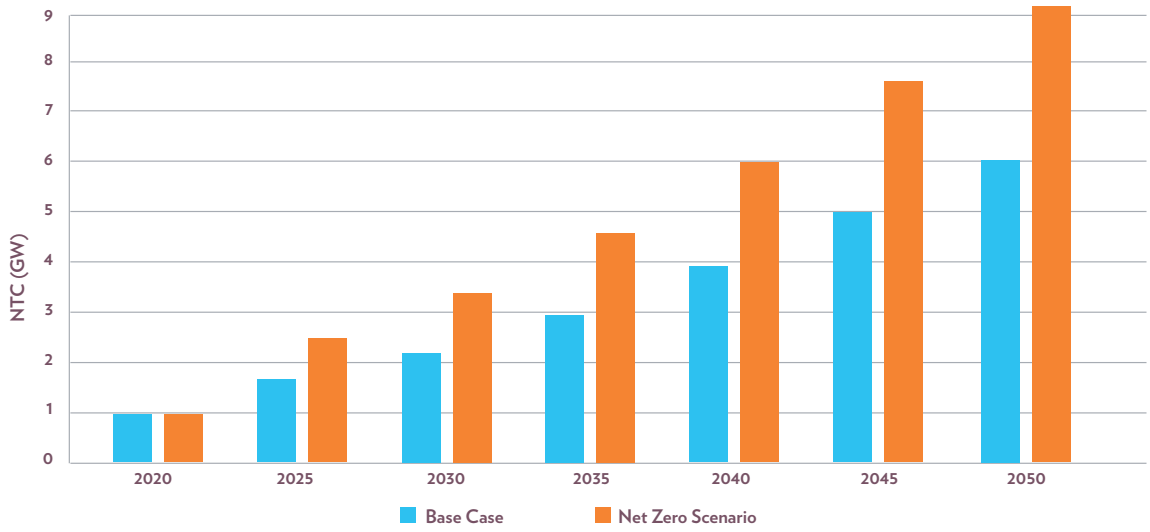
Figure 59. Development of Net Transfer Capacity of ENTSO-E and Georgia interconnections in the Net Zero scenario

Figure 60. Comparison of installed capacity of storage capacity in Base and Net Zero scenarios



Assumptions made in the Net Zero Scenario for storage capacity and interconnection lines are compared with Base Scenario in Figure 60 and Figure 61.

Figure 61. Comparison of hourly Net Transfer Capacity (NTC) of international interconnection lines in Base and Net Zero scenarios



1.5.1.Installed Capacity

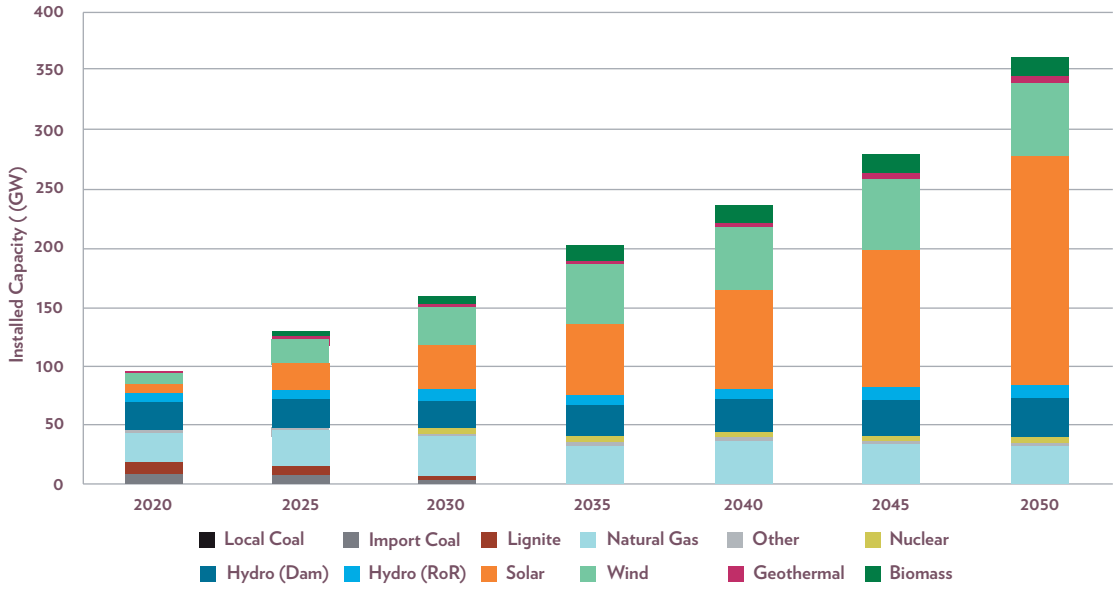
In the Net Zero Scenario, the change in installed power capacities according to resources in the electricity sector according to the projected years is fossil fuels (hard coal, imported coal, lignite, natural gas and other fossil fuel resources), nuclear energy, hydroelectric power plants (dam and river type) and modern renewable resources (solar), wind, geothermal and biomass) are shown in Table 14 and Figure 62.

In the Net Zero Scenario, compared to the Base Scenario, there is an increase in wind and solar installed capacity and production shortly after 2020, and after 2040, capacities for concentrated solar and offshore wind are added, albeit in small amounts. Coal is rapidly phased out of the system.

Table 14 Development of installed capacity (GW) by resources in the electricity sector in the Net Zero Scenario

Year	Local Coal	Import Coal	Lignite	Natural Gas	Other	Nuclear	Hydro (Dam)	Hydro (RoR)	Solar	Wind	Geothermal	Biomass	Total
2020	0.6	8.9	9.5	25.6	1.6		23	8.2	6.8	8.6	1.5	1.1	95.6
2025	0.5	8	7.2	30.3	1.9		23.5	8.2	22	20.9	2.5	3.8	128.9
2030	**0.2**	**4**	**2.9**	**33.8**	**2.1**	**4.8**	**23.5**	**9.1**	**36.4**	**32.6**	**3.4**	**6.1**	**158.9**
2035		1.3		32.5	2.6	4.8	25.5	9.1	59.7	50.1	3.4	13	202.1
2040				36.9	2.6	4.8	27.5	9.1	83.5	52.9	3.4	15	135.6
2045				34	2.7	4.8	29.5	11.5	116.3	59.1	5.1	15.4	278.4
2050				**32.7**	**2.7**	**4.8**	**32**	**12**	**192.7**	**62.4**	**5.4**	**16.1**	**360.8**

Figure 62. Development of installed capacity (GW) by resources in the electricity sector in the Net Zero Scenario



1.5.2. The phasing out of coal-fired thermal power plants

In the Net Zero Scenario, the installed capacities of fossil fuel sources decrease significantly and early compared to the Base Scenario. The installed capacity and share of lignite power plants decline substantially before 2030, with only 2.9 GW of lignite-based coal-fired thermal power plants remaining by 2030. By the first half of the 2030s, all thermal power plants using hard coal and lignite are closed. By 2035, only one thermal power plant with a capacity of 1.3 GW, operating with imported coal, remains in operation, and it is also shut down before 2040. The retirement of fossil fuel-fired power plants was determined based on criteria such as carbon emissions, air pollution[2], their role in the grid, age, and annual capacity factor. The retirement sequence for coal-fired power plants, including hard coal, imported coal, and lignite, is provided in Tables 15, 16, and 17, respectively.

2 Sağlık ve Çevre Birliği (HEAL-Health and Environment Alliance). (Ocak 2021). Türkiye kronik kömür kirliliği. Kömürün sağlık yükü ve kömür bağımlılığını sonlandırmak. https://www.env-health.org/wp-content/ uploads/2021/02/Chronic-Coal-Pollution-Turkey-TR.pdf

Table 15 The order of phase out of local coal units in Net Zero Scenario (green: on, red: off)

Unit Name	Installed Capacity (MW)	2020	2025	2030	2035	2040
KARDEMIR TES GR-1	13					
KARDEMIR TES GR-2	15					
KARDEMIR TES GR-4	50					
YENI CATALAGZI TES GR-1	150					
YENI CATALAGZI TES GR-2	150					
ISDEMIR GR-3	63					
ISDEMIR GR-4	63					
ERDEMIR BT-1(STG-1)	10					
ERDEMIR BT-3(STG-3)	29					
ERDEMIR BT-6(STG-6)	25					
ERDEMIR BT-7(STG-7)	39					
ERDEMIR GR-1(GTG-1)	39					
ERDEMIR GR-2(GTG-2)	39					
ERDEMIR TRT-1	7					
ERDEMIR TRT-2	7					
ISDEMIR GR-1	30					
ISDEMIR GR-2	30					
ISDEMIR GR-5	63					
ISDEMIR TRT-3	9					
ISDEMIR TRT-4	14					
Installed Capacity (MW)		**845**	**504**	**228**	**0**	**0**

Table 16 The order of phase out of import coal units in Net Zero Scenario (green: on, red: off)

Unit Name	Installed Capacity (MW)	2020	2025	2030	2035	2040
Hunutlu TES	1320					
ATLAS TES GR-1	600					
ATLAS TES GR-2	600					
SUGOZU ISKEN TES GR-1	605					
SUGOZU ISKEN TES GR-2	605					
ICDAS CELIK ENERJI GR-2	135					
ICDAS CELIK ENERJI GR-3	135					
CENAL TES GR-1	660					
CENAL TES GR-2	660					
ICDAS CELIK ENERJI GR-1	135					
IZDEMIR TES GR-1	350					
KIPAS KAGIT GR	25					
ZETES1 GR-1	160					
ZETES2 GR-3	615					
ZETES3 GR-4	700					
ZETES3 GR-5	700					
AKSA YALOVA BT-1	11					
AKSA YALOVA BT-2	11					
AKSA YALOVA BT-3	99					
AKSA YALOVA BT-4	25					
ALBAYRAK TES GR-1	40					
BEKIRLI TES GR-1	600					
BEKIRLI TES GR-2	600					
COLAKOGLU OP-2 GR-OP2	190					
GOKNUR GIDA GR	2					
KAHRAMANMARAS KAGIT GR-2	10					
ZETES2 GR-2	615					
Installed Capacity (MW)		**8,886**	**8,005**	**4,000**	**1,320**	**0**

Table 17 The order of phase out of lignite units in Net Zero Scenario (green: on, red: off)

Unit Name	Installed Capacity (MW)	2020	2025	2030	2035	2040
AFSIN ELBISTAN B TES GR-1	360					
AFSIN ELBISTAN B TES GR-2	360					
AFSIN ELBISTAN B TES GR-3	360					
AFSIN ELBISTAN B TES GR-4	360					
AKSA GOYNUK TES GR-1	135					
AKSA GOYNUK TES GR-2	135					
CAN-2 TES GR-1	330					
COBANYILDIZI (CUMRA) TES GR	37					
POLAT TES GR-1	51					
SOMA KOLIN TES GR-1	255					
SOMA KOLIN TES GR-2	255					
TUFANBEYLI TES GR-1	150					
TUFANBEYLI TES GR-2	150					
ALKIM AFYON GR-1	3					
ALKIM CAYIRHAN GR-1	3					
ALKIM KONYA BT	2					
AYNES GIDA GR-1	7					
BANDIRMA BORAKS GR-1	5					
BANDIRMA BORAKS GR-2	5					
CAN TES GR-1	160					
CAN TES GR-2	160					
CAYIRHAN TES GR-1	150					
CAYIRHAN TES GR-2	150					
CAYIRHAN TES GR-3	160					
CAYIRHAN TES GR-4	160					
CUMRA SEKER GR-1	20					
CUMRA SEKER GR-2	10					
CUMRA SEKER GR-3	7					
CUMRA SEKER GR-4	7					
ETI ALUMINYUM GR-1	13					

Table 17 The order of phase out of lignite units in Net Zero Scenario (green: on, red: off) (cont.)

Unit Name	Installed Capacity (MW)	2020	2025	2030	2035	2040
ETI SODA GR-1	12					
ETI SODA GR-2	12					
KANGAL TES GR-1	150					
KANGAL TES GR-2	150					
KANGAL TES GR-3	157					
KEMERKOY TES GR-1	210					
KEMERKOY TES GR-2	210					
KEMERKOY TES GR-3	210					
KUCUKER TERMIK GR-1	6					
MARMARA KAGIT GR-1	2					
ORHANELI TES GR-1	210					
SOMA-A GR-1	22					
SOMA-A GR-2	22					
SOMA-B GR-3	165					
SOMA-B GR-4	165					
SOMA-B GR-5	165					
SOMA-B GR-6	165					
SUSURLUK SEKER GR-1-2	12					
TUFANBEYLI TES GR-3	150					
YATAGAN TES GR-1	210					
YATAGAN TES GR-2	210					
YATAGAN TES GR-3	210					
YENIKOY TES GR-1	210					
YENIKOY TES GR-2	210					
SOMA-B GR-1	165					
SOMA-B GR-2	165					
SEYITOMER TES GR-1	150					
SEYITOMER TES GR-2	150					
SEYITOMER TES GR-3	150					
SEYITOMER TES GR-4	150					

Table 17 The order of phase out of lignite units in Net Zero Scenario (green: on, red: off) (cont.)

Unit Name	Installed Capacity (MW)	2020	2025	2030	2035	2040
ADA SEKER GR-1-2	10					
AFSIN ELBISTAN A TES GR-1	335					
AFSIN ELBISTAN A TES GR-2	340					
AFSIN ELBISTAN A TES GR-3	340					
AFSIN ELBISTAN A TES GR-4	340					
KUTAHYA SEKER GR-1-2	9					
MEDMAR SAGLIK GR-1	2					
CARSAMBA SEKER GR-1	6					
BOR SEKER GR-1	11					
ALPULLU SEKER GR-1	3					
ALPULLU SEKER GR-2-3	4					
AMASYA SEKER GR-1-2	10					
AFYON SEKER GR-1-2	13					
ELBISTAN SEKER GR-1-2	12					
KASTAMONU SEKER GR-1	9					
ILGIN SEKER GR-1	18					
KAYSERI SEKER GR-1	5					
KAYSERI SEKER GR-2	5					
KAYSERI SEKER GR-3	5					
PETLAS GR-1	7					
TUTES-A GR-3	65					
TUTES-B GR-4	150					
TUTES-GR-5 GR-5	150					
USAK SEKER GR-1	5					
YOZGAT SEKER GR-1	7					
YUNUS EMRE TES GR-1	145					
YUNUS EMRE TES GR-2	145					
Installed Capacity (MW)		**9,512**	**7,206**	**2,938**	**0**	**0**

The installed capacity of natural gas power plants does not decrease due to the flexibility requirements arising from the closure of coal plants. In fact, the installed capacity of natural gas, which was 26 GW in 2020, increases to 34 GW in 2030 and further to 37 GW in 2040. However, it slightly decreases after 2040, remaining at approximately 33 GW in 2050. Nevertheless, the installed capacity of natural gas in 2050 in the Net Zero Scenario is significantly below the expected 43 GW in the Base Scenario.

In the Net Zero Scenario, renewable sources are increasing at a rapid pace. Wind power installed capacity, which was 8.6 GW in 2020 and reached 48 GW by 2050 in the Base Scenario, shows a faster growth in the Net Zero Scenario, exceeding 62 GW in 2050. Solar power installed capacity experiences much more rapid growth, reaching 36 GW in 2030 and 193 GW in 2050. Geothermal energy, another renewable energy source, has a more limited increase in installed capacity, while biomass power plants, which had 1 GW in 2020, increase to 6 GW in 2030 and 16 GW in 2050. Hydroelectric power plants (HES) have a more limited increase in installed capacity compared to modern renewable energy plants (15% by 2030 and 55% by 2050).

In the Net Zero Scenario, the differences in installed power levels of electricity generation sources compared to the Base Scenario are illustrated in Figure 63. The distribution of installed capacity among TEİAŞ regional dispatching centers in the target years is shared between Figure 64 and Figure 69.

The changes in installed capacities for natural gas, total coal (hard coal, imported coal, and lignite), and total renewable (wind, solar, biomass, and geothermal) power by year in the Net Zero Scenario are shown in Figure 70, Figure 71, and Figure 72, respectively.

The locations and installed capacities of renewable power plants in the target years in the Net Zero Scenario are illustrated in Figures 73 to 78.

Figure 63 Change in installed capacity of technologies in Net Zero Scenario compared to Base Scenario in electricity sector

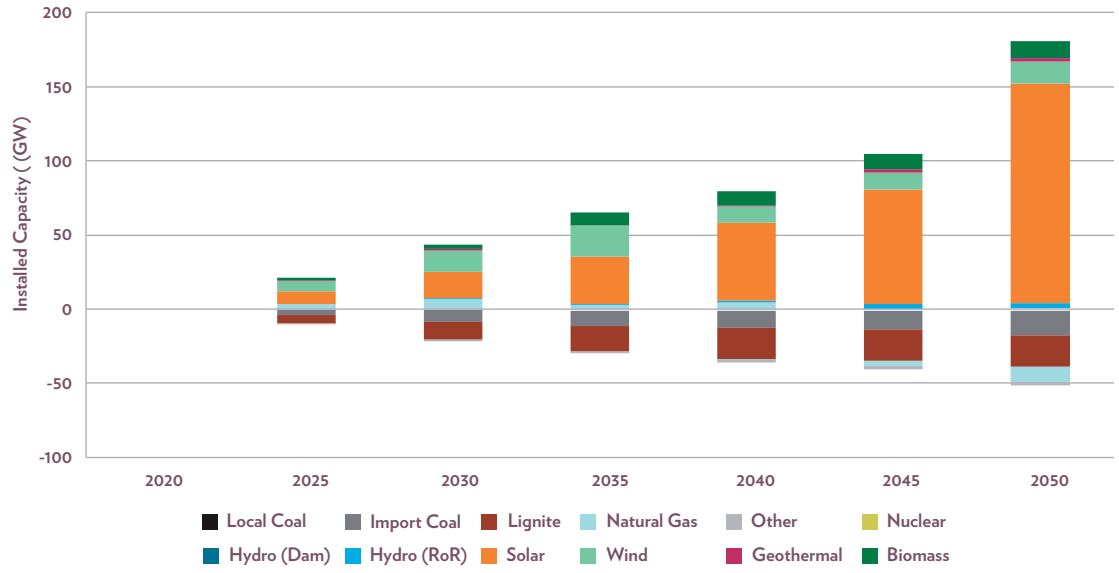
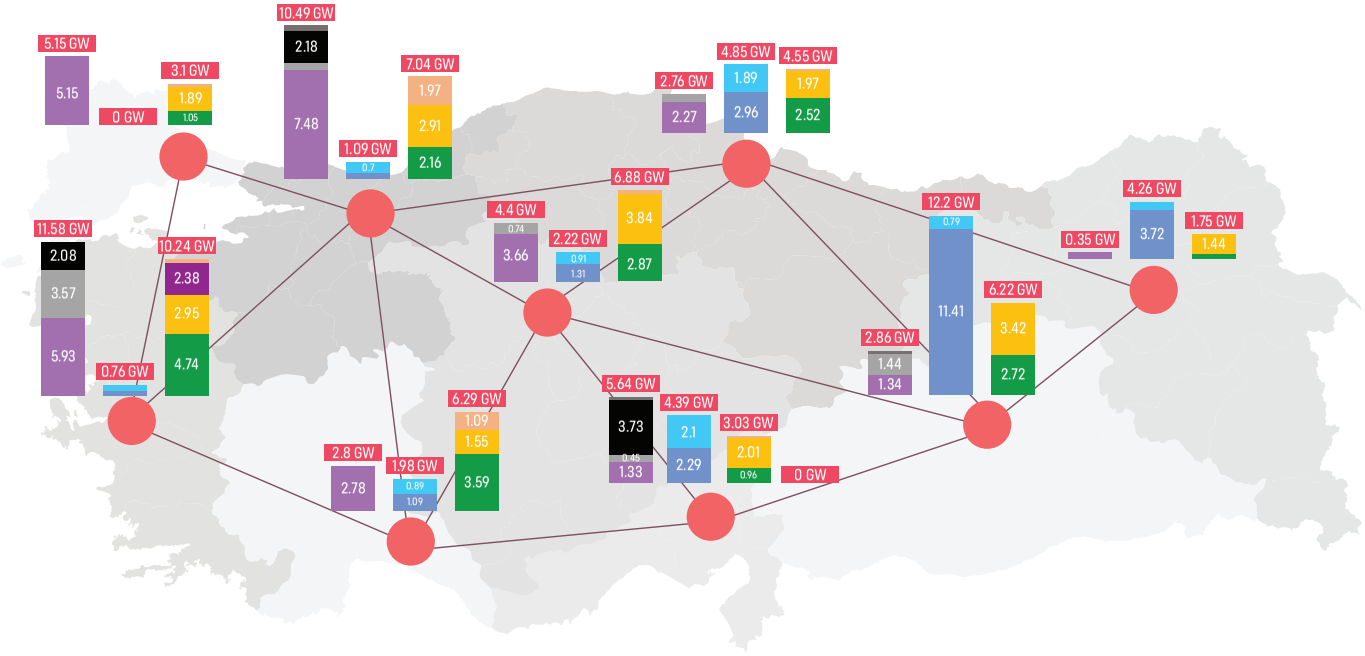


Figure 64 Distribution of installed capacity in TEİAŞ Regional Dispatching Centers in 2025 Net Zero Scenario



1st Column / Conventional

Natural Gas (GW) | Lignite (GW) | Import Coal (GW) | Local Coal (GW)

2nd Column / Hydro

Hydro (Dam) (GW) | Hydro (RoR) (GW)

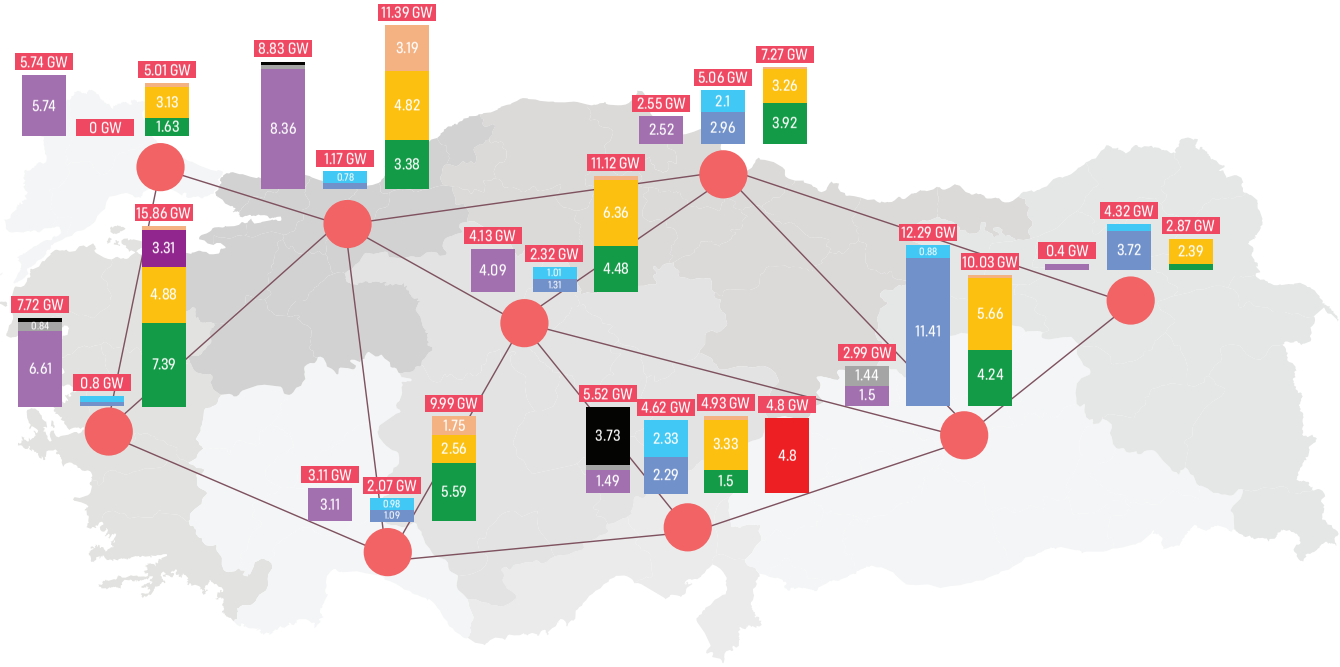
Wind (GW) | Solar (GW) | Geothermal (GW) | Biomass (GW)

3rd Column / Renewables

Nuclear (GW)

4th Column / Nuclear

Figure 65 Distribution of installed capacity in TEİAŞ Regional Dispatching Centers in 2030 Net Zero Scenario



1st Column / Conventional

Natural Gas (GW) | Lignite (GW) | Import Coal (GW) | Local Coal (GW)

2nd Column / Hydro

Hydro (Dam) (GW) | Hydro (RoR) (GW)

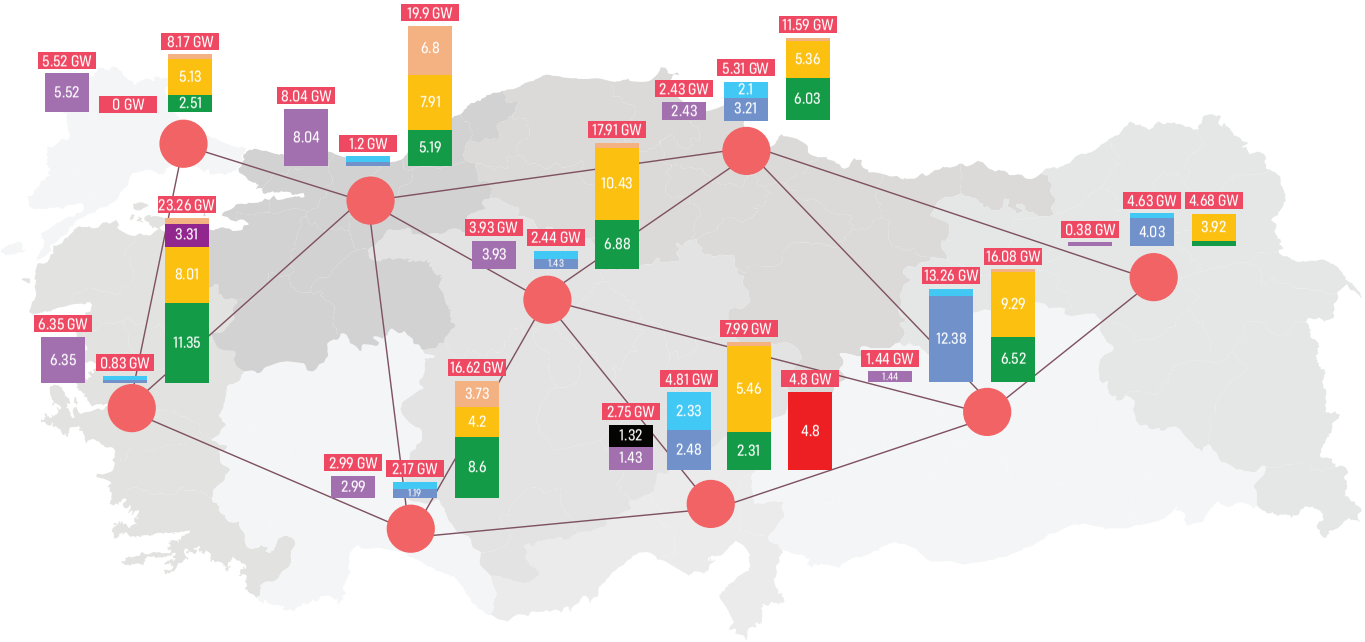
Wind (GW) | Solar (GW) | Geothermal (GW) | Biomass (GW)

3rd Column / Renewables

Nuclear (GW)

4th Column / Nuclear

Figure 66 Distribution of installed capacity in TEİAŞ Regional Dispatching Centers in 2035 Net Zero Scenario



1st Column / Conventional

Natural Gas (GW) | Lignite (GW) | Import Coal (GW) | Local Coal (GW)

Wind (GW) | Solar (GW) | Geothermal (GW) | Biomass (GW)

3rd Column / Renewables

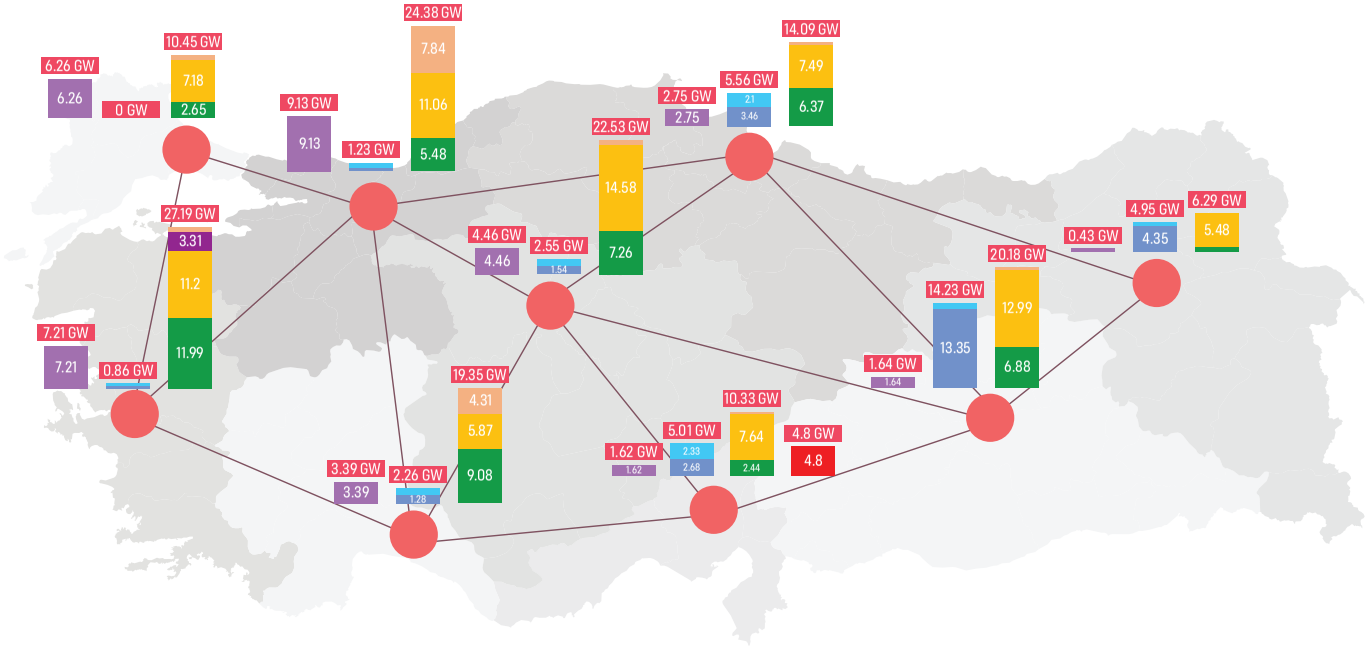
2nd Column / Hydro

Hydro (Dam) (GW) | Hydro (RoR) (GW)

Nuclear (GW)

4th Column / Nuclear

Figure 67 Distribution of installed capacity in TEİAŞ Regional Dispatching Centers in 2040 Net Zero Scenario



1st Column / Conventional

Natural Gas (GW) | Lignite (GW) | Import Coal (GW) | Local Coal (GW)

Wind (GW) | Solar (GW) | Geothermal (GW) | Biomass (GW)

3rd Column / Renewables

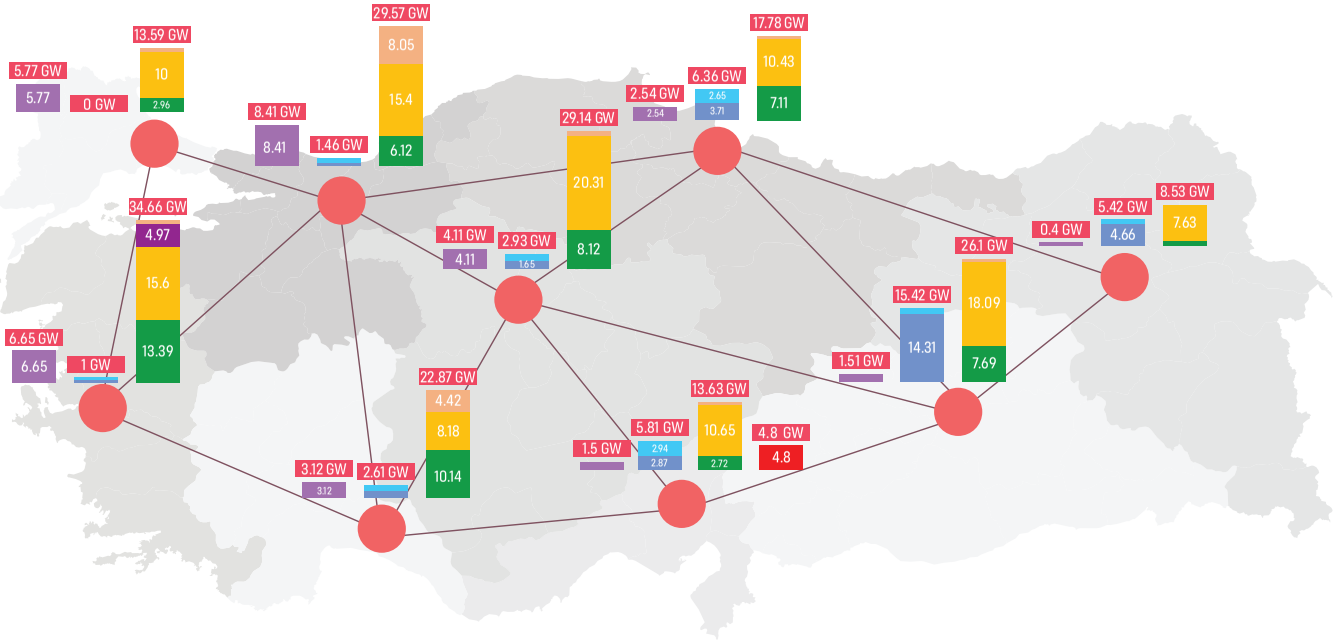
2nd Column / Hydro

Hydro (Dam) (GW) | Hydro (RoR) (GW)

Nuclear (GW)

4th Column / Nuclear

Figure 68 Distribution of installed capacity in TEİAŞ Regional Dispatching Centers in 2045 Net Zero Scenario



1st Column / Conventional

Natural Gas (GW) | Lignite (GW) | Import Coal (GW) | Local Coal (GW)

Wind (GW) | Solar (GW) | Geothermal (GW) | Biomass (GW)

3rd Column / Renewables

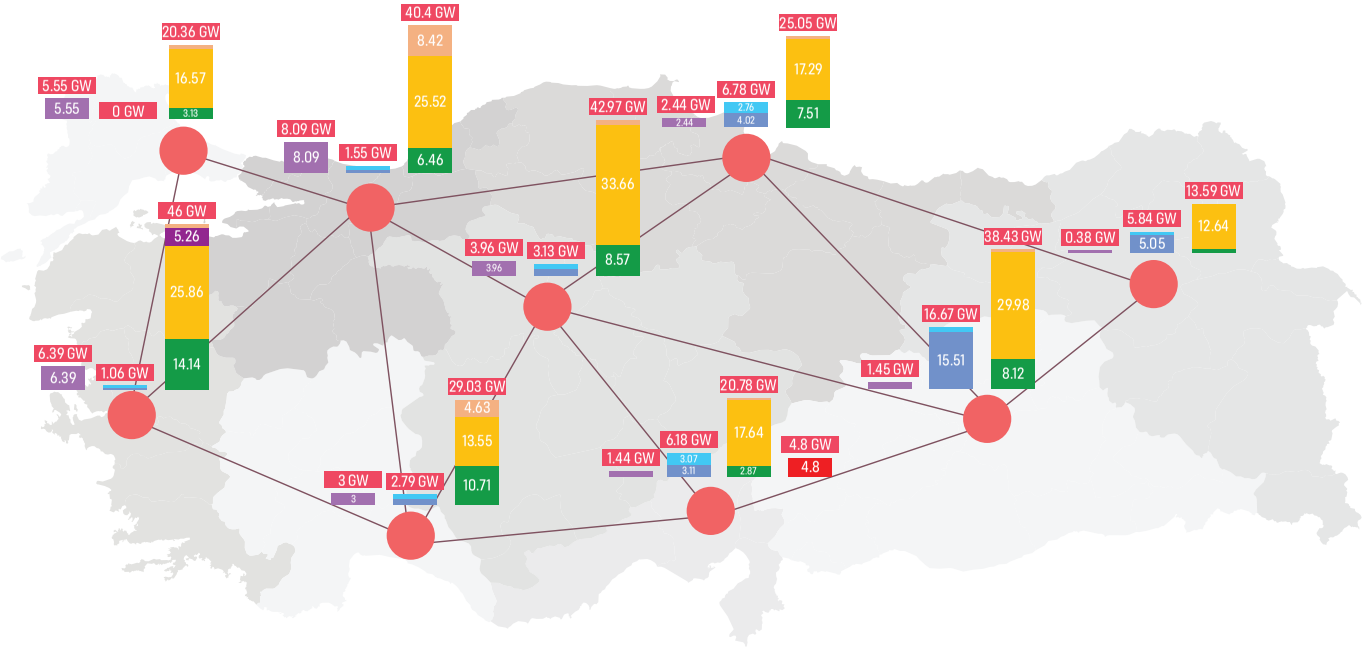
2nd Column / Hydro

Hydro (Dam) (GW) | Hydro (RoR) (GW)

Nuclear (GW)

4th Column / Nuclear

Figure 69 Distribution of installed capacity in TEİAŞ Regional Dispatching Centers in 2050 Net Zero Scenario



1st Column / Conventional

Natural Gas (GW) | Lignite (GW) | Import Coal (GW) | Local Coal (GW)

2nd Column / Hydro

Hydro (Dam) (GW) | Hydro (RoR) (GW)

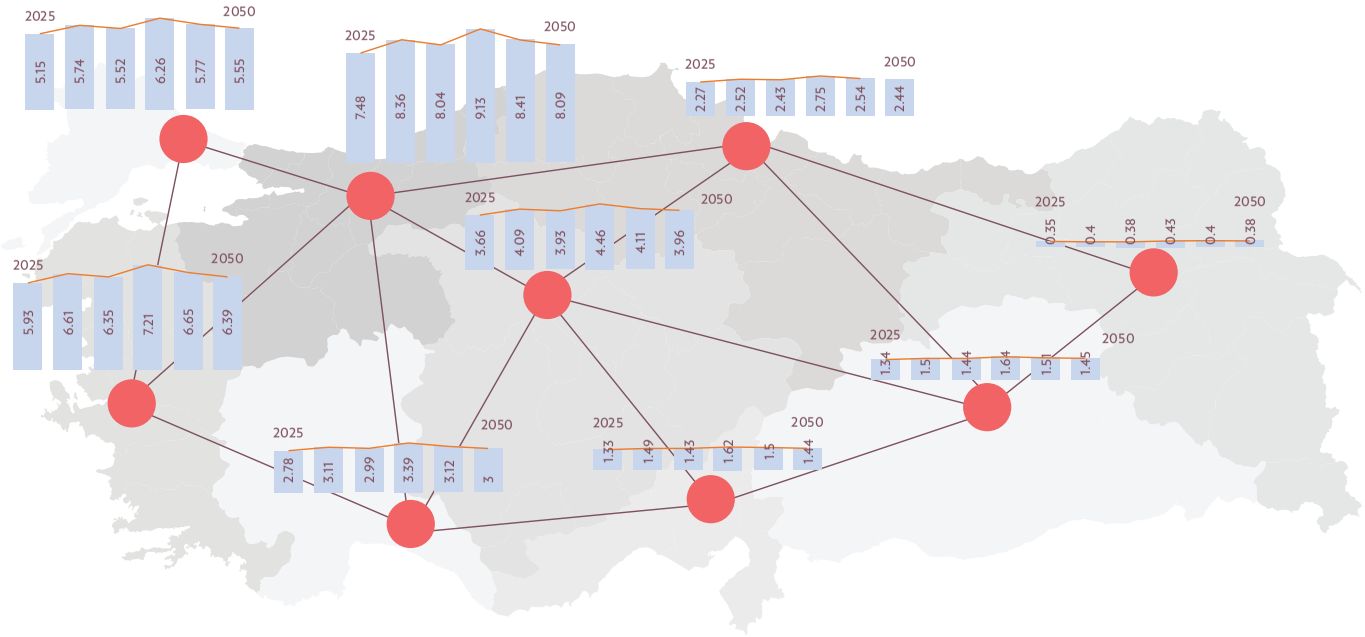
Wind (GW) | Solar (GW) | Geothermal (GW) | Biomass (GW)

3rd Column / Renewables

Nuclear (GW)

4th Column / Nuclear

Figure 70 Change of natural gas installed capacity over years in TEİAŞ Regional Dispatching Centers in Net Zero Scenario



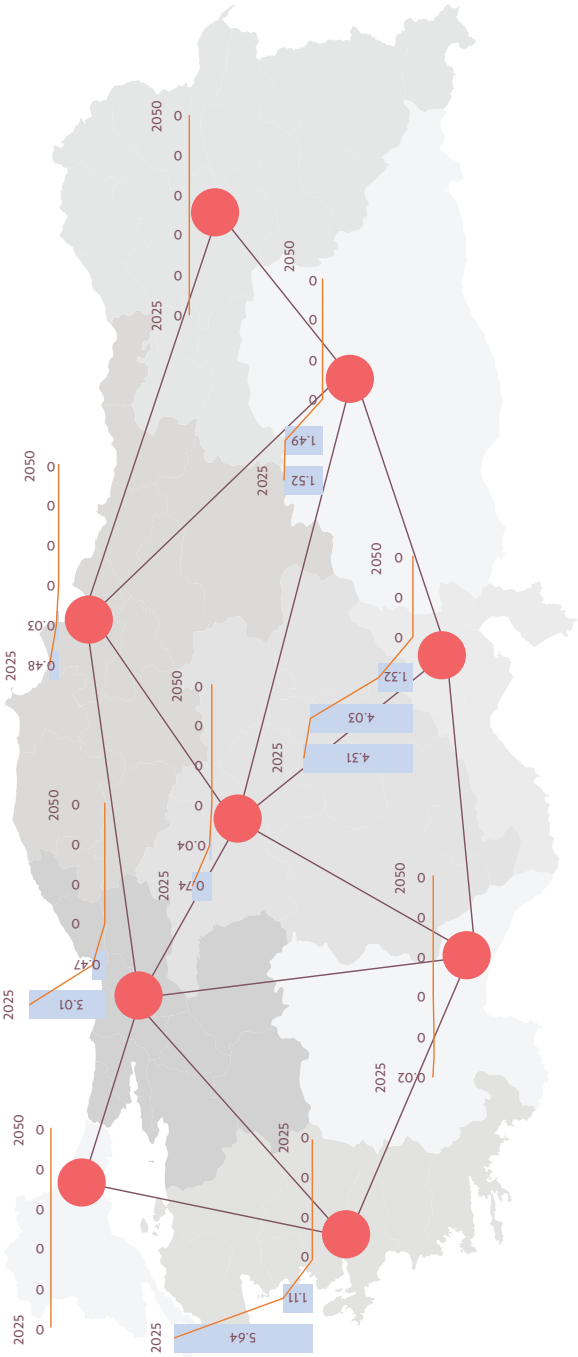


Figure 71 Change of total coal installed capacity over years in TEİAŞ Regional Dispatching Centers in Net Zero Scenario

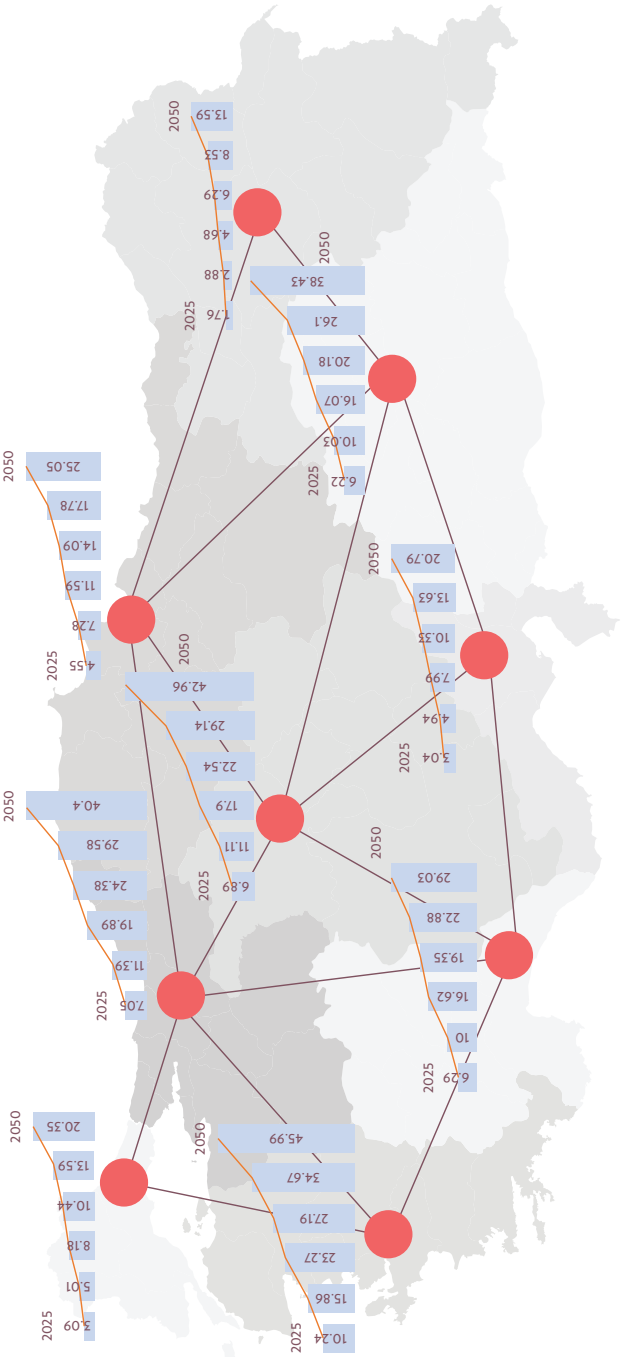
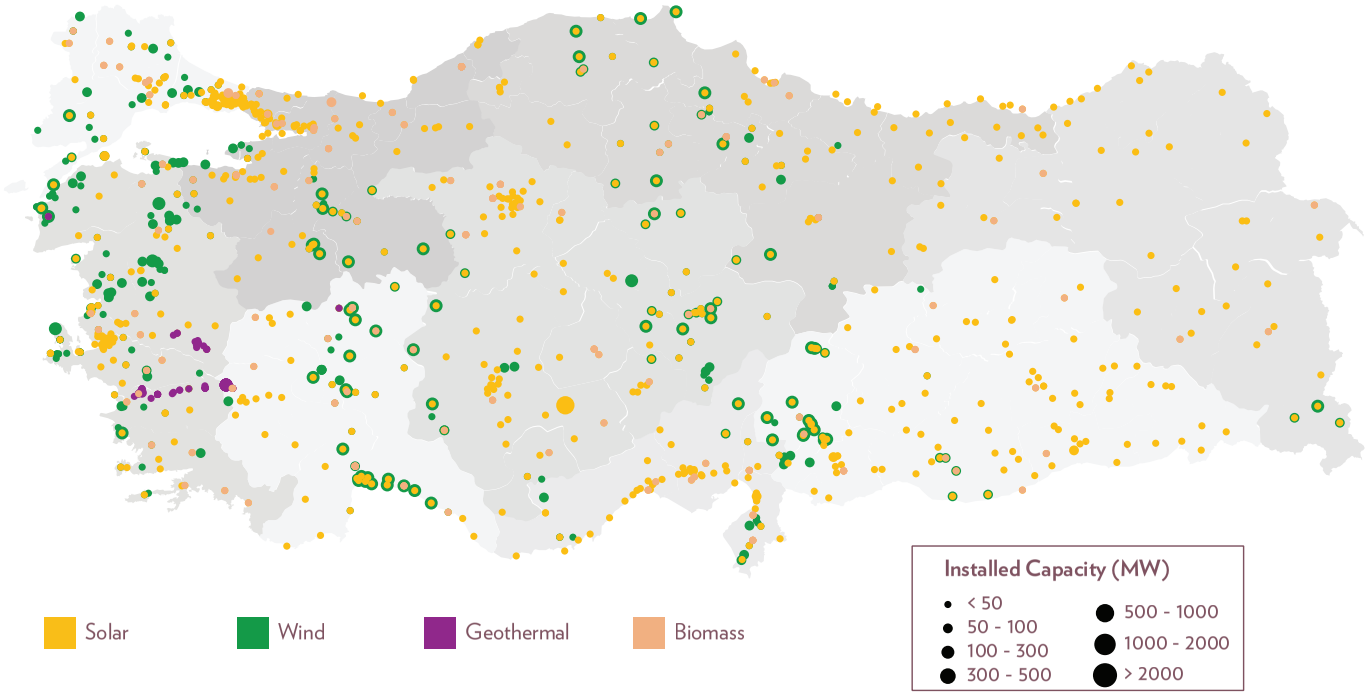


Figure 72 Change of total renewable installed capacity over years in TEİAŞ Regional Dispatching Centers in Net Zero Scenario

Figure 73 Location and installed capacity of renewable power plants in Net Zero Scenario in 2025



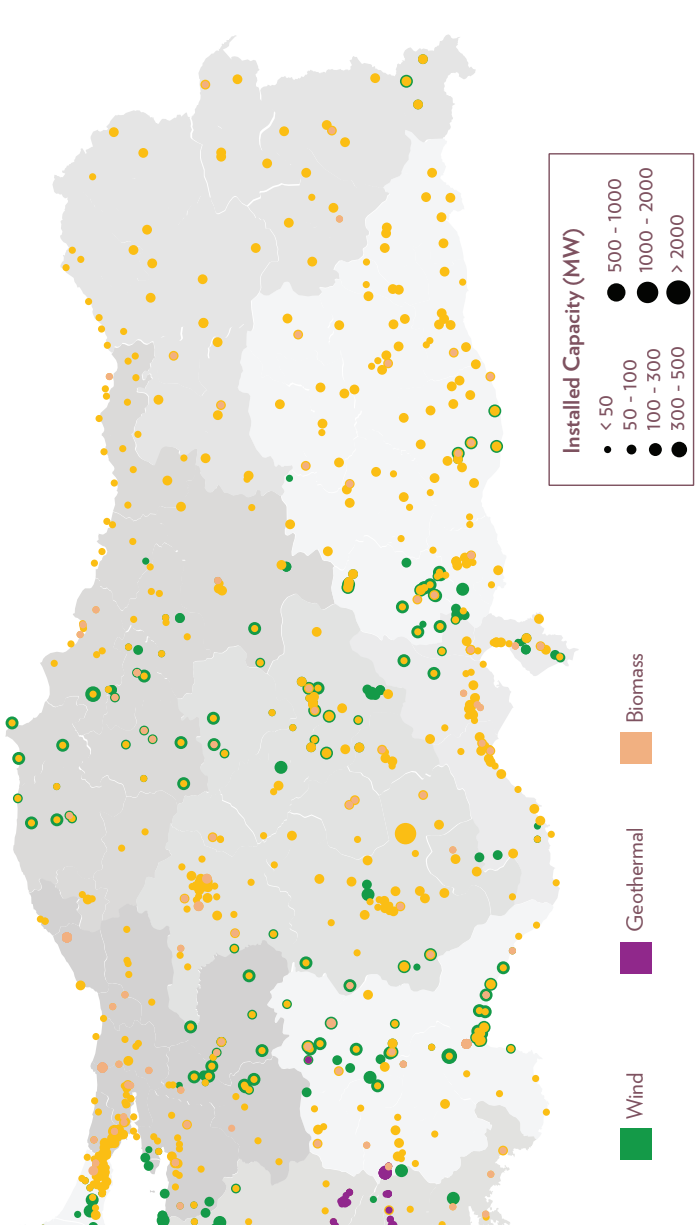
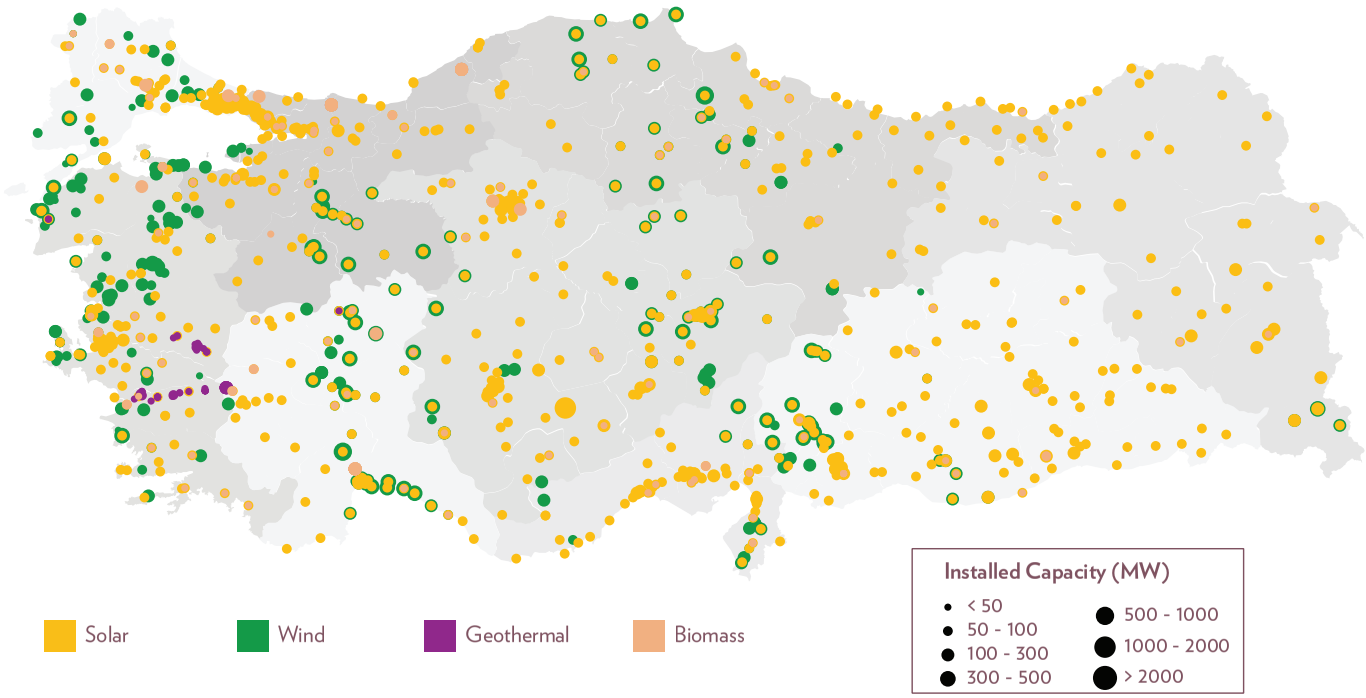


Figure 74 Location and installed capacity of renewable power plants in Net Zero Scenario in 2030

Figure 75 Location and installed capacity of renewable power plants in Net Zero Scenario in 2035



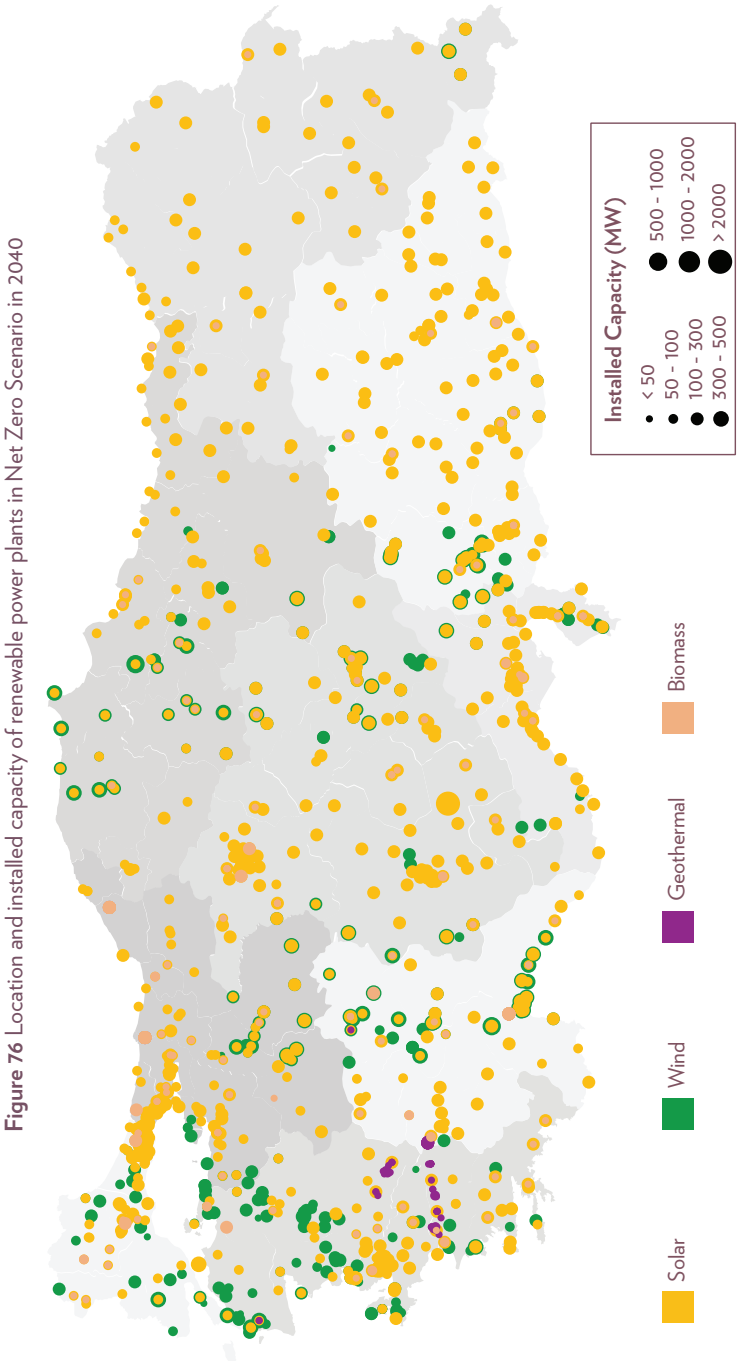
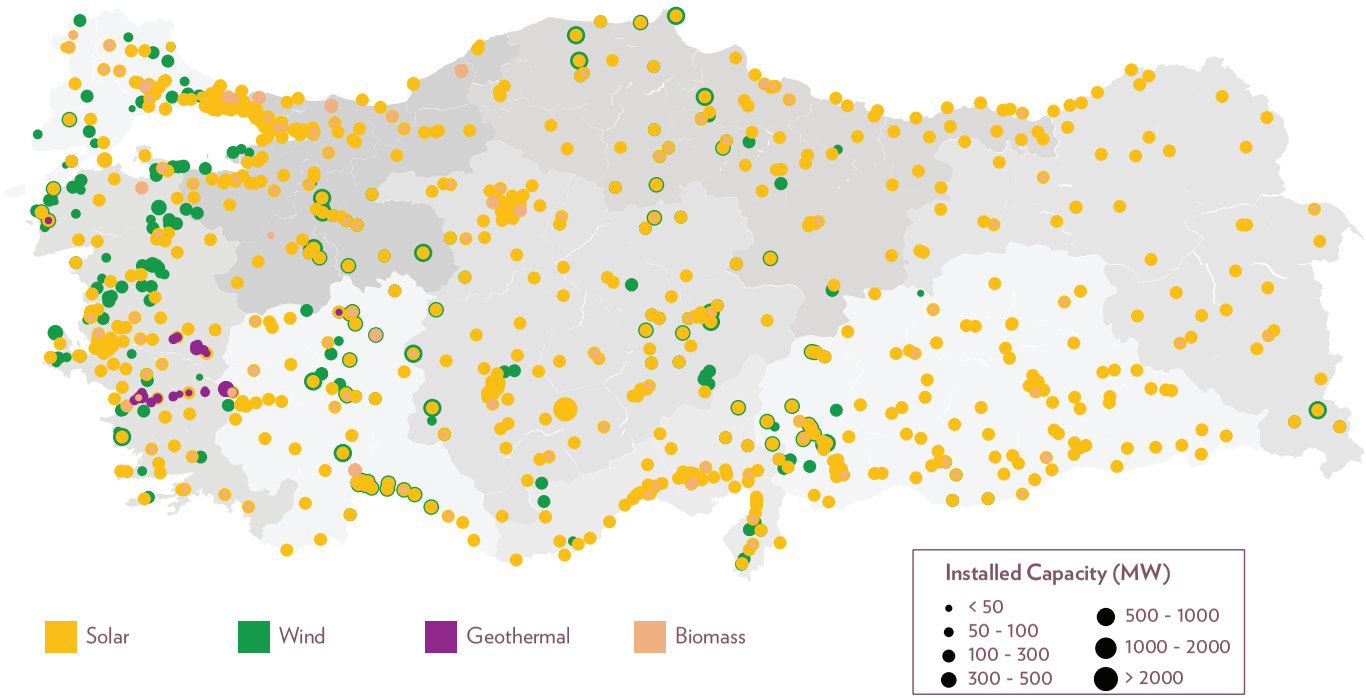


Figure 76 Location and installed capacity of renewable power plants in Net Zero Scenario in 2040

Figure 77 Location and installed capacity of renewable power plants in Net Zero Scenario in 2045



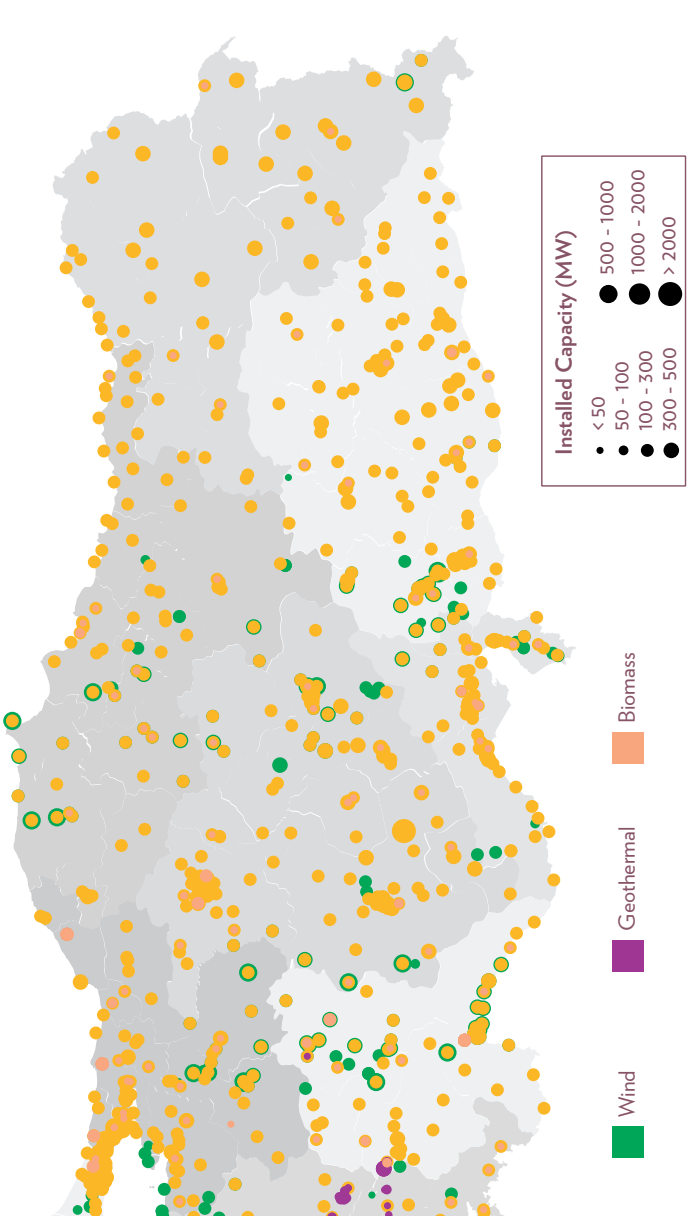


Figure 78 Location and installed capacity of renewable power plants in Net Zero Scenario in 2050

1.5.3. Energy Generation by Resources

In the Net Zero Scenario, the distribution of production by energy sources in the target years is presented in Table 18 and Figure 79.

When compared with Turkey's Decarbonization Roadmap: Net Zero by 2050 (IPCC, 2021) report, the differences in these values are attributed to the inclusion of grid simulations in this study in addition to market simulations. Considering grid constraints and the instructions given to address grid bottlenecks, there has been an increase in natural gas production to mitigate interruptions in renewable energy production.

Table 18 Development of generation by resources (GWh) in the electricity sector in Net Zero Scenario

Year	Local Coal	Imported Coal	Lignite	Natural Gas	Other	Nuclear	HPP	HPP	Solar	Wind	Geothermal	Biomass	Total
2020	4.110	60.090	39.850	68.400	2.463	0	55.810	21.010	11.530	23.790	10.690	4.279	302.022
2025	2.860	26.418	46.870	100.291	4.226	0	58.961	20.082	42.617	58.719	17.701	25.992	404.737
2030	**1.011**	**14.073**	**14.485**	**100.564**	**4.124**	**37.493**	**59.206**	**22.177**	**72.482**	**89.728**	**22.145**	**34.816**	**472.304**
2035	0	4.585	0	63.964	4.962	36.583	64.663	22.481	120.409	140.936	21.397	71.945	551.925
2040	0	0	0	73.166	4.957	37.263	69.029	22.274	172.863	149.194	21.279	82.098	632.123
2045	0	0	0	58.413	5.082	36.923	70.439	26.659	244.256	159.483	29.196	79.150	709.601
2050	**0**	**0**	**0**	**46.997**	**4.851**	**37.083**	**61.664**	**22.679**	**356.380**	**145.733**	**27.862**	**77.311**	**780.560**

Figure 79. Development of generation by resources in the electricity sector in Net Zero Scenario (TWh)

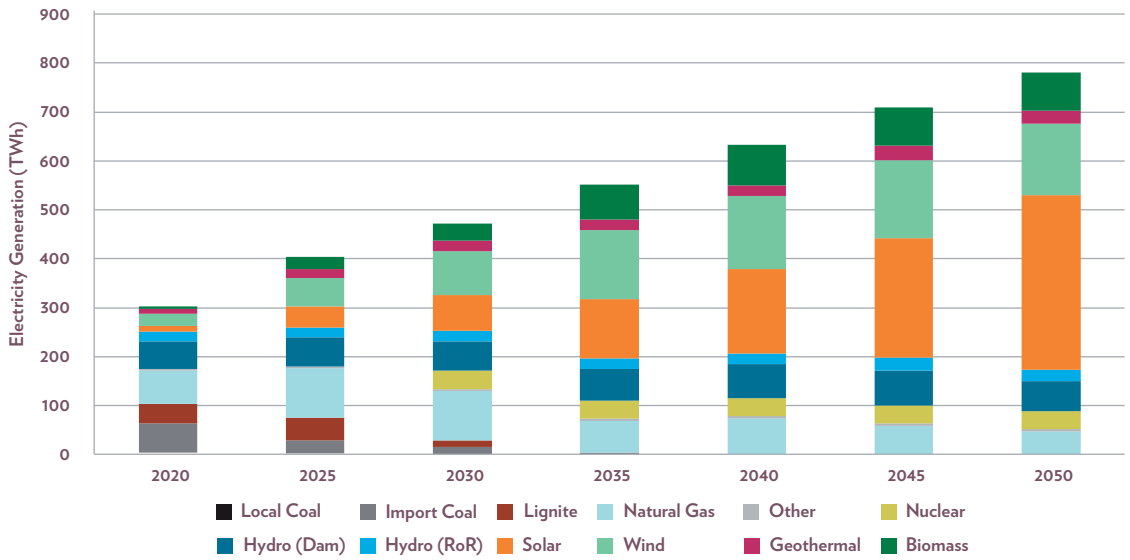
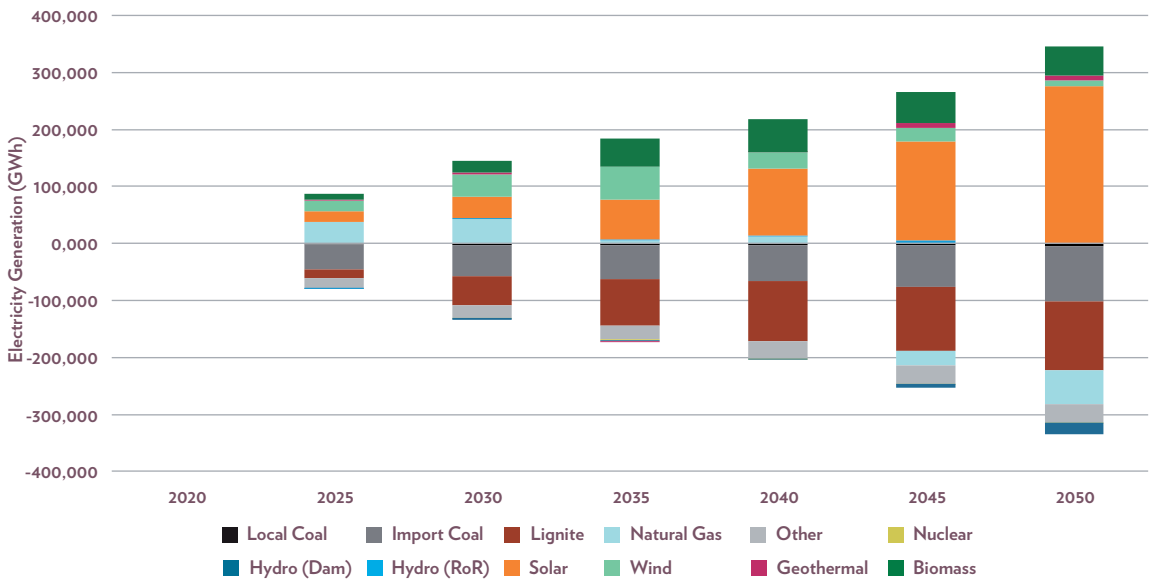


Figure 80 Change of generation levels of resources in the electricity sector in Net Zero Scenario compared to Base Scenario (GWh)

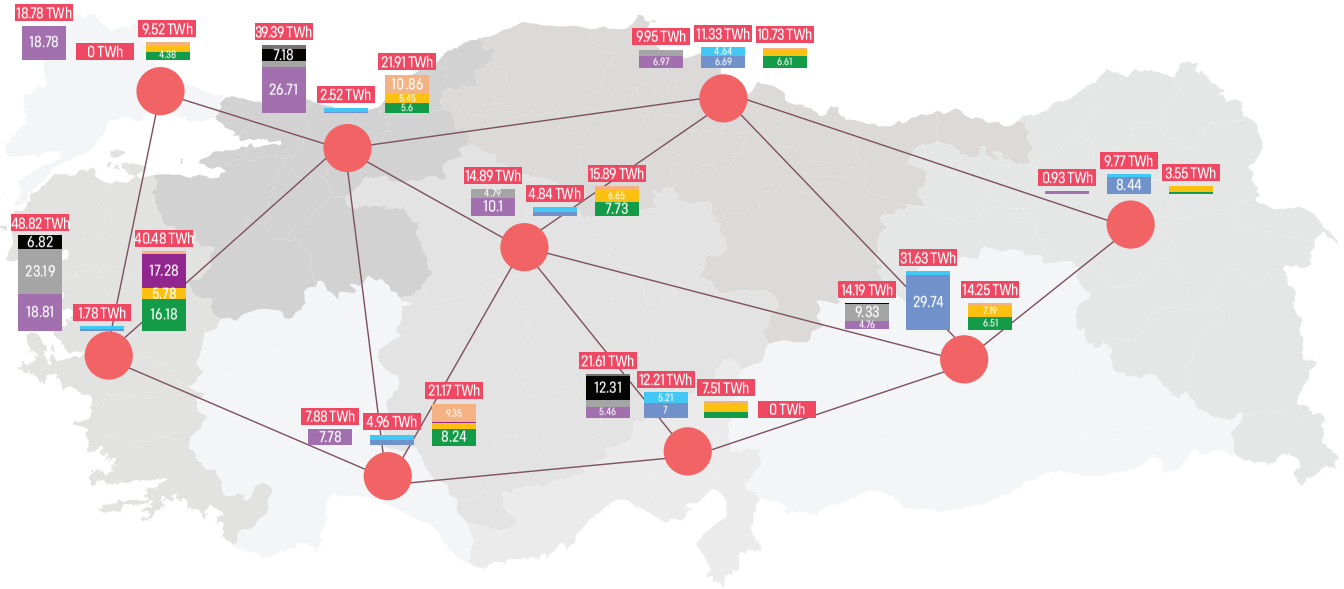


In the Net Zero Scenario, the differences in production levels of electricity production technologies compared to the Base Scenario are shown in Figure 80.

With the rapid phase-out of thermal power plants in the Net Zero Scenario, the share of fossil fuels in electricity generation decreases much earlier and significantly compared to the Base Scenario. The increase in installed capacities of modern renewable energy sources such as wind, solar, biomass, and geothermal power plants leads to a much higher share of modern renewables in production compared to the base scenario. In this scenario, the share of modern renewables, which was 17% in 2020, gradually increases to 80% in 2050, while the share of fossil fuel sources rapidly decreases from 58% in 2020 to 7% by 2050. Although hydroelectric power production shows an increase, its share in production decreases from 25.5% in 2020 to 11% by 2050 due to limited capacity growth. The share of nuclear power plants, which entered the electricity system with an 8% production share in 2030, decreases over the years to reach 5% in 2050.

The distribution of electricity production in TEIAS Regional Dispatching Centers according to production technology in the target years in the Net Zero Scenario is shown in Figures 81 to 86.

Figure 81 Distribution of energy generation by technology in TEİAŞ regions in 2025 in Net Zero Scenario



1st Column / Conventional

Natural Gas (TWh) | Lignite (TWh) | Import Coal (TWh) | Local Coal (TWh)

2nd Column / Hydro

Hydro (Dam) (TWh) | Hydro (RoR) (TWh)

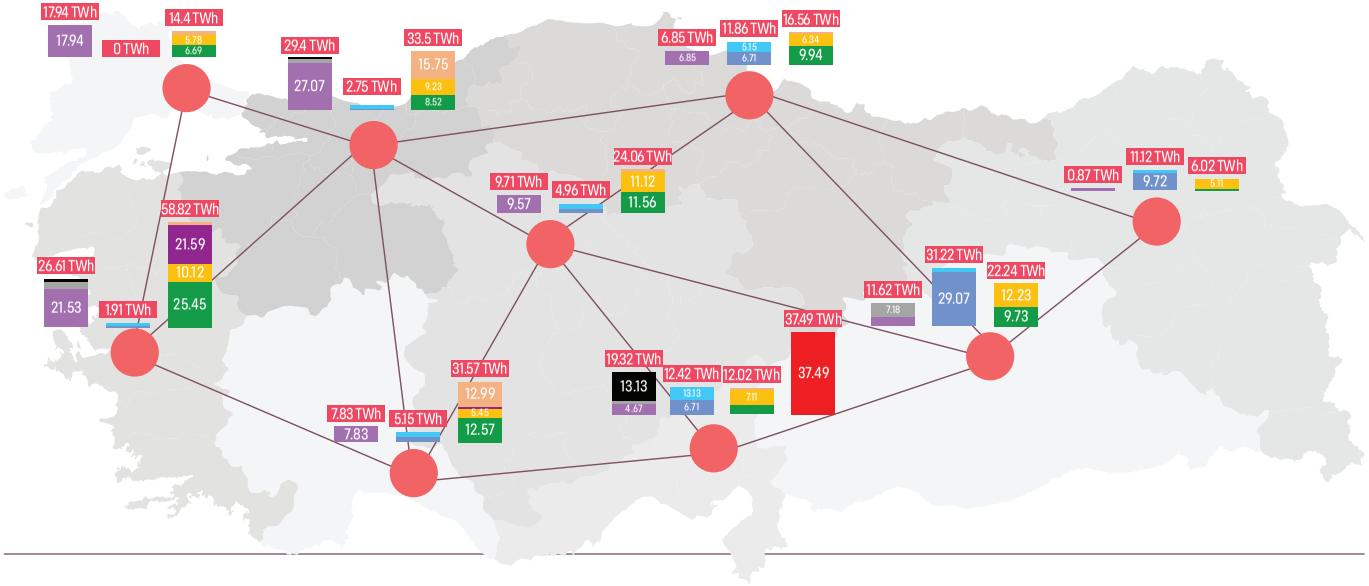
Wind (TWh) | Solar (TWh) | Geothermal (TWh) | Biomass (TWh)

3rd Column / Renewables

Nuclear (TWh)

4th Column / Nuclear

Figure 82 Distribution of energy generation by technology in TEİAŞ regions in 2030 in Net Zero Scenario



1st Column / Conventional

Natural Gas (TWh) | Lignite (TWh) | Import Coal (TWh) | Local Coal (TWh)

Wind (TWh) | Solar (TWh) | Geothermal (TWh) | Biomass (TWh)

3rd Column / Renewables

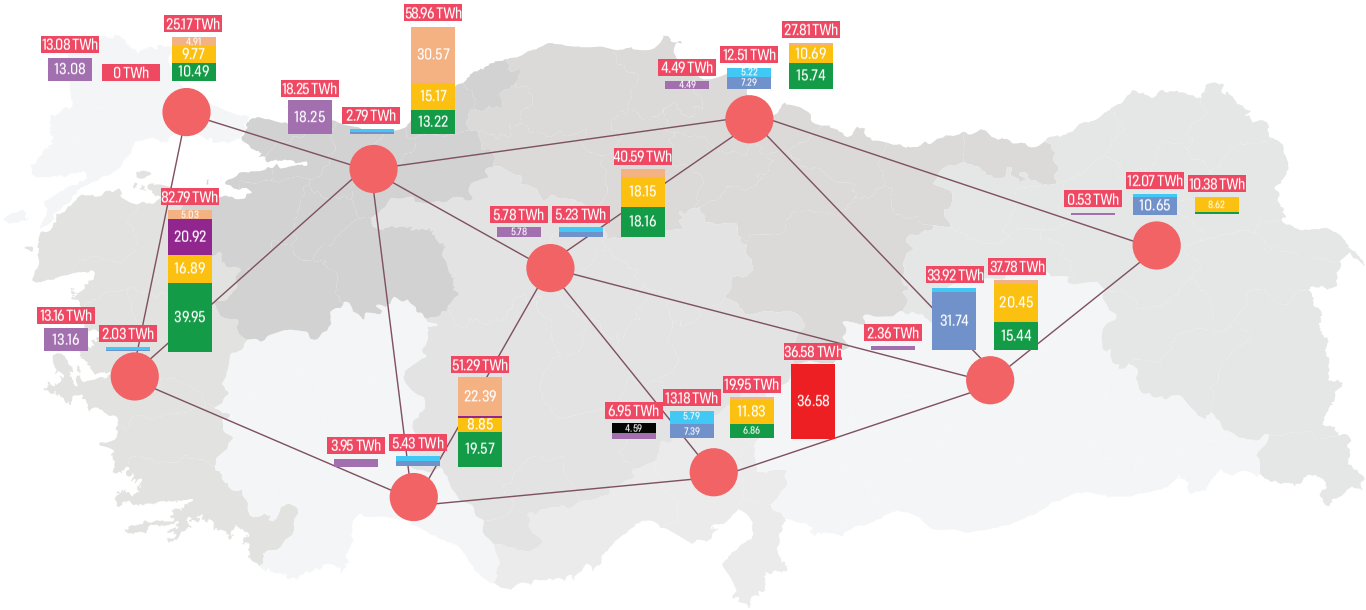
2nd Column / Hydro

Hydro (Dam) (TWh) | Hydro (RoR) (TWh)

Nuclear (TWh)

4th Column / Nuclear

Figure 83 Distribution of energy generation by technology in TEİAŞ regions in 2035 in Net Zero Scenario



1st Column / Conventional

Natural Gas (TWh) | Lignite (TWh) | Import Coal (TWh) | Local Coal (TWh)

Wind (TWh) | Solar (TWh) | Geothermal (TWh) | Biomass (TWh)

3rd Column / Renewables

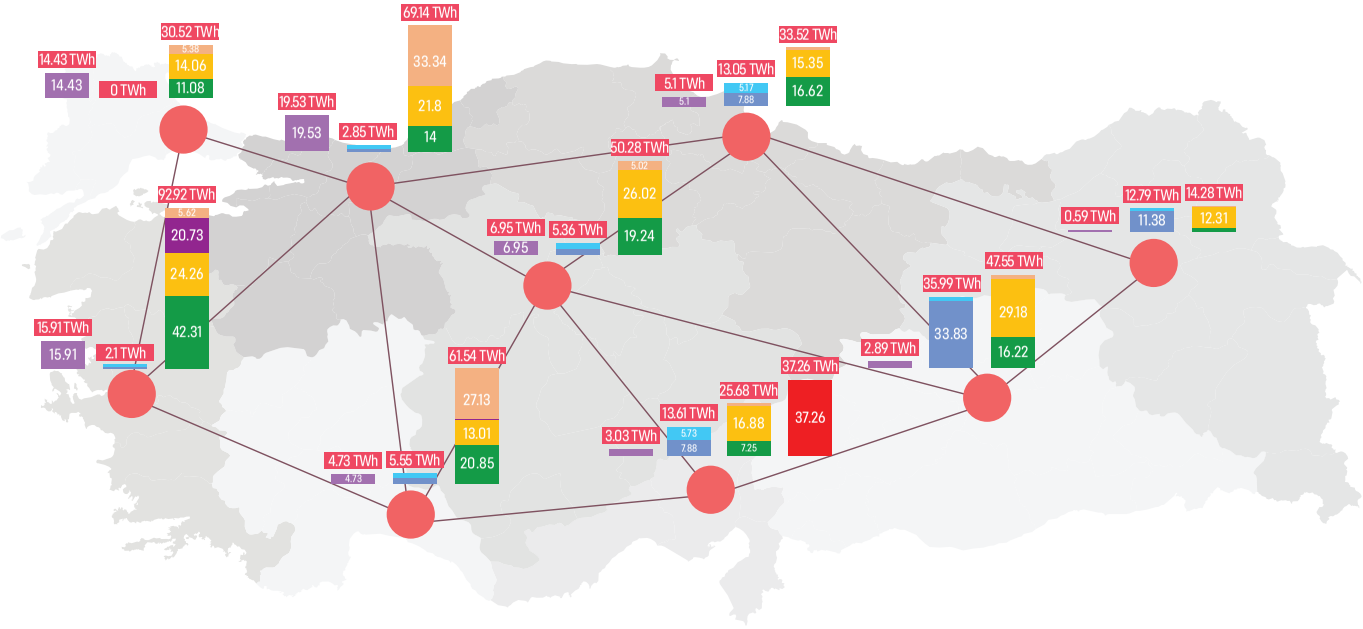
2nd Column / Hydro

Hydro (Dam) (TWh) | Hydro (RoR) (TWh)

Nuclear (TWh)

4th Column / Nuclear

Figure 84 Distribution of energy generation by technology in TEİAŞ regions in 2040 in Net Zero Scenario



1st Column / Conventional

Natural Gas (TWh) | Lignite (TWh) | Import Coal (TWh) | Local Coal (TWh)

2nd Column / Hydro

Hydro (Dam) (TWh) | Hydro (RoR) (TWh)

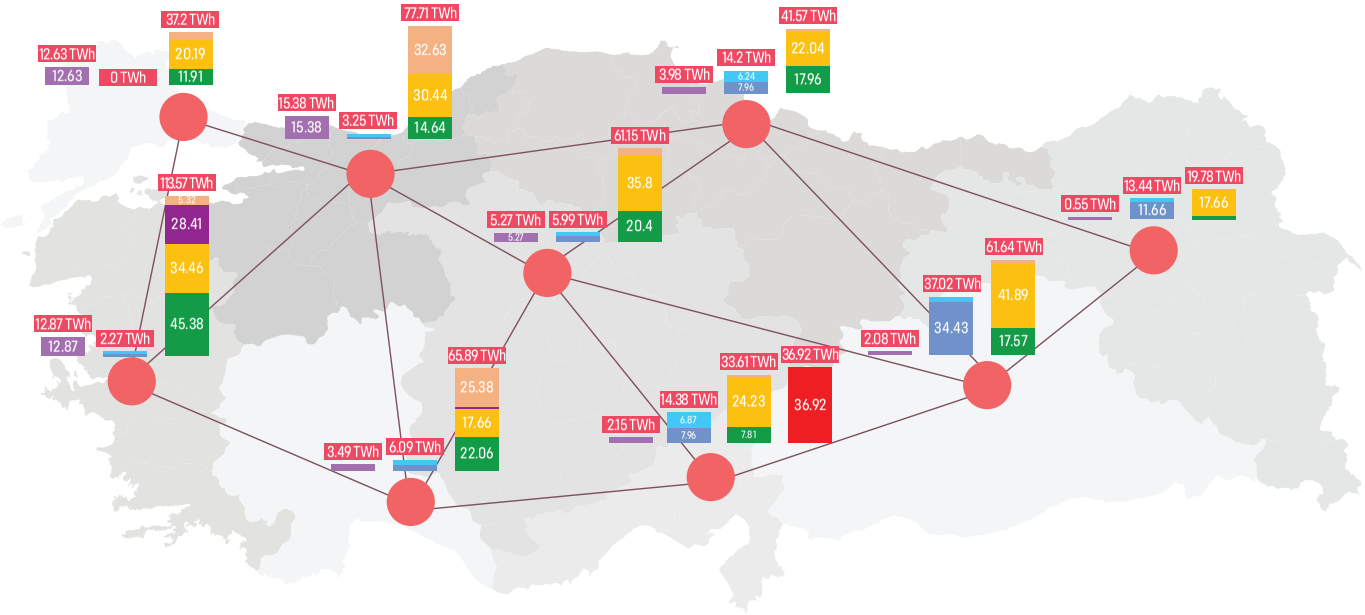
Wind (TWh) | Solar (TWh) | Geothermal (TWh) | Biomass (TWh)

3rd Column / Renewables

Nuclear (TWh)

4th Column / Nuclear

Figure 85 Distribution of energy generation by technology in TEİAŞ regions in 2045 in Net Zero Scenario



1st Column / Conventional

Natural Gas (TWh) | Lignite (TWh) | Import Coal (TWh) | Local Coal (TWh)

2nd Column / Hydro

Hydro (Dam) (TWh) | Hydro (RoR) (TWh)

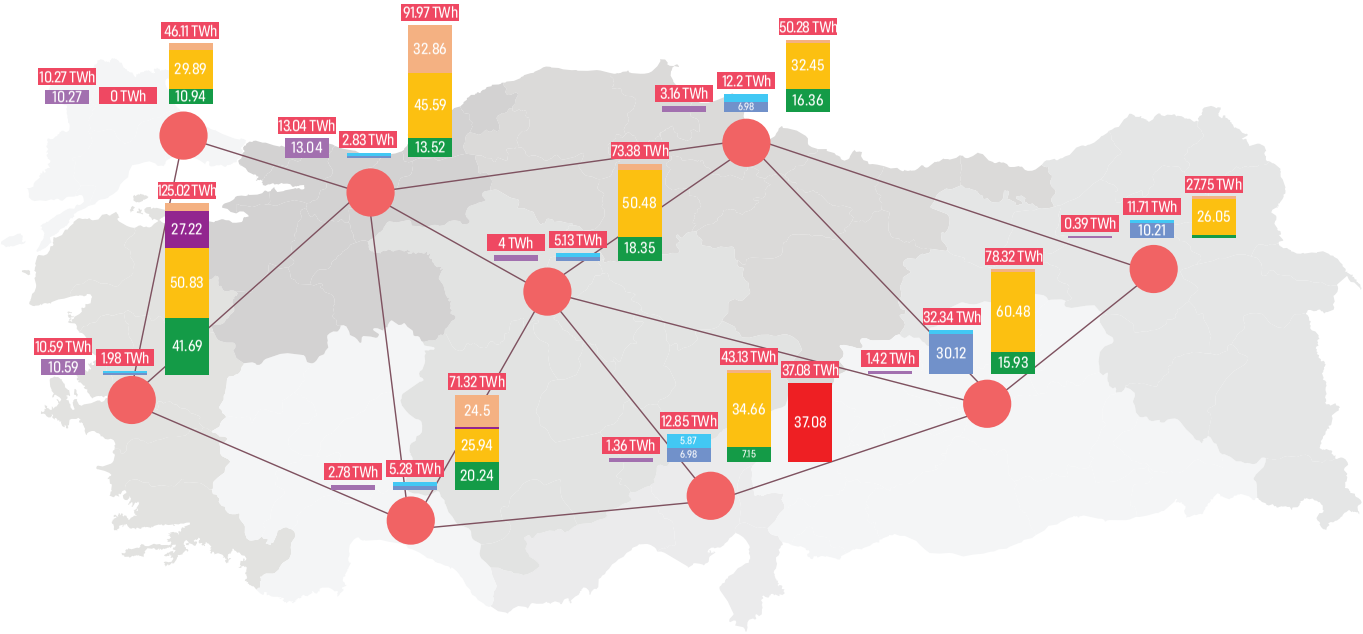
Wind (TWh) | Solar (TWh) | Geothermal (TWh) | Biomass (TWh)

3rd Column / Renewables

Nuclear (TWh)

4th Column / Nuclear

Figure 86 Distribution of energy generation by technology in TEİAŞ regions in 2050 in Net Zero Scenario



1.5.4. Redispatch Up/Down and Renewable Curtailment Amount

In the Net Zero Scenario, the total redispatch and renewable curtailment amounts in the target years are presented in Figure 87 and Table 19; the ratio of redispatch to total consumption and the ratio of curtailment in renewable production to total renewable production are shown in Figure 88 and Table 20. The rapid decrease in conventional power plants and the significant increase in renewable production generally lead to higher redispatch instructions and curtailment in renewable production in this scenario. However, the amounts of redispatch and renewable curtailment are also dependent on the capacity of storage systems and grid investments. The high penetration of storage and grid investments results in less redispatch and curtailment in 2040 compared to 2035.

Figure 87 Redispatch Up/Down and renewable curtailment amounts in Net Zero Scenario

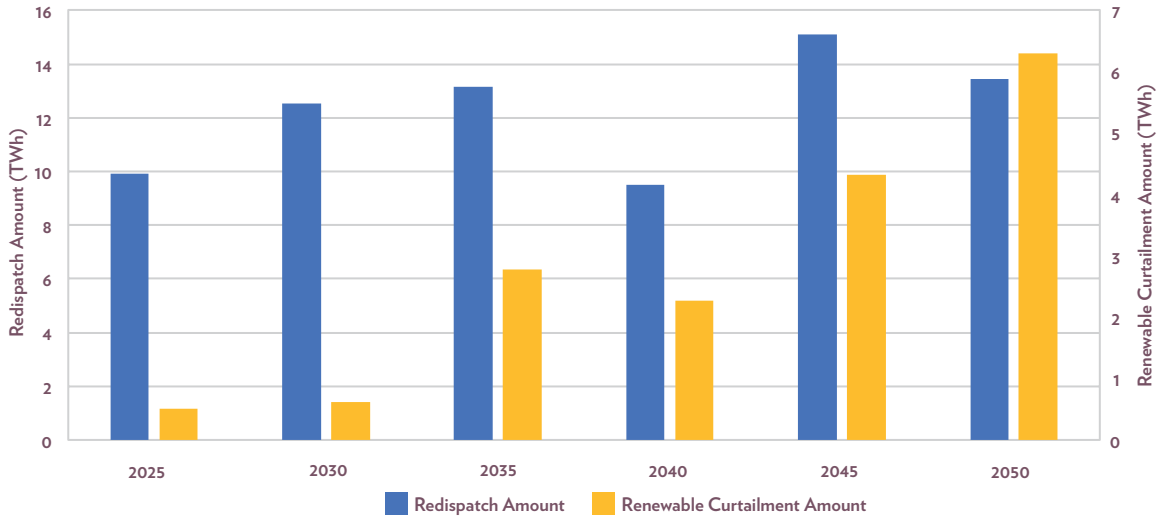


Table 19 Redispatch Up/Down and renewable curtailment amounts in Net Zero Scenario

	Redispatch amount (TWh)	Renewable curtailment amount (TWh)
2025	9.92	0.50
2030	12.53	0.62
2035	13.15	2.77
2040	9.49	2.28
2045	15.12	4.31
2050	13.43	6.29

Figure 88 Redispatch and curtailment ratios in Net Zero Scenario

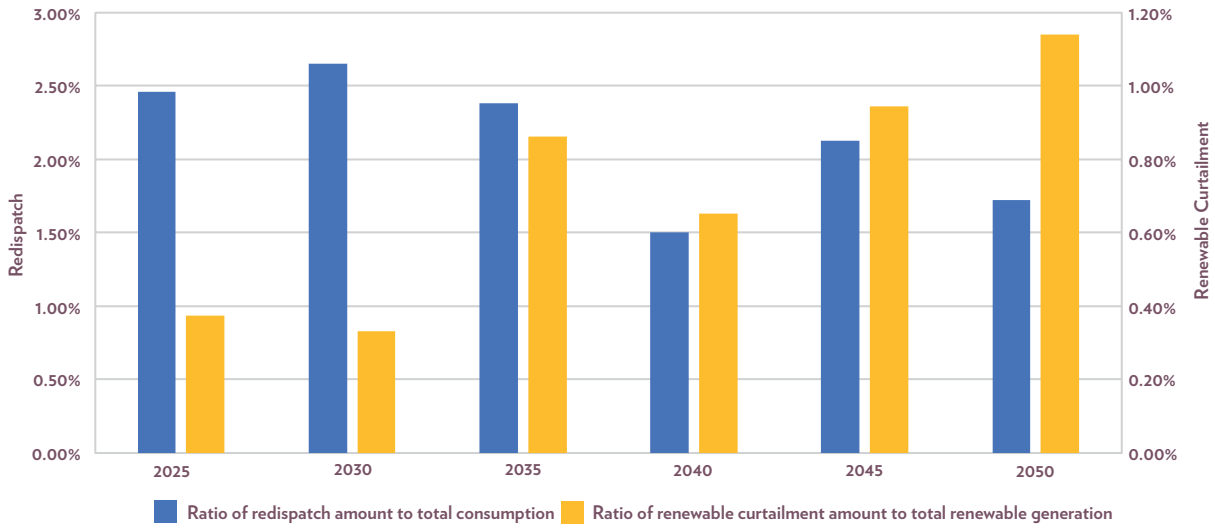
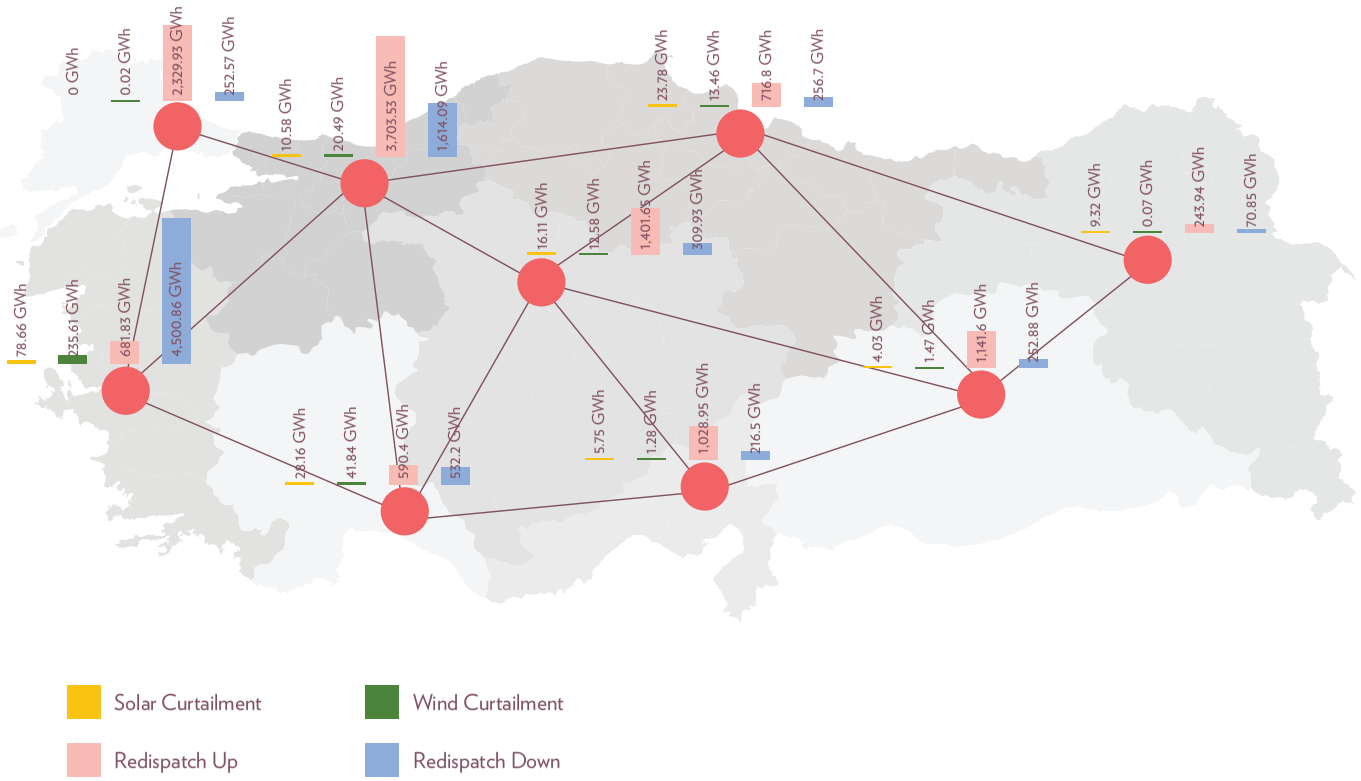


Table 20 Redispatch and curtailment ratios in Net Zero Scenario

	Ratio of redispatch amount to total consumption	Ratio of renewable curtailment amount to total renewable generation
2025	2.46%	0.38%
2030	2.65%	0.33%
2035	2.38%	0.86%
2040	1.50%	0.65%
2045	2.13%	0.94%
2050	1.72%	1.14%

Total redispatch and curtailment in renewable generation amounts in TEİAŞ regions in target years are shown in Figure 89–Figure 94.

Figure 89 Distribution of redispatch and renewable curtailment amounts based on regions in 2025 in Net Zero Scenario



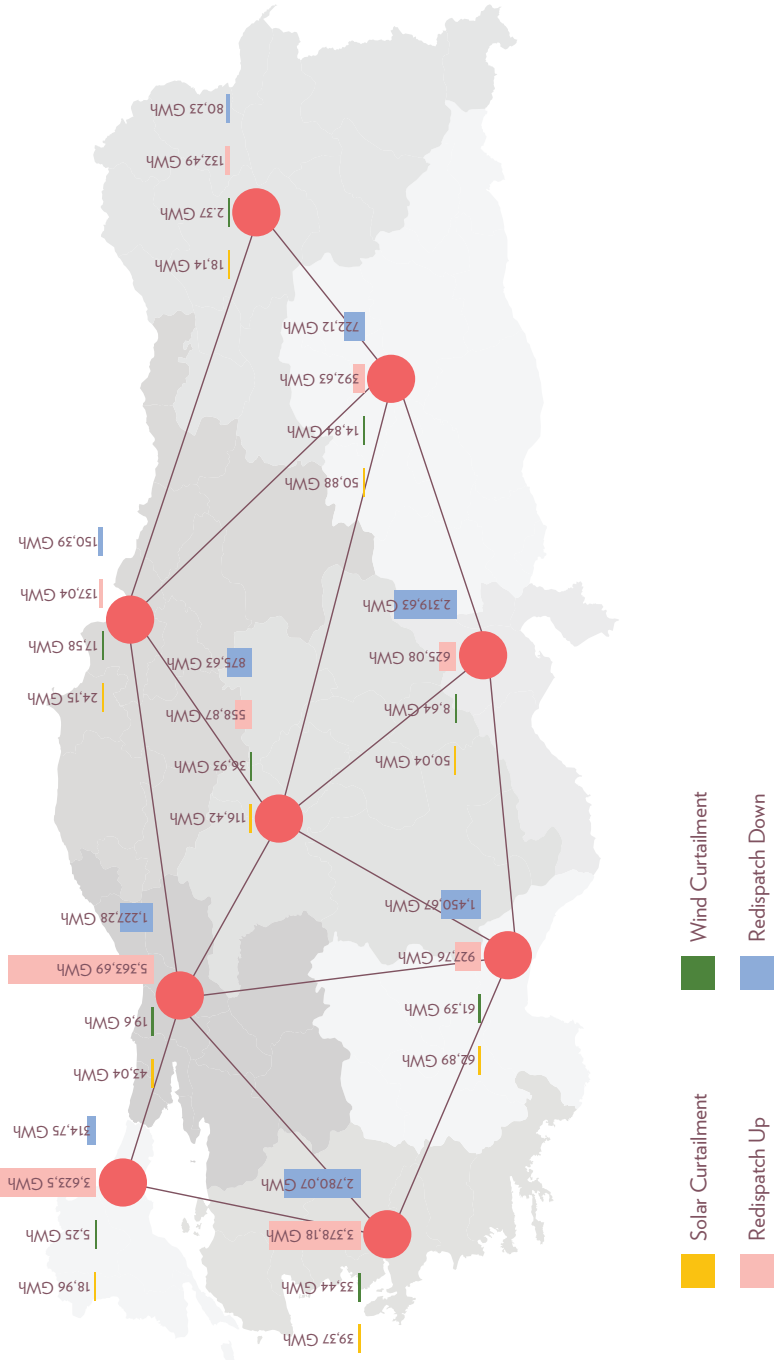
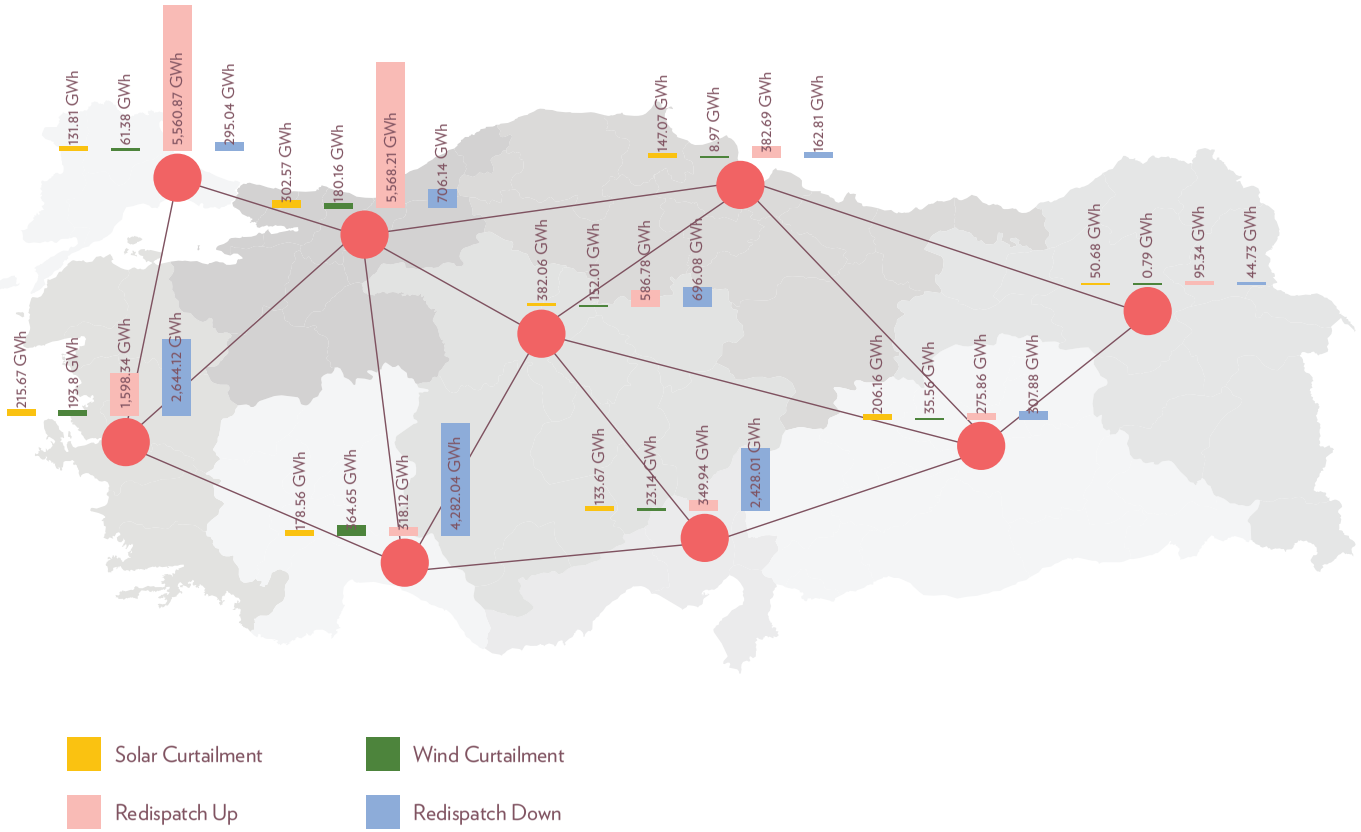


Figure 90 Distribution of redispatch and renewable curtailment amounts based on regions in 2030 in Net Zero Scenario

Figure 91 Distribution of redispatch and renewable curtailment amounts based on regions in 2035 in Net Zero Scenario



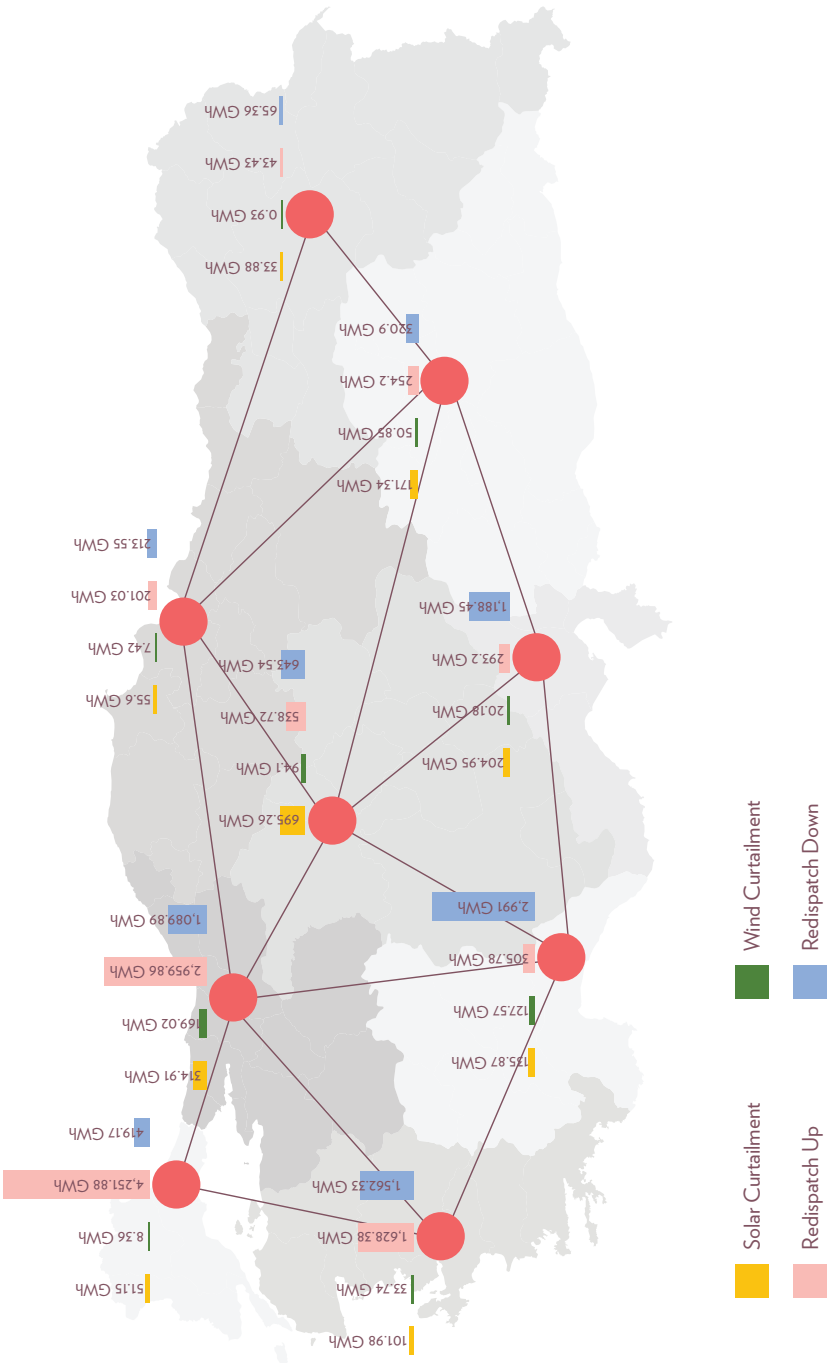
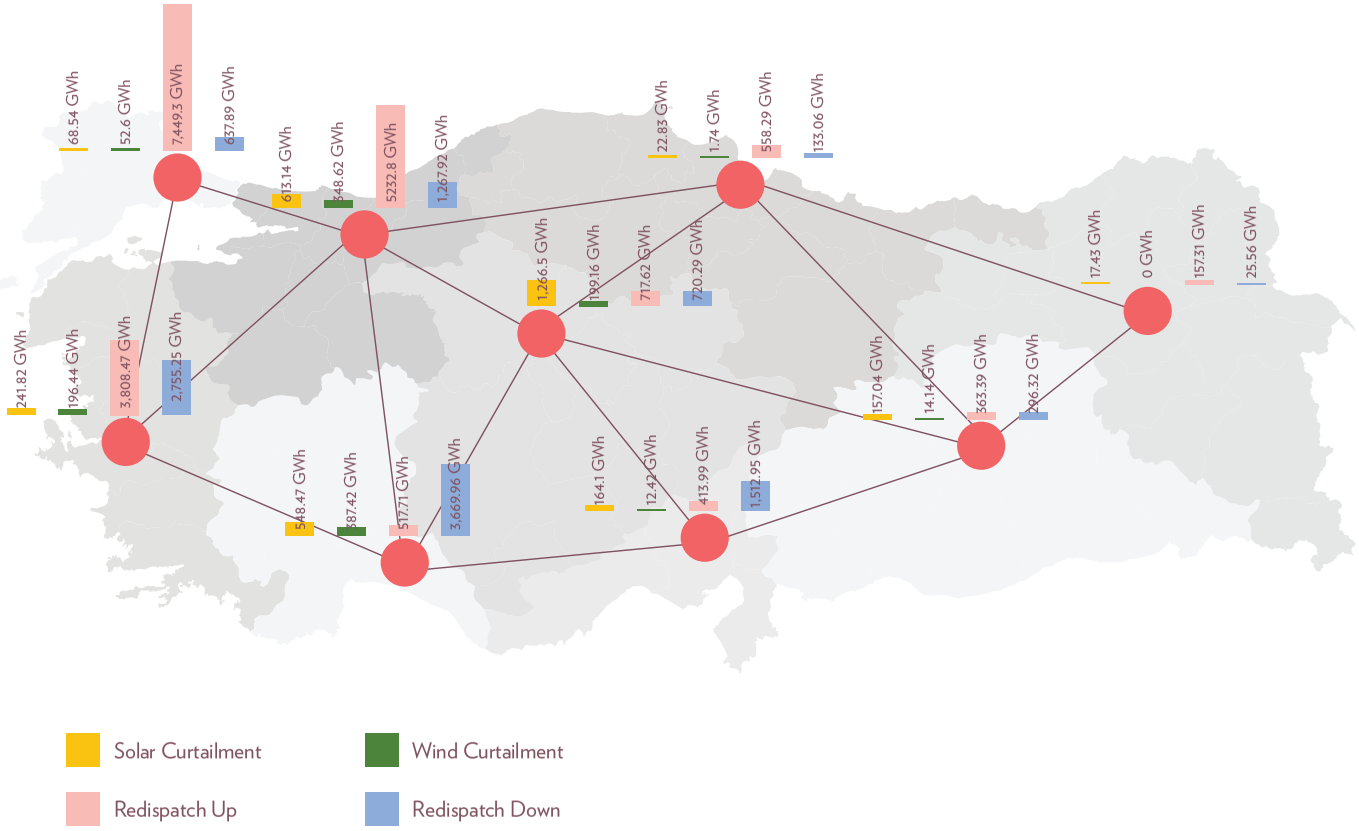


Figure 92 Distribution of redispatch and renewable curtailment amounts based on regions in 2040 in Net Zero Scenario

Figure 93 Distribution of redispatch and renewable curtailment amounts based on regions in 2045 in Net Zero Scenario



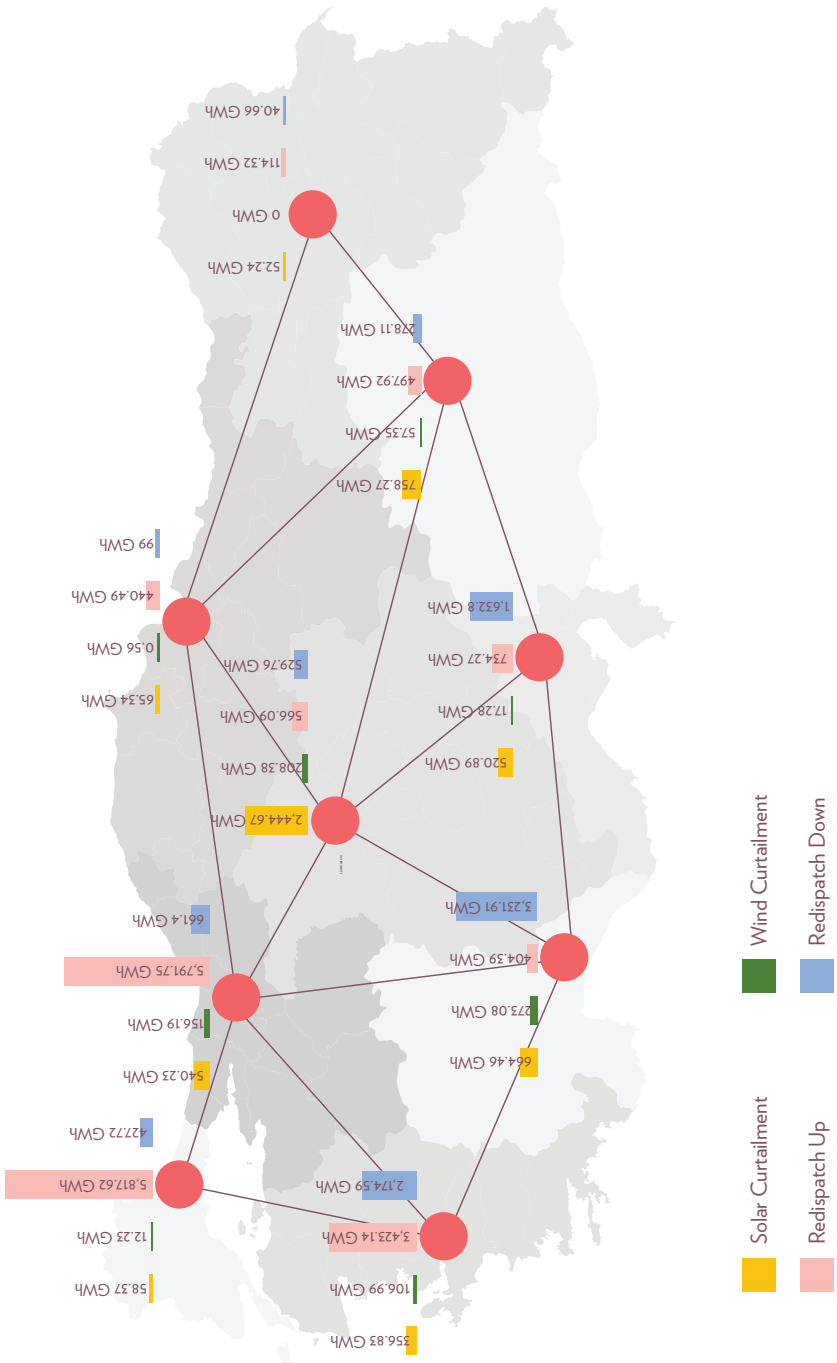
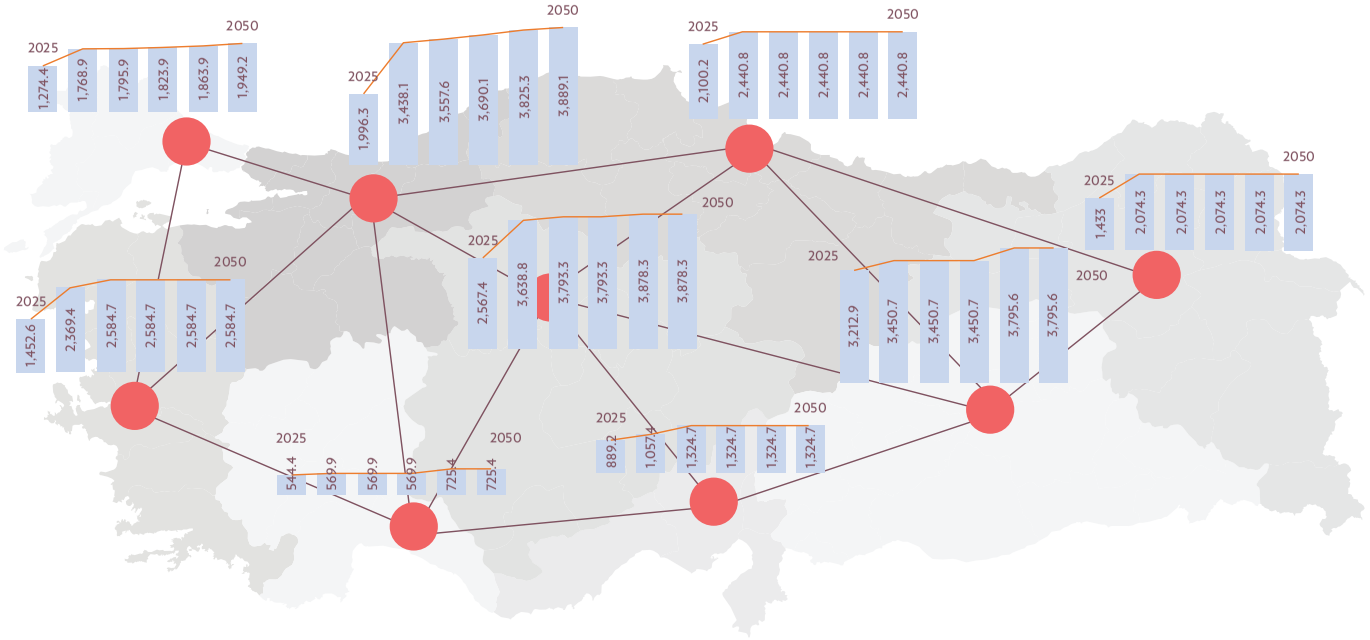


Figure 94 Distribution of redispatch and renewable curtailment amounts based on regions in 2050 in Net Zero Scenario

Figure 95 Development of total line lengths in TEİAŞ Regional Dispatching Centers in Net Zero Scenario (km)



1.5.5. Network Investment Requirement

The development of the total length (km) of 400 kV lines in TEİAŞ regional dispatching centers with grid investment requirements is shown in Figure 95.

In the Net Zero Scenario, there is no additional investment requirement for corridors in the year 2025 based on the 2020 grid model. However, in the Net Zero Scenario for the year 2030, there is an additional investment requirement on top of the 2030 TEİAŞ grid investment plan (Figure 96). With these investments, there is no additional investment requirement for corridors in the year 2035. Additional investments in corridors in the year 2040 (Figure 97) are sufficient for the corridors in 2045 and 2050, and there is no additional investment requirement.

Figure 96 Additional investment requirement for 2030 corridors on top of 2030 TEİAŞ investment plan in Net Zero Scenario

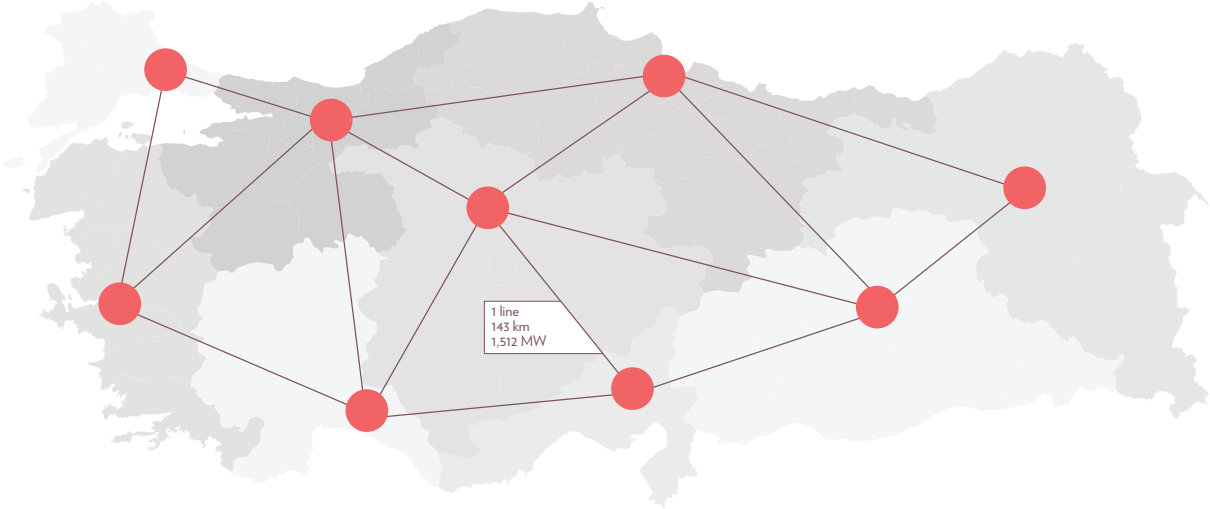


Figure 97 Additional investment requirement for 2040 corridors on top of 2030 corridors in Net Zero Scenario

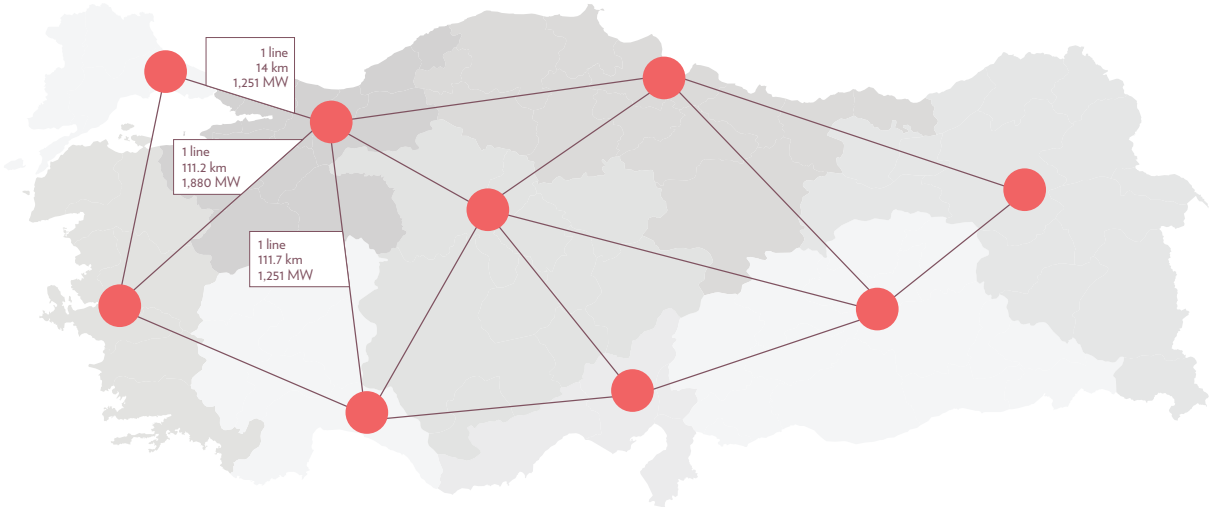


Table 21 CO_2 emissions of the electricity sector by fossil fuel sources in the base scenario ($MtCO_2$)

	Local Coal	Imported Coal	Lignite	Natural Gas	Total
2020	4.19	57.09	47.42	26.68	135.38
2025	2.26	48.90	43.10	33.81	122.9
2030	0.63	21.09	10.59	36.25	70.86
2035	0.00	3.52	0.00	32.95	29.3
2040	0.00	0.00	0.00	38.69	28.53
2045	0.00	0.00	0.00	37.31	22.78
2050	0.00	0.00	0.00	18.33	18.33

1.5.6. Carbon Dioxide Emissions

In the Net Zero Scenario, CO_2 emissions from electricity generation based on fossil fuels are presented in Table 21 and Figure 98.

In the Net Zero Scenario, CO_2 emissions from the electricity sector begin to decrease after 2020. The emissions, which were 135 $MtCO_2$ in 2020, decrease by 48% to 71 $MtCO_2$ in 2030 and further decrease by 87% to 18 $MtCO_2$ in 2050. After the closure of all lignite power plants in the first half of the 2030s and the remaining coal-fired power plant in the second half of the 2030s, all remaining emissions in the electricity sector are attributed to natural gas from 2040 onwards.

Figure 98 CO_2 emissions of the electricity sector by fossil fuel sources in the net zero scenario ($MtCO_2$)

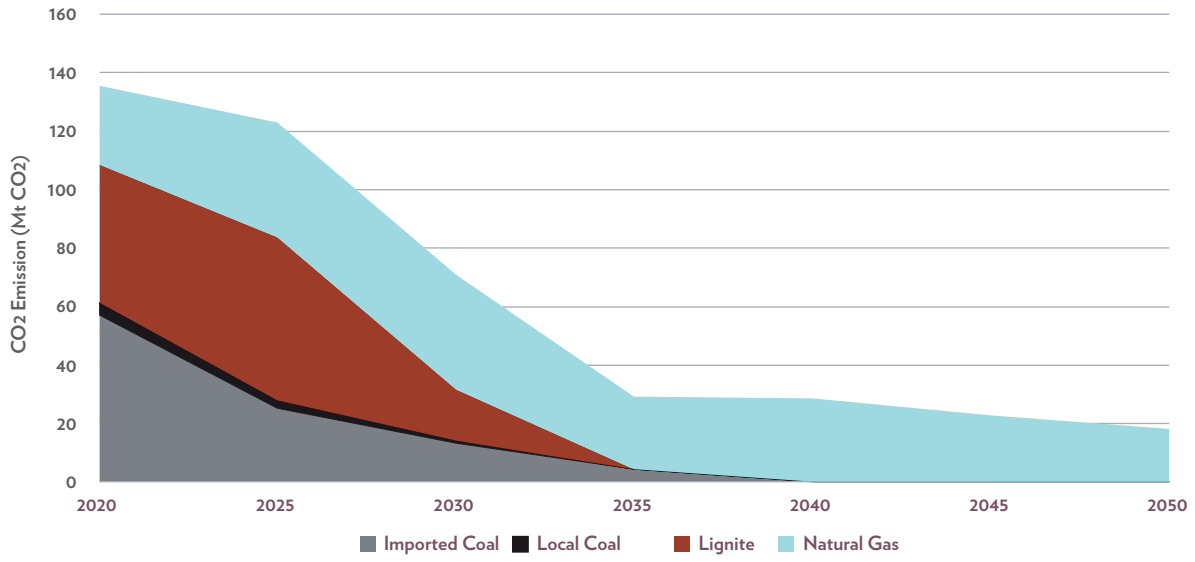
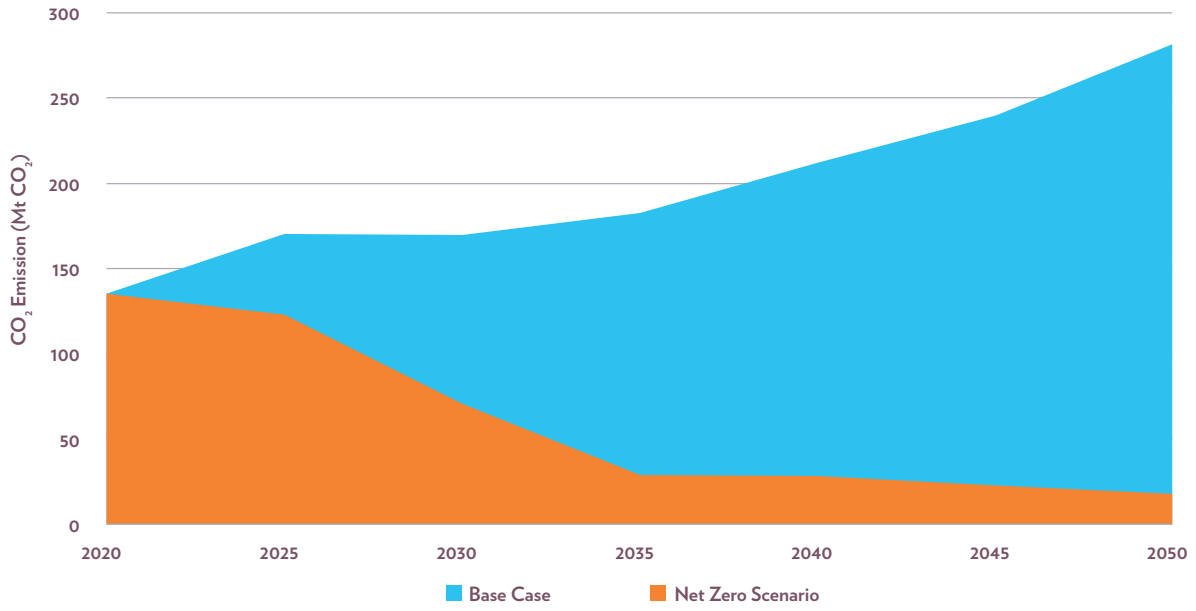


Figure 99 Comparison of CO_2 emissions of the electricity sector ($MtCO_2$) in Base and Net Zero Scenarios



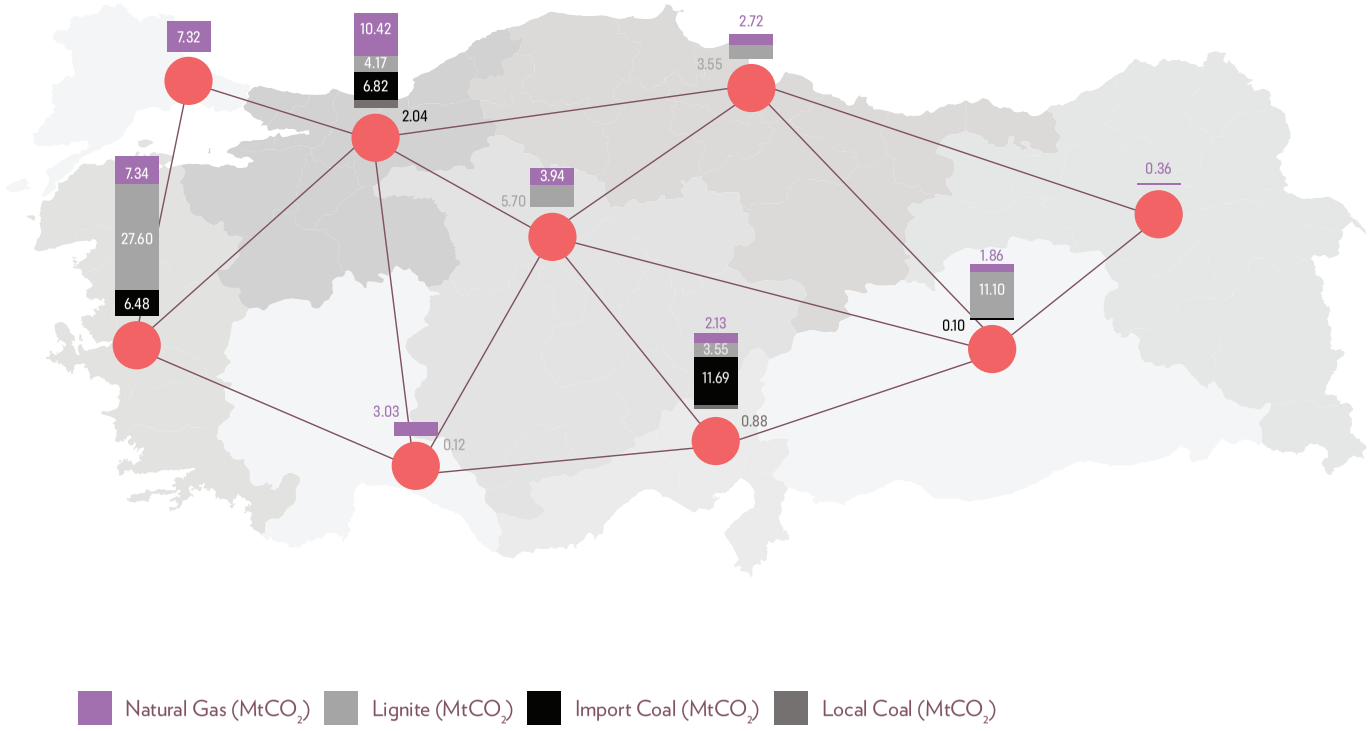
Electricity sector emissions from 2020 to 2050 in the Base Scenario and Net Zero Scenario are comparatively shown in Figure 99. According to this comparison, emissions peak in 2020 in the Net Zero Scenario, unlike the Base Scenario.

Carbon dioxide emissions from the electricity sector cannot be completely eliminated by 2050 in the Net Zero Scenario, and there are residual emissions of 18 $MtCO_2$. These emissions originate from natural gas power plants that are kept ready for dispatch with a low capacity factor due to the increased need for grid flexibility, driven by the high use of renewable energy sources. If the increased flexibility demand in the grid can be completely met through methods such as demand management, in addition to storage and interconnection, the remaining natural gas power plants may also be closed by 2050, making it possible to eliminate the remaining residual emissions.

In the Net Zero Scenario, the distribution of CO_2 emissions from the electricity sector in TEIAS regional dispatching centers based on production technology is shown in Figure 100 to Figure 105. After 2040, since there are only carbon dioxide emissions from natural gas sources, and these power plants are concentrated in the Thrace, Western Anatolia, and Northwestern Anatolia regional dispatching centers, carbon dioxide emissions are concentrated in these regions.

As mentioned in Section 1.5.3, natural gas emissions in the net zero scenario in this study are higher compared to the IPC 2021 study. Therefore, to reach the carbon emission levels of the previous study, the storage capacity should be increased by 10-15%, resulting in a carbon emission of 18 $MtCO_2$ for the year 2050 in this study, compared to the 15 $MtCO_2$ calculated in the IPC 2021 study.

Figure 100 Distribution of CO_2 emissions from the electricity sector in 2025 by regions in the Net Zero Scenario



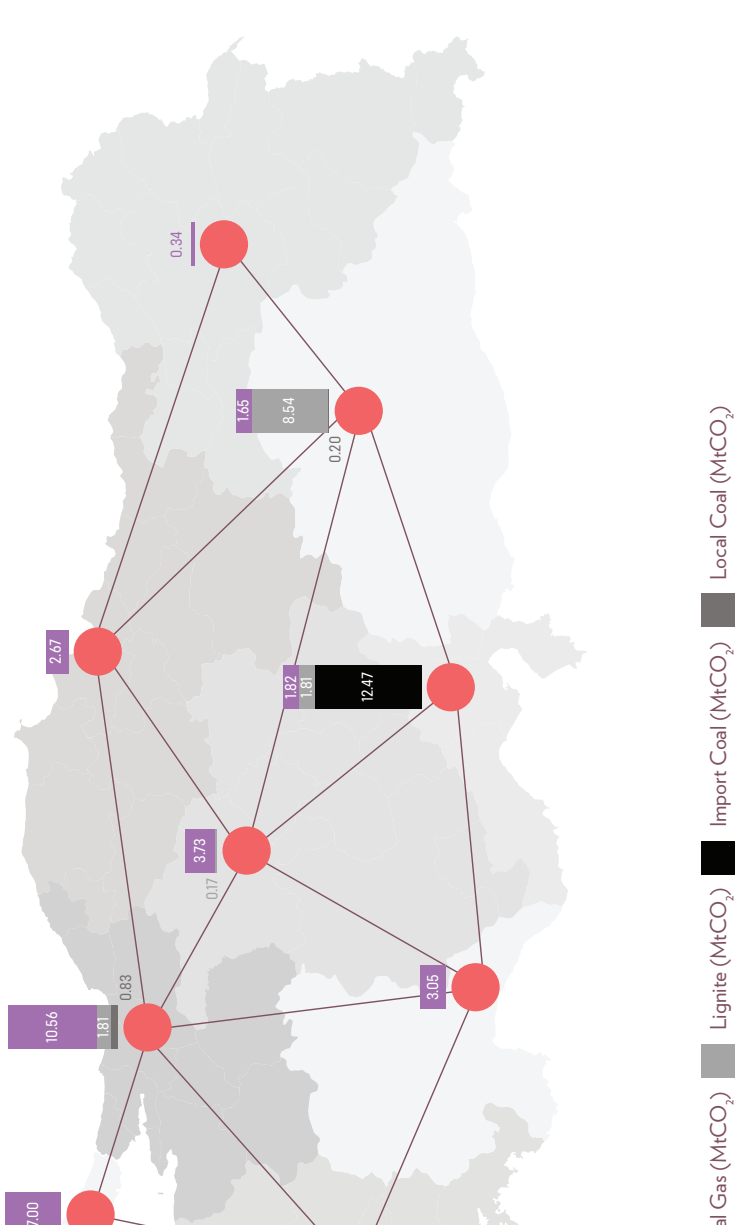


Figure 101 Distribution of CO_2 emissions from the electricity sector in 2030 by regions in the Net Zero Scenario

Figure 102 Distribution of CO_2 emissions from the electricity sector in 2035 by regions in the Net Zero Scenario

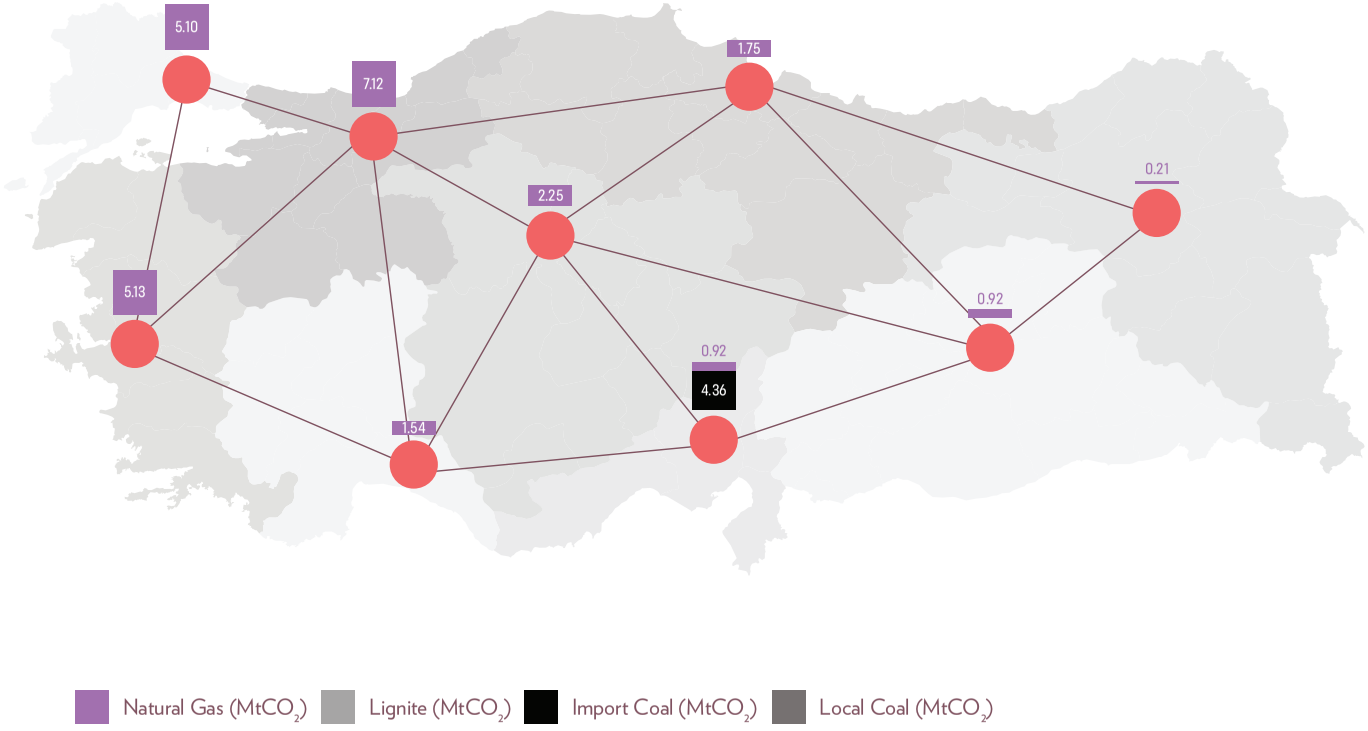


Figure 103 Distribution of CO_2 emissions from the electricity sector in 2040 by regions in the Net Zero Scenario

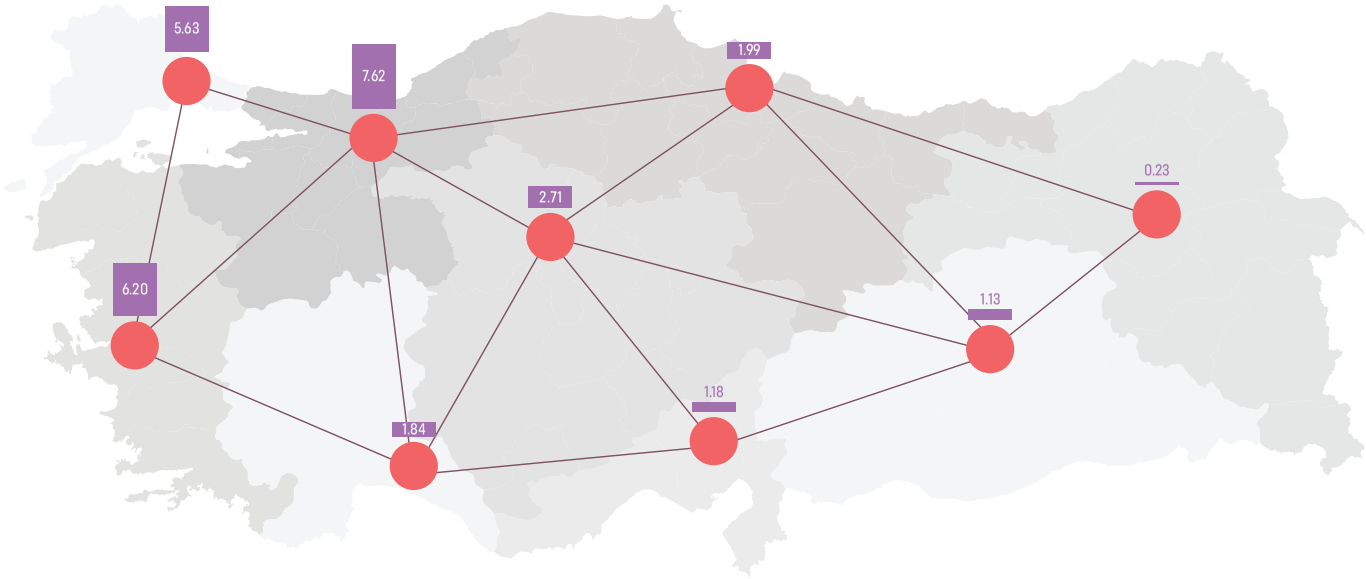
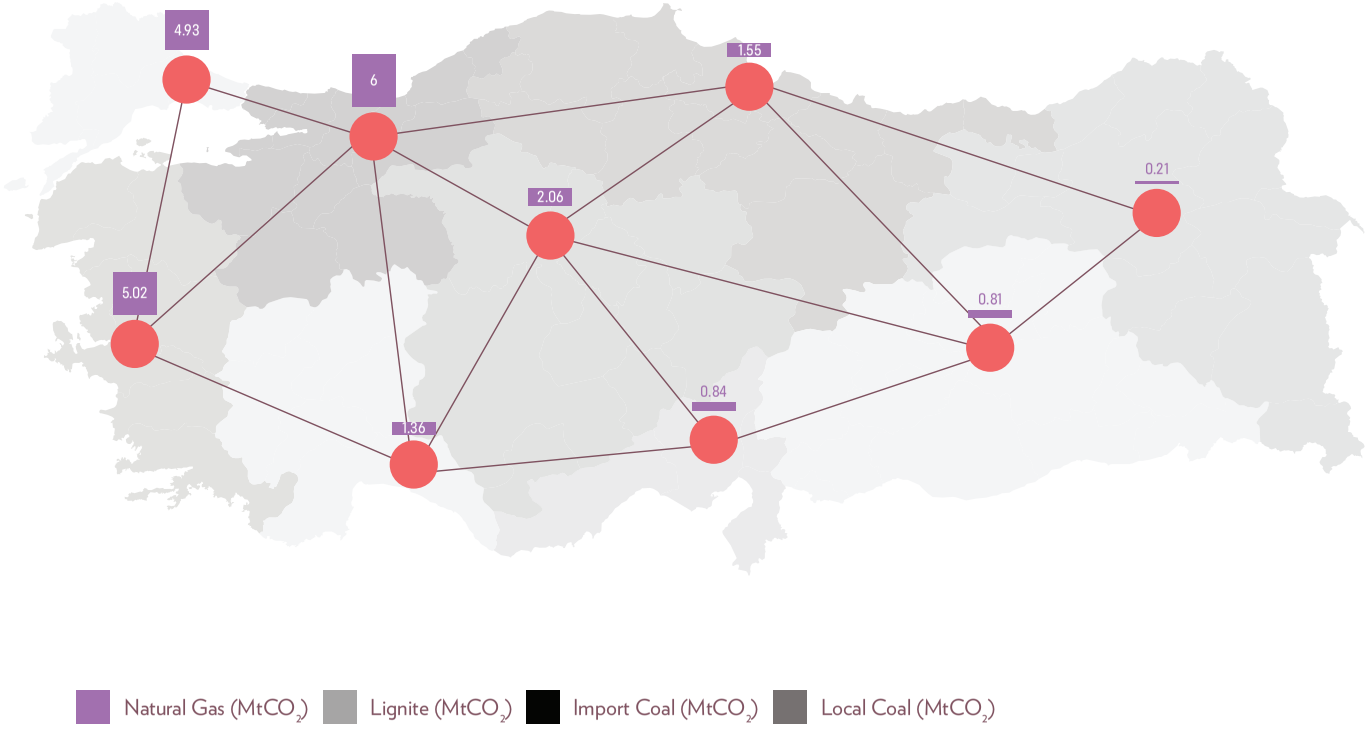


Figure 104 Distribution of CO_2 emissions from the electricity sector in 2045 by regions in the Net Zero Scenario



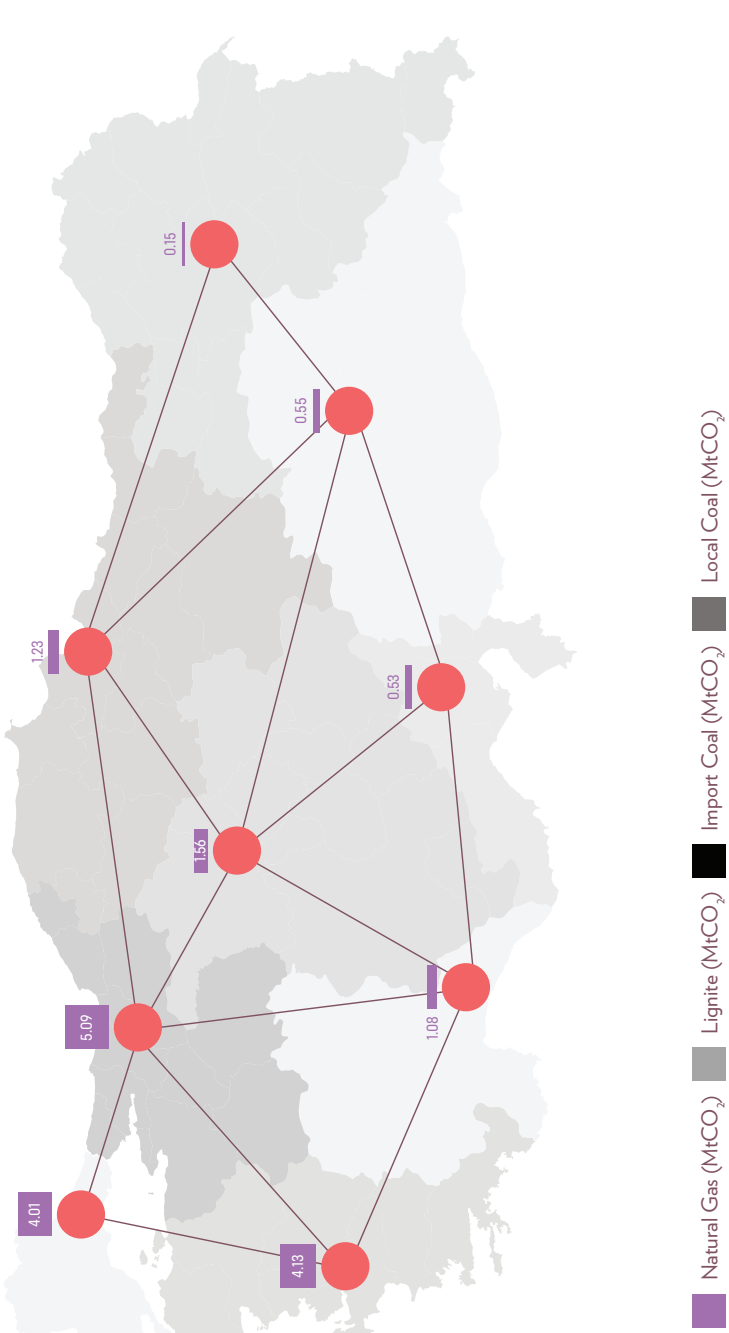


Figure 105 Distribution of CO_2 emissions from the electricity sector in 2050 by regions in the Net Zero Scenario

In this section, the emission reduction pathway in the electricity sector towards the Net Zero target in 2050 is investigated through two scenarios: the Base Case and the Net Zero Scenario, with a focus on 5-year intervals. Initially, market simulations were performed where grid topology and associated constraints (such as line/transformer loadings) are ignored, and only cost-oriented optimization is performed. However, simulations targeting minimum marginal cost can result in grid congestion. Therefore, the transmission network of Turkey is modeled, and simulations addressing grid congestions were conducted by redistributing the production obtained from market simulations, called redispatch. Network simulations were conducted at 5-year intervals, and the results included the distribution of production by energy sources, grid investment needs, redispatch up/down and renewable curtailment quantities, as well as CO_2 emissions. The detailed distribution of results are presented across the TEIAS regional dispatching centers.

In the Net Zero Scenario, due to the high renewable production potential, the amount of renewable energy curtailment is increased compared to the Base Case despite the growing storage capacity (0.36 TWh in 2050 in the Base Scenario and 6.29 TWh in the Net Zero Scenario). On the contrary, in the Net Zero Scenario, the observed amounts of redispatch up/down are lower than that of Base Case due to the reduction in power plants which are eligible for redispatch up/down. The main reason is phasing out of the high-emission fossil fuels, that is 21.37 TWh in 2050 in the Base Case and 13.43 TWh in the Net Zero Scenario.

In the Net Zero Scenario, there is an increased need for grid investments compared to the Base Case. In 2050, on top of TEIAS's investment plan for 2030, additional 4054 km of 400 kV overhead line investment in the Net Zero Scenario, compared to 2596 km in the Base Scenario.

In the electricity sector, CO_2 emissions, which were 135.4 $MtCO_2$ in 2020 in the Base Scenario, are projected to increase to 282 $MtCO_2$ in 2050. However, in the Net Zero Scenario, with the phasing out of fossil fuel power plants and the increase in renewable production, CO_2 emissions are expected to decrease to 18 $MtCO_2$.

2. TRANSPORTATION SECTOR

The share of carbon dioxide emissions in the transportation sector in Turkey is approximately 23%, with over 90% of this coming from[3] road transportation. The energy consumption of the transportation sector is modeled in TEP (Ton of Oil Equivalent), and the CO_2 emissions for each type of transportation vehicle (passenger cars, public transport, freight transport, railway, maritime, and aviation) are calculated separately for both the Base Scenario and the Net Zero Scenario. In this section, the key assumptions for the transportation sector in the Base Scenario and the Net Zero Scenario (Table 22, Table 23, and Table 24) are summarized, and the CO_2 emission results are outlined in five-year intervals. Solutions critical to achieving the goals of the Net Zero Scenario are detailed.

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Table 22 Assumptions used in modeling the transportation sector regarding passenger vehicles

	Base Case				Net Zero Scenario			
Year	Motorization Rate (per thousand)	Number of Electric Vehicles (Million)	Share of Electric Vehicles in Total Passenger Cars (%)	Travel behaviour change (%)	Motorization Rate (per thousand)	Number of Electric Vehicles (Million)	Share of Electric Vehicles in Total Passenger Cars (%)	Travel behaviour change (%)
2020	286	0.1	0.77	0	286	0.1	0.77	0
2025	313	1	5	0	313	2	10	0
2030	340	1.9	10	0	340	3.8	20	0
2035	357	3.85	15.75	0	357	7.7	31.5	1.25
2040	374	5.8	21.5	0	374	11.6	43	2.5
2045	391	7.75	27.25	0	391	15.5	54.5	3.75
2050	408	9.7	33	0	408	19.4	66	5

Table 23 The assumptions used in modeling the transition rate from road transport to rail transport in the transportation sector (%)

	Base Case			Net Zero Scenario		
Year	Ratio of Electric Vehicles to the Total Vehicles in Public Transport (%)	Ratio of Electric Vehicles to the Total Vehicles in Freight Transport (%)	Ratio of Heavy Vehicles with Green Hydrogen to the Total Heavy Vehicles (%)	Ratio of Electric Vehicles to the Total Vehicles in Public Transport (%)	Ratio of Electric Vehicles to the Total Vehicles in Freight Transport (%)	Ratio of Heavy Vehicles with Green Hydrogen to the Total Heavy Vehicles (%)
2020	0	0	0	0	0	0
2025	2.5	2.5	0	5	5	0
2030	5	5	0	10	10	0
2035	6.25	6.25	0	12.5	12.5	1.25
2040	7.5	7.5	0	15	15	2.5
2045	8.75	8.75	0	17.5	17.5	3.75
2050	10	10	0	20	20	5

Table 24 The assumptions used in modeling the transition rate from road transport to rail transport in the transportation sector (%)

	Net Zero Scenario		
Year	Ratio of Transition from Individual Vehicles to Rail Public Transportation on Road Transport (%)	Ratio of Transition from Road Public Transportation to Rail Public Transportation (%)	Ratio of Transition from Road Freight Transportation to Rail Freight Transportation (%)
2020	0	0	0
2025	2.5	5	5
2030	5	10	10
2035	7.5	20	20
2040	10	30	30
2045	12.5	40	40
2050	15	50	50

2.1. BASE CASE

According to the calculations of energy consumption and CO_2 emissions for the transportation sector in the Base Scenario at five-year intervals, the energy consumption of the transportation sector increases from approximately 28.5 million TOE in 2018 to about 38 million TOE in 2030 and doubles to around 58 million TOE in 2050. As shown in Table 25, about two-thirds of this energy consumption comes from road freight transport.

The increase in CO_2 emissions from the transportation sector in the Base Scenario is shown in Table 26 at five-year intervals. CO_2 emissions, starting at 83 $MtCO_2$ in 2018, increase by 17% to 97 $MtCO_2$ in 2030 and by 44% to 120 $MtCO_2$ in 2050. Road freight transport has the largest share in CO_2 emissions from the transportation sector (67% in 2030 and 69% in 2050).

Table 25 Base Scenario – Total energy consumptions by vehicles (1000 TOE)

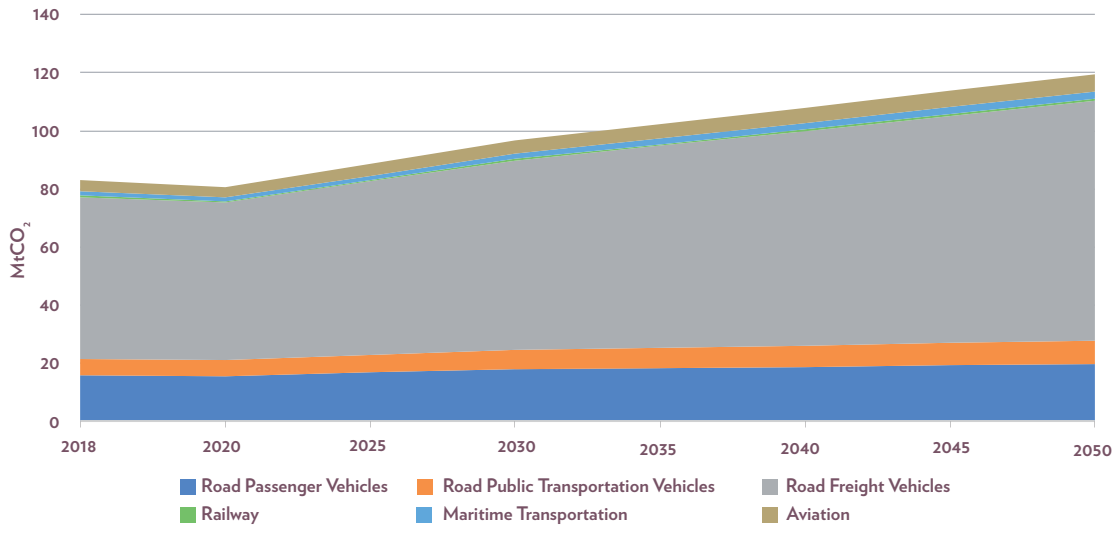
Year	Road Passenger Vehicles	Road Public Transportation Vehicles	Road Freight Vehicles	Railway	Maritime Transportation	Aviation	Total
2020	5,055	1,937	19,366	217	705	1,250	28,530
2025	5,909	2,256	22,556	253	821	1,456	33,250
2030	6,763	2,575	25,745	288	937	1,662	37,970
2035	7,668	2,909	29,086	325	1,059	1,878	42,924
2040	8,572	3,243	32,428	363	1,180	2,094	47,879
2045	9,477	3,577	35,769	400	1,302	2,309	52,833
2050	10,381	3,911	39,110	437	1,423	2,525	57,787

Table 26 Base Scenario – CO_2 emissions ($MtCO_2$)

Year	Road Passenger Vehicles	Road Public Transportation Vehicles	Road Freight Vehicles	Railway	Maritime Transportation	Aviation	Total
2018	15.90	5.60	55.80	0.40	1.50	3.70	82.80
2020	15.60	5.40	54.30	0.40	1.40	3.60	80.70
2025	16.80	5.95	59.80	0.45	1.60	4.05	88.60
2030	18.00	6.50	65.30	0.50	1.80	4.50	96.50
2035	18.43	6.93	69.55	0.55	1.98	4.90	102.25
2040	18.85	7.35	73.80	0.60	2.15	5.30	108.00
2045	19.28	7.78	78.05	0.65	2.33	5.70	113.75
2050	19.70	8.20	82.30	0.70	2.50	6.10	119.50

In the Base Scenario, the share of electric heavy-duty vehicles in the total heavy-duty vehicles is assumed to be 5% in 2030 and 10% in 2050. Under this assumption, CO_2 emissions from road freight transport continue to increase dramatically in the Base Scenario (Figure 106). The ratio of electric passenger cars to total passenger cars in the Base Scenario is assumed to increase from almost zero in 2018 to 10% (1.9 million electric passenger cars) in 2030 and 33% (9.7 million electric passenger cars) in 2050. Under this assumption, although there is an increase in CO_2 emissions from passenger cars by 2050, it is not as dramatic as in road freight transport. These results indicate that a much higher rate of electrification (e-mobility) in transportation is needed to achieve net-zero targets.

Figure 106 Base Scenario – CO_2 emissions ($MtCO_2$)



2.2. Net Zero Scenario

The transition from fossil fuel usage to electricity and another emission-free fuel, green hydrogen, is essential in energy transformation. In the Net Zero Scenario, the ratio of electric vehicles, which had almost zero share in individual car usage in 2020 and is assumed to be 10% in 2030 and 33% in 2050 in the Base Scenario, is assumed to be 20% (3.8 million electric passenger cars) in 2030 and 66% (19.4 million electric passenger cars) in 2050, which is twice that of the Base Scenario. The ratio of electric heavy-duty vehicles to total heavy-duty vehicles, assumed to be 5% in 2030 and 10% in 2050 in the Base Scenario, is assumed to be 10% in 2030 and 20% in 2050 in the Net Zero Scenario, again twice that of the Base Scenario.

In addition to the transition to e-mobility in road passenger cars and heavy-duty transport, the Net Zero Scenario includes assumptions about changes in travel behavior (such as transitioning from cars to bicycles or reducing long-distance travel) and the transformation to electric rail transport (e-mobility). Furthermore, in the Net Zero Scenario, the ratio of heavy-duty vehicles running on hydrogen in road transport is assumed to be zero in 2030 and 5% in 2050.

Under these fundamental assumptions, the energy consumption of the transportation sector by vehicle type in the Net Zero Scenario is provided in Table 27 at five-year intervals. Energy consumption, which was approximately 28.5 million TEP in 2018, decreases to approximately 26.4 million TEP in 2030 and further decreases to 15.2 million TEP in 2050. Similar to the Base Scenario, road freight transport has the highest share in this energy consumption.

Table 27 Net Zero Scenario – Total energy consumptions by vehicles in the Base Scenario (1000 TOE)

Year	Road Passenger Vehicles	Road Public Transportation Vehicles	Road Freight Vehicles	Railway	Maritime Transportation	Aviation	Total
2020	5,040	1,931	19,315	216	703	1,247	28,452
2025	5,055	1,937	19,366	217	705	1,250	28,530
2030	4,524	1,778	17,778	145	716	1,456	26,396
2035	3,993	1,619	16,189	72	727	1,662	24,262
2040	3,328	1,380	13,880	54	712	1,878	21,231
2045	2,664	1,140	11,572	36	697	2,094	18,201
2050	1,999	901	9,263	18	681	2,309	15,170

Figure 107 Total energy consumption by vehicles (1000 TOE) in the Base Scenario and Net Zero Scenario

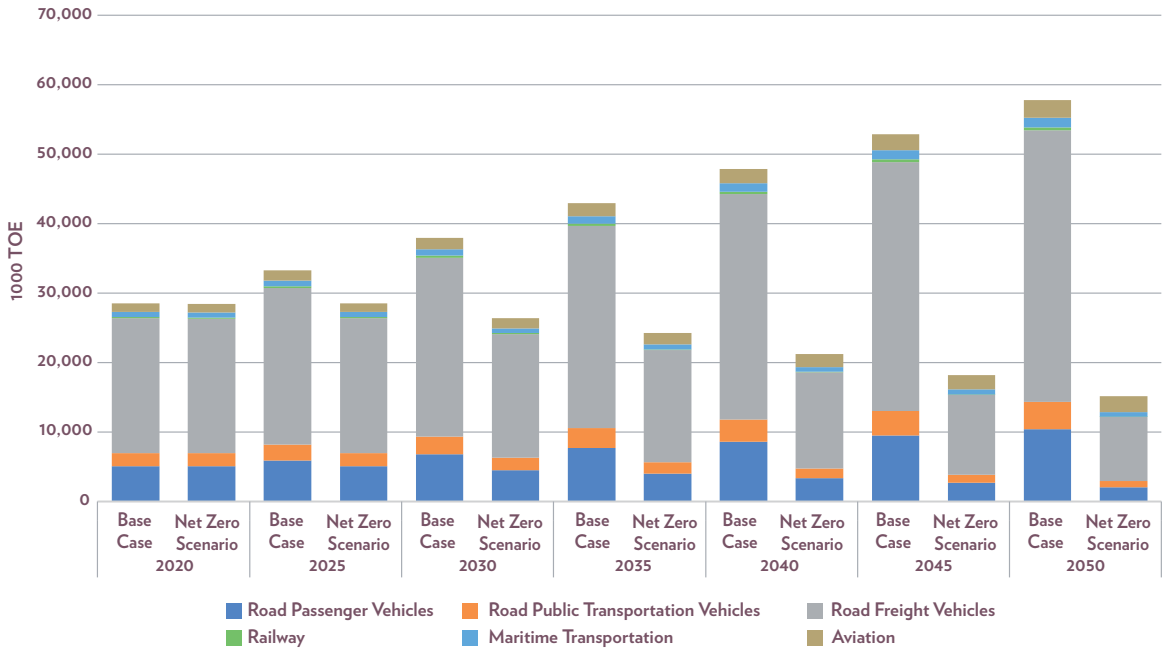


Figure 108 The change in total energy consumption in the transportation sector between the Net Zero Scenario and the Base Scenario

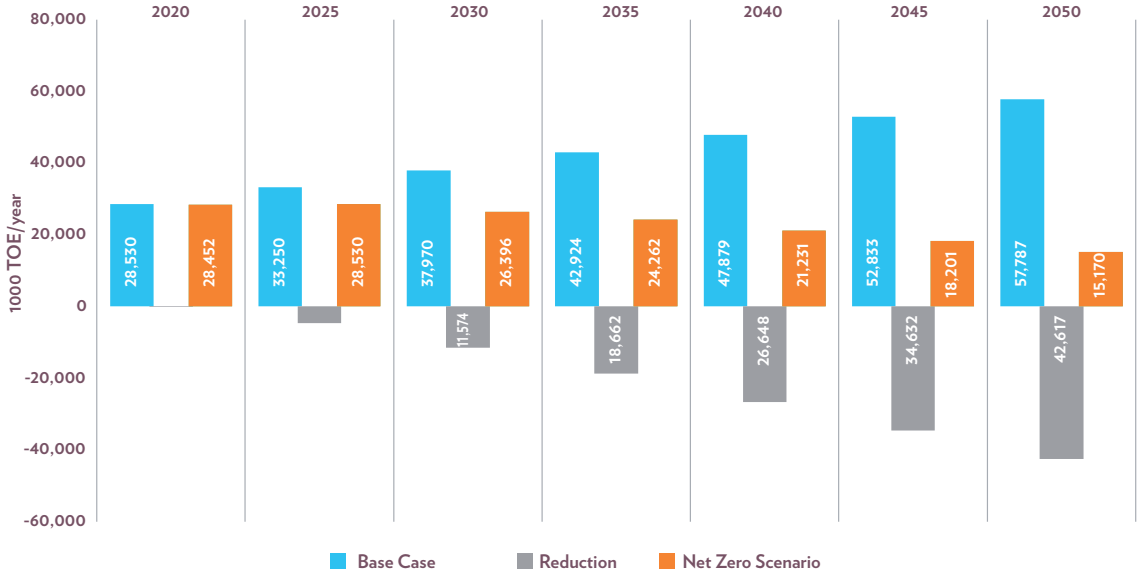
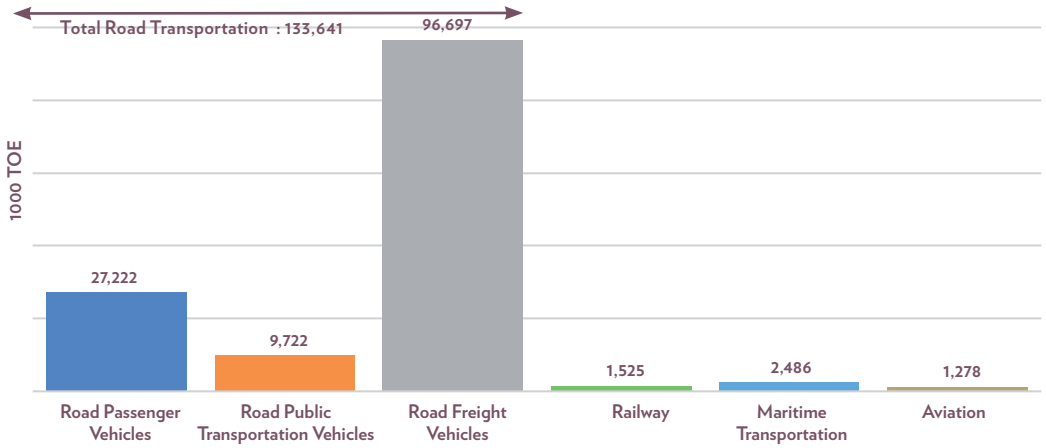


Figure 109 The distribution of the decrease in energy consumption across sector categories in the Net Zero Scenario to the Base Scenario



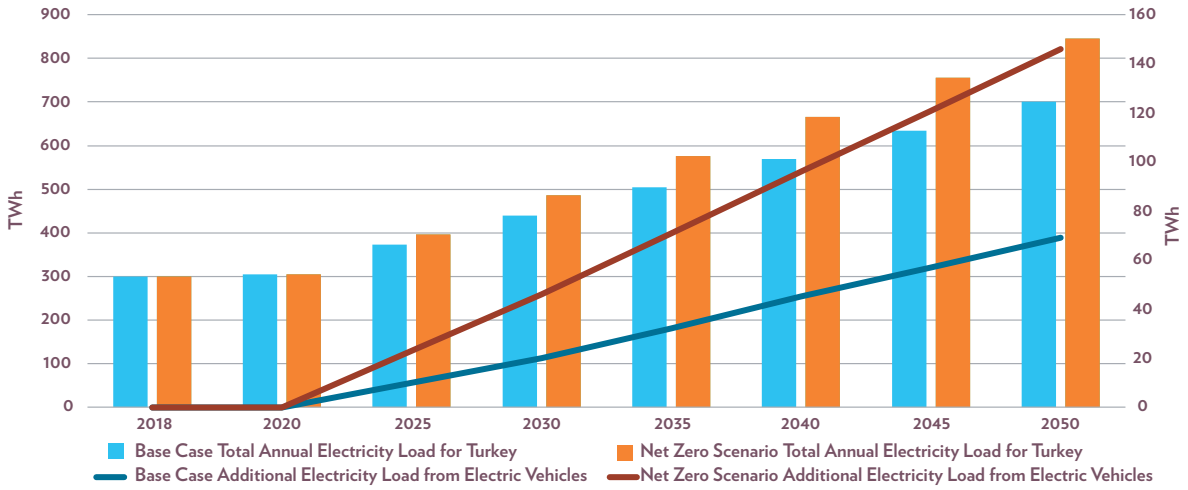
The comparison of energy consumption by vehicles in the Net Zero Scenario with the Base Case is presented in Figure 107 at five-year intervals. The change in total energy consumption in the transportation sector in the Net Zero Scenario compared to the Base Case is shown in Figure 108. It is observed that energy consumption in the Net Zero Scenario has decreased by 73% compared to the Base Case. The distribution of cumulative energy consumption reduction by sector categories in the Net Zero Scenario compared to the Base Case is provided in Figure 109.

The electrification in road transportation and freight will lead to an increase in electricity consumption. The impact of electrification on total electricity consumption in the transportation sector at five-year intervals is shown in Table 28 and Figure 110. In the Base Scenario, the electricity

Table 28 The impact of electrification on the total electricity consumption in the transportation sector

Year	Base Scenario Total Annual Electricity Load for Turkey (TWh)	Base Scenario Additional Electricity Load from Electric Vehicles (TWh)	Net Zero Scenario Additional Electricity Load from Electric Vehicles (TWh)	Net Zero Scenario Total Annual Electricity Load for Turkey (TWh)
2018	300	-	-	300
2020	305	-	-	305
2025	373	10	23	396
2030	440	20	46	486
2035	505	32	71	576
2040	570	45	96	666
2045	635	57	121	756
2050	700	69	146	846

Figure 110 The effect of electrification on the total electricity consumption in the transportation sector



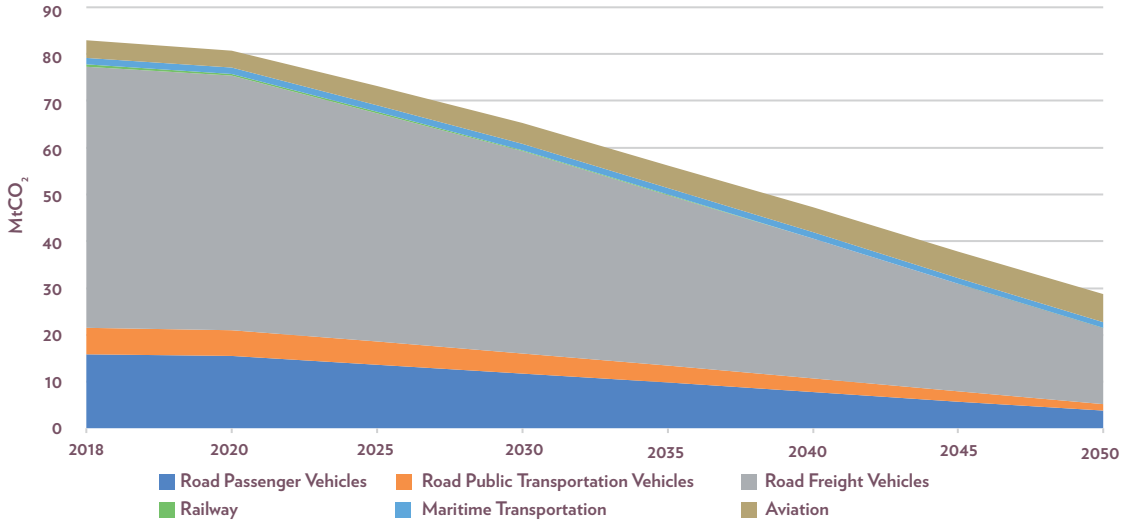
demand from electric vehicles constitutes 4% and 9% of the total load in 2030 and 2050, respectively. In contrast, these proportions increase to 9% and 17% in the Net Zero Scenario.

With the assumptions outlined above (e-mobility, e-transformation, and changes in travel behavior), when examining the CO_2 emissions in the transportation sector in the Net Zero Scenario (Table 29), it is observed that the CO_2 emissions from the transportation sector, which were 83 $MtCO_2$ in 2018, decrease by 21% to 65.3 $MtCO_2$ in 2030 and by 65% to approximately 29 $MtCO_2$ in 2050. In the Net Zero Scenario, as in the Base Case, road freight transportation continues to have the largest share in CO_2 emissions from the transportation sector.

Table 29 Net Zero Scenario – CO_2 emissions ($MtCO_2$)

Year	Road Passenger Vehicles	Road Public Transportation Vehicles	Road Freight Vehicles	Railway	Maritime Transportation	Aviation	Total
2018	15.9	5.6	55.8	0.4	1.5	3.7	82.8
2020	15.6	5.4	54.3	0.4	1.4	3.6	80.7
2025	13.7	4.9	48.8	0.3	1.4	4.1	73.0
2030	11.8	4.3	43.2	0.1	1.4	4.5	65.3
2035	9.8	3.6	36.5	0.1	1.3	4.9	56.2
2040	7.8	2.9	29.8	0.1	1.3	5.3	47.1
2045	5.8	2.2	23	0	1.2	5.7	38.0
2050	3.8	1.5	16.3	0	1.1	6.1	28.9

Figure 111 Net Zero Scenario – CO_2 emissions ($MtCO_2$)



In the Net Zero Scenario, the reduction in emission levels in road passenger cars and transportation sectors by vehicle type is shown in Figure 111, and it is compared with the Base Scenario in Figure 112. In the Net Zero Scenario, CO_2 emissions in 2050 have decreased by 65% compared to 2020. When comparing the CO_2 emissions in both scenarios, it is observed that in the Net Zero Scenario, the CO_2 emissions in 2050 are 75% lower than in the Base Scenario. Figure 113 provides a comparison of the CO_2 emissions in both scenarios by sub-sectors of the transportation sector.

Figure 112 Comparison of total CO_2 emissions between the Base Scenario and the Net Zero Scenario

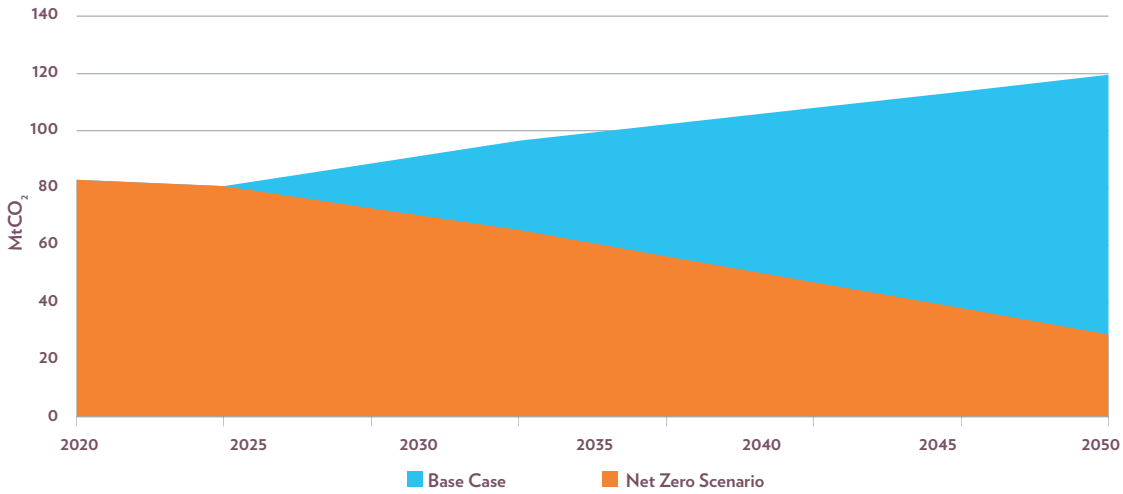
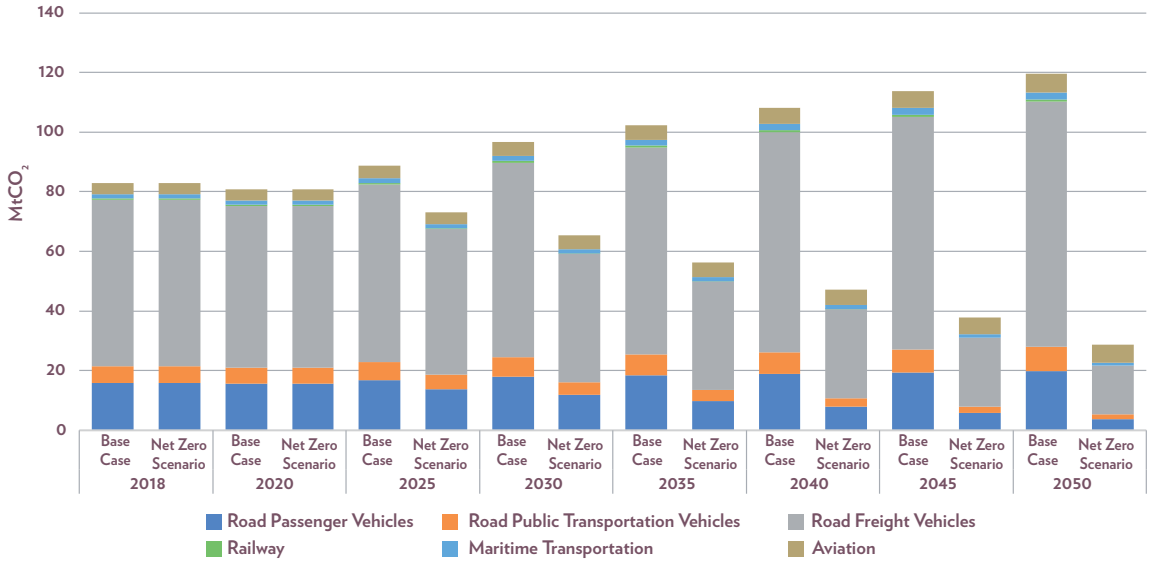


Figure 113 Comparison of CO_2 emissions in the transportation sector between the Base Scenario and the Net Zero Scenario based on sub-sectors



The assumptions made in the Net Zero Scenario and a summary of CO_2 emissions are provided in Table 30. In the Base Scenario, the annual emission amounts calculated for the transportation sector are 97 $MtCO_2$ in 2030 and 120 $MtCO_2$ in 2050. After considering the e-mobility, e-transformation, and travel behavior changes outlined in the Net Zero Scenario, these amounts decrease to 65 $MtCO_2$ and 29 $MtCO_2$, respectively. Following these solutions, an additional electricity load of 46 TWh in 2030 and 146 TWh in 2050 is expected to be added to the electricity grid. It is observed that electrification in the Net Zero Scenario significantly contributes to reducing CO_2 emissions, and the impact of the increase in electric passenger vehicles on CO_2 emissions is shown in Figure 114.

Figure 114 The impact of the increase in the number of electric passenger vehicles on the total CO_2 emissions in the transportation sector

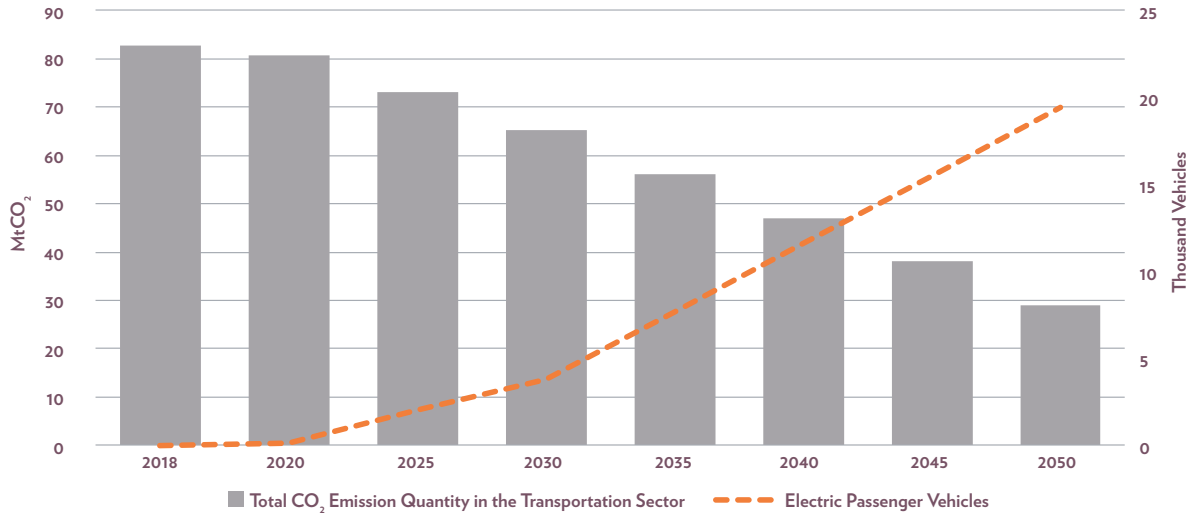


Table 30 The impacts of e-mobility, e-transformation, and changes in travel behavior on CO_2 emissions and electricity consumption

Year	Total CO_2 Emission Quantity in the Transportation Sector ($MtCO_2$)	Electric Passenger Vehicles (Thousand Vehicle)	Change in Travel Behavior (%)	Percentage of Electric Vehicles in Public Transportation among Total Vehicles (%)	Percentage of Electric Vehicles in Freight Transportation among Total Vehicles (%)	Percentage of Heavy-duty Vehicles Running on Green Hydrogen among Total Heavy-duty Vehicles (%)	Transition Rate from Individual Vehicles to Rail Mass Transit on Roadways (%)	Transition Rate from Road Public Transportation Vehicles to Rail Mass Transit (%)	Transition Rate from Road Freight Transport to Rail Freight Transport on Highways (%)	Total Additional Electricity Load (TWh)
2018	82.8	-	-	-	-	-	-	-	-	-
2020	80.7	0.1	0	0	0	0	0	0	0	-
2025	73	2	0	5	5	0	3	5	5	23
2030	65.3	3.8	0	10	10	0	5	10	10	46
2035	56.2	7.7	1	13	13	1	8	20	20	71
2040	47.1	11.6	3	15	15	3	10	30	30	96
2045	38	15.5	4	18	18	4	13	40	40	121
2050	28.9	19.4	5	20	20	5	15	50	50	146

3. BUILDING SECTOR

Chapter 8 of the report titled "Turkey's Decarbonization Roadmap - Net Zero in 2050" presents an assessment of emissions from buildings in Turkey under the base case pathway and the studied Net Zero Scenario. In Turkey, buildings are responsible for around 12% of energy-related carbon dioxide (CO_2) emissions, of which 73.5% comes from residential buildings and 26.5% from commercial and institutional buildings (2018 data).

3.1. ASSUMPTIONS

3.1.1. Base Case

In the Base Scenario, emissions from buildings in Turkey were calculated based on the total primary energy consumption projected until 2050 using the Ministry of Environment and Urbanization's Building Sector Energy Efficiency Technology Atlas (MoEU, 2021). The breakdown of electricity consumption by building type for the base years 2018 and 2019 was determined using TURKSTAT data and energy balance tables. Energy balance tables were also utilized for calculating the final energy consumption based on fuel (TURKSTAT, 2021; MoEU, 2020). Final consumption was obtained by calculating the primary energy factor on a year-by-year basis, considering the electricity sector production model. Emission factors from Turkey's National Greenhouse Gas Inventory were employed for calculating CO_2 emissions from energy consumption in buildings (TURKSTAT, 2021). Building CO_2 emissions were calculated based on building type (residential and commercial/institutional buildings) and the type of fuel used (MoEU, 2020).

3.1.2. Net Zero Scenario

In the Net Zero Scenario, the calculation of energy consumption in buildings involved categorizing buildings into two groups: "existing" and "new" buildings. For residential and commercial/institutional buildings, the renovation rate of buildings was calculated on a yearly basis using the rates of new building construction, demolition, and renovation. The consumption of electricity, natural gas, LPG, coal, liquid fuels, biomass, and renewable sources was accounted for.

Energy consumption performance for new buildings and renovated buildings, compared to existing ones, was determined using assumptions based on literature. Improvement rates in energy performance on a yearly basis were found for electric household and office appliances using literature-based assumptions. The energy consumption of existing and new buildings, as well as their total consumption, was calculated on a yearly basis.

Projection has been made based on the emission budget using intervention options to reduce greenhouse gas emissions. The variables used for this purpose are as follows:

4 | Improved energy performance of electrical appliances
5 | Ratio of building demolition, building renovation and new building construction
6 | Switching to electricity in old buildings (for heating purposes)
7 | Electricity utilization rate in new buildings,
8 | Behavior change

Consumptions not included in building performance and the sources for heating needs (electricity, coal, liquid and gas fuels, biomass, etc.) have been calculated on an annual basis. Energy consumptions for lighting, cooking, electric appliances, and the improvements anticipated in building performance and electric appliances, along with the final energy consumptions after these enhancements, have been calculated (Shura,

2020). The International Energy Agency's Net Zero by 2050 Report was used to confirm assumptions (IEA, 2021). The following variables were used to reflect intervention options determined to achieve the allocated emission budget for buildings in the model:

1 | Heat pump coefficient of performance (COP)

2 | Heat pump utilization rate

3 | Coal-to-hydrogen transition rate

4 | Natural gas to hydrogen transition rate

5 | Coal-to-electricity transition rate

6 | Rate of transition from natural gas to electricity

7 | Rate of transition from liquid fossil fuels to electricity.

3.2. ELECTRICITY CONSUMPTION IN BUILDINGS (BASE CASE AND NET ZERO SCENARIO)

In this report, key findings for buildings under the Base Case and Net Zero Scenarios are summarized at five-year intervals. As a summary, in the Net Zero Scenario compared to the Base Case, assumptions for electricity consumption in buildings (TWh) are provided in Table 31; final electricity consumption by building types and fuel types is presented in Table 33; and total electricity consumption is given in Table 32 and Figure 115.

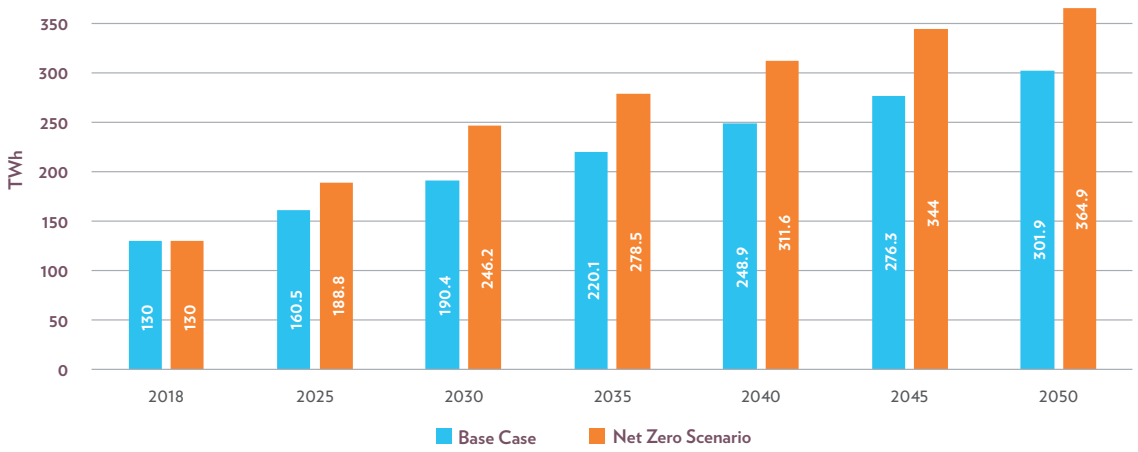
Table 31 Assumptions for electricity consumption in buildings in the Base Scenario and Net Zero Scenario (TWh)

Assumptions	Current	Base Case			Net Zero Scenario	
	2018	2030	2050	2070	2030	2050
Residential Electricity Consumption for Heating Purposes	20.4	27.4	38	47.1	61.4	98.4
Electricity Consumption of Household Electrical Appliances	34.1	58.5	38	126.1	71.5	113.1
Electricity Consumption for Heating Purposes in Commercial/Institutional Buildings	24.1	32.5	98.3	65.5	31.7	30.4
Electricity Consumption of Electrical Office Equipment	51.4	72	51.5	145.2	81.6	122.9
Natural Gas and LPG Consumption in Residences	121.4	207.6	114.2	260	106	0
Natural Gas and LPG Consumption in Commercial/ Institutional Buildings	38.3	75.9	240.2	95.1	30.2	0
Coal Consumption in Residences	34.9	24.2	87.8	10.8	0	0
Coal Consumption in Commercial/Institutional Buildings	10.4	6.2	16.2	2.7	0	0
Liquid Fuel Consumption in Residences	2.6	2.3	4.1	1.9	0	0
Liquid Fuel Consumption in Commercial/Institutional Buildings	9.3	10.4	2.1	8.8	0	0
Biomass Consumption in Residences	18.1	40.3	47.4	52.9	0	0

Table 32 Electricity consumption from buildings in the Base Scenario and Net Zero Scenario (TWh)

	Base Case: Building Electricity Consumption (TWh)	Net Zero Scenario: Building Electricity Consumption (TWh)
2018	130	130
2025	160.5	188.8
2030	190.4	246.2
2035	220.1	278.5
2040	248.9	311.6
2045	276.3	344
2050	301.9	364.9

Figure 115 Assumptions for electricity consumption in buildings in the Base Scenario and Net Zero Scenario (TWh)



In both scenarios, residential electricity consumption for heating purposes increases compared to the 2018 levels. However, in the Net Zero Scenario, it is 2.6 times higher than the Base Case in 2050. Fossil fuel consumption in residential buildings decreases by over 50% in the Base Case by 2050 compared to 2018, while in the Net Zero Scenario, coal consumption in residential buildings is eliminated from 2030 onwards.

Natural gas and LPG consumption in residential and commercial buildings in the Base Case doubles by 2050 due to the transition from coal to natural gas. In the Net Zero Scenario, due to electrification, consumption of natural gas and LPG is eliminated by 2050, and liquid fuel and biomass consumption are also phased out by 2030.

This study examines the total electricity consumption of buildings under two categories: residential electricity consumption and commercial/institutional electricity consumption. In 2050, in the Net Zero Scenario, residential electricity consumption increases by 52% compared to the Base Case (Figure 116), while in the same year, commercial/institutional buildings experience a 7% decrease in electricity consumption in the Net Zero Scenario compared to the Base Case (Figure 117).

Table 33 Electricity consumption assumptions for residential and commercial buildings in the Base Scenario and Net Zero Scenario (TWh)

	Base Case: Residential Electricity Consumption (TWh)	Net Zero Scenario: Residential Electricity Consumption (TWh)	Base Case: Commercial/Institutional Electricity Consumption (TWh)	Net Zero Scenario: Commercial/Institutional Electricity Consumption (TWh)
2025	71.2	89.9	89.4	93.5
2030	85.9	127.6	104.5	113.4
2035	99.3	146.9	120.8	126.8
2040	112.3	168.5	136.6	138.7
2045	124.6	192.6	151.6	147.6
2050	136.2	208.4	165.7	153.3

Figure 116 Residential electricity consumption assumptions in the Base Scenario and Net Zero Scenario (TWh)

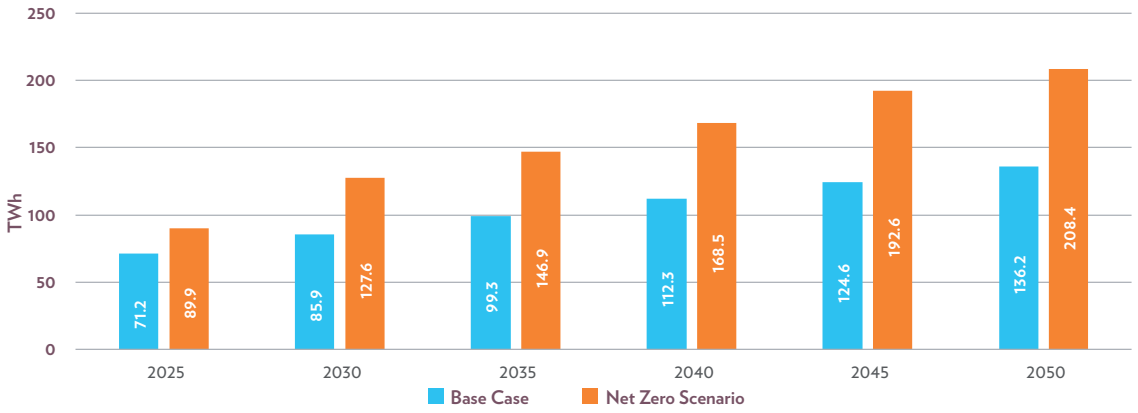
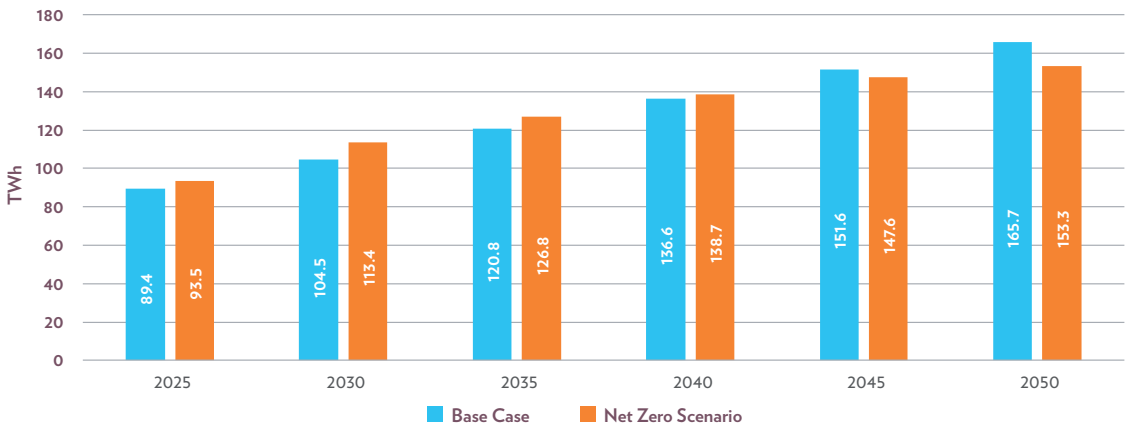


Figure 117 Electricity consumption assumptions in commercial buildings in the Base Scenario and Net Zero Scenario (TWh)



3.3. CARBON DIOXIDE EMISSIONS (BASE CASE AND NET ZERO SCENARIO)

In the previous section, CO_2 emissions based on building type (residential and commercial/institutional buildings) and fuel type were calculated for each five-year interval up to 2050 using the electricity consumption figures provided. The total CO_2 emissions from electricity consumption in buildings in the Net Zero Scenario are compared to the Baseline Scenario in Table 34 and Figure 118.

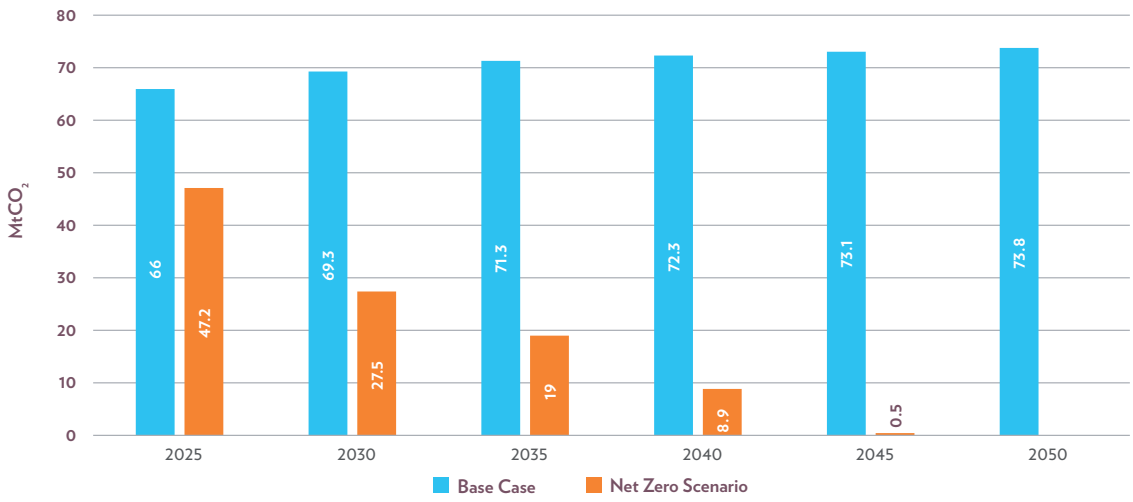
The distribution of CO_2 emissions by building type is presented in Table 35. CO_2 emissions from electricity consumption in residential and commercial buildings are compared by scenario in Figures 119 and 120.

The total emissions from buildings decrease by 46% from the 2018 level to 27.5 million tons in 2030 and are completely eliminated by 2046 in the Net Zero Scenario. The most significant

Table 34 Carbon dioxide emission assumptions for buildings in the Base Scenario and Net Zero Scenario ($MtCO_2$)

	Base Case: Building CO_2 Emissions ($MtCO_2$)	Net Zero Scenario: Building CO_2 Emissions ($MtCO_2$)
2025	66	47.2
2030	69.3	27.5
2035	71.3	19
2040	72.3	8.9
2045	73.1	0.5
2050	73.8	0

Figure 118 Carbon dioxide emission assumptions for buildings according to the Base Scenario and Net Zero Scenario



intervention contributing to this reduction in the Net Zero Scenario is the discontinuation of the use of coal and liquid fuels for heating in residential and commercial/institutional buildings starting from 2030, with a partial shift to natural gas and a substantial transition to electric heating.

Recent initiatives, such as the "Public Buildings Energy Efficiency (KABEV)" program launched in 2022 with the support of the World Bank, commitments by municipalities to achieve a 40% emission reduction by 2030 in their "Sustainable Energy and Climate Action Plans (SECAP)," the requirement to build "nearly zero-energy buildings" for structures over 5000 m2 starting in 2023, efforts to transition to heat pumps, regional heating projects, and other positive developments enhance the likelihood of achieving the net-zero target for buildings by 2050.

Table 35 Carbon dioxide emission assumptions for residential and commercial buildings in the Base Scenario and Net Zero Scenario ($MtCO_2$)

	Base Case: Residential CO_2 Emission ($MtCO_2$)	Net Zero Scenario: Residential CO_2 Emission ($MtCO_2$)	Base Case: Commercial/Institutional CO_2 Emission ($MtCO_2$)	Net Zero Scenario: Commercial/Institutional CO_2 Emission ($MtCO_2$)
2025	47.6	34.7	18.4	12.6
2030	49.9	20.7	19.4	6.8
2035	51.4	14.8	20	4.1
2040	52	7.3	20.3	1.6
2045	52.6	0.4	20.5	0.7
2050	53.1	0	20.7	0

Figure 119 Residential carbon dioxide emissions assumptions in the Base Scenario and Net Zero Scenario ($MtCO_2$)

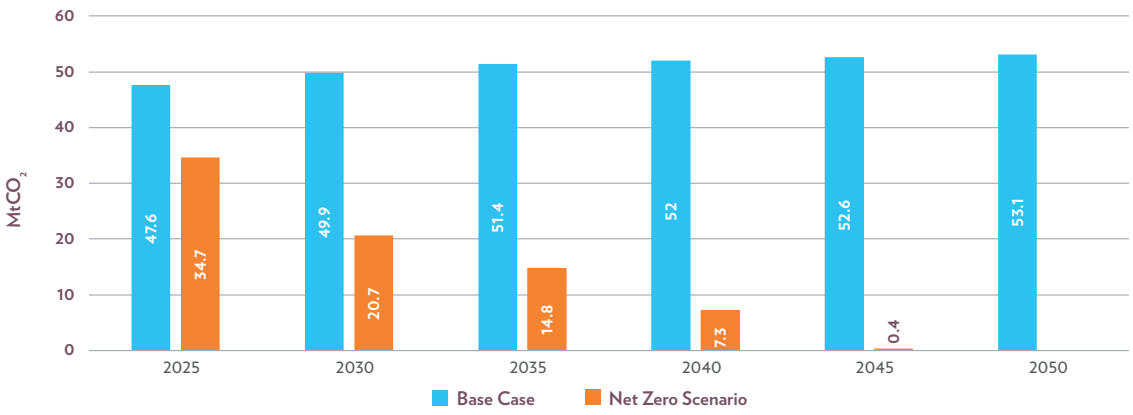
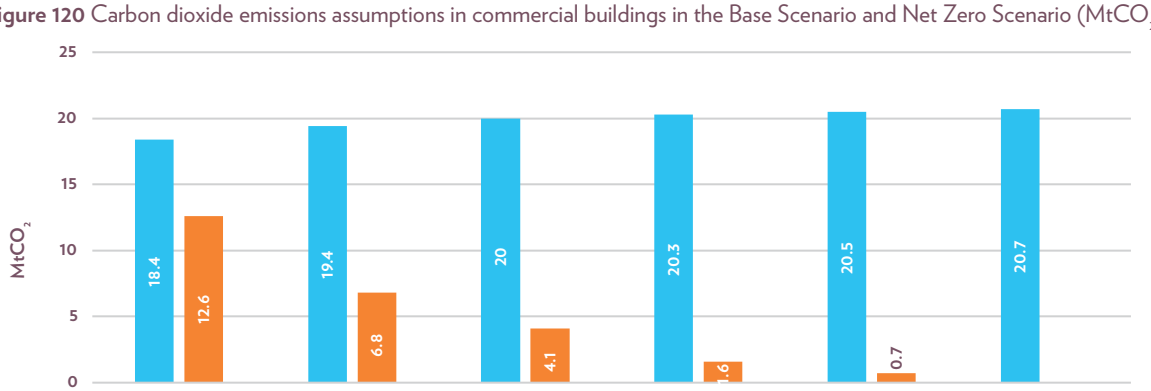


Figure 120 Carbon dioxide emissions assumptions in commercial buildings in the Base Scenario and Net Zero Scenario ($MtCO_2$)



4. INDUSTRIAL AND OTHER PRODUCTIVE SECTORS

The 9th section of the report titled "Turkey's Decarbonization Roadmap - Net Zero by 2050" evaluates energy consumption and emissions from industrial processes in Turkey according to the Base Scenario and Net Zero Scenario. As emphasized in the report, emissions from industry, as well as carbon dioxide emissions from energy consumption in producer sectors such as agriculture and services, constitute approximately 35% of the total carbon dioxide emissions (2018 data) in Turkey. The report provides details on the assumptions used for the Base Scenario and Net Zero Scenario in the macroeconomic model and consolidates the 17 sectors included in the macroeconomic model into 5 categories.

Table 36 summarizes the total production and export shares of producer sectors in the Turkish economy, along with energy intensity, the share of different fuel types in energy usage, and carbon dioxide emissions.

The key findings for producer sectors in both the Base Scenario and Net Zero Scenarios are summarized at five-year intervals in this report. Solutions critical to achieving the goals of the Net Zero Scenario are also detailed.

Table 36 Shares of producer sectors in total production and exports, energy intensity, share of fuels in energy use and CO_2 emissions in 2018

Major Sectors		Share in Production (%)	Share in Exports (%)	Energy Density: Energy (TOE) / Generation (2018 TL)	Share of fuels in the Energy Consumption (TOE) of the Sector (%)						CO_2 Emissions of Industry Sectors (Mt)		
					Coal	Oil	Natural Gas	Electricity	Other	Total	Caused by Energy Consumption	Caused by Industrial Processes	Total
High Energy Intensive Sectors (HES)	Minerals other than metals: Cement etc.	2.2	2.5	57.5	26.7	35.7	17.7	11.6	8.4	100	30	43.9	73.9
	Iron-Steel	3.2	7.3	35.3	54.5	0.1	14.5	27.1	3.8	100	4.2	12.8	17
	High Energy Industry Sectors	8.7	15.7	7.8	10.8	0.3	49.6	32	7.3	100	11.2	1.8	13
Low Energy Intensive Sectors (LES)		24.9	56.9	5.1	11.7	1.3	27.5	36.8	22.7	100	18.1	1.4	19.5
Agriculture (AGR)		10.2	7.7	5.6		65.1	3.8	17.4	13.7	100	9.4	0	9.4
Services (SER)		47.7	7.8	3.7	7.1	6.5	29.7	52.8	4	100	9.2	0	9.2
Energy (EN)		3.1	2	-	-	-	-	-	-	-	8	0	8
Total		100	100								90.2	59.8	150

4.1. ASSUMPTIONS

The trajectory of CO_2 emissions from producer sectors starting from 2018 in the Base Case and Net Zero Scenario is determined based on the assumptions of demand dynamics in the macroeconomic model, as well as the assumptions of energy efficiency, electrification, renewable energy (wind, solar, biomass and geothermal), green hydrogen and carbon capture and sequestration technologies (CCSU) that cause a reduction in emissions.

Demand Change

For the Turkish economy, the assumption was made that demand in high-emission sectors (HES), given in Table 37, would change in line with the global demand projections of the International Energy Agency. Accordingly:

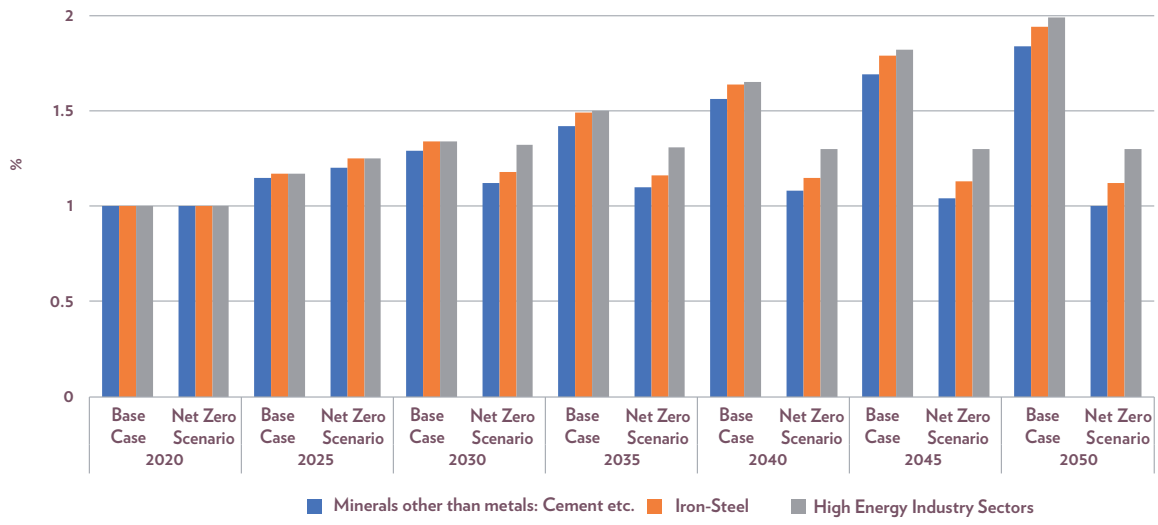
- Global demand in the non-metallic minerals sector, such as cement, will first increase but then decline, reaching 2020 levels in 2050,
- Global demand in the iron and steel sector will increase, reaching 12% above 2020 levels in 2050;

In other energy-intensive sectors, such as the chemical sector, global demand is assumed to be 30% above 2020 levels in 2050 (see Table 37 and Figure 121)

Table 37 Assumed demand change over the years in High Emission Industry sectors (HES)

	Base Case							Net Zero Scenario						
	2020	2025	2030	2035	2040	2045	2050	2020	2025	2030	2035	2040	2045	2050
Minerals other than metals: Cement etc	1	1.15	1.29	1.42	1.56	1.69	1.84	1	1.2	1.12	1.1	1.08	1.04	1
Iron-Steel	1	1.17	1.34	1.49	1.64	1.79	1.94	1	1.25	1.18	1.16	1.15	1.13	1.12
High Energy Industry Sectors	1	1.17	1.34	1.5	1.65	1.82	1.99	1	1.25	1.32	1.31	1.3	1.3	1.3

Figure 121 Assumed demand change over the years in High Emission Industry sectors (HES)



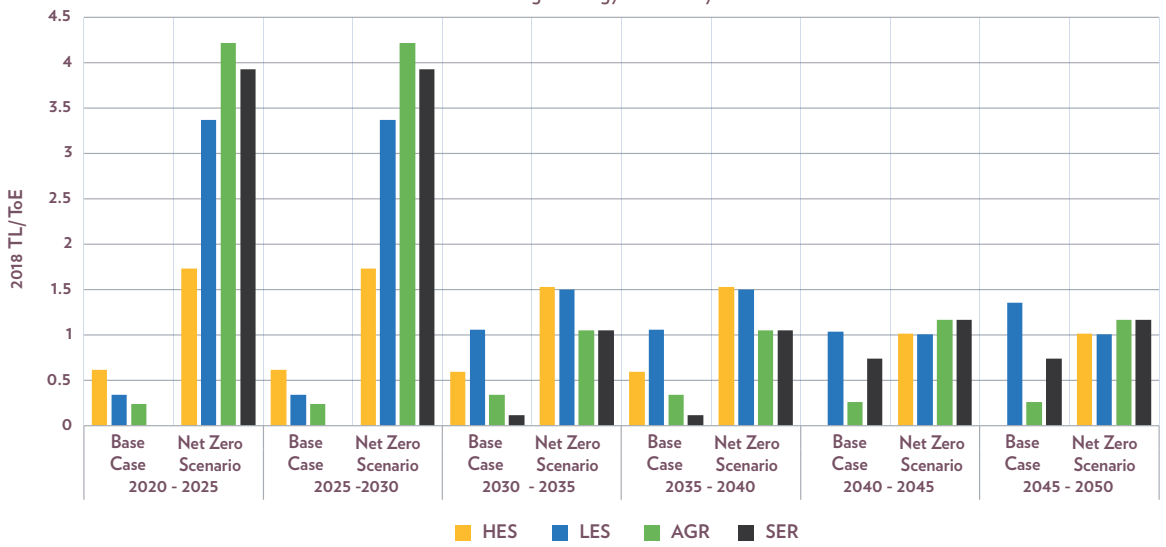
Energy (and process) efficiency

It is assumed that the contribution of the increase in energy efficiency in high-emitting industrial sectors to the Net Zero Scenario will be relatively higher for the 2020-2030 period and that this contribution will be realized at a slower pace in the following period (IEA, 2021). The contribution of the increase in energy efficiency is assumed to be higher in other sectors between 2020 and 2030, as in the case of the HEP. In the low-emission industrial sectors (LES), an average annual energy efficiency growth rate of 3.4% between 2020 and 2030 (relative to the Base Case), 1.5% between 2030 and 2040, and around 1% between 2040 and 2050 (IRENA, 2018; Material Economics, 2019; IEA, 2021). The assumptions on the rate of increase in energy efficiency in the productive sectors under the Base Case and Net Zero Scenario (Net Zero Scenario relative to the Base Case) at five-year intervals are summarized in Table 38 and Figure 122.

Table 38 The assumed rate of increase in average energy efficiency in the Base Case (2018 TL/TEP) and the assumed rate of increase in average energy efficiency in the Net Zero Scenario compared to the Base Case (2018 TL/TEP) over the years in all productive sectors (excluding energy)

	Base Case						Net Zero Scenario					
	2020 - 2025	2025 - 2030	2030 - 2035	2035 - 2040	2040 - 2045	2045 - 2050	2020 - 2025	2025 - 2030	2030 - 2035	2035 - 2040	2040 - 2045	2045 - 2050
HES	0.62	0.62	0.6	0.6	0	0	1.73	1.73	1.53	1.53	1.02	1.02
LES	0.34	0.34	1.06	1.06	1.04	1.36	3.37	3.37	1.5	1.5	1.01	1.01
AGR	0.24	0.24	0.34	0.34	0.26	0.26	4.22	4.22	1.05	1.05	1.17	1.17
SER	0	0	0.12	0.12	0.74	0.74	3.93	3.93	1.05	1.05	1.17	1.17

Figure 122 The assumed rate of increase in average energy efficiency in all productive sectors (excluding energy) over the years in the Base Case and the assumed rate of increase in average energy efficiency in the Net Zero Scenario relative to the Base Case



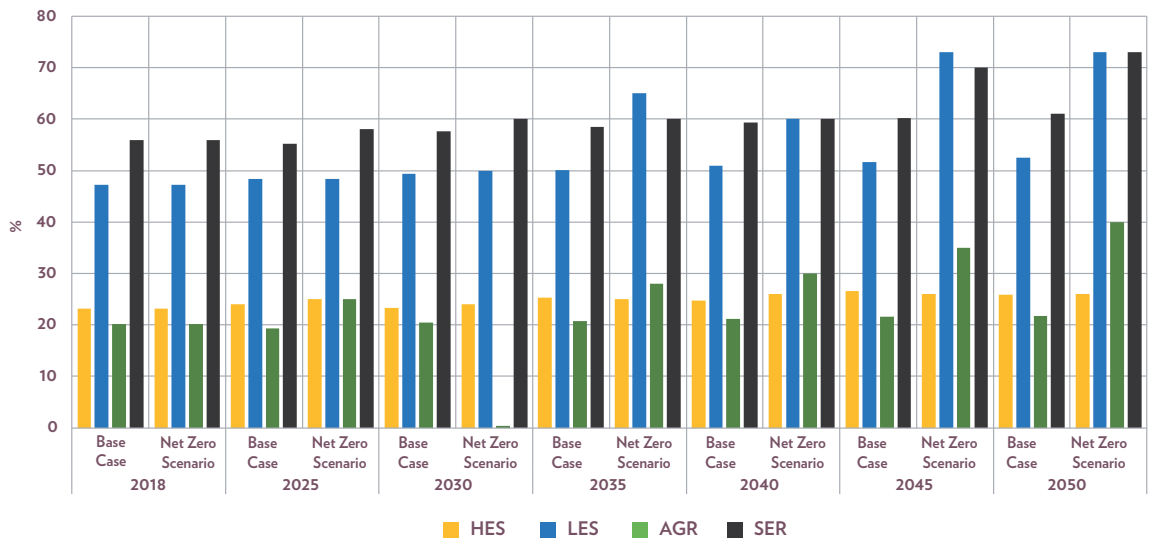
Electrification

The share of electricity in total energy consumption in all sectors is based on assumptions in line with international reports (IRENA, 2018; IEA, 2021). Table 39 and Figure 123 summarize the share of electricity in total energy use for different sectors for the period 2018-2050 (shares in 2018 are obtained from energy balance tables, MENR, 2020). As can be seen from the table, the increase in the rate of electrification is assumed to be low for HES and higher for LES and agriculture (AGR).

Table 39 Assumed change in the share of electricity in total energy in all productive sectors (excluding energy) over the years (%)

	Base Case							Net Zero Scenario						
	2018	2025	2030	2035	2040	2045	2050	2018	2025	2030	2035	2040	2045	2050
HES	23.2	24	23.3	25.3	24.7	26.6	25.9	23.2	25	24	25	26	26	26
LES	47.2	48.4	49.3	50.1	50.9	51.7	52.5	47.2	48.4	50	65	60	73	73
AGR	20.2	19.3	20.5	20.8	21.2	21.6	21.8	20.2	25	0.3	28	30	35	40
SER	55.9	55.2	57.7	58.5	59.4	60.2	61.1	55.9	58	60	60	60	70	73

Figure 123 Assumed change in the share of electricity in total energy in all productive sectors (excluding energy) over the years (%)



Use of renewable energy

Sanayi ve diğer üretici sektörlerde doğrudan Regarding the direct use of renewable energy in energy demand, assumptions of an increase in the share of renewable energy in total energy consumption in all other productive sectors (excluding renewable resources in the electricity consumed by the sector), except for the production of energy resources such as RES and fossil fuels, etc. are given in Table 40 and Figure 124 (IRENA, 2018; Saygin et al., 2011; Saygin et al., 2014). The assumptions here are again based on international literature (IRENA, 2018; Saygin et al., 2011; Saygin et al., 2014). For 2018, the shares of renewable resources were obtained from energy balance tables (MENR, 2020). Since direct renewable resource utilization is negligible in the relevant sectors, it is assumed to be zero and no change is assumed in the Base Case.

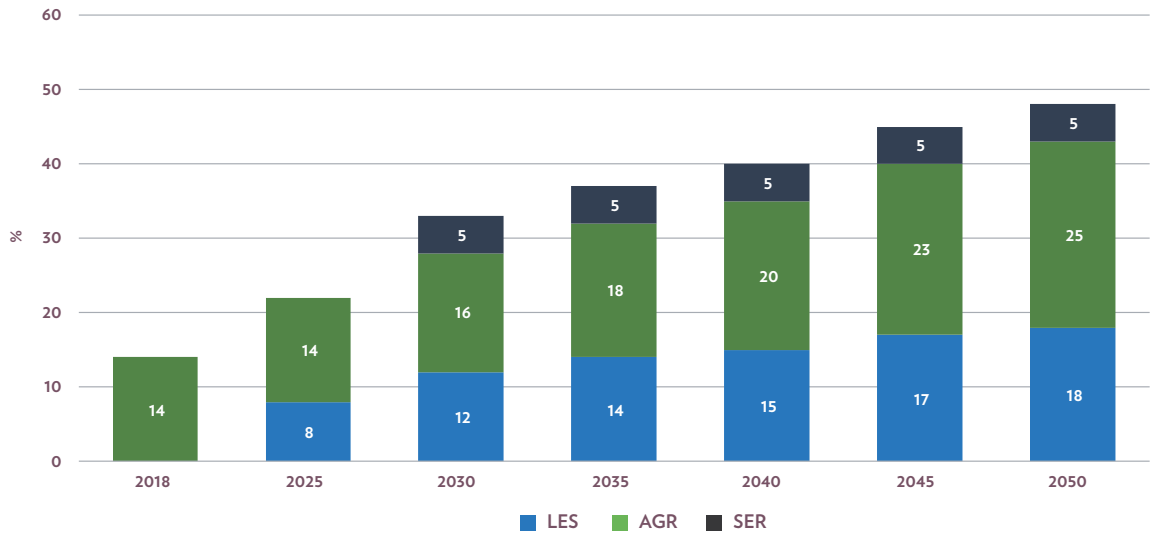
Yeşil Hidrojen ve Karbon Yakalama ve Gömme
Green Hydrogen and Carbon Capture and Sequestration (CCUS)

It is assumed that the use of green hydrogen technologies for HES will not be feasible in the near term, but could be deployed starting after the

Table 40 Assumed change in the share of directly used renewable resources in total energy in all productive sectors (excluding HES and Energy) over the years in the Net Zero Scenario (%)

	2018	2025	2030	2035	2040	2045	2050
LES	0	8	12	14	15	17	18
AGR	14	14	16	18	20	23	25
SER	0	0	5	5	5	5	5

Figure 124 Assumed change in the share of directly used renewable resources in total energy in all productive sectors (excluding HES and Energy) over the years in the Net Zero Scenario (%)



2040s, and that the share of these sectors in total energy consumption will only reach 5% in 2050.

The use of Carbon Capture and Sequestration Technologies (CCUS) in the HES is also assumed to start towards the 2040s, leading to reductions of up to 5% of total sectoral emissions in 2040 and 10% in 2050. The use of green hydrogen and CCUS technologies in other producer sectors is not assumed for the period 2020-2050.

4.2. CARBON DIOXIDE EMISSIONS

Base Case

The path of energy demand in productive sectors in the Base Case Scenario is given in Table 41 and Figure 125, in detail. Under the Base Case Scenario, energy demand for productive sectors in the economy increases close to 2-fold by 2050 (Figure 126). Although the increase is higher in the services and agriculture sectors, energy demand growth in high energy-intensive sectors affects emissions more.

Table 41 Increase in energy demand (TOE) in productive sectors (excluding energy) in the Base Case Scenario

	2018	2025	2030	2035	2040	2045	2050
HES	21,301	24,478	28,070	30,713	33,563	36,482	39,219
LES	9,986	11,333	12,970	13,883	14,921	15,936	16,747
AGR	3,954	5,162	5,795	6,405	7,040	7,703	8,390
SER	12,406	15,544	18,696	20,946	23,323	25,770	28,077
Total	47,647	56,516	65,530	71,947	78,847	85,890	92,433

Figure 125 Increase in energy demand in productive sectors (excluding energy) in the Base Case Scenario

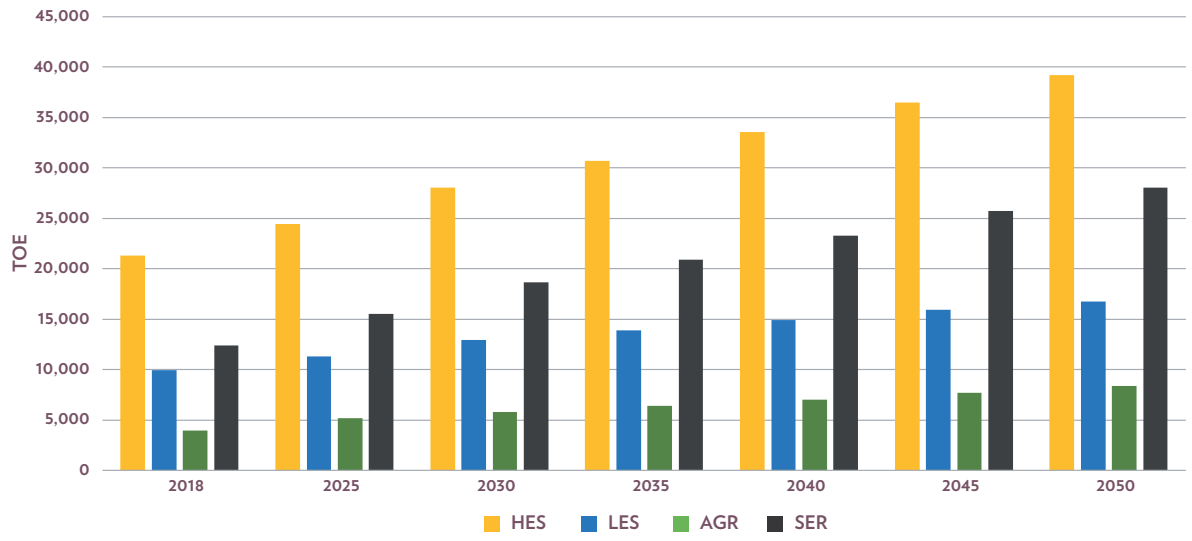
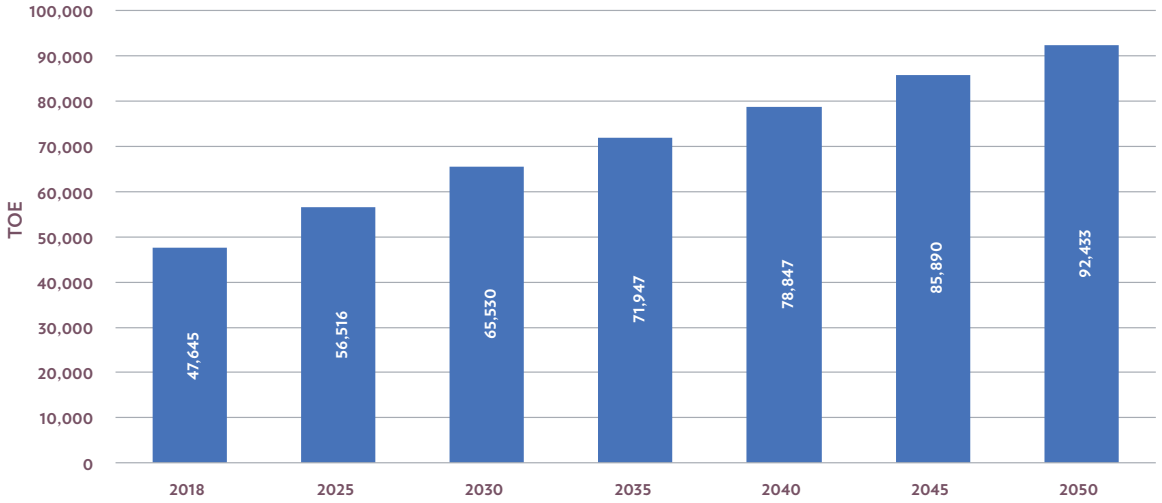


Figure 126 Increase in total energy demand in productive sectors (excluding energy) in the Base Case Scenario



The increase in emissions of producer sectors in the Base Case is presented in Table 7 at five-year intervals by sector. Accordingly, CO_2 emissions from energy consumption in the HES and LES, agriculture and services sectors increase by 17% in 2030 and 42.5% in 2050 compared to 2018 levels, but due to the much higher increase in industrial processes (23% in 2030 and 78% in 2050), the increase in total emissions of industry and other producer sectors including process emissions is more significant. While the largest share of emissions from energy consumption in industry is from RES, which is also responsible for industrial process emissions, the share of these sectors has been hovering around 50% over the years. The share of industrial process emissions in total emissions has been increasing over time: 40.0% in 2018, 41.1% in 2030, 57.0% in 2040 and 54.7% in 2050.

Table 42 Emissions from energy consumption in industry and other productive sectors and process emissions of industry in the Base Case ($MtCO_2$)

	2018	2025	2030	2035	2040	2045	2050
HES	45.5	49	53.6	56.5	59.1	61.3	62.9
LES	26.6	25.5	28.4	30.6	32.5	34.4	36.4
AGR	9.4	11.8	12.8	13.7	14.5	15.2	16
SER	9.2	10.1	11.3	12.1	12.7	13.3	13.8
Total Emissions from Energy Consumption	90.7	96.5	106.1	112.9	118.8	124.2	129.2
Emissions from Industrial Processes	59.8	65.5	73.9	82	89.9	98.1	106.9
Total Emissions from Industry and Other Producing Sectors	149.8	162	180	194.9	208.7	222.3	236.1

In the Base Case the majority of emissions from energy consumption in high-energy intensive sectors are from nmm-coded sectors such as cement, which accounts for 66% of emissions in 2018. The share of this sector decreases slightly until 2050, reaching 63.8% in 2050 (Table 8 shows the sectoral breakdown of emissions from energy consumption for the HES in five-year resolution).

The cement sector accounts for 73 percent of emissions from industrial processes (for 2018). The share of the cement sector in emissions from industrial processes continues to hover above 70% throughout the period (Table 9). In addition, the sectoral breakdown of emissions from industrial processes in the High Energy Intensive Sectors in Net Zero and Base Case are compared in Figure 7.

Table 43 In the Base Scenario, the distribution of emissions from energy consumption in High Energy Intensive Sectors (HES) by sector ($MtCO_2$)

	2018	2025	2030	2035	2040	2045	2050
Nmm (Cement etc.)	30.1	32.6	35.4	36.8	38.2	39.3	40.1
Irst (Iron and steel)	4.2	4.5	5	5.4	5.7	6	6.2
Eint (Chemistry etc.)	11.2	12	13.3	14.3	15.2	16	16.7
HES(Total)	45.5	49	53.6	56.5	59.1	61.3	62.9

Figure 127 The distribution of emissions from industrial processes in High Energy Intensive Sectors (HES) by sector in the Base Case and Net Zero Scenario

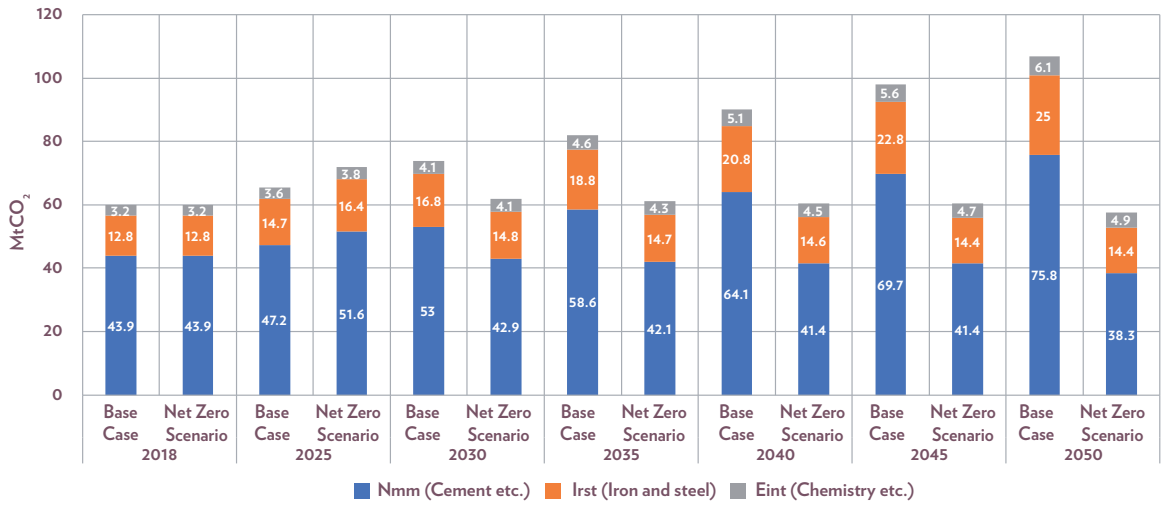


Table 44 The distribution of emissions from industrial processes in High Energy Intensive Sectors (HES) in the Base Case by sector ($MtCO_2$)

	2018	2025	2030	2035	2040	2045	2050
Nmm (Cement etc.)	43.9	47.2	53	58.6	64.1	69.7	75.8
Irst (Iron and steel)	12.8	14.7	16.8	18.8	20.8	22.8	25
Eint (Chemistry etc.)	3.2	3.6	4.1	4.6	5.1	5.6	6.1
HES(Total)	59.8	65.5	73.9	82	89.9	98.1	106.8

Net Zero Scenario

Energy-related CO_2 emissions

Net Zero Scenario assumptions lead to a decrease in energy demand in high energy intensive sectors until 2050 (0.06% increase in 2030 compared to 2018, equal energy demand to 2018 in 2040, and a 30% decrease compared to 2018 in 2050). On the other hand, an increase in energy demand is observed in low-energy-intensive sectors and agriculture (Table 45). The change in CO_2 emissions from energy consumption in the industry and other production sectors is presented in Table 46 and Figure 128 at five-year intervals from 2018 to 2050, comparing the Net Zero Scenario with the Base Scenario:

- Reduction in CO_2 emissions in high emission intensive sectors accelerates, especially after 2030. The total emissions, which are 4.5% lower in 2030 compared to 2018, decrease by 36% in 2040 and by 62.2% in 2050 compared to the 2018 levels.
- In low-emission intensive sectors as well, emission reduction accelerates, particularly after 2030. Emissions are notably reduced, with a 56.1% decrease in 2040 and a 73.3% decrease in 2050 compared to the 2018 levels.

In the agriculture sector, the reduction in CO_2 emissions from energy begins after 2020 and by 2050, emissions are approximately 63% lower. In the services sector, emissions in 2050 are about 74% below the 2018 levels.

Table 45 In the Net Zero Scenario, changes in energy demand (in TEP) in the manufacturing sectors (excluding energy)

	2018	2025	2030	2035	2040	2045	2050
HES	21,301	22,601	21,314	19,921	18,616	17,855	14,718
LES	9,986	9,642	9,908	10,540	10,840	11,062	12,005
AGR	3,954	3,769	3,604	3,575	3,911	4,026	4,124
SER	12,406	11,051	10,043	10,477	10,824	10,612	11,312
Total	47,647	47,065	44,870	44,513	44,191	43,557	42,160

Table 46 Decrease in CO_2 emissions from energy in productive sectors in the Net Zero Scenario compared to the Base Scenario ($MtCO_2$)

a. High Energy Intensive Sectors

	2018	2025	2030	2035	2040	2045	2050
Base Case	45.5	49	53.6	56.5	59.1	61.3	62.9
Net Zero Scenario	45.5	45.8	43.4	32.5	28.9	22	17.2

b. Low Energy Intensive Sectors

	2018	2025	2030	2035	2040	2045	2050
Base Case	26.6	25.5	28.4	30.6	32.5	34.4	36.4
Net Zero Scenario	26.6	15.7	15.9	14.4	11.7	7.1	7.1

c. Agriculture

	2018	2025	2030	2035	2040	2045	2050
Base Case	9.4	11.8	12.8	13.7	14.5	15.2	16
Net Zero Scenario	9.4	6.5	5.9	5.2	5.1	4.3	3.5

d. Services

	2018	2025	2030	2035	2040	2045	2050
Base Case	9.2	10.1	11.3	12.1	12.7	13.3	13.8
Net Zero Scenario	9.2	6.9	5	5.1	3.9	2.9	2.4

Figure 128 Decrease in CO_2 emissions from energy in productive sectors in the Net Zero Scenario compared to the Base Scenario ($MtCO_2$)

a. High Energy Intensive Sectors

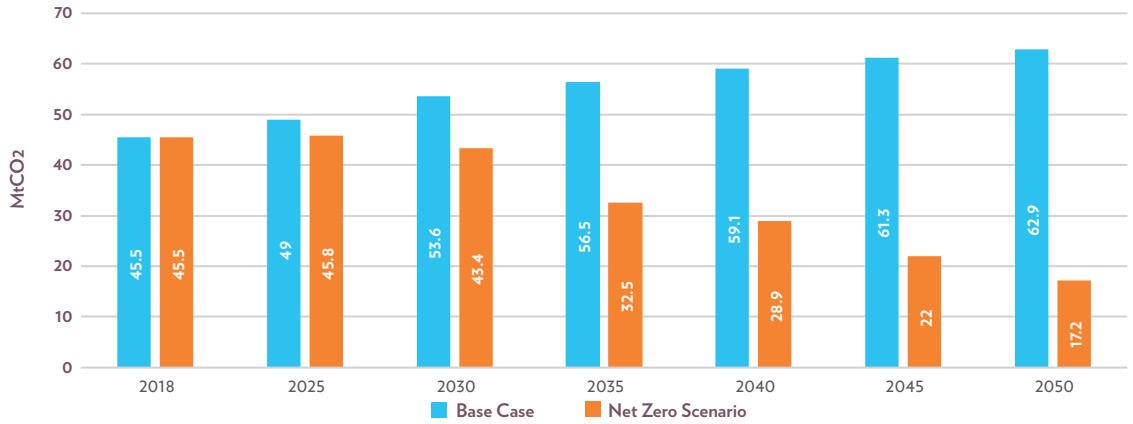
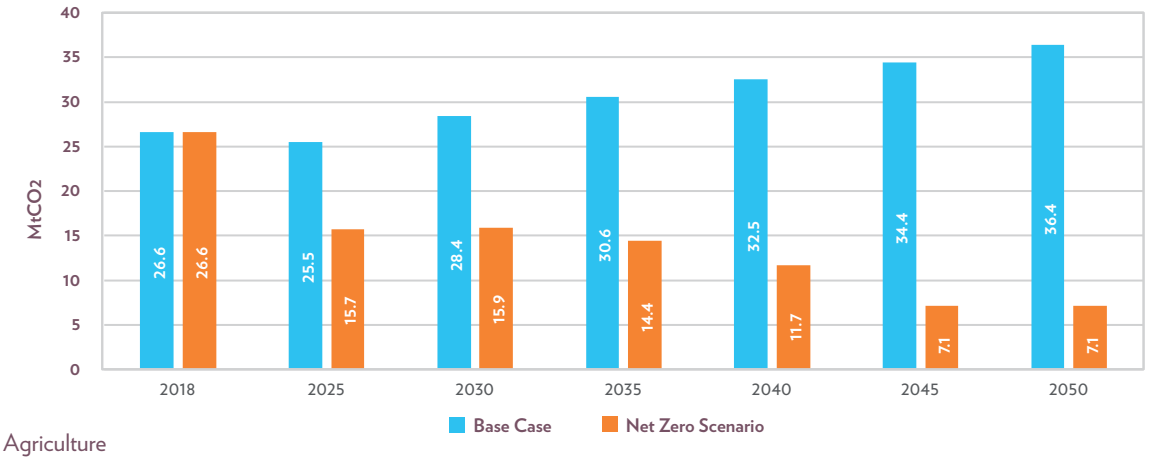
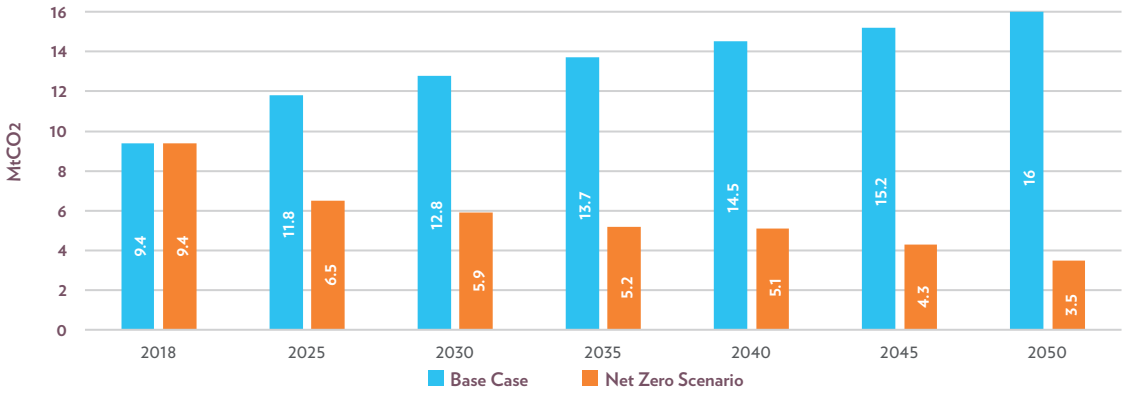


Figure 128 Decrease in CO_2 emissions from energy in productive sectors in the Net Zero Scenario compared to the Base Scenario ($MtCO_2$)

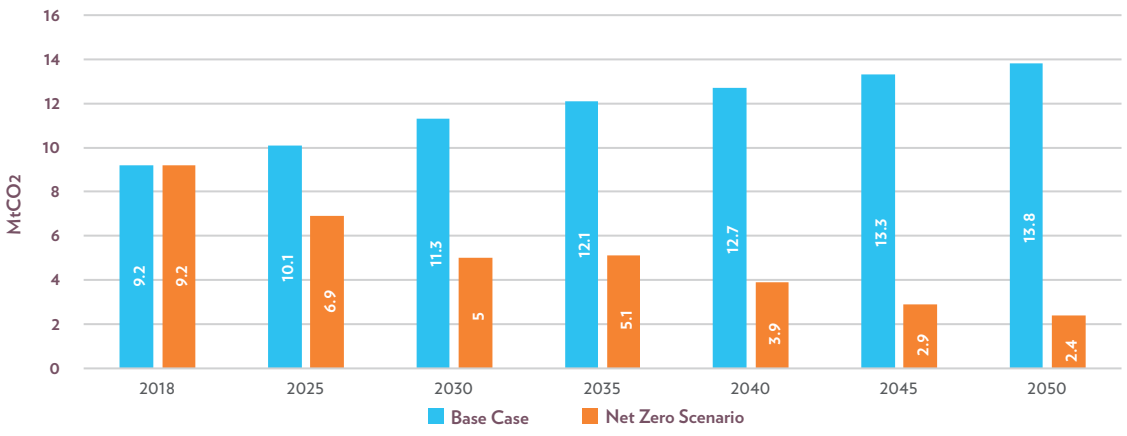
b. Low Energy Intensive Sectors



c. Agriculture



d. Services

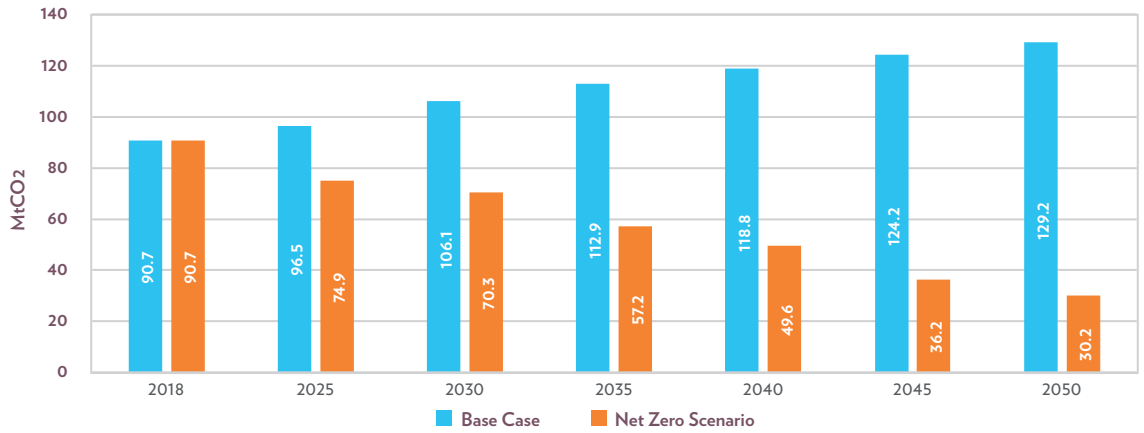


In the Net Zero Scenario, the emissions from industry and other producer sectors due to energy consumption are collectively presented in Table 47. Total emissions decrease by 22.5% in 2030, 45.3% in 2040, and 66.7% in 2050 compared to the 2018 level. In 2050, the remaining 30 $MtCO_2$ emissions consist of 57% from high energy intensive and 23.5% from low energy intensive industrial sectors. In 2050, the carbon dioxide emissions in the Baseline Scenario are more than 4 times those in the Net Zero Scenario (Figure 129).

Table 47 In the Net Zero Scenario, a reduction in carbon dioxide emissions from energy consumption in the producer sectors (excluding energy)

	2018	2025	2030	2035	2040	2045	2050
HES	45.5	45.8	43.4	32.5	28.9	22	17.2
LES	26.6	15.7	15.9	14.4	11.7	7.1	7.1
AGR	9.4	6.5	5.9	5.2	5.1	4.3	3.5
SER	9.2	6.9	5	5.1	3.9	2.9	2.4
Total	90.7	74.9	70.3	57.2	49.6	36.2	30.2

Figure 129 In the Net Zero Scenario, there is a decrease in total CO_2 emissions from energy consumption in all producer sectors (excluding energy) compared to the Base Case



CO_2 Emissions from Industrial Processes

Yüksek enerji yoğunluklu sektörlerde, sanayi The most significant factor contributing to the reduction of emissions from industrial processes in high-energy-intensive sectors is the difference in demand increase between the Base Scenario and the Net Zero Scenario, as it is for emissions from energy consumption. In Turkey's high-energy-intensive industrial sectors, the demand change, as shown in Table 37 based on the assumption that the demand will change in line with the International Energy Agency's global demand projections, reduces emissions from industrial processes in sectors such as cement, iron and steel over time. According to this, the demand change could lead to process emissions that are 12% lower in 2030, 29.3% lower in 2040, and 43.4% lower in 2050 compared to 2018 (Table 48)[4].

Table 48 The distribution of emissions from industrial processes in High Energy Intensive Sectors (HES) in the Net Zero Scenario by sector ($MtCO_2$)

	2018	2025	2030	2035	2040	2045	2050
Nmm (Cement etc.)	43.9	51.6	42.9	42.1	41.4	41.4	38.3
Irst (Iron and steel)	12.8	16.4	14.8	14.7	14.6	14.4	14.4
Eint (Chemistry etc.)	3.2	3.8	4.1	4.3	4.5	4.7	4.9
HES(Total)	59.8	71.8	61.8	61.1	60.4	60.5	57.6

4 In addition to the demand change effect, the European Cement Association's assumptions regarding the reduction of clinker emissions for the cement sector were also used for the post-2030 period

CONCLUSION

This report outlines the trajectory of decarbonization in Turkey's economy in accordance with the net-zero national target set for 2053. The example Net Zero Scenario presented in the report details how decarbonization will unfold in the key sectors of electricity, transportation, buildings, industry, and other producer sectors at five-year intervals. The report specifically focuses on carbon dioxide (CO_2) emissions, which constitute approximately 80% of national greenhouse gas emissions, while other greenhouse gases are not addressed. The transformation timeline of the electricity sector, the geographical distribution of this transformation, and its impact on the grid are highlighted. The report also addresses when and in what order, existing coal-fired power plants will be phased out, completing the transition away from coal in the electricity sector. Additionally, it outlines the regions, timelines, and capacities for deploying new natural gas and renewable energy plants, along with the necessary storage facilities. The report provides insights into the investment requirements for the grid during this transformation.

Electricity Sector

Electricity grid simulations were conducted based on the 2020 grid model, starting from 2025 and continuing in 5-year intervals until 2050 for both the Base Case and the Net Zero Scenario. As a result, the changes in electricity installed capacity and energy production by energy sources were illustrated for both national and 9 TEIAS (Turkish Electricity Transmission System Operator) regional dispatching centers. Additionally, for the electricity sector in both scenarios, simulations were performed for the increased redispatch up and redispatch down orders, along with the renewable energy interruption amounts. Based on these simulations, additional investments needed for the electricity grid in the Net Zero Scenario were determined.

Considering Turkey's second Nationally Determined Contribution (NDC) to be submitted in 2025 with the target year of 2035, the results obtained for the electricity sector can be summarized as follows:

In the Net Zero Scenario designed to align with Turkey's net-zero target in 2053, the renewable energy installed capacity is rapidly increasing. To ensure the necessary system flexibility for this transformation, storage systems that are currently not present in the system, such as pumped hydroelectric power plants (HES) and battery storage, are rapidly integrating. By 2030, the total capacity of these storage systems is expected to reach 5.7 GW, increasing to 10.7 GW by 2035 and reaching approximately 40 GW by 2050, which is 13 times the assumption in the Base Case (3 GW). The locations of renewable energy power plants and the distribution of storage systems among regional dispatching centers play a significant role. For example, the high solar energy potential in the Middle Anatolia region, along with the planned introduction of the Gökçekaya pumped storage HES in this region, leads to a greater increase in storage systems in Central Anatolia. The Net Transfer Capacity of international interconnection lines that could be used as a flexibility mechanism (ENTSO-E and Georgia) is expected to increase from 0.96 GW in 2020 to 3.35 GW in 2030 and 9.22 GW in 2050. The forecasted Net Transfer Capacity in the Net Zero Scenario is slightly higher than 1.5 times the forecast in the Base Case.

In the Net Zero Scenario, immediately after 2020, there is a rapid increase in wind capacity and production, followed by a significant growth in

solar capacity and production. After 2040, albeit in low amounts, concentrated solar and offshore wind capacities are also added to the system. In the Net Zero Scenario, onshore and offshore wind installed capacity surpasses 32 GW in 2030, reaches over 50 GW in 2035, and exceeds 62 GW by 2050.

Solar energy capacity is expected to grow much faster, reaching 36 GW in 2030, 60 GW in 2035, and 193 GW in 2050. Geothermal energy, among renewable energy sources, is projected to have a more limited increase in installed capacity (1.5 GW in 2020, 3.5 GW in 2035, and 5.5 GW in 2050). Biomass power plants, with an installed capacity of 1 GW in 2020, are anticipated to increase to 6 GW by 2030 and 16 GW by 2050. Hydropower plant capacity shows a more modest increase compared to modern renewable energy plants (31 GW in 2020, 34.5 GW by 2035, and 44 GW by 2050).

In the distribution of renewable energy according to TEİAŞ regional dispatching centers, it is assumed that newly added renewable energy plants to the electricity generation system will be located near the main load centers. The YEKA mechanism also aims to position new renewable plants in grid-friendly locations. Storage systems are assumed to be located similarly, prioritizing main load centers and centrally controlling them based on the grid's flexibility needs. Consequently, the highest installed capacity of modern renewable energy (wind, solar, geothermal, and biomass) is developing in Western Anatolia (10 GW in 2025, 23 GW in 2035, and 46 GW in 2050), followed by Northwestern Anatolia and Central Anatolia (7 GW each in 2025, 20 GW and 18 GW in 2035, and 40 GW and 43 GW in 2050, respectively). The region with the least developed renewable capacity is Eastern Anatolia.

Looking specifically at solar energy, installations are rapidly increasing in Central Anatolia and Southeastern Anatolia, reaching 10 GW each in 2035 and 34 GW and 30 GW, respectively, in 2050. Wind energy capacities are concentrated in Western Anatolia and Western Mediterranean (11 GW and 9 GW in 2035, 14 GW and 11 GW in 2050, respectively). Geothermal energy is entirely concentrated in Western Anatolia, while biomass installed capacity is concentrated in Northwestern Anatolia and Western Mediterranean. The installed capacity of storage systems that need to be established together with renewable energy is also most concentrated in Middle Anatolia, Southeastern Anatolia, Western Anatolia, and Northwestern Anatolia.

Net Zero Scenario reveals a significant shift in the share of modern renewable energy sources in electricity generation. In 2020, the associated share is 17%, gradually increasing to 46% in 2030, 64% in 2035, and reaching nearly 80% by 2050. In contrast, the share of fossil fuel sources in electricity generation decreases rapidly from 58% in 2020 to 29% in 2030, 13% in 2035, and finally, dropping to 7% by 2050. Although hydropower production shows an increase, limited growth in installed capacities leads to a decrease in their share from 25% in 2020 to 17% in 2030, 16% in 2035, and 11% in 2050.

In the Net Zero Scenario, there is a single nuclear power plant under construction with a capacity of 4.8 GW in Akkuyu. It is assumed that no additional nuclear power plants will be built. The share of nuclear energy in electricity production, entering the electric system at 8% in 2030, decreases over the years to 6.5% in 2030 and 5% in 2050.

In terms of the regional distribution of electricity generation from modern renewable sources, in 2025, it is concentrated mainly in Western Anatolia, followed by Northwestern Anatolia, Western Mediterranean, Middle Anatolia, and Southeastern Anatolia. However, in the following

years, Southeastern Anatolia's share increases, ranking it third by 2050.

In the Net Zero Scenario, all coal-fired thermal power plants, including those using hard coal and lignite, are phased out by the first half of the 2030s. Only one thermal power plant with a capacity of 1.3 GW, fueled by imported coal, remains operational between 2035 and 2040, and all coal-fired thermal power plants are closed before 2040. When determining the decommissioning order of fossil fuel power plants, criteria such as carbon emissions, air pollution, installed capacities, their position in the grid, age, and annual capacity factors were taken into account.

Looking at the decommissioning schedule of coal-fired thermal power plants, the total installed capacity of hard coal power plants, which was 845 MW in 2020, decreases to 228 MW by 2030, and all of them are phased out by 2035. The installed capacity of lignite power plants, which was 9.5 GW in 2020, decreases to 3 GW by 2030, and all are phased out by 2035. The lignite power plants remaining operational between 2030 and 2035 are Afşin Elbistan B, Aksa Göynük, Çan 2, Çobanyıldızı Çumra, Polat Kütahya, Soma Kolin, and Tufanbeyli. The installed capacity of imported coal power plants, which was approximately 9 GW in 2020, decreases to 4 GW by 2030 and 1.3 GW by 2035, closing entirely by 2040. The imported coal-fired thermal power plants remaining open between 2030 and 2035 are Atlas İskenderun, Sugözü İsken, İçdaş Çelik Çanakkale 1 and 2, and Hunutlu Adana. The only coal-fired thermal power plant remaining open between 2035 and 2040 is the Hunutlu thermal power plant, commissioned in 2022.

The rapid decline of conventional power plants and a significant increase in renewable production leads to generally higher redispatch up/down instructions and interruptions in renewable production in the Net Zero Scenario compared to the Base Scenario. However, redispatch up/down and renewable curtailment quantities depend on the capacity of storage systems and grid investments. The high penetration of storage and grid investments results in less redispatch up/down and curtailments in 2040 compared to 2035. When examining the grid investment requirements, there is no additional investment requirement on the corridors in the Net Zero Scenario in 2025 compared to the 2020 grid model. However, in 2030, there is an additional investment requirement based on the 2030 TEIAS grid investment plan. With these investments, no additional investment requirement is expected in the corridors in 2035. The additional investments made in the corridors in 2040 are sufficient for the 2045 and 2050 corridors, and no additional investment requirement arises. As a result, on top of the investment plan determined by TEIAS for 2030, it is expected that there will be a need for 2,596 km of 400 kV overhead line investment in the Base Case and 4,054 km in the Net Zero Scenario.

In the Net Zero Scenario, carbon dioxide (CO_2) emissions from the electricity sector begin to decrease after 2020. Emissions, which were 135 $MtCO_2$ in 2020, decrease by 48% to 71 $MtCO_2$ in 2030, by 78% to 29 $MtCO_2$ in 2035, and by 87% to 18 $MtCO_2$ in 2050. After the closure of all lignite power plants in the first half of the 2030s and the last remaining imported coal power plant in the second half of the 2030s, all remaining emissions in the electricity sector come from natural gas from 2040 onwards.

As demonstrated, the CO_2 emissions from the electricity sector cannot be completely eliminated in 2050, and there are still 18 $MtCO_2$ residual emissions. These emissions originate from natural gas power plants that are kept ready in the system to be operated with low capacity factors due to the increased need for grid flexibility, resulting from the high use of renewable energy sources. If the

increased flexibility requirement in the grid can be entirely met by methods such as demand management, in addition to storage and interconnection, it might be possible to shut down the remaining natural gas power plants by 2050 and achieve zero emissions. In the Net Zero Scenario, the remaining CO_2 emissions after 2040, which are only from natural gas sources, are concentrated in the regions where these plants are mainly located, namely Thrace, Western Anatolia, and Northwestern Anatolia.

Other Sectors

This report outlines the roadmap for decarbonization in the transportation, buildings, industry, and other manufacturing sectors, remodeled with the same assumptions every five years, and the general findings remain consistent with those presented in the initial report (IPM, 2021). Some key points highlighted in the results for these sectors can be summarized as follows:

In the transportation sector, transitioning from fossil fuel usage to electricity and another emission-free fuel, green hydrogen, is crucial. The assumption is made that the share of electric vehicles (EVs), which was almost zero in 2020, in the total number of passenger vehicles will be more than double that of the Base Case in the Net Zero Scenario, reaching 20% (3.8 million electric passenger vehicles) by 2030 and 66% (19.4 million electric passenger vehicles) by 2050. The ratio of electric heavy vehicles to total heavy vehicles is assumed to be 10% by 2030 and 20% by 2050. Additionally, a 5% change in travel behavior (such as transitioning from cars to bicycles or reducing long-distance travel, etc.) is assumed in the Net Zero Scenario. It is also assumed that there will be a 50% shift from road transportation to electric rail transportation and a 15% shift from individual motor vehicles on the road to rail public transportation.

Furthermore, in the Net Zero Scenario, it is assumed that the proportion of heavy vehicles running on hydrogen in road transportation will increase to 5% by 2050. In the transportation sector, energy consumption, which was approximately 28.5 million TOE in 2018, is projected to decrease to about 26.4 million TEP by 2030 and further to 15.2 million TOE by 2050 in the Net Zero Scenario. The highest share of this energy consumption is attributed to road freight transportation. In the Net Zero Scenario, energy consumption is observed to decrease by 73% compared to the Base Case. However, the electrification of road transportation leads to an increase in electricity consumption, with electricity demand from electric vehicles rising by 9% in 2030 and 17% in 2050, reaching 46 TWh and 146 TWh, respectively. CO_2 emissions from the transportation sector, which were 83 $MtCO_2$ in 2018, are projected to decrease by 21% to 65 $MtCO_2$ in 2030, by 32% to 56 $MtCO_2$ in 2035, and by 65% to approximately 29 $MtCO_2$ in 2050 in the Net Zero Scenario. In 2050, there are residual emissions of 7.2 $MtCO_2$ from marine and air transportation and 3.8 $MtCO_2$ from individual passenger vehicles on the road, mainly due to the transition to highly electrified automobiles. Therefore, 56% of the remaining 29 $MtCO_2$ emissions in 2050 are attributed to road freight transportation. If there is a higher shift to rail transportation than road freight transportation or a higher level of electrification and/or green hydrogen usage in heavy vehicles operating on roads, more than half of the residual emissions in the transportation sector can be eliminated.

Interventions that can be implemented to reduce greenhouse gas emissions in buildings include improving energy performance in electrical appliances, renovating buildings to be lower in carbon, using electricity (heat pumps) for heating in new buildings, transitioning to the use of electricity for heating purposes (heat pumps) in existing buildings, and behavioral changes (energy efficiency).

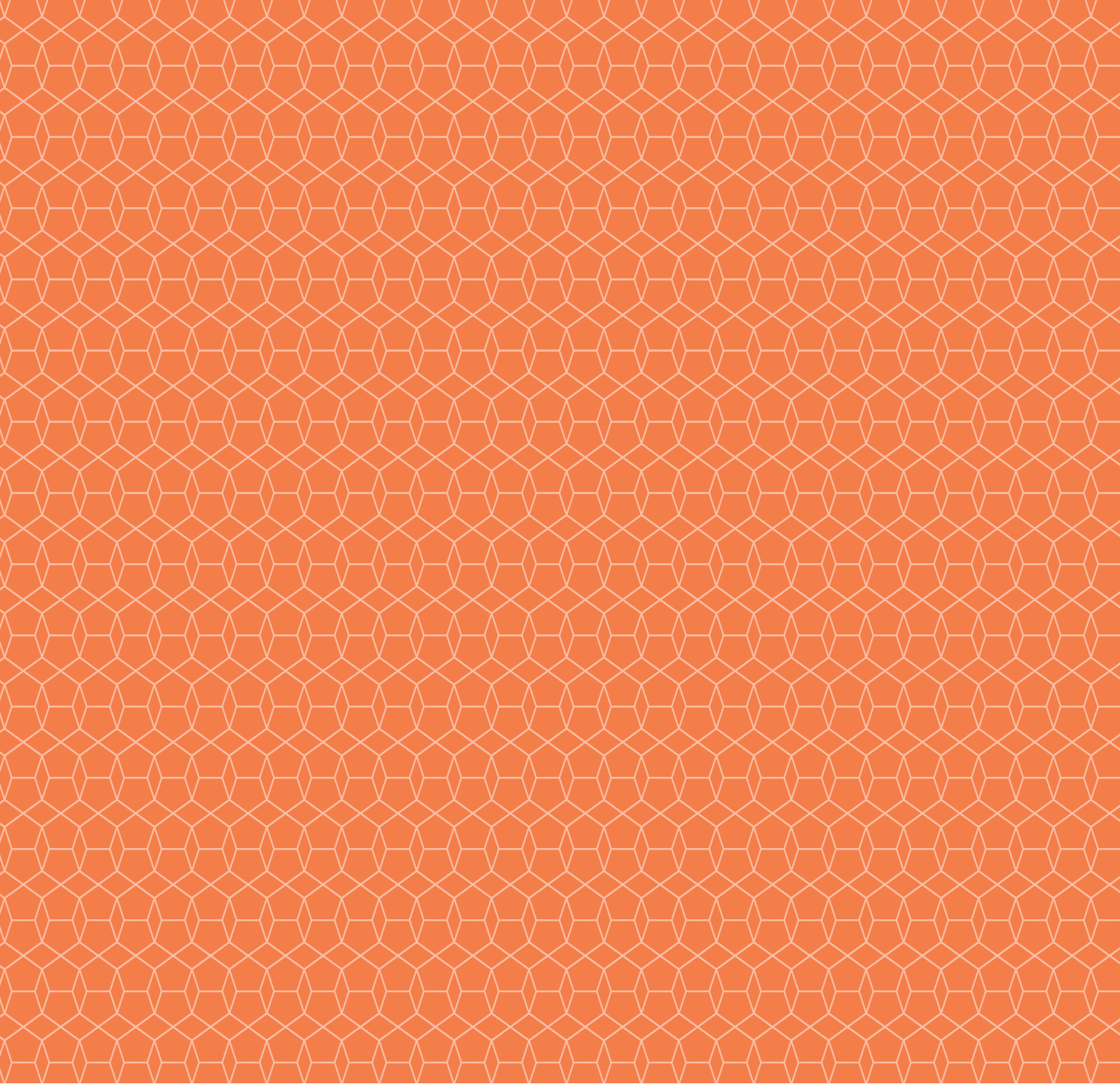
In the Net Zero Scenario, heating electricity consumption in residences is 2.6 times higher in 2050 compared to the Base Scenario, and coal consumption in residences is phased out from 2030 onwards. In the Net Zero Scenario, natural gas and LPG consumption in residences and commercial/institutional buildings are eliminated by 2050 due to electrification. Liquid fuel and biomass consumption in all buildings are also phased out by 2030 in the Net Zero Scenario.

In the Net Zero Scenario in 2050, residential electricity consumption increases by 52% compared to the Base Scenario, while in commercial/institutional buildings, it decreases by 7% in the Net Zero Scenario compared to the Case. Total emissions from buildings decrease by 46% in 2030 compared to the 2018 level, reaching 27.5 $MtCO_2$, further decreasing to 19 $MtCO_2$ by 2035, and being completely phased out from 2046 onwards. The most significant intervention contributing to this reduction is the cessation of coal and liquid fuel usage for heating purposes in residential and commercial/institutional buildings from 2030 onwards, transitioning partially to natural gas first and then predominantly, eventually entirely to electric heating. Although large-scale electricity usage replaces fossil fuels in buildings, it is assumed that small-scale green hydrogen will be introduced into the system starting from 2035, particularly increasing after 2045, with an equivalent of 10 TWh of green hydrogen used for heating and other purposes in buildings by 2050. Positive developments such as the recent requirement to build "near-zero energy buildings," transition efforts to heat pumps, and public projects related to the transition to district heating increase the likelihood of achieving the net-zero target in buildings by 2050.

The trajectory of carbon dioxide emissions from the industrial and other manufacturing sectors is determined based on assumptions regarding demand dynamics in the macroeconomic model, as well as the entry of energy efficiency, electrification, modern renewable energy sources (wind, solar, biomass, and geothermal), green hydrogen, and carbon capture and storage (CCSU) technologies into the system by year. The share of demand change, especially for high energy-intensive sectors, is crucial in emissions from industrial sources. In this study, it is assumed that demand in high energy-intensive sectors will change according to the International Energy Agency's global demand projections, with global demand for non-metallic minerals in sectors like cement initially increasing but decreasing to 2020 levels by 2050; for other energy-intensive sectors like iron and steel and chemicals, global demand is assumed to increase by 12% and 30%, respectively, above 2020 levels by 2050. The contribution of increased energy efficiency in the industry to the Net Zero Scenario is assumed to be relatively higher from 2020 to 2030 and to occur at a lower pace in the following period. The increase in electrification is assumed to be lower in high energy-intensive sectors and higher in low energy-intensive sectors and agriculture. The study assumes that the increase in the share of renewable energy directly used in industry (excluding renewable sources within the sector's consumed electricity) will be higher in low energy-intensive sectors and agriculture. The study employs conservative assumptions regarding green hydrogen technologies, suggesting that meaningful usage of green hydrogen in high energy-intensive sectors in Turkey will only begin in the 2040s, reaching a share of only 5% in the total energy consumption of these sectors by 2050. The use of Carbon Capture and Storage (CCUS) technologies in high energy-intensive sectors is assumed to start around the 2040s and could provide a reduction of up to 5% in total emissions in these sectors by 2040 and up to 10% by 2050. The study does not assume the use of green hydrogen and CCUS technologies in other manufacturing sectors between 2020 and 2050.

Under the assumptions used in the Net Zero Scenario, energy demand decreases in high energy-intensive sectors until 2050, while it increases in low energy-intensive sectors and agriculture. Looking at the changes in CO_2 emissions from energy consumption in the industry and other manufacturing sectors, emissions from high energy-intensive sectors notably decrease, especially after 2030. Total emissions, which are 5% lower in 2030 than in 2018, decrease by 29% in 2035, 36% in 2040, and 62% in 2050. Emission reduction in low energy-intensive sectors accelerates, particularly after 2030, with a 40% reduction in 2030, 46% in 2035, and 73% in 2050 compared to 2018. Energy-related emissions from the agricultural sector decrease by 37% in 2030, 45% in 2035, and 63% in 2050 compared to 2018. In the services sector, emissions decrease by 46% in 2030 and 2035, and 74% in 2050 compared to 2018. In the Net Zero Scenario, total emissions from energy consumption in the industry and other manufacturing sectors decrease by 23% in 2030, 37% in 2035, and 67% in 2050 compared to 2018. In 2050, the remaining 30 $MtCO_2$ residual emissions from energy use in industry and other manufacturing sectors are 57% from high-energy and 23.5% from low-energy-intensive industries. In 2050, carbon dioxide emissions in the Base Case are more than four times higher than in the Net Zero Scenario. Achieving the complete elimination of remaining emissions in industry, particularly in high-energy-intensive sectors like iron and steel, will require more significant and earlier investments in energy efficiency, electrification, and green hydrogen usage. In other manufacturing sectors, greater electrification can contribute to the elimination of residual emissions.

Reducing process emissions from industry is identified as the most challenging area in our study. In high-energy-intensive sectors, the Net Zero Scenario assumes that the demand growth difference will be a key component leading to the reduction of emissions from industrial processes compared to the Base Case. When assuming that demand in high-energy-intensive industrial sectors in Turkey will change according to the International Energy Agency's global demand projections, emissions from industrial processes in sectors such as cement, iron, and steel are expected to decrease over time. Accordingly, demand changes could result in process emissions that are 12% lower in 2030, 29% in 2040, and 43% in 2050 compared to 2018. However, even in this case, only the increase in process emissions is halted, and by 2050, there will still be approximately 58 $MtCO_2$ residual emissions, almost the same level as in 2030. However, if demand growth remains high in these sectors in the coming years, it is possible for process emissions to exceed 106 million $MtCO_2$ as in the Base Case. Therefore, considering alternative technologies and material use will be necessary to address emissions from industrial process emissions.



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