

# TURKEY'S DECARBONIZATION PATHWAY: SECTORAL COST-BENEFIT ANALYSIS (2020–2030)

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SABANCI UNIVERSITY
STIFTUNG MERCATOR INITIATIVE

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# EXECUTIVE SUMMARY

The Turkish Parliament ratified the Paris Agreement on October 6, 2021 by unanimously passing the Law on the Approval of the Ratification of the Paris Agreement, following Turkey's announcement at the United Nations General Assembly on September 21, 2021 that it would be party to the agreement and would accept the 2053 net-zero target. From this date on, Turkey's pathway to achieve its 2053 net-zero target has become a key topic of discussion in climate policy design.

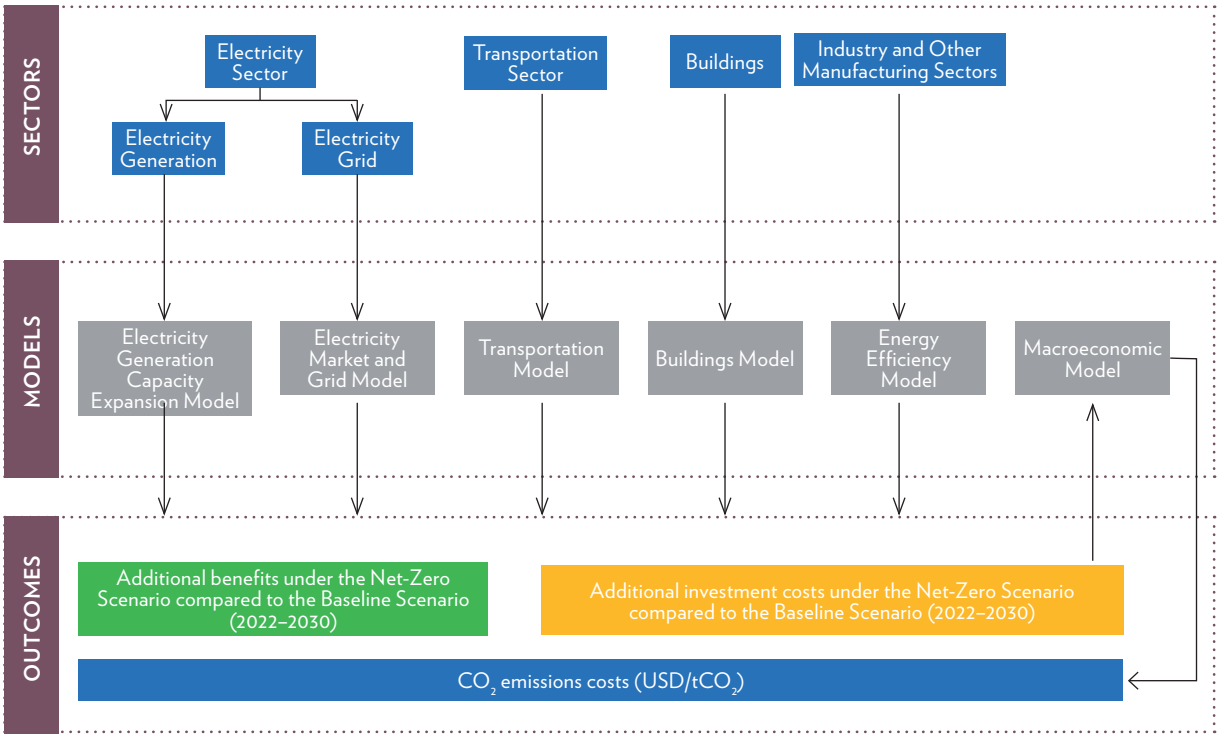
The report "Turkey's Decarbonization Pathway: Net Zero in 2050" published in October 2021 brought together the results of research initiated by Istanbul Policy Center, Sabancı University in 2020.[1] The research strived to prepare a roadmap that would reveal the transformations that the Turkish economy should undergo if it were to ratify the Paris Agreement and accept the 2050 net-zero target. The report "Turkey's Decarbonization Pathway: Sectoral Cost-Benefit Analysis" builds on the previous report's Baseline Scenario and Net-Zero Scenario's 2020–2030 assumptions and sets out to analyze and discuss the costs and benefits that would arise if the Net-Zero Scenario were to be realized during this period.

This study features cost-benefit analyses for sectors that were discussed in detail in the report "Turkey's Decarbonization Pathway: Net Zero in 2050" (Electricity, Transportation, Buildings, Industry and Other Manufacturing The cost-benefit analysis for each sector uses Turkey's 2018 economic indicators and emissions and covers the Baseline Scenario and Net-Zero Scenario from the report "Turkey's Decarbonization Pathway: Net Zero in 2050" for the 2020–2030 period. The study addresses energy-related carbon dioxide ($CO_2$) emissions from the electricity power sector, transportation sector, and buildings and $CO_2$ emissions from industrial processes. The $CO_2$ emissions 2020–2030 pathway under the Net-Zero Scenario requires a transition that is different than the Baseline Scenario, and this study calculates the components of the transition under the Net-Zero Scenario and analyzes the additional benefits.

The model that constitutes the basis of this research uses the modeling framework from the report "Turkey's Decarbonization Pathway: Net Zero in 2050" for the 2020–2030 period. Furthermore, while addressing the electricity sector, which is responsible for the majority of Turkey's national $CO_2$ emissions, this research uses the analytical framework from the report "Turkey's Decarbonization Pathway: Net Zero in 2050" and takes it further by modeling power generation and the power grid separately. The study's models and outcomes are illustrated in Figure 1.

1 Istanbul Policy Center, "Turkey's Decarbonisation Pathway: Net Zero in 2050", Executive Summary https://ipc.sabanciuniv.edu/Content/Images/CKeditorImages/20211103-20111678.pdf

Figure 1. Flowchart of the study's models and outcomes




## MAIN RESULTS

### Electricity generation

For electricity generation, the Net-Zero Scenario foresees that solar and wind power plants will be integrated into the system with increasing momentum. Thus, the share of renewable resources in electricity generation rises to 69 percent in 2030 under the Net-Zero Scenario, exceeding the 45 percent threshold of the Baseline Scenario. With this significant increase in the share of intermittent technologies in the system, the storage capacity also increases significantly and reaches 5.67 GW in 2030. Concurrently, the partial transition that occurs in the Net-Zero Scenario's 2020–2030 period leads to a 31 percent decrease in cumulative $CO_2$ emissions, reducing emissions by 587.7 million tons.

According to the calculations, electricity generation in 2020–2030 under the Net-Zero Scenario will require an additional generation and storage capacity investment of USD 35 billion compared to the Baseline Scenario. On the other hand, the transition envisaged under the Net-Zero Scenario includes operational and maintenance costs and fuel costs. Here, a part of the fuel and operational savings obtained from the decrease in coal and lignite-fired power plants compensates for the fuel and operational costs that arise from the increasing number of gas-fired power plants. Still, calculations indicate that in the 2020–2030 period, operational and maintenance savings will reach USD 1 billion, and fuel savings will reach USD 6.4 billion.

For the 2020–2030 period, it is estimated that the total costs from the retirement or early closure of coal-fired power plants can reach up to approximately USD 12.5 billion.

### Electricity Grid

From a market simulation perspective, all power plants with a given technology are accorded the same priority for phase out. The main reason for this is that the market simulation disregards the transmission grid and, consequently, the geographical location of the power plants. However, from a grid perspective, the distribution of power plants within the grid is very important. For the grid simulation for the 2020–2030 period under the Net-Zero Scenario, the coal-fired power plants to be phased out were chosen using certain criteria (installed capacity, generation technology, year of installation, ownership). These inputs were also used to calculate the requirements and costs related to transmission, distribution, and renewable energy constraints in the electricity grid model. Accordingly, comparing the Net-Zero Scenario to the Baseline Scenario for 2020–2030, the additional total operational cost of the grid (re-dispatch, renewable energy curtailment) is estimated to be USD 180 million, and the cost of total grid investment is USD 1.32 billion. The Baseline Scenario assumes that approximately 800 km of new 400kV transmission lines will be added to the grid annually between 2020 and 2030. Although this annual average investment seems like a significant target, it is comparable to the average amount invested by the Turkish Electricity Transmission Corporation (TEİAŞ) in recent years and is therefore an achievable target. The Net-Zero Scenario assumes that the total international interconnection line capacity will reach 3.35 GW in 2030, and the flexibility provided by interconnections will be maximized through appropriate market mechanisms, including market coupling and imbalance netting.

### Transportation

In this report, the electrification infrastructure investment cost is considered as the main investment item for the transportation sector. To calculate the investment costs, this study used the "Türkiye-Country Climate and Development Report" [2] published by the World Bank Group in June 2022 as the main reference for the additional electrification infrastructure needed for the 2020–2030 period in the Net-Zero Scenario. Compared to the Baseline Scenario, the Net-Zero Scenario for the 2020–2030 period estimates a total $CO_2$ emissions reduction of 171.7 million tons in the transportation sector.

For the 2020–2030 period, the Baseline Scenario foresees an additional electrification infrastructure investment cost of USD 12.5 billion in the transportation sector. On the other hand, under the Net-Zero Scenario for the same period, the estimated fuel savings obtained from decreasing fuel use reaches USD 10.3 billion according to the Baseline Scenario.

### Buildings

The investments required by the buildings sector—residential and commercial buildings—for the 2020–2030 period were calculated for both the Baseline and Net-Zero Scenarios. While calculating the investment requirement, in addition to the transformation requirement in buildings, additional costs such as fuel conversion, electrical home/office appliances, etc. were also considered in addition to the headings affecting building energy performance.. The main investment items considered were energy performance improvement, urban transformation, electrification (heat pump), fuel transformation (from coal to natural gas), and only for 2030, the transition to green

2 World Bank Group, "Country Climate and Development Report – Turkey" https://openknowledge.worldbank.org/handle/10986/37521

hydrogen at very low rates. Additional calculations took into account building expenses and electricity/fuel bills borne by end-users. The Net Zero Scenario for the building sector provides a total $CO_2$ emission reduction of 248.2 million tonnes in the period 2020-2030 compared to the Baseline Scenerio.

The additional investment costs of a fundamental transformation of the buildings sector for the 2020–2030 period in the Net-Zero Scenario is USD 99.4 billion relative to the Baseline Scenario. On the other hand, under the Net-Zero Scenario the additional fuel savings obtained from components such as electrification and energy efficiency during the same period is USD 40.9 billion.

### Industry and Other Production Sectors

The 2020-2030 projection for $CO_2$ emissions from energy in the Net Zero Scenario defined in this study includes the effects of components such as energy (and process) efficiency, electrification, direct utilization of renewable energy (wind, solar, biomass, geothermal) that lead to a reduction in emissions, in addition to the effects of demand change. It is foreseen that the manufacturing sectors' 2020–2030 energy demand-related cumulative $CO_2$ emissions under the Net-Zero Scenario will be reduced by 34.6 percent (258.6 Mt $CO_2$) relative to the Baseline Scenario. Process emissions during the same period will be reduced by 74.8 Mt $CO_2$.

Under the Net-Zero Scenario, energy efficiency applications are projected to contribute the most to $CO_2$ emission reductions for the 2020–2030 period. Not only do they contribute the most to emission reduction, but they also provide additional benefits in terms of energy savings. The Net-Zero Scenario for 2020–2030 estimates a USD 16.3 billion energy efficiency investment cost. According to the scenario, the investment cost for the direct use of renewable energy in industry is an estimated USD 2 billion, whereas fuel savings obtained through efficiency applications during the same period amount to USD 11.4 billion.

The reduction in emissions from industrial processes in the Net-Zero Scenario is due to demand dynamics as well as the use of new carbon-free raw materials in clinker production and cement substitute. The cost of emission reduction from industrial processes for the 2020–2030 period is an estimated USD 4.7 billion.

### Health Savings

Health savings from decreased fossil fuel use in the electricity and transportation sectors in 2020–2030 under the Net-Zero Scenario and the Baseline Scenario are an estimated USD 15.9 billion and USD 26.2 billion, respectively. These calculations assume a USD 0.03/kWh health unit cost for Turkey, the lowest cost among all European countries.

### The Social Cost of Carbon

The simulation results of the macroeconomic model attribute a carbon price (social cost of carbon) of USD 169.5/t$CO_2$ for the 2020–2030 period under the Net-Zero Scenario.

Results - Summary

| Investment–Maintenance and Fuel Costs | 2020–2030 Cumulative (Relative to Baseline Scenario) | |
|---|---|---|
| **Sectors** | **Cost (USD billion)** | **$CO_2$ emissions (million tons)** |
| **ELECTRICITY SECTOR** | | |
| Generation and storage capacity investment costs | +35.04 | **-587.66** |
| Operational and maintenance costs | -1.02 | |
| Fuel costs | -6.38 | |
| Grid operation costs (redispatch and RES curtailment) | +0.18 | |
| Grid invesment costs | +1.32 | |
| **Total investment, operational and maintenance costs** | **+29.1** | |
| **TRANSPORTATION SECTOR** | | |
| Electrification costs | +12.50 | **-171.68** |
| Brent oil costs | -10.30 | |
| **Total costs** | **+2.2** | |
| **BUILDINGS** | | |
| Investment Costs | +99.35 | **-248.18** |
| Fuel + Electricity Costs | -40.94 | |
| **Total cost** | **+58.4** | |
| **INDUSTRY AND OTHER PRODUCTION SECTORS - ENERGY** | | |
| Energy efficiency investment costs (for all manufacturing sectors) | +16.3 | **-258.60 (including change in demand effect)** |
| Renewable energy investment costs | +2.00 | |
| *Fuel costs* | *-11.40* | |
| *(Imported fuel)* | *(-8.50)* | |
| **Total costs** | **+6.9** | |
| **INDUSTRY AND OTHER PRODUCTION SECTORS – PROCESSES** | | |
| **Total cost** (carbon-free raw material in clinker production and cement substitute) | **+4.7** | **-74.82 (including change in demand effect)** |
| **ALL SECTORS – INVESTMENT, OPERATION, MAINTENANCE, FUEL** | | |
| **Total costs** | **171.4** | **-1.340.94** |
| **Total benefits** | **70.0** | |
| **HEALTH COSTS/BENEFITS** | | |
| Energy sector | -15.93 | |
| Transportation sector | -26.20 | |
| **Total health costs/benefits** | **-42.1** | |

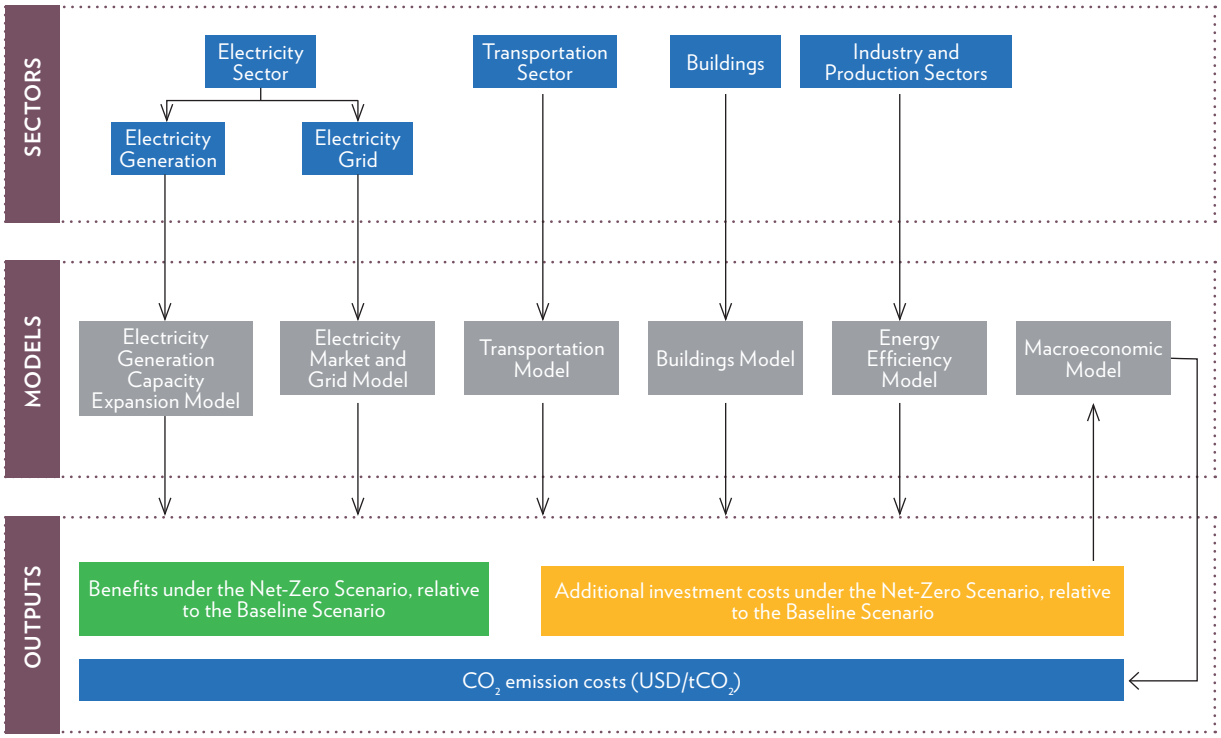
| | |
|---|---|
| **SOCIAL COST OF CARBON – Carbon price for energy-related $CO_2$ emissions (USD/ton $CO_2$)** | **169.45** |

# 1. INTRODUCTION

This study features sectoral calculations for the additional costs and benefits (according to Baseline Scenario) that are required to achieve the Net-Zero Scenario for 2020–2030 as outlined in Istanbul Policy Center's report "Turkey's Decarbonization Pathway: Net Zero in 2050."3 Our report assesses the electricity, the transportation , buildings, the industry and manufacturing sectors.

To address the electricity sector, which is the largest contributor to Turkey's national $CO_2$ emissions, this report models electricity generation and the electricity grid separately. The additional benefits of the Net-Zero Scenario, relative to the Baseline Scenario, include savings in fuel, health, and operational costs. The additional costs include the investment costs and operational costs that are required to achieve this transition. The flowchart of the models and outputs are illustrated in Figure 1.

**Figure 1. Flowchart of the models and outputs**




3 İstanbul Policy Center, "Turkey's Decarbonization Pathway: Net-Zero in 2050," Executive Summary, https://ipc.sabanciuniv.edu/Content/Images/CKeditorImages/20211026-23105368.pdf

# 2. ELECTRICITY SECTOR

## 2.1. ELECTRICITY GENERATION SECTOR

### 2.1.1. Overview

The electricity sector is responsible for 35 percent of $CO_2$ emissions in Turkey and has the highest emissions reduction potential globally.[4] The Turkish electricity sector is on the eve of a transition and is undergoing significant changes. This transformation and transition cannot be addressed without taking into account economic and environmental developments. Table 1 summarizes the electricity sector's indicators and the basic economic, energy, and environmental indicators for the 1990–2020 period. Table 1 shows that the growth of the electricity sector exceeds all other indicators. With the national and international economic developments of 2017–2020 and the emergence of the COVID-19 pandemic at the end of this period, electricity generation had stagnated at around 300 TWh. With the end of the pandemic, electricity generation increased to close to 330 TWh in 2021. Over the same period, installed capacity values continued to increase significantly, in contrast to production. As illustrated in Figure 2 and Figure 3, the substantial growth in solar and wind power played a significant role in the increase of total installed capacity. On the other hand, the increase in lignite and imported coalbased electricity generation in recent years is the main reason for maintaining the level of total $CO_2$ emissions.

**Table 1.** Main indicators: economy, energy and the environment (1990–2020).

| | 1990 | 2000 | 2010 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|---|---|---|---|
| Population (million)[5] | 56.5 | 67.8 | 73.7 | 78.7 | 79.8 | 80.8 | 82.0 | 83.2 | 83.6 |
| GDP (fixed 2015 billion USD)[6] | 288.7 | 413.8 | 614.2 | 864.3 | 893.0 | 960.0 | 988.6 | 997.4 | 1015.3 |
| Total Primary Energy Demand (Million TOE)[7] | 51.4 | 76.3 | 105.7 | 128.8 | 136.7 | 146.8 | 144.2 | 146.5 | 147.1 |
| Electricity Generation (TWh)[8] | 57.5 | 124.9 | 211.2 | 261.8 | 274.4 | 297.3 | 304.8 | 303.9 | 306.7 |
| Electricity Installed Capacity (GW)[6] | 16.3 | 27.3 | 49.5 | 73.1 | 78.5 | 84.5 | 88.5 | 91.3 | 95.9 |
| $CO_2$ emissions (Mt $CO_2$e)[3] | 219.7 | 299.0 | 398.7 | 474.5 | 500.8 | 528.3 | 524.0 | 508.1 | 523.9 |

4 Emissions Gap Report 2017 https://wedocs.unep.org/bitstream/handle/20.500.11822/22105/EGR_2017_ch_4.pdf?isAllowed=y&sequence=1

5 TurkStat, http://www.tuik.gov.tr/UstMenu.do?metod=kategorist

6 World Bank, https://data.worldbank.org/indicator/NY.GDP.MKTP.CD?locations=TR

7 IEA, https://www.iea.org/countries/turkey

8 MENR of Turkey, Turkish Electricity Transmission Corporation (TEİAŞ), https://ytbsbilgi.teias.gov.tr/ytbsbilgi/frm_istatistikler.jsf

Even though the share of natural gas-fired power plants gradually decreased in the second decade of the 2000s, it still ranked second in 2020 both in terms of installed capacity and the amount of electricity generated. Furthermore, total fossil fuel-generated electricity accounts for 57 percent of total electricity generation. This indicates how particularly significant the planned and immediate decommissioning of coal- and lignite-fired power plants is for the transition to net zero by 2053.

**Figure 2.** Installed capacity by technology, 2010, 2015, 2020. Source: TEİAŞ

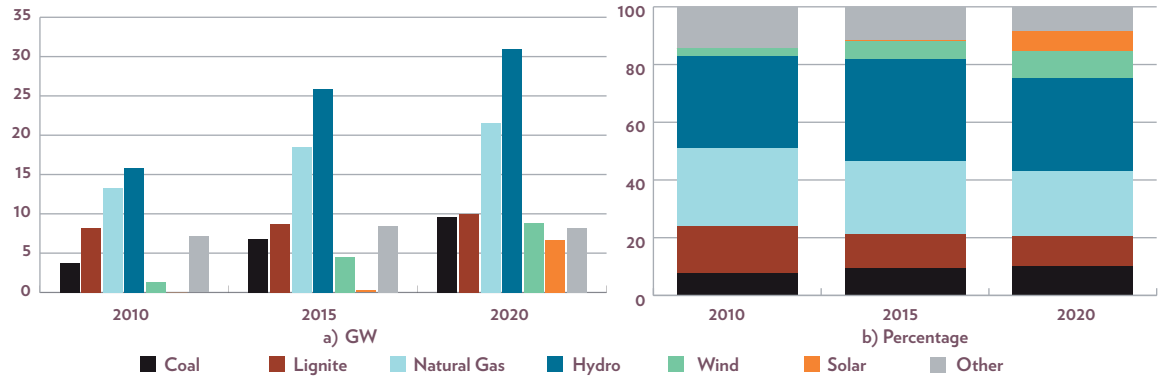
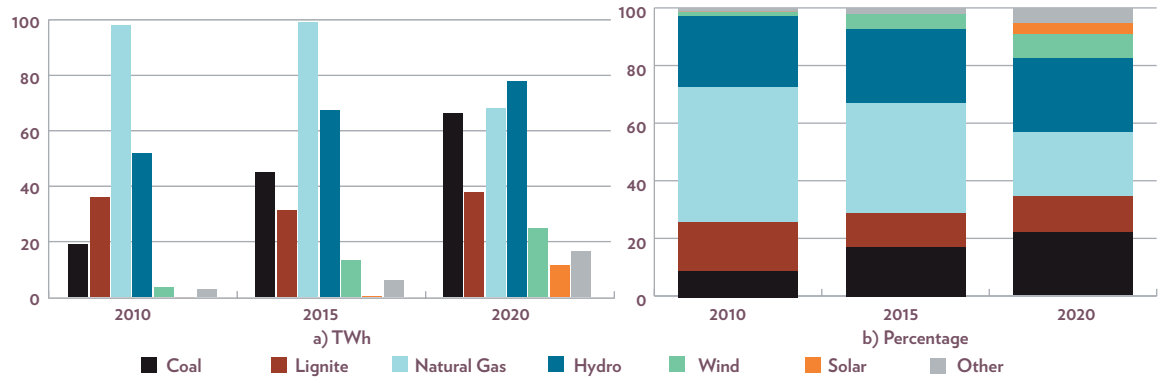



**Figure 3.** Electricity generation by technology, 2010, 2015, 2020. Source: TEİAŞ



### 2.1.2. Modeling

This study analyses the costs needed in the 2020-2030 period for the implementation of the results obtained from the modelling study based on two baseline scenarios in the "Turkey's Decarbonisation Roadmap: Net Zero in 2050" report prepared by Istanbul Policy Center. In this section, the three sub-models used in the modelling framework (electricity generation capacity expansion model, electricity market simulation model and macroeconomic model) and how these models are used in an integrated framework will be summarised. This section features the macroeconomic model's general framework and its relationship with energy models; however, the macroeconomic model is designed as an integrated structure not only with the electricity sector but also with all other economic sectors, and the assumptions and details of the model are provided in the relevant report.

#### *2.1.2.1. Electricity Generation Capacity Expansion Model (TR-Power)*

The generation capacity expansion model used in the study is an improved version of the TR-Power optimization model (Kat, 2021). In this context, the storage technologies-integrated model also includes cross-border interconnection lines. The model is based on a large-scale linear programming methodology that includes generation capacity increases and operational planning. The objective of the model is to minimise the total discounted cost of the total power system.Annual investment, operating and fuel costs and electricity outage costs are taken into consideration.. The technical and cost parameters were taken from the literature ( (Aksoy, et al., 2020) (Kat, 2021)). Demand projections are finalized with data from the macroeconomic, transportation, and building models. The rationality of the generation capacity expansion model results was validated by the electricity market simulation model. The generation capacity expansion model was iteratively corrected using the market simulation model results.

#### *2.1.2.2. Electricity Market Simulation Model*

The energy system's supply and demand, general scheme, assumptions, and input-output relations are covered with hourly minimum production costs during the target year, taking into account the generation capacity expansion model and using the method shown in Figure 4. To ensure consistency with the Turkish day-ahead power exchange (PX) market, grid security and reliability constraints are ignored in the model, but they are taken into account in grid simulations (details are explained in the Electricity Market and Grid Model section of the report). Figure 5 illustrates a 48-hour planning example of the model output. Details of the market simulation model can be found in Shura Energy Transition Center's report "Increasing the Share of Renewables in Turkey's Power System: Options for Transmission Expansion and Flexibility" (Philipp Godron, et al., 2018) and in the scientific article published by the model developers (Cebeci, et al., n.d.).

#### *2.1.2.3. Macroeconomic Model*

An applied general equilibrium model (AGE) was developed for the macroeconomic model using the Global Trade Analysis Project (GTAP) 10 dataset (Aguiar, et al., 2019) as the main data source. The sectors in this database were aggregated into 17 sectors under five main sectors (high electricity-intensive industry, low electricity-intensive industry, agriculture, services, and energy) and were integrated with other sectors, which are individually addressed in the study.

**Figure 4.** Market simulation model: Key inputs, assumptions and outputs

**Key Inputs**

- Total demand time series in hourly resolution
- Installed capacity by technology (coal, gas, hydro, renewable, etc.)
- Short-run marginal cost-based production cost benefit ranking (Merit order)
- Energy generation constraints of hydroelectric dams (water flow constraints)
- Renewable power generation time series in hourly resolution
- Hourly hot reserve requirement
- Technical constraints of power plants (minimum and maximum generation, minimum unit commitment, and the time of activation etc.)

**Market Simulation (hourly resolution)**

**Outputs**

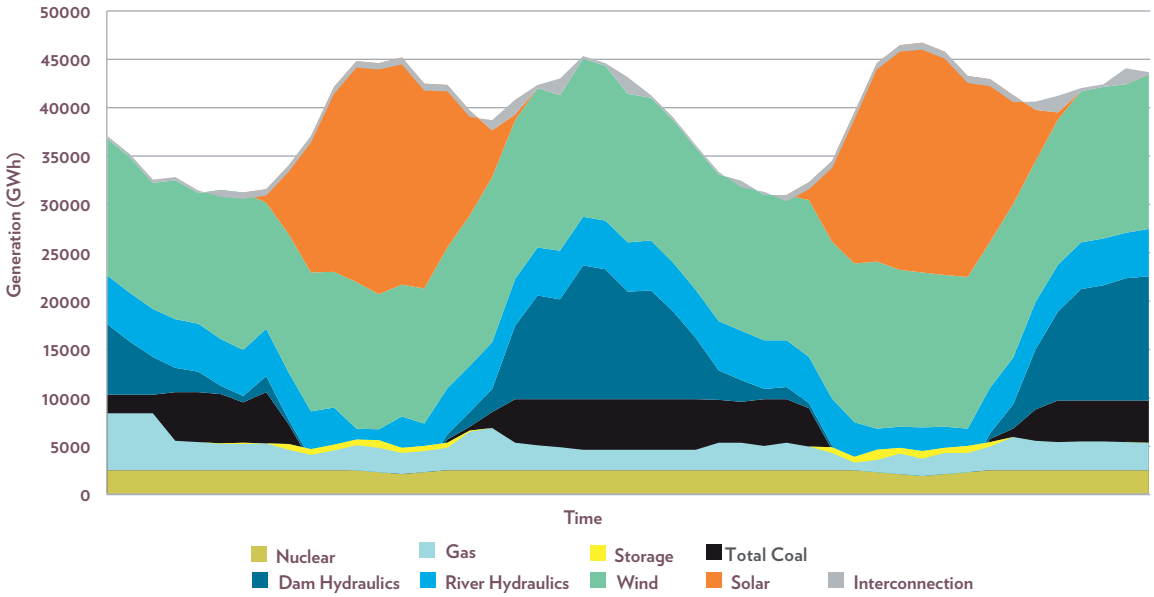
**Scenario-based:**

- Availability of conventional power plants at hourly resolution (unit commitment)resolution and their production amount
- Hot reserve distribution to power plants
- The amount of curtailment from renewable energy production (if necessary)

**Key Assumptions**

- Grid constraints are ignored (day-ahead market model)
- Past regional renewable energy generation figures were used as references for projecting renewable power plants' energy generation
- Past weekly generation figures were used as references for the energy generation constraints of hydroelectric dams (water flow constraints)
- It was assumed that nuclear power plants would be under maintenance during religious holidays
- An escalation from past hourly profiles was used to determine the total hourly load profile of the system. Distributed power plants were modeled as negative loads
- Interconnection lines were modeled as Net Transfer Capacity, and it was assumed that they would provide flexibility (market coupling)
- It was assumed that storage systems would be run to meet grid flexibility requirements
- It was assumed that the hot reserve would increase in proportion to its share in the net load (load minus renewable generation).

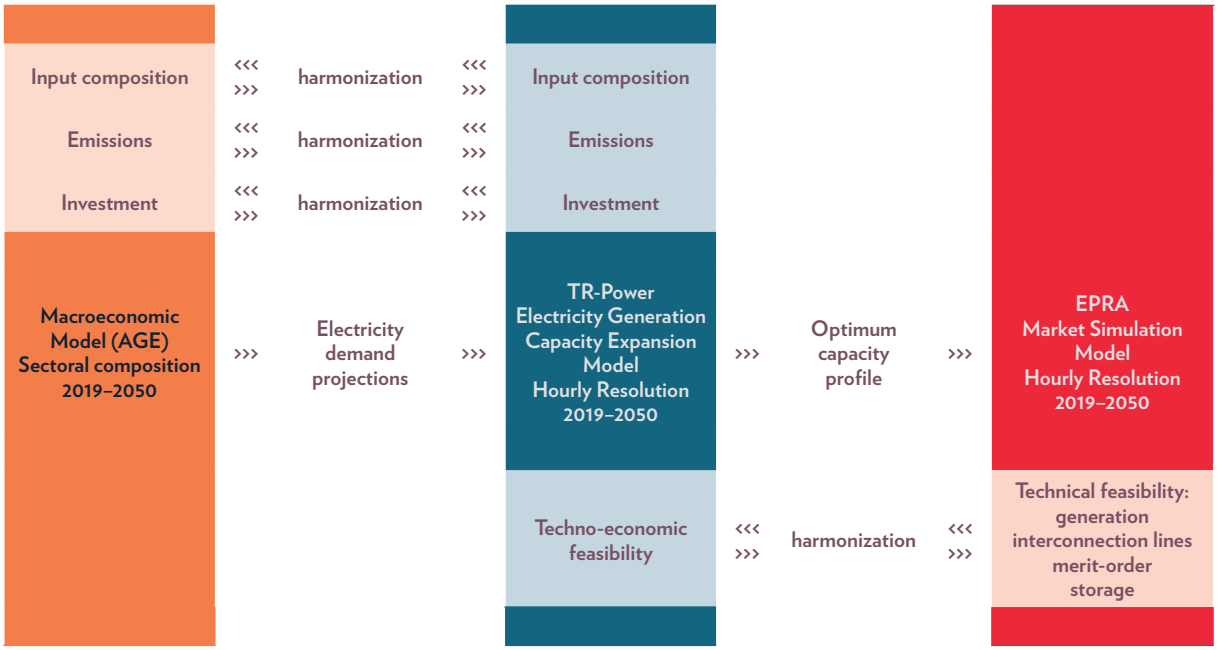
**Figure 5.** Example of market simulation outputs (48-hour)



### *2.1.2.4. Integrated Modeling Framework*

The integrated modeling framework is illustrated in Figure 6. The electricity generation capacity expansion model is located in the center as it exchanges data with both models and ensures that all models harmonize with certain parameters and variables. The process begins with the solution ofthis model over the initial electricity demand and continues with the the electricity sector's input values, emissions, and investment costs into the macroeconomic model. The electricity generation capacity expansion model is solved again using the new electricity demand projections produced by the macroeconomic model solved under the transmitted values.. The iterative structure continues until both models are harmonized. On the other hand, the more detailed technical feasibility of the results obtained by the capacity expansion model is checked in the market simulation model at each iteration; sub-iterations continue until a feasible solution is obtained in the market model run under detailed technical generation and transmission constraints.

**Figure 6.** Integrated modeling framework



### 2.1.3. Scenarios and Assumptions

This study focuses on the Baseline Scenario and the Net-Zero Scenario featured in Istanbul Policy Center's report "Turkey's Decarbonization Roadmap: Net Zero in 2050." It addresses the component costs of the results obtained from these scenarios for the 2020–2030 period and provides comparative analyses. Table 2 shows the key assumptions for both scenarios.

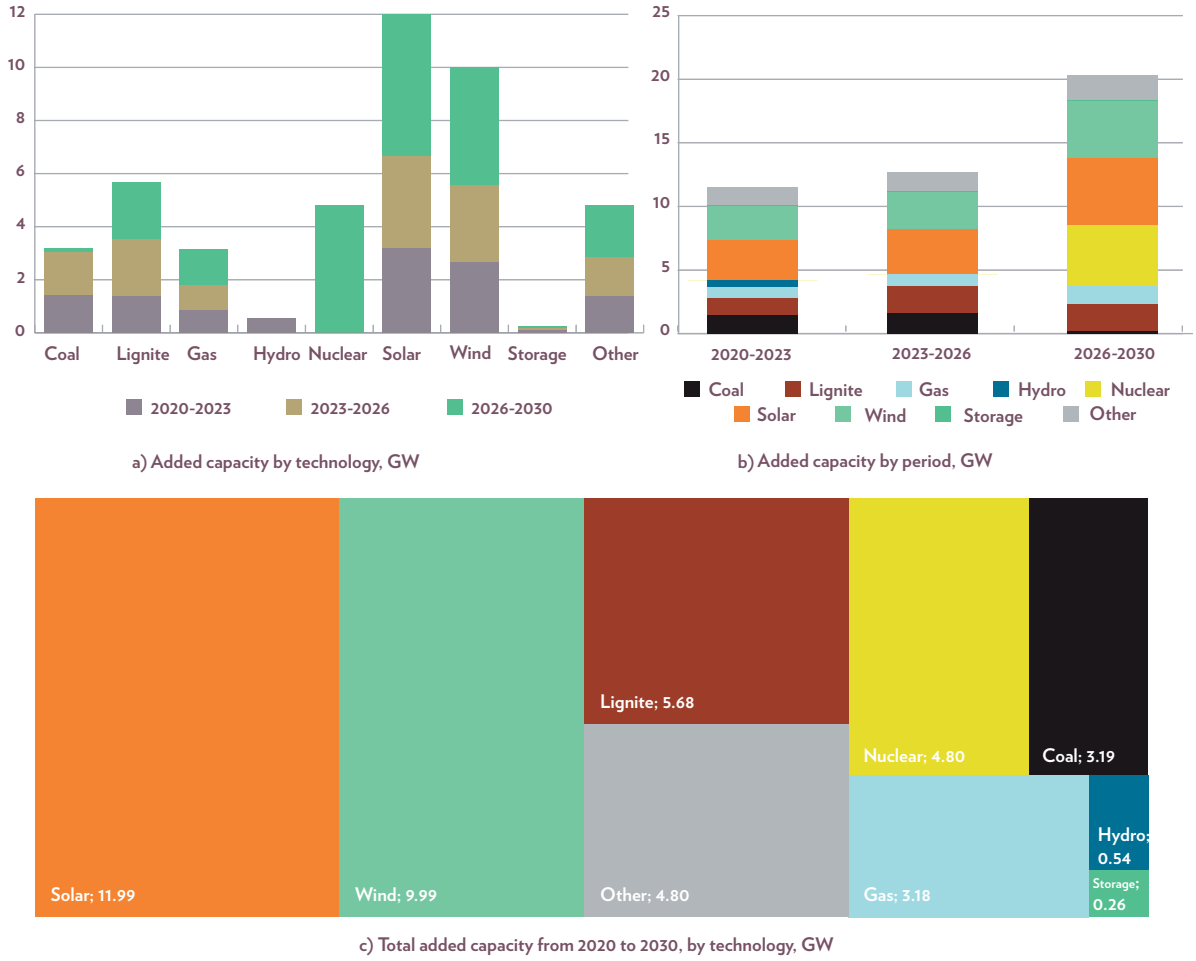
### 2.1.4. Results

This section details the costs of the electricity sector from 2020–2030 under the Baseline Scenario and Net-Zero Scenario featured in the report "Turkey's Decarbonization Roadmap: Net Zero in 2050" and provides the total costs as well as the additional sub-component costs that are required for the Net-Zero Scenario.

**Table 2.** Key assumptions for the Baseline Scenario and Net-Zero Scenario

| Baseline Scenario (BS) | Net-Zero Scenario (NZS) |
|---|---|
| • Low level (0.26 GW) integration of storage technologies into the systemLow increase in international interconnection line capacity (2.18 GW)Electricity demand in 2030 is 461 TWh<br>• Tight constraints on natural gas capacity (starting at 0.25 GW annually and increasing)<br>• Solar and wind capacity increases are relatively slow (starting below 1 GW annually and increasing)<br>• The Akkuyu Nuclear Power Plant (4 units, total 4.8 GW) begins operations in 2026 and becomes fully operational in 2030. | • Integration of storage technologies into the system is high (5.67 GW)<br>• International interconnection line capacity significantly increases (3.35 GW)<br>• Electricity demand in 2030 is 472 TWh<br>• Loose constraints on the increase of natural gas installed capacity (starting at 0.50 GW annually)<br>• Relatively high rate of increase in solar and wind installed capacity (starting from over 1 GW per year and increasing) No new coal-fired power plants (only 1.32 GW added in 2020–2023) and decommissioning existing coal-fired power plants after 2030<br>• Gradual integration of offshore wind power and concentrated solar power (CSP) technologies begin in 2026<br>• The Akkuyu Nuclear Power Plant (4 units, total 4.8 GW) begins operations in 2026 and becomes fully operational in 2030. |

**Figure 7.** Baseline Scenario




a) Added capacity by technology, GW

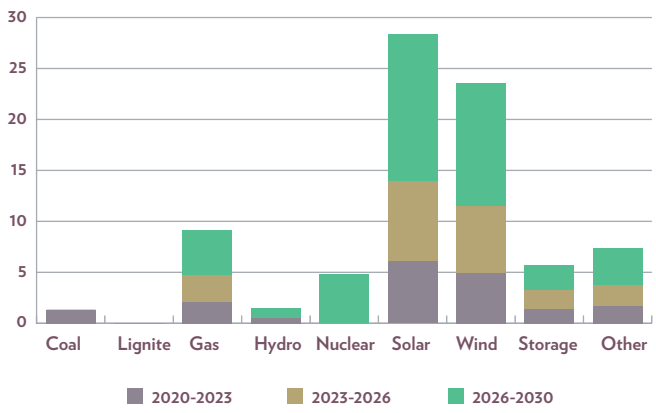
b) Added capacity by period, GW

c) Total added capacity from 2020 to 2030, by technology, GW

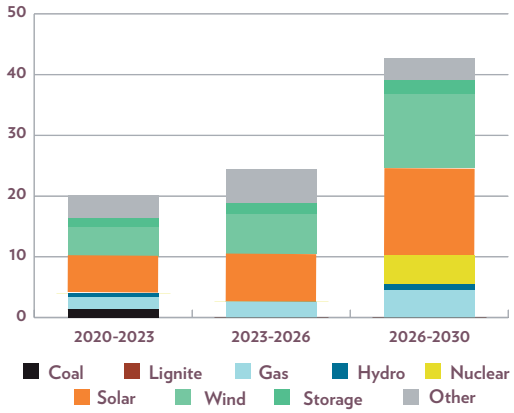
Figure 7 summarizes the total capacity added to the electricity generation sector from 2020–2030 under the Baseline Scenario. The highest increase takes place in wind and solar energy, with approximately 12 GW of new solar and 10 GW of new wind power plants being commissioned. Total capacity increases between 10 GW to 15 GW for the 2020–2023 and 2023–2026 periods, respectively, and exceeds 20 GW from 2026–2030. The reason behind this rise is the assumption that all four units of the nuclear power plant (Akkuyu Nuclear Power Plant) become operational during this period. On the other hand, coal- and lignite-fired power plant capacity continue to increase at the same rate as they did in the last decade. Gas-fired power plant capacity ranks first among all fossil fuel plants and increases by 3.18 GW.

It is observed that the increase in fossil fuel power plant capacity and the commissioning of the nuclear power plant significantly reduce the risks that may

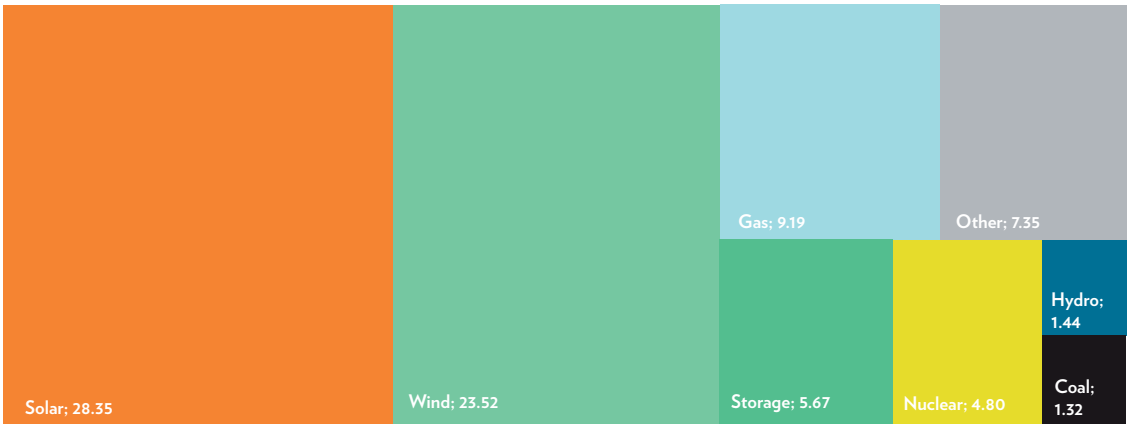
**Figure 8.** Net-Zero Scenario




a) Added capacity by technology, GW




b) Installed capacity added to the system by years GW



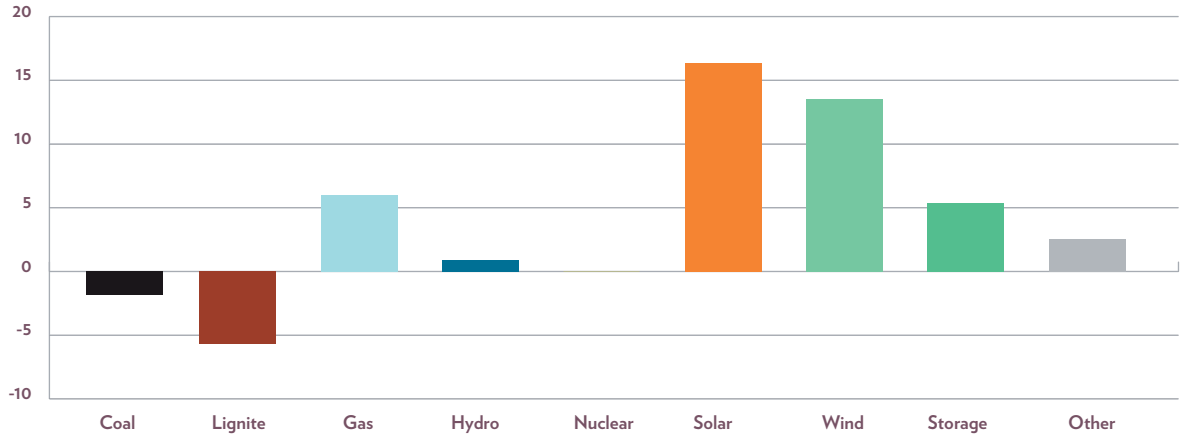

c) Total added capacity from 2020 to 2030 by technology, GW.

arise in meeting base load demand; therefore, storage requirements to balance increasing intermittent technologies (solar and wind) remain quite low.

Figure 8 summarizes the newly commissioned capacity under the Net-Zero Scenario. Under this scenario, the integration of solar and wind power plants into the system accelerates over time. Due to this considerable increase in the share of intermittent technologies, storage capacity significantly increases and reaches a total of 5.67 GW in 2030.

As previously mentioned, the Net-Zero Scenario assumes that no new coal- or lignite-fired power plants are integrated into the system, except for one coal-fired power plant that is nearly completed. The difference between the Net-Zero Scenario and the Baseline Scenario can be seen more clearly in Figure 9. The increase in solar and wind power is almost 30 GW and is largely due to increased storage capacity. Furthermore, some of the base load requirements, which emerge following the partial phase-out of coal

**Figure 9.** Technology based newly added installed capacity differences between Net Zero Scenario and Baseline Scenario GW, 2020–2030




and lignite, are met by increasing gas-fired power plant capacity.

While the transformation of energy-generation technologies in the electricity sector is mainly evaluated on the basis of the investment costs for newly commissioned power plants, it also affects the operational and maintenance expenses and fuel costs.

Figure 9 shows the difference in added capacity under the Baseline Scenario and the Net-Zero Scenario. The total costs provided in Figure 10 include investment costs that arise from the capacity differences under the Net-Zero Scenario and the Baseline Scenario as illustrated in Figure 9 as well as operational and maintenance expenses and fuel costs. A closer look at these cost components, which are relatively low compared to investment costs, reveals that some of the fuel and operating savings obtained from reducing coal- and lignite-fired power plant capacity are partially offset by fuel and

**Figure 10.** Technology-based cost differences between the Net-Zero Scenario and the Baseline Scenario, billion USD, 2020–2030

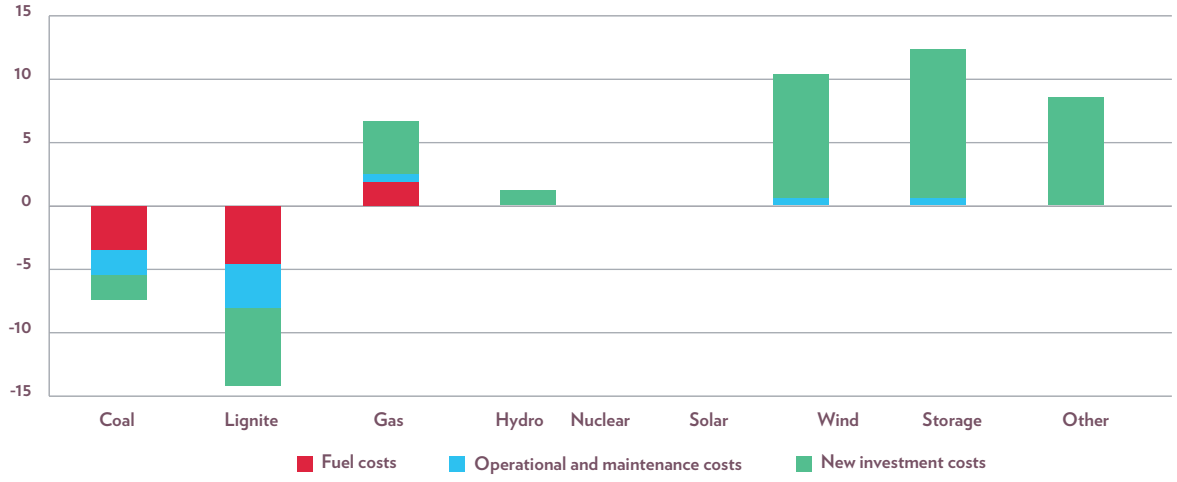


**Table 3.** Net-Zero Scenario and Baseline Scenario Comparison: Main Indicators

| Indicator | Unit | Period | Difference |
|---|---|---|---|
| Generation and storage capacity investment | Billion USD | 2020-2030 | 35.0 |
| Operational and maintenance costs | Billion USD | 2020-2030 | -1.0 |
| Fuel costs | Billion USD | 2020-2030 | -6.4 |
| RES generation | % | 2030 | 40.6% |
| Electricity demand | TWh | 2030 | 11.7 |
| Market clearing price | % | 2030 | -17.8% |
| Curtailment + transmission line costs | Billion USD | 2020-2030 | < 1 |
| Cumulative $CO_2$ emissions | Mton | 2020-2030 | -587.7 |

operating costs from increases in natural gas-fired power plant capacity.

The differences in key indicators such as electricity generation, electricity market clearing price and emissions, together with the additional costs required under the Net Zero Scenario compared to the Baseline Scenario are summarised in Table3. The total difference in investment costs for 2020–2030 is around USD 35 billion, as shown in Figure 10. The average annual nominal investment required under the Baseline Scenario is approximately USD 7 billon and increases to USD 10 billion under the Net-Zero Scenario. When calculated using a specific interest rate (for example, 6 percent), they total USD 5.6 and 8.5 billion, respectively. While the decrease in operational and maintenance costs is limited, the decrease in fuel costs exceeds USD 6 billon. It is important to note that this study analyzes the outcomes of (Ümit Şahin, 2021), where the baseline year for the models is 2018, and uses fuel costs until 2020 and projections for 2020–2030 (Aksoy, et al., 2020) (Kat, 2021). Therefore, considering that the recent extraordinary increase in international energy prices will continue (contrary to the relatively fixed trend shown in the relevant projections), fuel cost savings are expected to increase by several fold and reach around USD 20 billion.

Comparing the total electricity demand and the share of renewable resources in meeting this demand in the Net-Zero Scenario relative to the Baseline Scenario, in 2030 electricity demand increases from 460.6 TWh to 472.3 TWh, and the share of renewables in electricity generation increases from 45 percent to 69 percent. The partial transition that occurs from 2020–2030 under the Net-Zero Scenario reduces cumulative $CO_2$ emissions by 31 percent, or 587.7 million tons.

Stranded costs that occur with the early retirement and early decommissioning of coal-fired power plants are not included in the table but constitute a significant issue that should be noted. Under the Net-Zero Scenario, the total capacity of coal- and lignite-fired power plants decreases from 19.6 GW in 2020 to 7.2 GW in 2030. Taking into account that a 1.3-GW coal-fired power plant will be commissioned during the 2020–2030 period, total decommissioned coal capacity reaches 13.6 GW. The non-recoverable initial investment costs (Zhang, 2022) , which is the non-recoverable cost components, is estimated to be approximately USD 6.9 billion, arising from the decommissioning of young imported coal plants.

Decommissioning and environmental regulation costs are estimated at $1.6 billion using unit costs for coal plants (Raimi, 2017). On the other hand, the upper limit for the compensation of foregone profits from early decommissioning is expected to be USD 4 billion(World Bank Group, 2022) .

## 2.2. ELECTRICITY MARKET AND THE GRID MODEL

### 2.2.1. Introduction

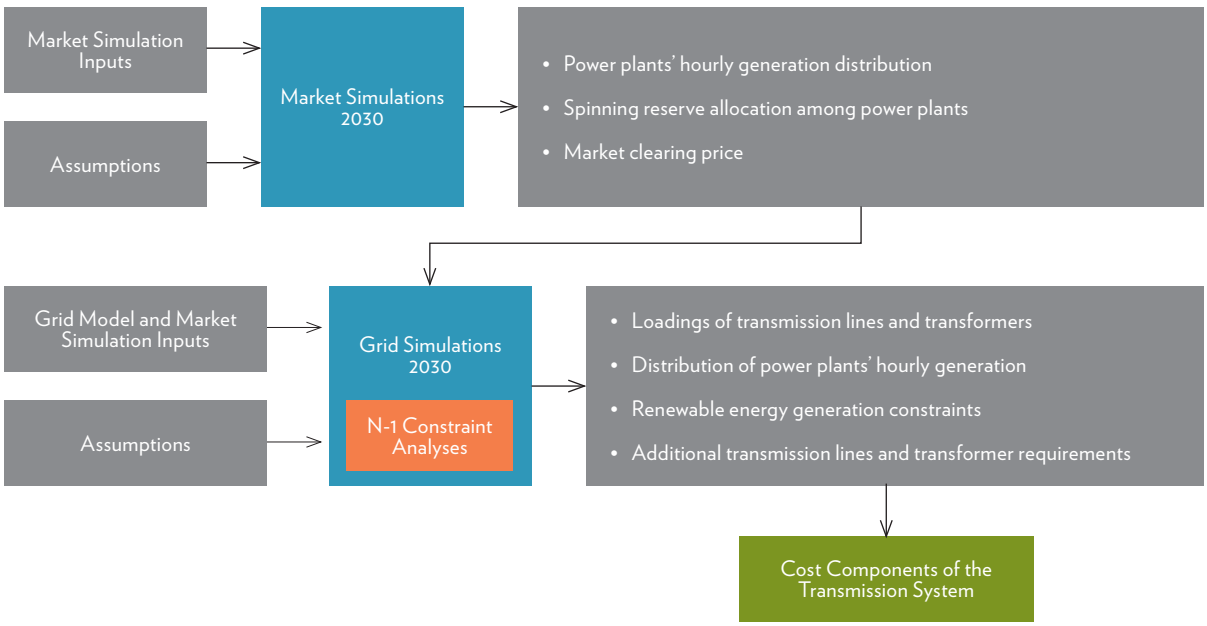
The main purpose of the market simulation is to investigate the adequacy of Turkey's electricity generation capacity up to the target year, 2050, considering the changes in load and generation (renewables). An analysis that is based on market simulation provides insights into the state of Turkey's electricity generation system and the associated requirements but assumes an ideal transmission system without any capacity limits. Therefore, the market simulation only reflects the costs of a production system that is on the path of decarbonization. However, there are other cost components that impact the transmission and distribution systems that are addressed in this report. For this purpose, a study called "Network Simulation" is carried out, to assess these cost factors. The methodology, assumptions, and results of the simulation are covered in the following sections.

### 2.2.2. Modeling and Assumptions

#### *2.2.2.1. Market and Grid Simulations*

The outline of the proposed methodology for the calculation of the cost components imposed by the transmission system is shown in Figure 11.

**Figure 11.** Methodology flowchart



According to Figure 11, the first step is conducting market simulations. The market simulation engine simulates the day-ahead Power Exchange (PX) market using the following inputs:

- System's total hourly load profile
- Generation capacity of conventional power plants (coal, lignite, gas, and nuclear)
- Merit order of different generation technologies
- Weekly energy constraints of hydroelectirc power plants
- Generation profiles of wind, solar, run-of-the-river hydro, and other renewable energy power plants
- Spinning reserve requirements
- Generator constraints (Pmaks/min, ramp up/down, etc.)

The merit order of power plants is a way of ranking available power generation technologies based on ascending price order (which may reflect the order of short-run marginal generation costs) and sometimes pollution and the corresponding amount of energy to be produced (see Figure 12). In the market simulation, the merit order is such that those with the lowest marginal costs will be commissioned first, and those with the highest marginal costs will be used last. This method of distributing generation (Economic Power Distribution) minimizes the costs of electricity generation.

The market simulation engine places the aforementioned input data into an optimization model with the intent to minimize the total operating costs of a system that has a number of technical constraints. Some examples of primary constraints are the ramp requirement of various power plants, the minimum start and stop times of generators, the permitted operating intervals of generators, maintenance requirements, and the weekly energy constraints of hydroelectric power plants.

The market simulation assumptions are as follows:

- Network constraints are ignored.
- Wind, solar, and run-of-the-river generation is modelled as a negative load (feed-in).
- The weekly constraints of hydroelectric dams are based on historical data.
- Maintenance at nuclear power plants takes place during minimum demand periods.

**Figure 12.** Merit order concept in market simulation

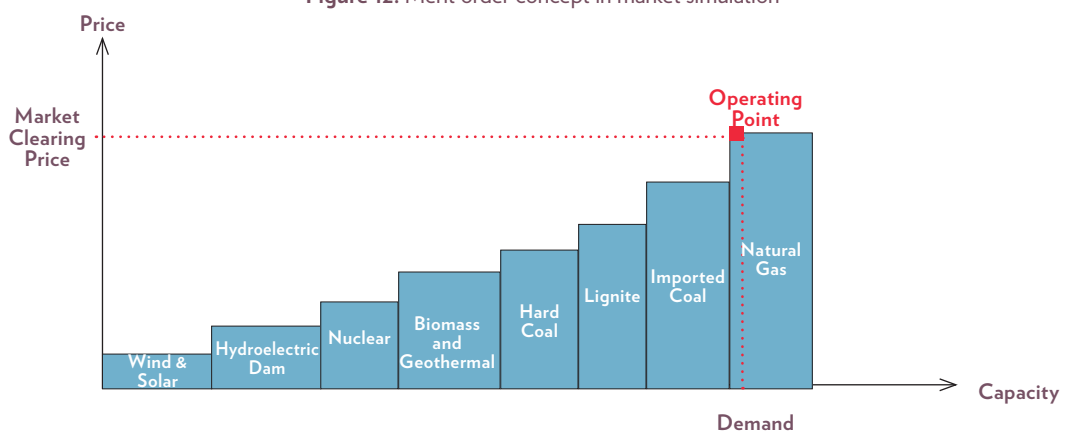
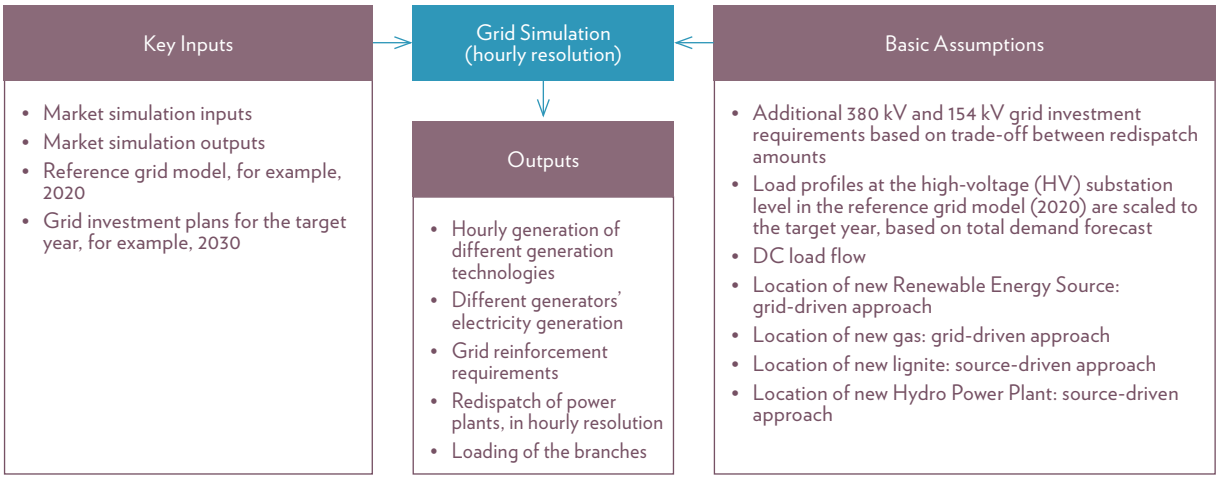


**Figure 13.** Grid simulation inputs, outputs and key assumptions




- The system demand profile is scaled based on an average annual increase ratio (%).
- Distributed renewables resources are concentrated at high voltage substations.
- The spinning reserve requirement is adjusted considering the increase in renewable generation.

The market simulation outputs are as follows:

- Hourly production distributions of different generation technologies
- The power generation of different generators
- Marginal generator per hour
- Renewable restriction per hour

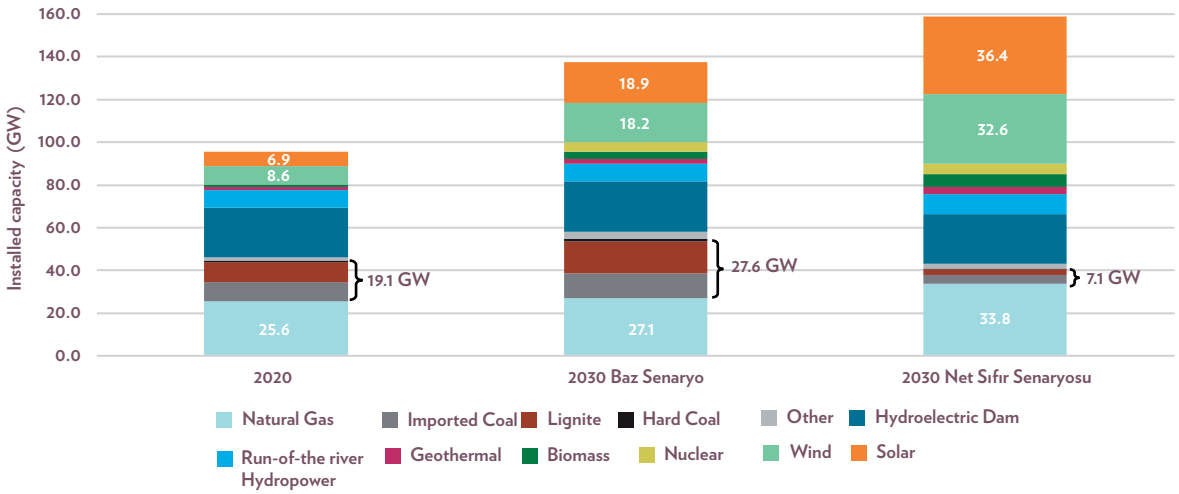
After the market simulation is conducted, the relevant outputs are added to the grid simulation to investigate the impact of the transmission grid on electricity generation by different technologies. The inputs, outputs, and basic assumptions for the grid simulation are presented in Figure 13.

Using the outputs of the market and grid simulations, the cost components of the grid are as follows:

- **Redispatch requirement:** "Redispatch" is the annual total orders given to conventional power plants (natural gas, coal, and lignite power plants) to resolve grid constraints. It is calculated as the annual sum of hourly differences between market and grid simulation results. Market simulations ignore the transmission grid and offer an ideal solution (redispatch). On the other hand, grid simulation takes into account grid constraints and offers new solutions (redispatch). Since market solutions are the least costly solutions, the redispatch amount reflects the additional costs of transmission grid constraints. The total cost of redispatch is calculated by multiplying the redispatch amount by the market clearing price.[9]

9 SHURA Energy Transition Center. Increasing the Share of Renewables in Turkey's Power System. May 2018 (https://www.shura.org.tr/increasing-the-share-of-renewables-in-turkeys-power-system/)

**Figure 14:** Generation capacities under the Baseline and Net-Zero Scenarios




- **Reneweble Energy Source Curtailment:** RES curtailment is a cost component that reflects the amount of renewable capacity that is used. Since renewable resources are modelled as the lowest cost power generation option, the generation capacities are used to the maximum extent possible in market simulations and and only during hours when the total amount of renewable generation is greater than the total amount of consumption, renewable generation is constrained up to this difference. However, in grid simulations, there may also be constraints in the generation of renewable energy sources due to constraints in the transmission grid. The RES curtailment cost is the opportunity cost of the generation because of transmission grid constraints. The RES curtailment cost is the sum of the curtailment amount multiplied by the market clearing price[10].

- **Additional grid investment requirement:** The grid simulation accounts for operational constraints, and as previously mentioned, it uses redispatch to mitigate violations. If the violations is not mitigated through redispatch, the additional grid investment will be determined by the grid simulation.7 Grid investments include investments for transmission lines, transmission substations, transformer investments, and distribution lines and distribution substations and transformer investments.

### *2.2.2.2. Generation Capacity*

The 2030 generation capacities under the Baseline Scenario and the Net-Zero Scenario are the key inputs in the market and grid simulations. As seen in Figure 14, the main difference in conventional generation technologies is regarding coal-fired power plants. In the current policy paradigm, the installed capacity of coal-fired power plants will be increased from 19.1 GW in 2020 to 27.6 GW in 2030 (Baseline Scenario). However, under the 2050 Net-Zero Scenario, the capacity of coal-fired power plants drops to 7 GW in 2030.

10 SHURA Energy Transition Center. Integration of Renewable Energy into the Turkish Electricity System. April 2022. https://shura.org.tr/en/integration-of-renewable-energy-into-the-turkish-electricity-system/

From a market simulation perspective, all power plants of a particular technology, such as imported coal, are given the same priority for phase-out. The main reason for this is that the market simulation ignores the transmission grid and, consequently, the geographical location of the power plants. Thus, an equivalent representative power plant can be used. However, from a grid perspective, the distribution of power plants within the grid is of great importance. For grid simulation under the Net-Zero Scenario, the order of the coal-fired power plants to be phased out is based on the following criteria:

- **Installed Capacity:** Coal-fired power plants smaller than 50 MW are prioritized.
- **Generation Technology:** The priority order is as follows: 1. Hard Coal; 2. Lignite; 3. Imported Coal. This prioritization is based on the average efficiency and emissions of coal plant technologies.
- **Year of Installation:** Older power plants are given priority.
- **Ownership:** State-owned power plants are prioritized.

### *2.2.2.3. System Load and Renewable Generation Profile*

The total system load illustrated in Figure 15 is based on the report "Turkey's Decarbonization Pathway: Net Zero in 2050."

This study takes into account the renewable energy generation profiles from the report 'Increasing the Share of Renewable Energy in the Turkish Electricity System'. This report8 takes a system-oriented approach to the distribution of renewable energy sources. The aggregated generation profiles of wind and solar power plants are shown in Figure 16 (Baseline Scenario).

The annual load and renewable energy data under the Baseline Scenario and the Net-Zero Scenario are illustrated in Table 4.

**Figure 15.** Total load for 2020 and 2030, in hourly resolution (Baseline Scenario)

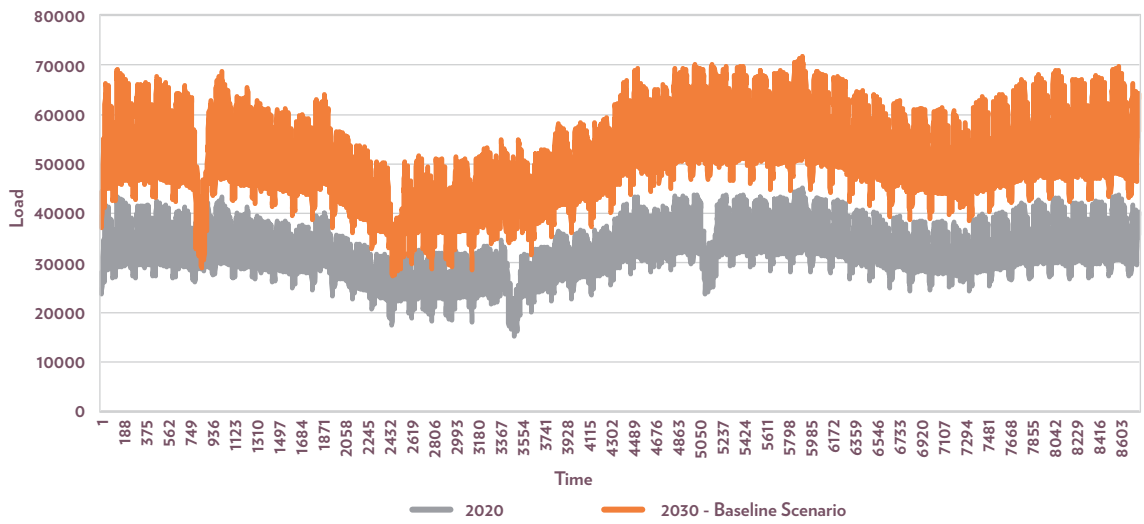


**Figure 16:** Total generation profiles of wind and solar power plants (weekly resolution) (Baseline Scenario)

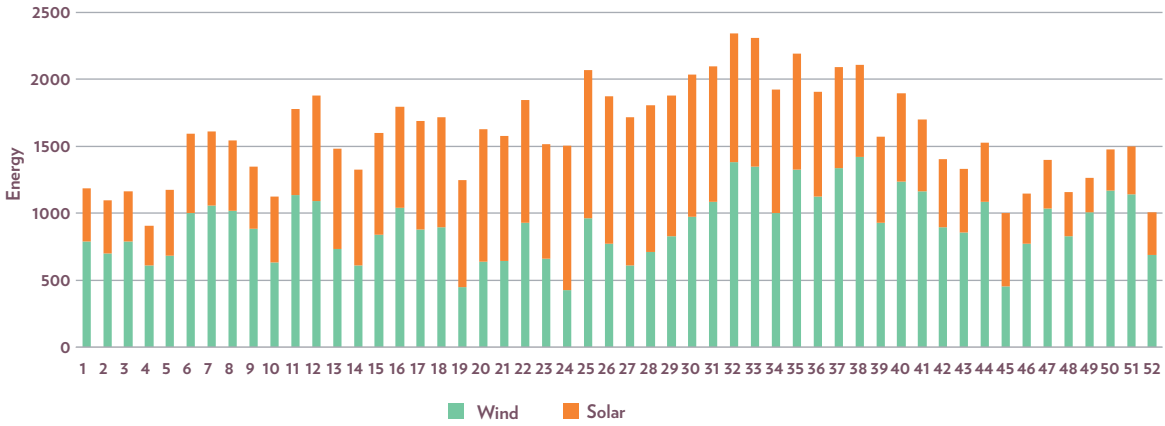


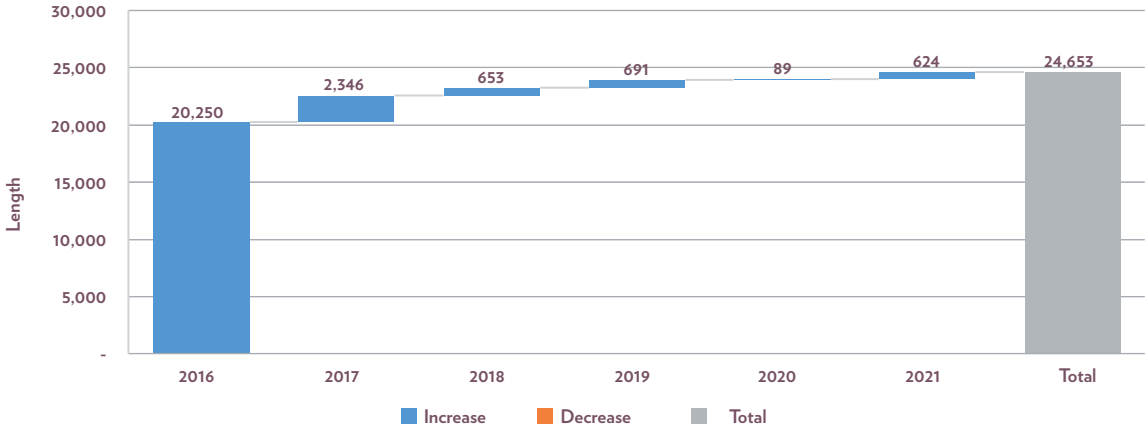

**Table 4.** Annual load and renewable energy data under the Baseline and Net-Zero Scenarios

| Year | RES Installed Capacity (GW) | | Load (TWh) | |
|---|---|---|---|---|
| | Baseline Scenario | Net-Zero Scenario | Baseline Scenario | Net-Zero Scenario |
| 2020 | 15.5 | 15.5 | 304.9 | 304.9 |
| 2021 | 17.5 | 19.9 | 321.0 | 321.8 |
| 2022 | 19.4 | 24.2 | 337.0 | 338.8 |
| 2023 | 21.3 | 28.5 | 353.1 | 355.8 |
| 2024 | 23.5 | 33.3 | 367.9 | 371.7 |
| 2025 | 25.6 | 38.1 | 382.7 | 387.6 |
| 2026 | 27.8 | 42.9 | 397.5 | 403.5 |
| 2027 | 30.1 | 49.5 | 413.1 | 420.7 |
| 2028 | 32.4 | 56.0 | 428.7 | 437.9 |
| 2029 | 34.8 | 62.5 | 444.4 | 455.1 |
| 2030 | 37.1 | 69.0 | 460.0 | 472.3 |

### *2.2.2.4. Transmission Grid*

The 400-kV grid investments between 2016 and 2021 are illustrated in Figure 17. According to the latest 400-kV grid investment plans, Turkey will add 7,989 km of new transmission lines by 2030. This means that approximately 800 km of new transmission lines will be added annually between 2020 and 2030. Although this amount of annual average investment may look like an ambitious target, it is close to TEİAŞ's annual average investment and is therefore it is achievable.

**Figure 17:** The 400-kV transmission lines in Turkey's transmission grid



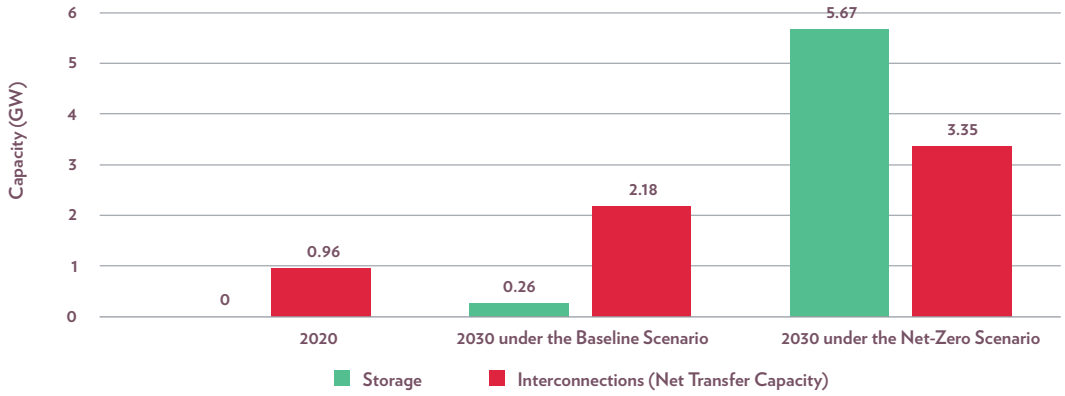

### *2.2.2.5. Grid Flexibility Options*

The flexibility solutions used in this study are storage systems (pumped hydropower plant and battery) and flexibility from market interconnections at the market connection. Flexibility options for each scenario can be seen in Figure 18.

In the 2030 Net Zero Scenario, the storage systems considered are the pumped hydroelectric power plant with a peak capacity of 1 GW at Gökçekaya Hydro Power Plant and a total of 4.67 GW peak Li-ion battery capacity distributed to 154 kV substations (substations with relatively larger demand are prioritised). The charge/discharge profiles of storage devices are determined according to the market and grid simulations.

The Turkish grid has a synchronous interconnection with the European Network of Transmission System Operators for Electricity (ENTSO-E) grid and High Voltage Direct Current Back-to-Back (HVDC B2B) interconnection with the Georgian grid. Its net transfer capacity (NTC) is 500 MW

**Figure 18.** Flexilibity options for each scenario



(minimum) and 700 MW (maximum).[11] Currently, trading on the interconnections is based on the allocation of NTCs to traders through a capacity auction mechanism.[12] Scheduled power transactions are controlled through TEIAS's automatic generation control (AGC) system. Since there is not any market coupling with spot markets in neighboring countries yet, the flexibility of interconnection lines is limited. The study assumes that the flexibility provided by interconnections will be maximized through the proper market mechanisms including market coupling and imbalance netting.

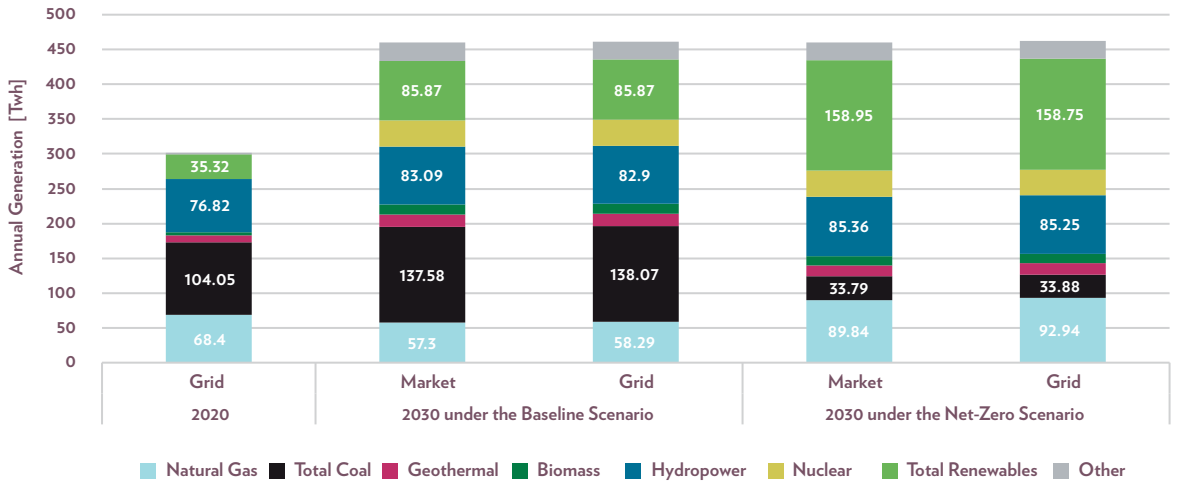
### 2.2.3. Results

#### *2.2.3.1. Market and Grid Simulation Results for 2030*

The market and grid simulation results for the year 2030 under the Baseline Scenario and Net-Zero Scenario are shown in Figure 19. Comparing the 2030 grid simulation results with the 2030 market simulation results reveals that gas-fired power generation increases by 1 TWh in the Baseline Scenario and by 3.1 TWh in the Net-Zero Scenario. This increase in the power generated by this relatively expensive technology is due to grid constraints.

Annual capacity factors, which represent the operating pattern of conventional power plants are shown in Figure 20 to assess the rationality of the market and grid simulations. It is observed that the values achieved in the Baseline and Net Zero Scenarios appear to be normal when compared to the values realised in 2020. This confirms that the market and grid simulations successfully represent Turkey's energy system.

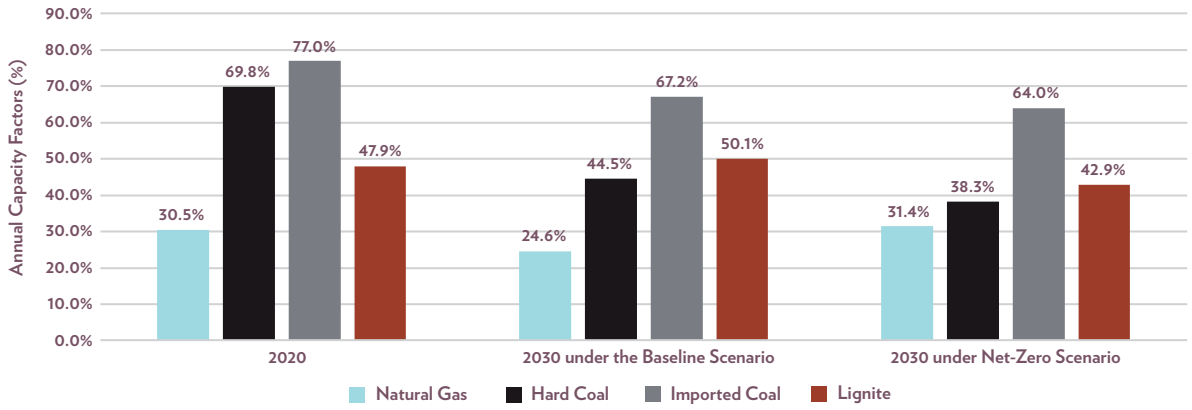
**Figure 19.** Market and grid simulation results for 2030 under the Baseline and Net-Zero Scenarios.




11 NTC of interconnection with Georgia varies according to seasons and is at a minimum level in spring and early summer. This is due to the fact that power generation in both countries is based on hydropower plants.

12 TEİAŞ report: https://tcat.teias.gov.tr/

**Figure 20.** Annual capacity factors of conventional power plants under the Baseline Scenario and the Net-Zero Scenario.




As mentioned in Section 2.2.2.2.1, regeneration dispatch and renewable constraints are among the main outputs of market and grid simulations for cost assessment. Figure 21 shows the annual re-dispatch quantities for 2020, 2030 Baseline and 2030 based on the 2050 Net Zero Scenario. Even though the annual redispatch amount increases from 2020 to 2030, the total load ratio remains almost the same.

Figure 21 reveals that the Net-Zero Scenario does not impose additional redispatch stress on Turkey's power system. The annual RES curtailment amounts under different scenarios are shown in Figure 22 and are negligible.

Another cost component that can be derived from the market and grid simulations is the additional grid investment requirement. Figure 23 shows the additional investments required for the 400-kV system under the 2030 Baseline Scenario and the Net-Zero Scenario. The current plan indicates an additional investment of 7,989 km of 400-kV transmission lines by 2030. This corresponds to about 800 km per year between 2020 and 2030. As discussed in Section 2.2.2.4, the annual average

**Figure 21.** Annual redispatch under the Baseline and Net-Zero Scenarios

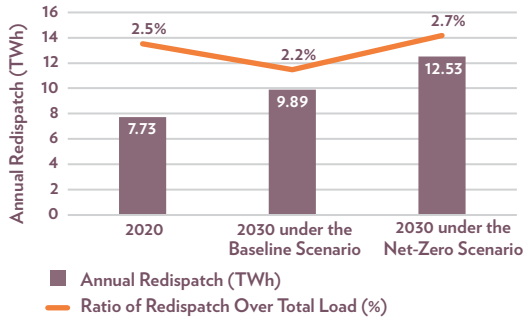



**Figure 22.** Annual RES curtailment under the Baseline and Net-Zero Scenarios

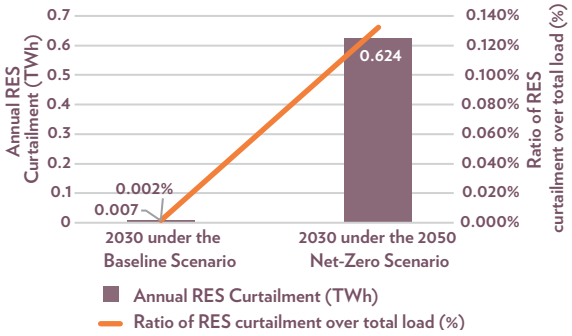
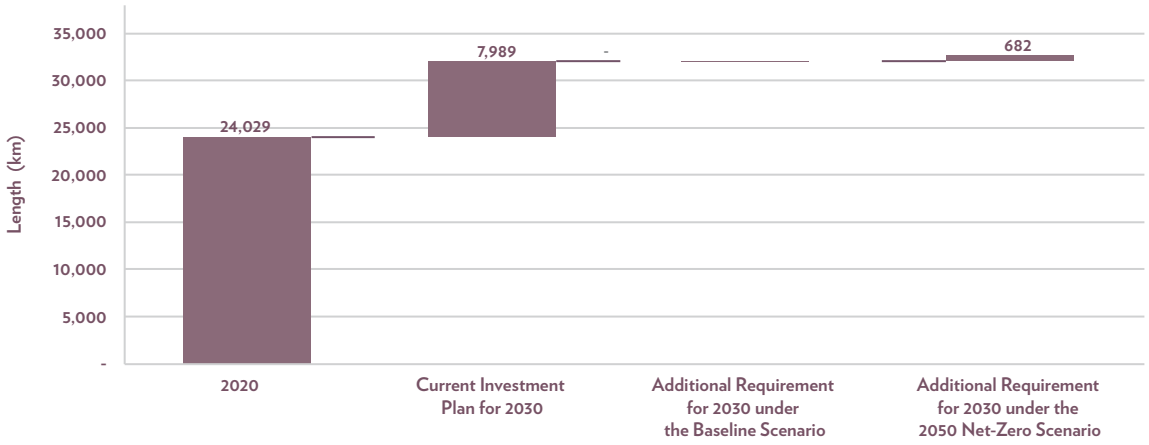


**Figure 23.** Additional investment needed at the 400-kV level under the Baseline and Net-Zero Scenarios




investment for 400-kV transmission lines is approximately 880 km per year from 2016 to 2020. According to the grid simulation results shown in Figure 22, the planned investments meet the 2030 Baseline Scenario requirements. However, in 2030, the 2050 Net-Zero Scenario requires 682 km of additional 400-kV transmission line investment, which corresponds to an 8.5-percent addition to the current investment plan for 2030.

### *2.2.3.2. Grid Costs*

The cost components of the transmission grid, redispatch, and RES curtailment from 2020 to 2030 are indicated in Table 5. As previously mentioned in Section 2.1, the cost components of redispatch and curtailment are considered as opportunity costs, and they are calculated by multiplying the redispatch and curtailment amounts with the market clearing price. According to Table 5, from the point of view of redispatch and RES curtailment, the 2050 Net-Zero Scenario costs USD 180 million more than the Baseline Scenario for the 2020–2030 period.

The results in Figure 23 are used to calculate the additional grid investment costs. In 2030, 682 km of additional 400-kV transmission lines will be required under the Net-Zero Scenario compared to the Base Scenario. However, this additional 682 km of 400-kV lines is the cumulative amount of 400-kV transmission lines added between 2020 and 2030. The reason for this is that transmission grid expansion plans are often added to the existing grid, and no transmission lines are phased out from 2020 to 2030. Another point to be noted here is that all investments for the 400-kV system lead to investments for lower voltage systems (154 kV investments, 400-kV/154-kV substation investments, distribution grid and distribution systems, and lower voltage system investments). Recent investment figures for transmission and distribution systems are used to calculate the investment requirements of lower voltage systems (see Table 6).

**Table 5.** Cost components of the transmission grid (redispatch and RES curtailment), 2020–2030

| Year | Redispatch (TWh) | | RES Curtailment (TWh) | | Annual Average Market Clearing Price (USD/MWh) | | Cost (Million USD) | |
|---|---|---|---|---|---|---|---|---|
| | Baseline Scenario | Net-Zero Scenario | Baseline Scenario | Net-Zero Scenario | Baseline Scenario | Net-Zero Scenario | Baseline Scenario | Net-Zero Scenario |
| 2020 | 7.73 | 7.73 | 0 | 0 | 35.2 | 35.2 | 272.1 | 272.1 |
| 2021 | 7.98 | 8.27 | 0.0008 | 0.0708 | 40.4 | 38.6 | 322.3 | 322.0 |
| 2022 | 8.21 | 8.77 | 0.0016 | 0.1346 | 45.0 | 41.6 | 370.0 | 370.5 |
| 2023 | 8.42 | 9.21 | 0.0022 | 0.1923 | 49.3 | 44.4 | 415.2 | 417.2 |
| 2024 | 8.67 | 9.69 | 0.0030 | 0.2543 | 54.3 | 47.3 | 470.7 | 470.6 |
| 2025 | 8.72 | 10.12 | 0.0032 | 0.3113 | 55.2 | 50.1 | 481.5 | 522.5 |
| 2026 | 9.11 | 10.53 | 0.0045 | 0.3637 | 63.2 | 52.6 | 575.6 | 572.6 |
| 2027 | 9.32 | 11.09 | 0.0052 | 0.4368 | 67.6 | 56.1 | 630.8 | 646.2 |
| 2028 | 9.53 | 11.61 | 0.0058 | 0.5041 | 71.7 | 59.3 | 683.7 | 717.9 |
| 2029 | 9.71 | 12.09 | 0.0064 | 0.5663 | 75.5 | 62.2 | 734.4 | 787.6 |
| 2030 | 9.89 | 12.53 | 0.007 | 0.624 | 79.1 | 65 | 782.9 | 855.0 |
| Total Cost (Billion USD) | | | | | | | 5.78 | 5.95 |
| 2050 Net-Zero Pathway Additional Redispatch and Curtailment Costs (Billion USD) | | | | | | | + 0.18 | |

**Table 6.** Recent transmission and distribution-level investment data

| Year | Additional Transmission Lines (km) | | Number of Additional Substation Centers | Number of Additional Substations | Investment (billion EUR) | Additional Distribution Lines (km) | | Number of Additional Substations | Investment (billion EUR) |
|---|---|---|---|---|---|---|---|---|---|
| | Voltage | | | | | Type | | | |
| | 400 kV | 154 kV | | | | Overhead Power Lines | Cables | | |
| 2017 | 2,346 | 2,612 | 237 | 126 | 0,63 | 2,364 | 23,659 | 14,528 | 1.44 |
| 2018 | 653 | 1,265 | 0 | 101 | 0,51 | 18,889 | 16,731 | 17,928 | 0.87 |
| 2019 | 691 | 1,129 | 51 | 111 | 0,43 | 12,568 | 13,431 | 17,178 | 1.14 |
| 2020 | 89 | 985 | 2 | 0 | 0,42 | 399 | 14,411 | 13,803 | 1.09 |
| 2021 | 624 | 646 | 31 | 264 | 0,61 | 95,612 | 62,728 | 9,144 | 1.40 |

According to the data in Table 6, the cost of adding 1km of 400-kV transmission lines is EUR 1.94 million, including all required downstream costs such as 154-kV lines, 400-kV/154-kV substation and distribution systems. Thus, the additional transmission and distribution system investment needed for the 2050 Net-Zero pathway is USD 1.32 billion, as shown in Table 7.

**Table 7.** Total transmission and distribution investment required for the 2050 Net-Zero Pathway

| Additional 400-kV lines needed for the Net-Zero Pathway | Total cost of adding 1 km of 400-kv transmission line, including lower level costs | Total transmission and distribution investment needed for the Net-Zero Pathway. |
|---|---|---|
| 682 km | USD 1.94 million | USD 1.32 billion |

## 2.3. HEALTH COSTS OF THE ENERGY SECTOR

Table 8 shows the health costs/savings under the Net-Zero Scenario compared to the Baseline Scenario. The health costs/savings are calculated using the annual coal-fired power plant generation figures and assuming a USD 3 cent/kWh health cost.[13,14] According to Table 8, the total savings by transitioning from the Baseline Scenario to the Net-Zero Scenario amounts to USD 15.93 billion.

**Table 8.** Health costs and benefits for 2020–2030

| Year | Annual Generation Baseline Scenario (TWh) | | | Annual Generation 2050 Net-Zero Scenario (TWh) | | | Total Coal-Fired Generation (TWh) | | | Unit Health Cost (USD Cent/kW) | Additional Health Cost (Billion USD) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Hard Coal | Imported Coal | Lignite | Hard Coal | Imported Coal | Lignite | Baseline Scenario | 2050 Net Zero | Difference | | |
| 2020 | 3.892 | 56.905 | 42.436 | 3.892 | 56.905 | 42.436 | 103.2 | 103.2 | 0.0 | | 0.00 |
| 2021 | 4.037 | 57.205 | 52.459 | 3.656 | 55.301 | 47.301 | 113.7 | 106.3 | -7.4 | | -0.22 |
| 2022 | 4.181 | 57.506 | 62.481 | 3.420 | 53.696 | 52.165 | 124.2 | 109.3 | -14.9 | | -0.45 |
| 2023 | 4.326 | 57.806 | 72.504 | 3.184 | 52.092 | 57.03 | 134.6 | 112.3 | -22.3 | | -0.67 |
| 2024 | 4.443 | 56.882 | 75.893 | 3.051 | 46.106 | 54.453 | 137.2 | 103.6 | -33.6 | | -1.01 |
| 2025 | 4.559 | 55.958 | 79.283 | 2.917 | 40.120 | 51.875 | 139.8 | 94.9 | -44.9 | 3.0 | -1.35 |
| 2026 | 4.676 | 55.034 | 82.672 | 2.784 | 34.134 | 49.298 | 142.4 | 86.2 | -56.2 | | -1.68 |
| 2027 | 4.792 | 54.11 | 86.061 | 2.65 | 28.148 | 46.72 | 145.0 | 77.5 | -67.4 | | -2.02 |
| 2028 | 4.975 | 52.203 | 86.139 | 2.100 | 23.506 | 36.618 | 143.3 | 62.2 | -81.1 | | -2.43 |
| 2029 | 5.159 | 50.297 | 86.216 | 1.551 | 18.865 | 26.517 | 141.7 | 46.9 | -94.7 | | -2.84 |
| 2030 | 5.342 | 48.39 | 86.294 | 1.001 | 14.223 | 16.415 | 140.0 | 31.6 | -108.4 | | -3.25 |
| Total Health Cost (Billion USD) | | | | | | | | | | | -15.93 |

13 1 Dolar= 1 EUR is as med

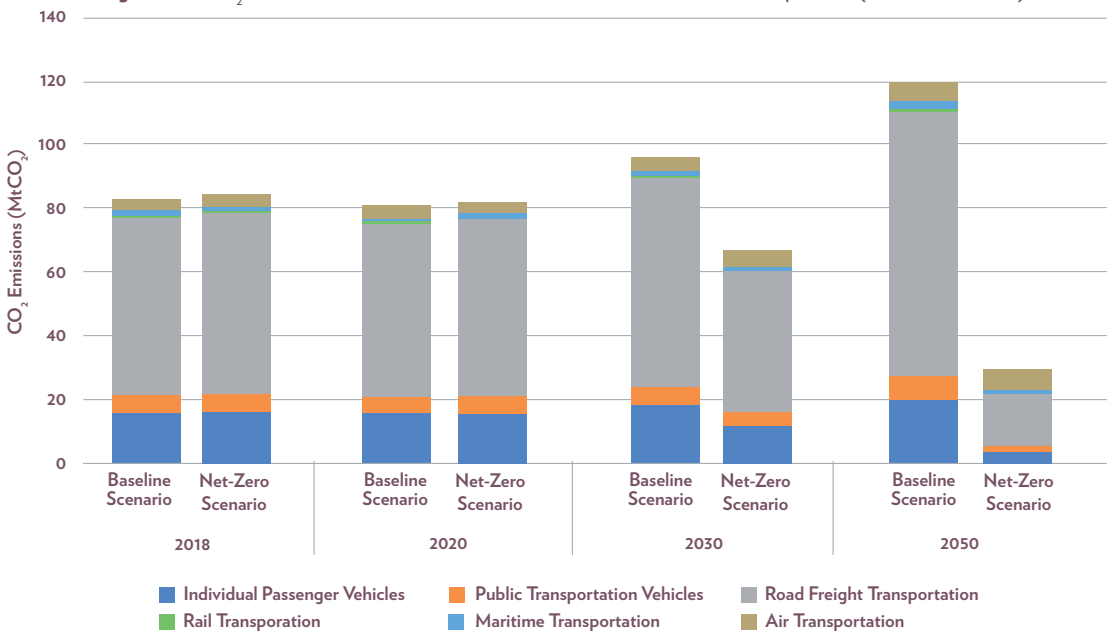
14 ATSE, "The Hidden Costs of Electricity: Externalities of Power Generation in Australia (https://www.atse.org.au/wp-content/uploads/2019/01/the-hidden-costs-of-electricity.pdf)

## 3. TRANSPORTATION SECTOR

This section presents the methodology, assumptions, references, and results for the transportation sector. The study used the scenarios featured in Istanbul Policy Center's report "Turkey's Decarbonization Pathway: Net Zero in 2050" and calculated the additional costs and benefits for the 2020–2030 period under the Net-Zero Scenario relative to the Baseline Scenario. For the transportation sector's investment costs, the study used the unit investment costs from the World Bank Group's June 2022 publication "Country Climate and Development Report-Turkey" [15] to calculate the additional electrification infrastructure required until 2030 under the Net-Zero Scenario relative to the Baseline Scenario. The assumptions and emissions for the 2020–2030 period under the Baseline Scenario and the assumptions and emissions under the World Bank Group's Business as Usual (BAU) Scenario by 2030 are quite similar.

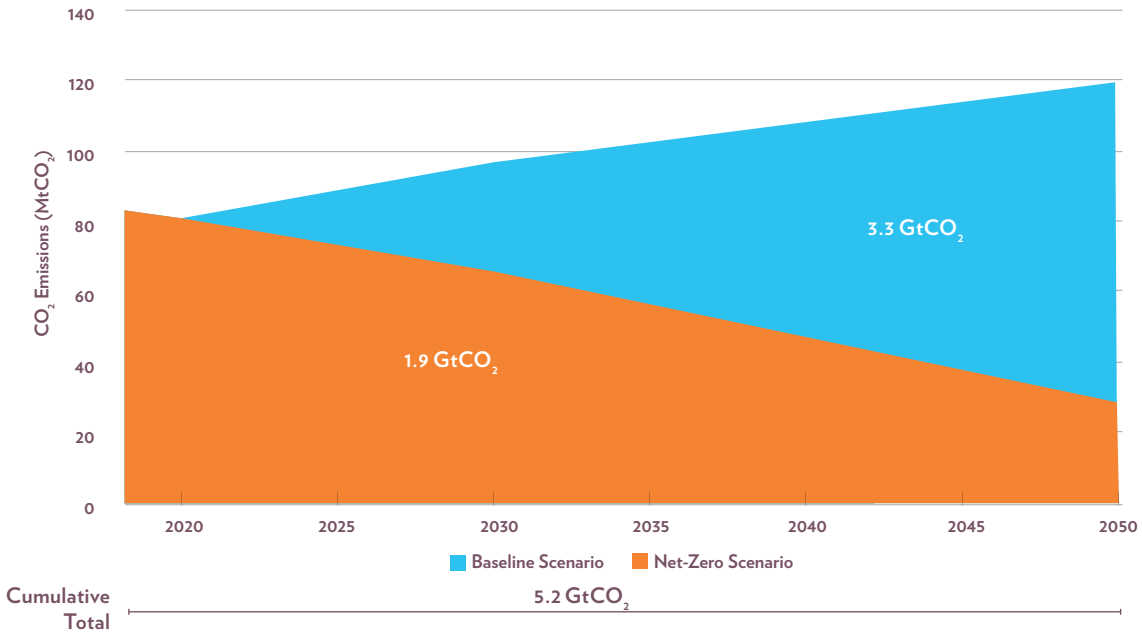
The details of the methodology, assumptions, and calculations of the transportation sector's $CO_2$ emissions under the Baseline Scenario and the Net-Zero Scenario are explained in the report "Turkey's Decarbonization Patway: Net Zero in 2050." Figure 24 compares the $CO_2$ emissions under the Baseline Scenario and the Net-Zero Scenario.

**Figure 24.** $CO_2$ emissions under the Baseline and Net-Zero Scenarios, comparison (annual emissions)




15 World Bank Group, "Country Climate and Development Report – Turkey," https://openknowledge.worldbank.org/handle/10986/37521

**Figure 25.** $CO_2$ emissions under the Baseline Scenario and Net-Zero Scenario (comparison of cumulative emissions)




As indicated in Figure 24, the annual $CO_2$ emissions of the transportation sector for 2030 under the Baseline Scenario and the Net-Zero Scenarios are 96.5 $MtCO_2$ and 65.3 $MtCO_2$, respectively. The transportation sector's cumulative $CO_2$ emissions by 2030 under the Baseline Scenario and the Net-Zero Scenario are 1,139.3 $MtCO_2$ and 967.6 $MtCO_2$, respectively (Figure 25). Road freight transportation is the largest contributor of $CO_2$ emissions in the transportation sector. In 2030, the share of road freight transportation in the transport sector's total $CO_2$ emissions under the Baseline Scenario and the Net-Zero Scenario is 67 percent and 56 percent, respectively.

The transportation sector's $CO_2$ emissions in 2030 are approximately 98.0 $MtCO_2$ under the World Bank Group's BAU Scenario and 96.5 $MtCO_2$ under the Baseline Scenario in the IPC report.

On the other hand, comparing the two report's Net-Zero Scenario pathways for the transportation sector reveals that the World Bank Group report foresees fewer emissions reductions by 2030 than the IPC report. (Transportation sector emissions in 2030 are approximately 86 $MtCO_2$ in the World Bank Group report compared to 65.32 $MtCO_2$ in the IPC report.) In line with these results, the additional electricity load from the electrification of the transportation sector in 2030 under the Net-Zero Scenario relative to the Baseline Scenario is approximately 14 TWh in the World Bank Group report and 26 TWh in the IPC report.

The level of electrification foreseen for the transportation sector in 2030 under the Net-Zero Scenario in the IPC report will not be reached until 2036 under the World Bank Group report's Net-Zero Scenario. Using this approach, the additional investment costs for the transportation sector in

2030 under the IPC report's Net-Zero Scenario is predicted to be approximately USD 12.5 billion relative to the Baseline Scenario (Table 9 and Figure 27). Compared to the Baseline Scenario, this additional investment cost includes new electrified rail tracks, converted electrified rail tracks, electrified locomotives, and high-speed charging stations.

**Table 9.** Additional electrification investments under the Net-Zero Scenario (compared to the Baseline Scenario, cumulative)

| Year | Additional investments compared to the Baseline Scenario (annual, billion USD ) | Additional investments compared to the Baseline Scenario (cumulative, billion USD) |
|---|---|---|
| 2022 | - | - |
| 2023 | 1.85 | 1.85 |
| 2024 | 1.76 | 3.61 |
| 2025 | 1.68 | 5.29 |
| 2026 | 1.59 | 6.89 |
| 2027 | 1.52 | 8.40 |
| 2028 | 1.44 | 9.84 |
| 2029 | 1.37 | 11.22 |
| 2030 | 1.31 | 12.52 |

**Figure 26.** Additional electrification investments under the Net-Zero Scenario (compared to the Baseline Scenario, cumulative)

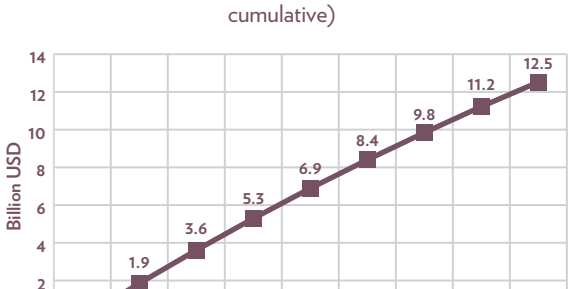



Figure 27 shows the yearly decrease in petroleum demand by 2030 under the Net-Zero Scenario compared to the Baseline Scenario, and Figure 28 shows the cumulative decrease in 1,000 TOE. The additional cumulative decrease in petroleum demand by 2030 under the Net-Zero Scenario relative to the Baseline Scenario is approximately 75 million TOE (Figure 28). As shown in Figure 29, 92 percent of this decrease occurred in road transport (passenger vehicles + public transport + freight), and the petroleum product equivalent is

**Figure 27.** Yearly 1,000 TOE requirements under the Baseline and Net-Zero Scenarios

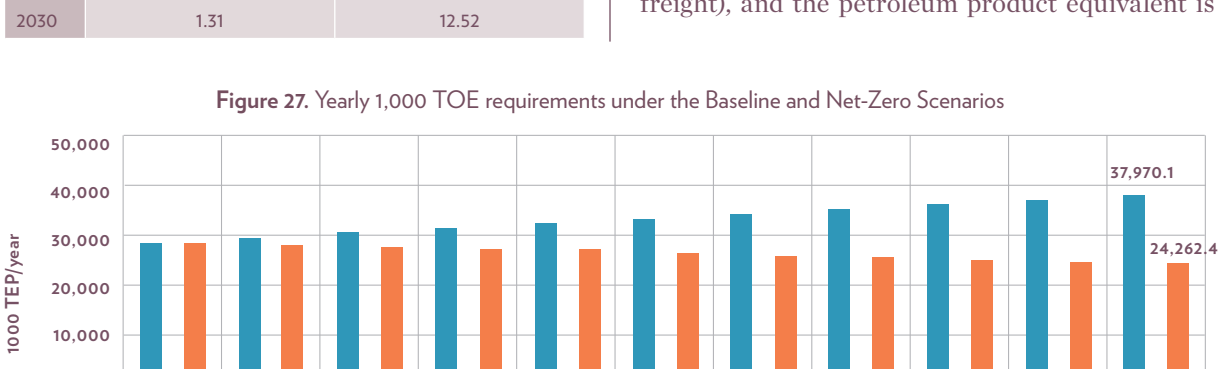
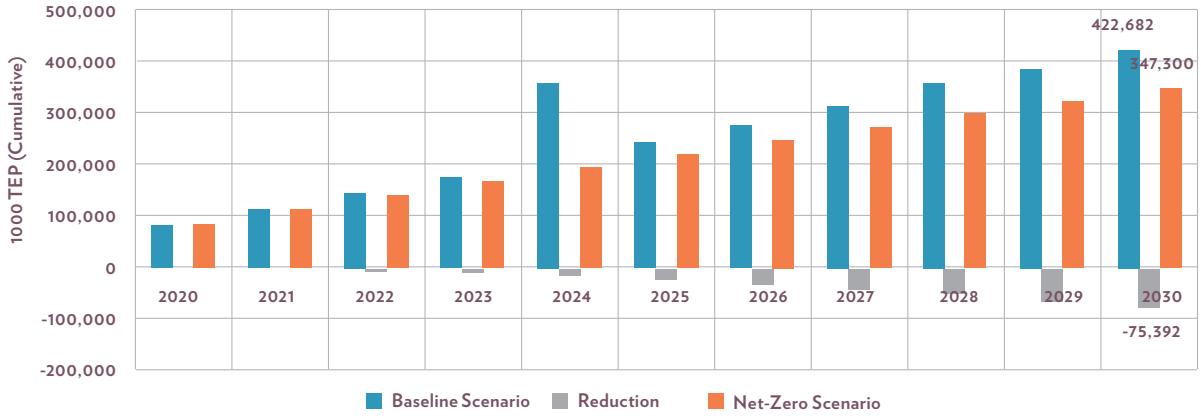


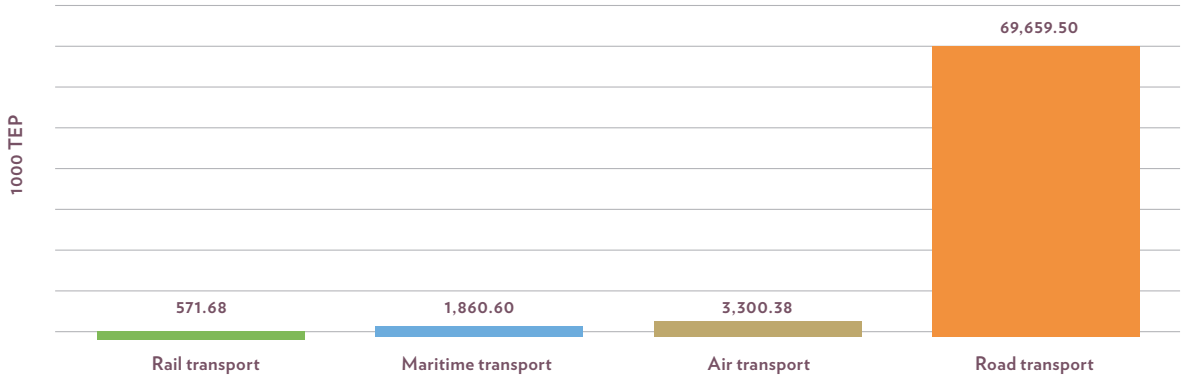
**Figure 28:** Cumulative 1,000 TOE requirements under the Baseline and Net-Zero Scenarios




approximately 72 million tonnes[16] (about 103,000 barrels of oil). Assuming that Brent oil price per barrel is USD 100, the transportation sector's total additional savings by 2030 under the Net-Zero Scenario compared to the Baseline Scenario amounts to USD 10.3 billion.

The most significant savings under the Net-Zero Scenario relative to the Baseline Scenario is the decrease in health costs. The prominent approach for establishing the relationship between health hazardous emissions and health costs in the energy sector is the unit health cost calculated per kWh of energy produced by the consumption of fossil fuels.. This unit cost varies between countries. The results obtained in a study conducted in power plants using oil as fuel in different European countries are shown in Table 10.[17] As can be seen in Table

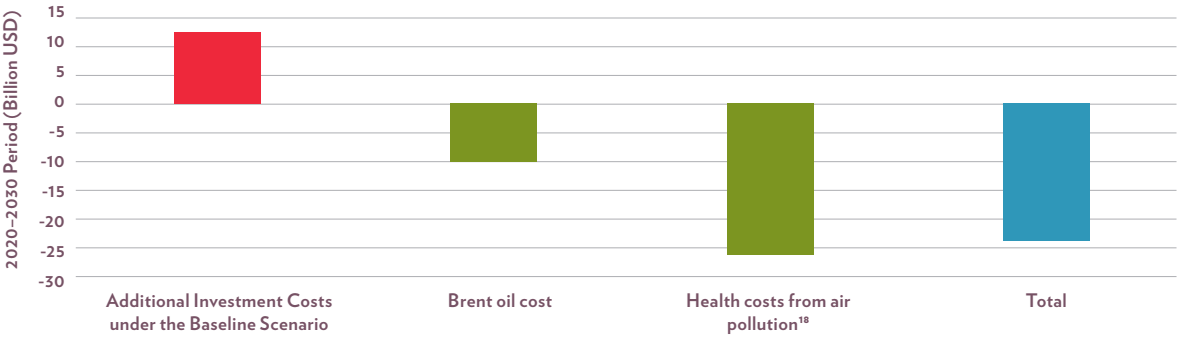
**Figure 29.** Sectoral distribution of a 1,000-TOE reduction under the Net-Zero Scenario compared to the Baseline Scenario




16 Turkish Ministry of Energy and Natural Resources, General Equilibrium Tables, 2020 (https://enerji.gov.tr/Preview/tr/63d0007a-f593-458b-9610-353eb2545897)

17 ATSE, "The Hidden Costs of Electricity: Externalities of Power Generation in Australia" (https://www.atse.org.au/wp-content/uploads/2019/01/the-hidden-costs-of-electricity.pdf)

**Figure 30.** The Transportation Sector Cost-Benefit Summary for 2020–2030




10, the lowest unit health cost is EUR 3 cent/kWh[18] and increases to EUR 11 cent/kWh in developed countries. The transportation sector's cumulative energy demand under the Net-Zero Scenario relative to the Baseline Scenario decreases by approximately 75 million TOE. Assuming a EUR 3-cent/kWh health cost for Turkey, the economic benefit amounts to approximately USD 26 billion.[19]

**Table 10.** Unit health costs in various countries

| Country | Unit Health Cost (EUR-cent/kWh) (Petroleum-fueled electricity generation) |
|---|---|
| Denmark | 5-8 |
| France | 8-11 |
| Greece | 3-5 |
| Italy | 3-6 |
| UK | 3-5 |

Figure 30 shows the results of the transportation sector's cost-benefit analysis. Inflation effect(discount rate) is disregarded in the calculations. Gains from traffic congestion due to the increase in the proportion of public transport and modal shift to the rail system are not taken into account.

18 Factors included in the unit health cost are global warming, public health, and occupational health.

19 Assuming 1 EUR = 1 USD, 1 TOE = 11,630 kWh.

20 The benefits from reduced traffic congestion (due to an increase in public transportation and modal shift to rail systems) are not included.

# 4. BUILDINGS

## 4.1. METHODOLOGY

The study calculated the buildings sector's investment needs for residential and commercial buildings until 2030 based on the scenarios used in the report "Turkey's Decarbonization Pathway: Net Zero in 2050." The calculations took into account factors that impact building energy performance as well as fuel transition and resources such as electrical home/office appliances.

The study uses the "S1-Business-As-Usual Scenario" as defined in the "Buildings Sector's Energy Efficiency Technology Atlas" published by the Ministry of Environment, Urbanization and Climate Change in 2021 as the Baseline Scenario. The investments that may be needed in addition to the Baseline Scenario are calculated for the Net-Zero Scenario.

In this framework, the study foresaw that the main investment items would consist of the improvement of building performance, urban transformation, electrification (heat pumps), fuel transition (transition from coal to natural gas), and a very small increase in hydrogen demand for 2030.

In the investment requirement calculations, the expenditures reflected on end-users for the building sector and the electricity/fuel tariffs paid by end-users were taken into account, and investment and fuel costs were used for both the Baseline scenario and the Net Zero scenario until 2030.

## 4.2. ASSUMPTIONS

The study defined the transition to highly energy-efficient home/office appliances, fuel transition, electrification (heat pumps), urban transformation, and building performance improvements as the most important expenditure items.

To calculate the investments related to electrical appliances, the study took into account the Net-Zero Scenario targets, the energy performance of widely sold and used electrical appliances and the additional expenses required to switch to the more energy-efficient appliances (price difference), and the annual energy savings that will be obtained. These calculations included electrical appliances used in residential, institutional, and commercial buildings.

The calculations for fuel transition expenses, particularly in the coal to gas transition scenario, take into account the average investment costs for central and individual heating systems and the increase in energy efficiency attained by the transition to natural gas.

The cost of converting to heat pumps is based on the investment needed per unit heating demand and the current cost of heat pump investment. By 2030, the cost of heat pumps is expected to decrease by 22 percent (NESTA, 02 March 2022).

Urban transformation (retrofit buildings) and building performance improvements are based on current average costs and are assumed to remain constant until 2030. Concerning urban transformation projects, the study assumes that the average energy performance of buildings that will be constructed by 2030 will exceed the current building performance by 50 to 65 percent, and that the efforts to improve building performance by 2030 will lead to an improvement of 35 to 48 percent compared to current buildings. Even though urban transformation/retrofitting of buildings is primarily aimed at ensuring earthquake resilience or for other purposes, this study assumes that all investments are also directed towards reducing emissions.

The study assumes that the use of hydrogen could begin in 2030 and includes a minimal investment cost for hydrogen production in 2030.

### 4.3. RESULTS

This study uses the "S1-Bussiness-As-Usual Scenario" featured in the "Building Sector's Energy Efficiency Technology Atlas" as the Baseline Scenario and foresees around EUR 20.5 billion of investment in the building sector for the 2022–2030 period. For the Net-Zero Scenario, the study assumes that about USD 90 billion of investment will be required, in addition to the Baseline Scenario investments. To achieve the net-zero emissions target, the cumulative investment required by 2030 will amount to approximately USD 100 billion (Figure 31). The investment foreseen in the Baseline Scenario does not impact building performance and therefore does not include electrical appliances. Figure 32 illustrates

**Figure 31.** Net-Zero Emissions Pathway Investment Costs (Billion USD)

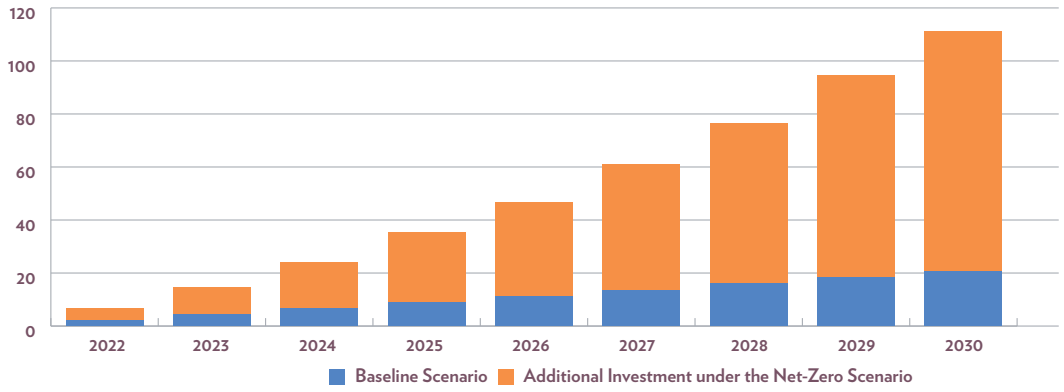



**Figure 32.** Additional investment needed under the Net-Zero Scenario (Billion USD)

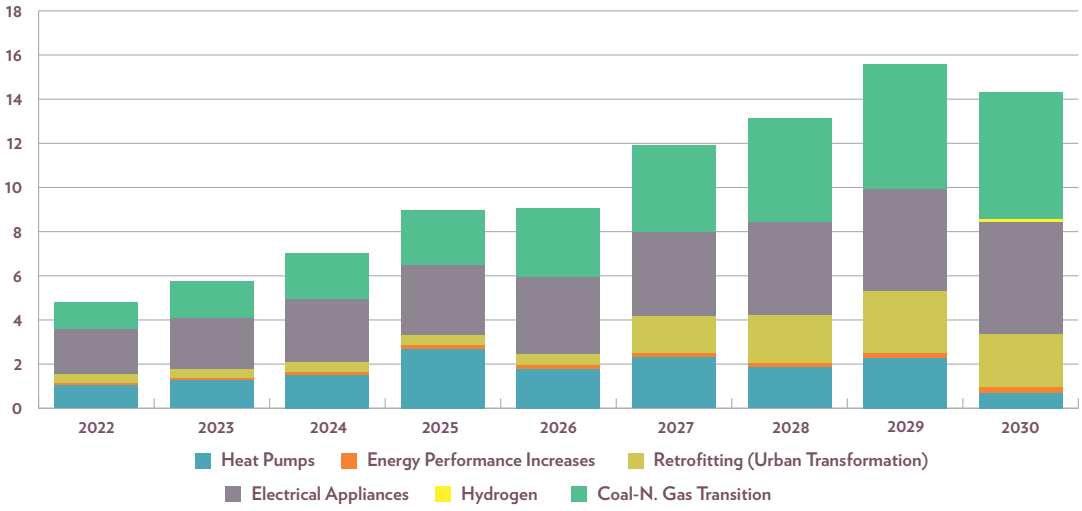
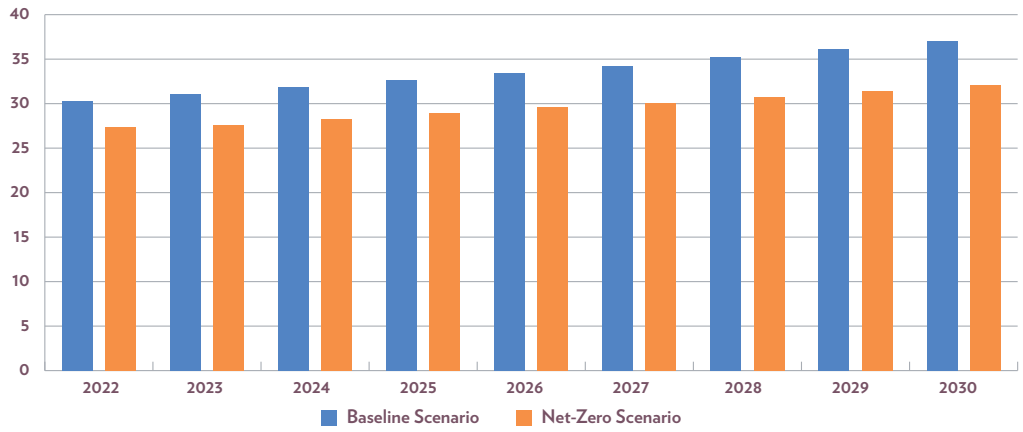


**Figure 33:** Fuel cost + electricity cost under the Baseline Scenario and the Net-Zero Scenario




the distribution of additional investments required to achieve the Net-Zero targets.

The Net-Zero Scenario foresees about a USD 4.5 billion average annual decrease in energy + electricity bills in buildings. The decrease in total energy costs for the 2022–2030 period is expected to amount to about USD 35 billion (Figure 33).

# 5. INDUSTRY AND OTHER PRODUCTION SECTORS

## 5.1. OUTLOOK

In Turkey, emissions from industry, $CO_2$ emissions from energy demand in manufacturing sectors such as agriculture and services, and industrial process emissions account for approximately 35 percent of total emissions. Table 11 provides a general outlook on the manufacturing sector, which was categorized into 17 sectors in the macroeconomic model featured in "Turkey's Decarbonization Pathway: Net Zero in 2050," the report upon which this study is based.

**Table 11:** Economic activities aggregated under 5 headings and 17 sectors that produce total GDP

| Main Sectors | Sector Code | Sectors | GTAP 2014 Sector Code | NACE Rev. 2 Sector Code |
|---|---|---|---|---|
| High-Energy Intensive Sectors (HES) | eint | Energy-Intensive Manufacturing Sectors: Manufacturing of chemical, rubber, plastic products; metal products and metals | 33, 36, 37 | 20-22, 24.4-24.4, 25 |
| | nmm | Manufacturing of other non-metallic mineral products: cement, plaster, limestone, concrete | 34 | 23 |
| | irst | Iron and steel: basic manufacturing and casting processes | 35 | 24.1-24.3 |
| Low-Energy Intensive Sectors (LES) | othr | Other Manufacturing Sectors: Manufacturing of food products, textiles, apparel, motor vehicles, electronics and other transportation vehicles | 19-30, 38-42, | C 10-12 |
| | tran | Transportation | 59-61 | 49-51 |
| | ppp | Paper Products, Printing | 31 | 17-18 |
| | otmn | Other Mining: metal ores, uranium, precious stones, other mining and quarrying | 18 | 07-08 |
| Agriculture (AGR) | agri | Agriculture, Animal Production, Forestry and Fishing | 1-14 | A 1-3 |
| Services (SER) | serv | Services | 56-58, 62-68 | 35.2, 35.3, 36, 37, 38, 39, 41, 42, 43, 45, 46, 47, 52, 53, 55, 56, J, K, L, M, N, O, P, Q, R, S, T, U |
| Energy (ENE) | oil | Petroleum: Extraction of crude petroleum and natural gas | 16 | 06.1 |
| | gas | Gas: Extraction of crude petroleum and natural gas and gas distribution | 17, 55 | 06.2 |
| | coal | Mining of Coal: hard coal and lignite mining, peat extraction and agglomeration | 15 | 05 |
| | roil | Manufacturing of Coal and Refined Petroleum Products | 32 | 19 |
| | NucE | Nuclear Electricity | 44 | 35,11 |
| | RnwE | Renewable Electricity | 47, 48, 50, 52, 54 | |
| | FosE | Fossil-Fuel Electricity | 45, 46, 49, 51, 53 | |
| | TnD | Transmission and Distribution | 43 | 35.12-35.14 |

**Table 12.** Production sectors' share in total production and exports, energy efficiency, fuel share in energy consumption and $CO_2$ emissions, 2018.

| Main Sectors | | Share in Production (%) | Share in Exports (%) | Energy Efficiency, Energy (TOE)/ Production (2018 TL) | Share of Fuels in the Sector's Energy Consumption (TOE) (%) | | | | | | $CO_2$ Emissions of Manufacturing Sectors (Mt) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Coal | Petroleum | Natural Gas | Electricity | Other | Total | From Energy Consumption | From Industrial Processes | Total |
| High-Energy Intensive Sectors (HES) | Non-Metal Minerals: Cement, etc. | 2.2 | 2.5 | 57.5 | 26.7 | 35.7 | 17.7 | 11.6 | 8.4 | 100.0 | 30.0 | 43.9 | 73.9 |
| | Iron-Steel | 3.2 | 7.3 | 35.3 | 54.5 | 0.1 | 14.5 | 27.1 | 3.8 | 100.0 | 4.2 | 12.8 | 17.0 |
| | High-Energy Intensive Manufacturing Sectors | 8.7 | 15.7 | 7.8 | 10.8 | 0.3 | 49.6 | 32.0 | 7.3 | 100.0 | 11.2 | 1.8 | 13.0 |
| Low-Energy Intensive Sectors (LES) | | 24.9 | 56.9 | 5.1 | 11.7 | 1.3 | 27.5 | 36.8 | 22.7 | 100.0 | 18.1 | 1.4 | 19.5 |
| Agriculture (AGR)* | | 10.2 | 7.7 | 5.6 | | 65.1 | 3.8 | 17.4 | 13.7 | 100.0 | 9.4 | 0 | 9.4 |
| Services (SER)* | | 47.7 | 7.8 | 3.7 | 7.1 | 6.5 | 29.7 | 52.8 | 4.0 | 100.0 | 9.2 | 0 | 9.2 |
| Energy (ENE)** | | 3.1 | 2.0 | - | - | - | - | - | - | - | 8.0 | 0 | 8.0 |
| Total | | 100.0 | 100.0 | | | | | | | | 90.2 | 59.8 | 150.0 |

* Only $CO_2$ emissions from energy demand and energy. ** Only the energy sector's $CO_2$ emissions from its own energy consumption.

Table 12 illustratesthe manufacturing sectors' share in total production and total exports as well as its energy intensity and $CO_2$ emissions in 2018, grouped into five main headings as featured in the report "Turkey's Decarbonization Pathway: Net Zero in 2050."

Assumptions regarding trends in the manufacturing sectors' energy demand-related $CO_2$ emissions and industrial process-related $CO_2$ emissions from 2018–2050 under the Baseline and the Net-Zero Scenarios are provided in detail in the report "Turkey's Decarbonization Roadmap: Net Zero in 2050" (Ümit Şahin, 2021, pp. 105-117). The projections for energy-related $CO_2$ emissions under the Net-Zero Scenario from 2020–2030 as defined in this study include the impacts of change in demand as well as the impacts of components such as energy (and process) efficiency, electrification, and direct use of renewable energy (wind solar, biomass, and geothermal), all of which lead to a decrease in emissions. Table 13 provides a summary of these impacts under the Net-Zero Scenario for the 2020–2030 period.

**Table 13.** Net-Zero Scenario – impacts on the production sectors

| | Baseline Scenario | | Net-Zero Scenario | |
|---|---|---|---|---|
| | 2020 | 2030 | 2020 | 2030 |
| CHANGE IN DEMAND INDEX (2020:1.00) | | | | |
| HES | | | | |
| Non-metal minerals (cement, etc.) | 1.00 | 1.29 | 1.00 | 1.12 |
| Iron-Steel | 1.00 | 1.34 | 1.00 | 1.18 |
| High energy-intensive manufacturing sectors | 1.00 | 1.34 | 1.00 | 1.32 |
| | 2020-30 | | 2020-30 | |
| ANNUAL INCREASE IN ENERGY EFFICIENCY (%) | | | | |
| HES | 0.62 | | 1.73 | |
| LES | 0.34 | | 3.37 | |
| AGR | 0.24 | | 4.22 | |
| SER | 0.00 | | 3.93 | |
| **ELECTRIFICATION (Share of Electricity in total energy demand, %)** | 2020 | 2030 | 2020 | 2030 |
| HES | 23.2 | 23.3 | 23.2 | 24.0 |
| LES | 47.2 | 49.3 | 47.2 | 50.0 |
| AGR | 20.2 | 20.5 | 20.2 | 25.0 |
| SER | 55.9 | 57.7 | 55.9 | 60.0 |
| RENEWABLE ENERGY USAGE (%) | | | | |
| LES | 8.0 | 8.0 | 8.0 | 12.0 |
| AGR | 14.0 | 14.0 | 14.0 | 16.0 |
| SER | 4.1 | 4.1 | 4.1 | 5.0 |

The study foresees a 34.6 percent decrease in cumulative $CO_2$ emissions from the energy demand of manufacturing sectors from 2020–2030 under the Net-Zero Scenario relative to the Baseline Scenario (2020-2030 Cumulatively from 1,070 million tonnes $CO_2$ under the Base Case to 700 million tonnes $CO_2$ under the Net Zero scenario) ). Table 13 also shows which components are responsible for the decrease in emissions from industrial and other manufacturing sectors' energy demand. According to Table 13, energy efficiency is the top contributor (67.6 percent) to the decrease in emis-

sions in the Net-Zero Scenario compared to the Baseline Scenario. Energy efficiency is followed by renewable energy use (15.7 percent) and the change in demand in high energy-intensive industrial sectors (Table 14). The effect of electrification is expected to be low in 2030; its share in reducing $CO_2$ emissions is 3.06 percent.

**Table 14.** $CO_2$ Emissions Under the Baseline Scenario and the Net-Zero Scenario

| | Baseline Scenario | | Net-Zero Scenario | |
|---|---|---|---|---|
| $CO_2$ Emissions (Mt) | 2020 | 2030 | 2020 | 2030 |
| HES | 43.4 | 53.6 | 43.4 | 40.0 |
| LES | 22.2 | 28.4 | 22.2 | 15.9 |
| AGR | 10.9 | 12.8 | 10.9 | 5.9 |
| SER | 8.7 | 11.3 | 8.7 | 5.00 |
| TOTAL – Energy | 85.2 | 106.1 | 85.2 | 66.8 |
| TOTAL – Energy (Except Commercial Buildings) | 69.2 | 99.3 | 69.2 | 60.06 |
| From industrial processes | 55.3 | 73.9 | 55.3 | 61.8 |

## 5.2. RESULTS

In this section, an analysis of the costs of key components for the 2020-2030 period will be presented in the context of the scenarios (Base Case and Net Zero Scenario) discussed in the report "Turkey's Decarbonisation Roadmap: Net Zero in 2050" report (Base Scenario and Net Zero Scenario).Thus, a projection will be provided on the possible additional costs and gains for industry and other producing sectors in relation to the Net Zero Scenario in total and in terms of sub-components.

Excluding the impact of the change in demand over the 2020–2030 period under the Net-Zero Scenario, the most prominent component is the increase in energy efficiency (78.2 percent of total emissions reduction in 2030, excluding the change in demand). This is why it is important to examine the figures in Table 13 as well as the approximate costs of achieving the annual energy efficiency increase under the Net-Zero Scenario.

The "National Energy Efficiency Action Plan 2017–2023" (NEEAP) was published in March 2018: it is an important document on energy efficiency practices, costs, and benefits in Turkey. According to this action plan, the energy efficiency investments foreseen in Turkey for the period from 2017–2023 amount to a total of USD 10.9 billion. These investments are expected to achieve a total energy savings of 23,901 ktoe for the 2017–2023 period. However, data from recent years indicate that there is a significant potential for the efficient use of energy in Turkey, but also highlights that this potential has not been fully realised (in terms of sectors). Figure 34 shows the energy intensity of high energy-intensive sectors during production (1,000 toe/real production value, 2003 TL), and Figure 35 and Figure 36 show the same variable for low energy-intensive sectors for the 2015–2020 period, which partly covers the Action Plan period. Both figures highlight that there is no significant efficiency increase in Turkey during this period (Source: TURKSTAT and Ministry of Energy General Equilibrium Tables).

**Figure 34.** Sectoral Energy Intensity, HES (TOE/Real Production Value, 2003 TL)

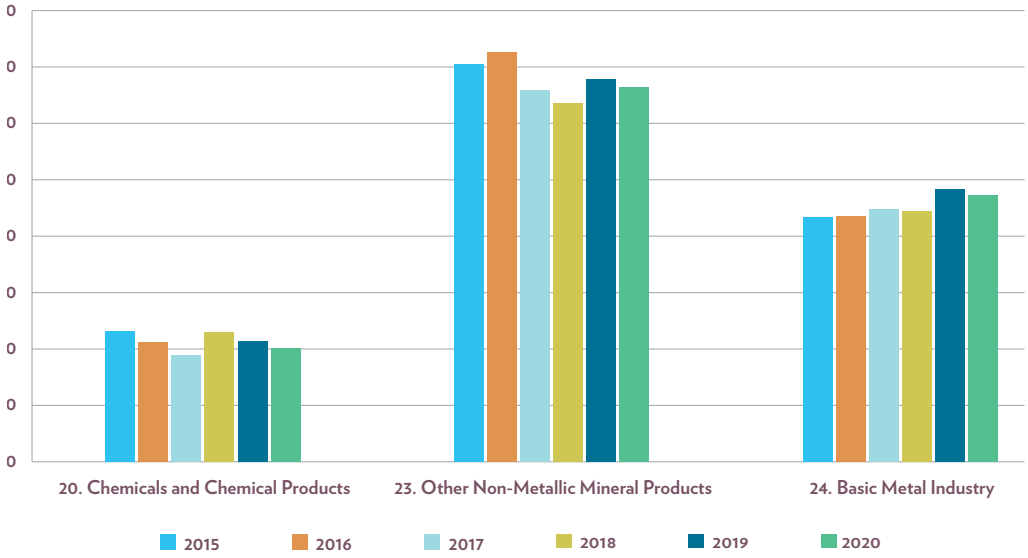
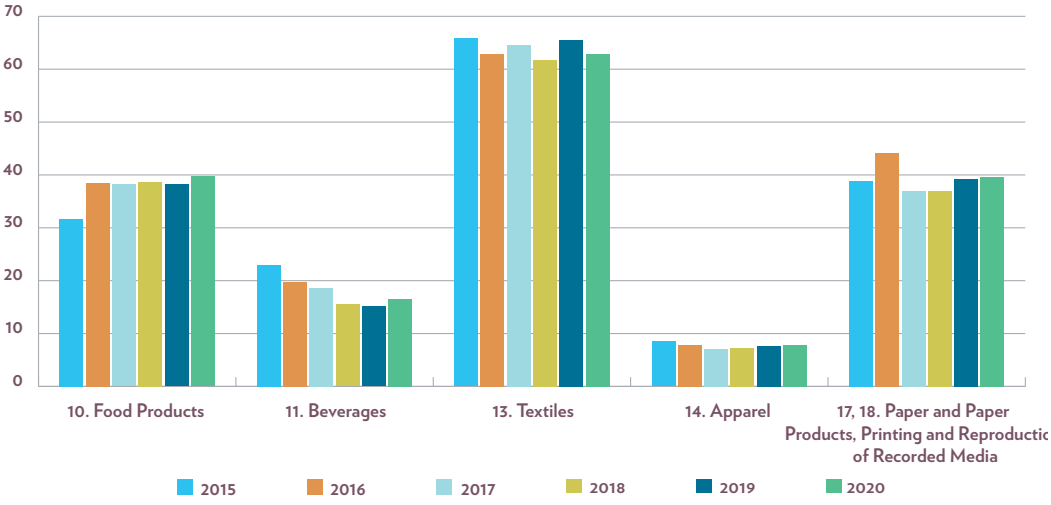



**Figure 35.** Sectoral Energy Intensity, LES (TOE/Real Production Value, 2003 TL)




According to International Energy Agency (IEA) data, the increase in energy efficiency in the manufacturing sector is negatively differentiated from other selected Turkish sectors for the 2015–2020 period, as shown in Figure 36.

Therefore, the increase in energy efficiency potential in Turkey between 2020 and 2030 may be significant, as identified in the report "Turkey's Decarbonization Pathway: Net Zero in 2050." For the Net-Zero Scenario, it is assumed that the share of the energy efficiency component in emissions

**Figure 36.** Sectoral Energy Intensity, LES (TOE/Real Production Value, 2003 TL)

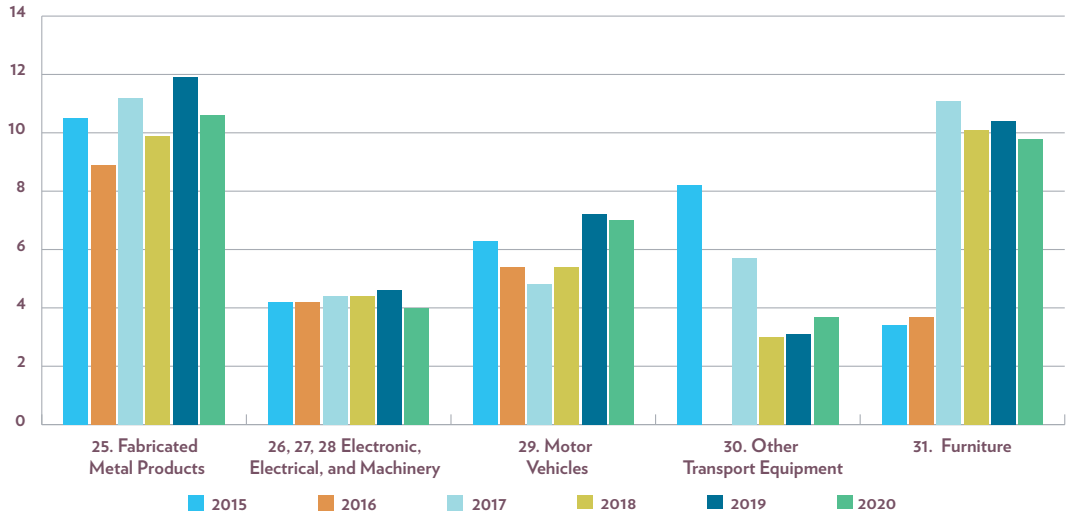



**Figure 37.** Annual Increase Rates of Energy Efficiency in the Manufacturing Sector




reduction will be higher in this first decade and will slow down in the following decades (IEA, 2021). To calculate the additional costs of $CO_2$ emissions reduction with increased energy efficiency in the Baseline Scenario, the study used the IEA (Energy Efficiency Indicators, World Energy Investment) and World Bank (World Development Indicators) databases. Table 15 summarizes the data and methods used for the calculations, and Table 16 presents annual and total costs in line with the Net-Zero Scenario from the report "Turkey's Decarbonization Pathway: Net Zero in 2050."

Table 15 shows that approximately 60 to 65 percent of global energy efficiency investments are realized by developed countries, and the remaining 35 to 40 percent by China and other developing countries. China's annual energy efficiency investments account for about 20 percent of global investments. The share of energy efficiency investments in total global GDP is around 0.30 to 0.35 percent. As for

**Table 15.** Selected Energy Efficiency-Related Indicators

| | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 |
|---|---|---|---|---|---|---|---|---|---|
| Total Energy Efficiency Investments (Billion USD, Current) | | | | | | | | | |
| World | 264 | 295 | 281 | 266 | 289 | 260 | 328 | 367 | |
| Developed Countries | 157 | 167 | 171 | 159 | 162 | 173 | 215 | 218 | |
| (Europe) | 89 | 98 | 94 | 91 | 88 | 101 | 127 | 129 | |
| Developing Countries | 59 | 66 | 56 | 57 | 75 | 31 | 54 | 86 | |
| China | 47 | 62 | 54 | 50 | 52 | 57 | 60 | 63 | |
| Total Energy Efficiency Investments (Billion USD, Current) | | | | | | | | | |
| World | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | |
| Developed Countries | 59.6 | 56.5 | 60.8 | 59.7 | 56.0 | 66.4 | 65.3 | 59.5 | |
| (Europe) | 88.8 | 97.9 | 93.6 | 91.3 | 88.4 | 100.8 | 126.7 | 129.4 | |
| Developing Countries | 22.5 | 22.4 | 20.1 | 21.4 | 25.9 | 11.8 | 16.3 | 23.4 | |
| China | 17.9 | 21.1 | 19.2 | 18.9 | 18.1 | 21.7 | 18.4 | 17.1 | |
| Energy Efficiency Investments in the Industrial Sector (Billion USD, Current) | | | | | | | | | |
| World | | 39 | 40 | 40 | 38 | 37 | 40 | 42 | |
| Energy Efficiency Investments in the Industrial Sector (Billion USD, Current, %) | | | | | | | | | |
| World | | 13.2 | 14.0 | 15.1 | 13.0 | 14.4 | 12.2 | 11.3 | |
| Total Energy Efficiency Investments/GDP (Current USD, %) | | | | | | | | | |
| World | 0.35 | 0.39 | 0.35 | 0.31 | 0.33 | 0.31 | | | |
| Developed Countries | 0.33 | 0.34 | 0.34 | 0.29 | 0.30 | 0.33 | | | |
| (Europe) | 0.47 | 0.51 | 0.47 | 0.42 | 0.42 | 0.49 | | | |
| Developing Countries | 0.09 | 0.10 | 0.08 | 0.08 | 0.10 | 0.04 | | | |
| China | 0.43 | 0.55 | 0.44 | 0.36 | 0.36 | 0.38 | | | |
| TÜRKİYE | | | | | | | | | |
| GDP (Billion USD, Current) | 864.3 | 869.7 | 859.0 | 778.5 | 761.0 | 720.0 | | | |
| Energy Efficiency Investments (NEEAP. 2017–2023. Billion USD, Current) | | | 0.958 | 1.279 | 1.593 | 1.681 | 1.748 | 1.824 | 1.846 |
| Energy Efficiency Investments /GDP (%) | | | 0.11 | 0.16 | 0.21 | 0.23 | | | |

Europe, this share was recorded as 0.46 percent for the 2015–2020 period. For Turkey, the energy efficiency investments/GDP ratio foreseen in the NEEAP document varies between 0.11 percent and 0.23 percent for the 2017–20 period, with an average of around 0.18 percent. The energy efficiency benefits that will be obtained when these investments are realized also need to be assessed in terms of Turkey's comparative energy efficiency performance during this period (one-third of total energy efficiency investments, under the scenario where total energy efficiency investments account for 0.3 percent of GDP). Table 16 provides a summary of these additional costs foreseen for the Net-Zero Scenario under these assumptions. Accordingly, the cumulative additional energy efficiency investments in industry and other manufacturing sectors for the 2021–2030 period can be expected to reach USD 16.3 billion.

In line with the Net-Zero Scenario, energy efficiency policies and implementations, which are the top contributors to $CO_2$ emission reduction from 2020–2030, also provide additional benefits in terms of energy savings. Increases in energy efficiency from 2020–2030 under the Net-Zero Scenario reduce cumulative energy demand by 21.6 percent. This can be used to calculate both total energy cost savings and savings from energy import requirements. Accordingly, energy efficiency applications are expected to contribute approximately USD 10.9 billion in savings for the 2020–2030 period. Breaking up total savings into domestic and imported energy components, savings from energy imports for the 2020–2030 period are expected to reach approximately USD 8.1 billion.

Another important component for the industrial and other manufacturing sectors' $CO_2$ emissions reduction for 2020–2030 is meeting direct energy demand in low energy-intensive sectors (LES), agriculture (AGR), and services (SER) with renewable energy (wind, solar, biomass, and geothermal). To a lower extent (3.5 per cent of the total emission reduction in 2030 excluding demand change), these sectors are expected to benefit from the contribution of electrification. Currently, geothermal energy accounts for almost all renewable energy used to directly meet the total energy demand in these sectors (Table 3) (see the General Balance Tables of the Ministry of Energy). Studies on the direct use of renewable energy in industry, particularly in the LES, draw attention to the significant potential and benefits, since processes in these sectors do not require reaching very high temperatures. IRENA (IRENA, 2018) analyzed the costs and benefits of global and regional renewable energy alternatives in the manufacturing industry by 2030. According to these analyses in LES, renewable energy, and particularly biomass (residue), has the potential to generate energy at costs comparable to fossil fuels.

For LES, a capacity increase of about 4 points is needed to meet approximately 12 percent of

**Table 16.** Energy Efficiency - Total Cost, Net-Zero Scenario Baseline Scenario / Net-Zero Scenario GDP (2018–2050)

| | GDP Real Economic Growth Rate (%) | Total Additional Energy Efficiency Investments, Manufacturing Sectors, Billion USD (0.10%) |
|---|---|---|
| 2022 | 4.12 | 0.82 |
| 2023 | 4.05 | 0.85 |
| 2026 | 3.98 | 0.96 |
| 2028 | 3.80 | 1.03 |
| 2029 | 3.74 | 1.07 |
| 2030 | 3.82 | 1.11 |
| Total Investments for 2021–2030, in line with the Net-Zero Scenario | | 16.3 |

total energy demand with renewable resources in 2030, compared to the Baseline Scenario (and to 2020 levels). Excluding geothermal energy and assuming that this increase is met with the most cost-effective renewable energy resource (mostly biomass), the total additional investment costs for the 2021–2030 period is estimated to be around USD 2 billion (using (IRENA, 2018)data to compare investment costs in USD per unit of kWth).

For LES, using renewable energy instead of fossil fuels for 2021–2030 will generate benefits valued at approximately USD 0.5 billion, in addition to emission reductions.

The study assumed that the additional costs of minor increases in electrification (relative to the Base Scenario investment path) for the 2020–2030 period in LES, AGR, and SER sectors are negligible and equivalent to the energy savings generated in these sectors.

The study also assumed that the additional costs brought by minor increases in renewables (relative to the Baseline Scenario investment pathway) for the 2020–2030 period for the AGR and SER sectors are negligible and equivalent to the energy savings generated in these sectors.

The impact of the change in demand, summarized in Table 13 for the high energy-intensive sectors (HES), accounts for approximately 75 percent of the total reduction of emissions from industrial processes under the Net-Zero Scenario in 2030 (from 73.9 $MtCO_2$ in the Baseline Scenario to 61.8 $MtCO_2$ in the Net-Zero Scenario). It is predicted that approximately 25 percent of this change in 2030 will result from the use of new carbon-free raw materials and cement substitutes in clinker production. In the literature, the cost of decarbonizing the cement sector includes the total unit cost for carbon capture and storage, energy efficiency, heat recovery, and the use of new carbonless raw materials and cement substitutes (for example, (Fischedick, et al., 2014, p. 768); (Pee, et al., 2018, p. 51). This unit cost (as the upper limit) ranges from approximately USD 190 to 250/ton $CO_2$. Since emission reductions from using new carbon-free raw materials and cement substitutes for clinker production account for approximately 7 to 10 percent[21] of total emission reduction in clinker production, this study sets the upper limit at 25 percent of the total unit cost.

21 https://lowcarboneconomy.cembureau.eu/carbon-neutrality/our-2050-roadmap-the-5c-approach-clinker/

## 6. COST OF THE NET-ZERO SCENARIO - SUMMARY

The carbon price used in this study was calculated using the macroeconomic model's (AGE model, see Chapter 1.3.) Net-Zero Scenario pathway featured in the report "Turkey's Decarbonization Pathway: Net Zero in 2050" and a carbon pricing pathway in line with the cumulative $CO_2$ emissions benefits summarized in Table 17. The average carbon price for 2022–2030 is calculated as USD 169.5/ton $CO_2$. In 2022, the carbon price was USD 124.7/ton $CO_2$, in line with the reduction target, and in 2030, it will increase to USD 192.9/ton $CO_2$.

**Table 17.** Results - Summary

| Investments, Operations – Maintenance and Fuel Costs (Billion USD) | 2020–2030 Period, Cumulative (Relative to the Baseline Scenario) | |
|---|---|---|
| **Sectors** | **Cost (Billion USD)** | **$Co_2$ emissions (million tons)** |
| **ELECTRICITY SECTOR** | | |
| Generation and storage capacity investment costs (billion USD) | +35.04 | -587.66 |
| Operational and maintenance costs (billion USD) | -1.02 | |
| Fuel costs (billion USD) | -6.38 | |
| Grid operation costs (redispatch and RES curtailment) (billion USD) | +0.18 | |
| Grid investment costs (billion USD) | +1.32 | |
| **Total investment, operational and maintenance costs (billion USD)** | **+29.1** | |
| **TRANSPORTATION SECTOR** | | |
| Electrification costs (billion USD) | +12.50 | -171.68 |
| Brent oil costs (billion USD) | -10.30 | |
| **Total costs (billion USD)** | **+2.2** | |
| **BUILDINGS** | | |
| Investment Costs | +99.35 | -248.18 |
| Fuel + Electricity Costs | -40.94 | |
| **Total Costs** | **+58.4** | |

**Table 17.** Results - Summary (cont.)

| Investments, Operations – Maintenance and Fuel Costs (Billion USD) | 2020–2030 Period, Cumulative (Relative to the Baseline Scenario) | |
|---|---|---|
| **Sectors** | **Cost (Billion USD)** | **$Co_2$ emissions (million tons)** |
| **INDUSTRY AND PRODUCTION SECTORS – Energy** | | |
| Energy efficiency investment costs (all manufacturing sectors) (billion USD) | +16.3 | -258.60 (including the impact of change in demand) |
| RES investment costs (billion USD) | +2.00 | |
| *Fuel costs (billion USD)* | *-11.40* | |
| *Imported fuel (billion USD)* | *(-8.50)* | |
| **Total costs (billion USD)** | **+6.9** | |
| **INDUSTRY AND PRODUCTION SECTORS – PROCESSES** | | |
| **Clinker production** – carbon-free raw material and cement substitute (billion USD) | **+4.7** | **-74.82 (including the impact of change in demand)** |
| **ALL SECTORS – INVESTMENT, OPERATION, MAINTENANCE, FUEL** | | |
| **Total Costs (billion USD)** | **171.4** | **-1,340.94** |
| **Total Benefits (billion USD)** | **70.0** | |
| **HEALTH COSTS/BENEFITS (Billion USD)** | | |
| Energy Sector | -15.93 | |
| Transportation Sector | -26.20 | |
| **Total health costs/benefits** | **-42.1** | |

| | |
|---|---|
| **SOCIAL COST OF CARBON – Carbon price for energy- related $CO_2$ emissions (USD/ton $CO_2$)** | **169.45** |

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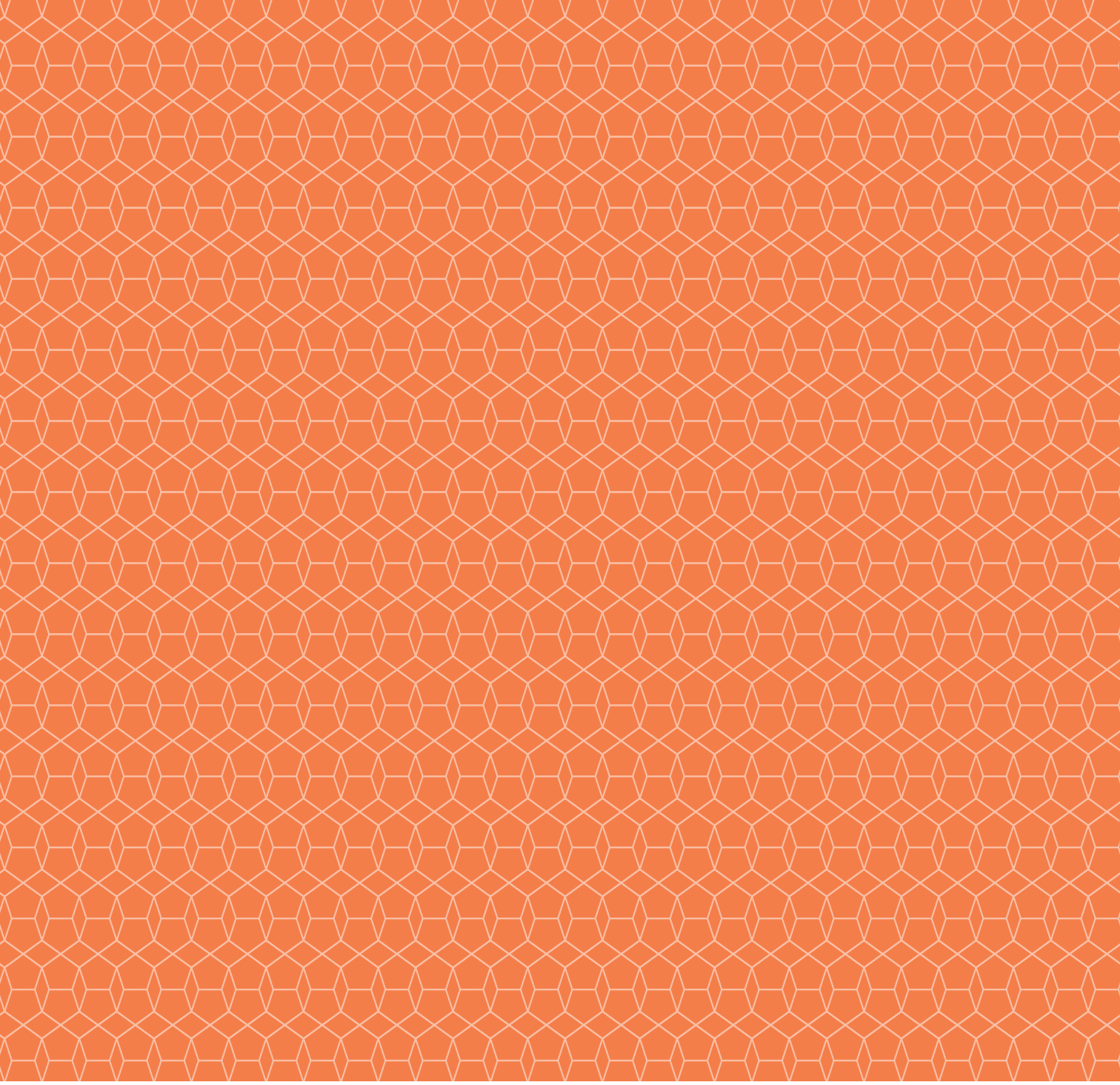
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