Executive Summary:

Net Zero 2053: A Roadmap for the Turkish Electricity Sector

About SHURA Energy Transition Center

SHURA Energy Transition Center, founded by the European Climate Foundation (ECF), Agora Energiewende and Istanbul Policy Center (IPC) at Sabancı University, contributes to decarbonisation of the energy sector via an innovative energy transition platform. It caters to the need for a sustainable and broadly recognized platform for discussions on technological, economic, and policy aspects of Turkey's energy sector. SHURA supports the debate on the transition to a low-carbon energy system through energy efficiency and renewable energy by using fact-based analysis and the best available data. Taking into account all relevant perspectives by a multitude of stakeholders, it contributes to an enhanced understanding of the economic potential, technical feasibility, and the relevant policy tools for this transition.

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This report is available for download from www.shura.org.tr.
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Disclaimer

This report and the assumptions made within the scope of the study have been drafted based on different scenarios and market conditions as of 2022 mid-year. Since these assumptions, scenarios and the market conditions are subject to change, it is not warranted that the forecasts in this report will be the same as the actual figures. The institutions and the persons who have contributed to the preparation of this report cannot be held responsible for any commercial gains or losses that may arise from the divergence between the forecasts in the report and the actual values.

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With the signing of the Paris Climate Accords in 2015, a global majority of countries committed to taking action to mitigate global warming ideally below 1.5°C. In accordance, the European Commission approved the European Green Deal in 2020, which is a strategic policy program that aligns economic and social development with the aim of making the European Union (EU) climate neutral by 2050. The Deal includes a Carbon Border Adjustment Mechanism (CBAM), which enforces a carbon tax for third-party exports into the EU beginning in 2026. Motivated by the emerging global environment toward achieving climate neutrality by mid-century, Türkiye announced its "Green Deal Action Plan" in July 2021, which comprises targets and actions to transform Türkiye into a more sustainable and circular economy. In October 2021, Türkiye took significant steps in the fight against climate change by ratifying the Paris Agreement and, shortly thereafter, pledging to reach net-zero GHG emissions by 2053. These developments represent a decisive turning point for Türkiye's energy and climate policies. In this regard, the focus is currently on providing a new energy transition policy platform to design the necessary policies and action plans that enable economy-wide GHG emission reductions.

Türkiye requires a comprehensive energy transition roadmap that addresses economic and climate resilience, as well as environmental and human health. For the energy transition, the focus should be on reducing GHG emissions in buildings, transport and industry, which are the largest energy consumers. One of the most utilised strategies to achieve this is through electrification, which can be integrated to the system either directly (e.g., electric vehicles (EV), heat pumps etc.) or indirectly (e.g., green hydrogen or e-fuels produced by electrolysis). Yet, this strategy can only be successful if electricity generation is decarbonized first. In that regard, the power sector stands as the backbone for economy-wide decarbonization to achieve net-zero emissions.

By the end of 2022, approximately 54% (56 GW) of Türkiye's installed power capacity is based on renewable energy sources. When total electricity generation is considered, the share of the renewables is almost 40%, demonstrating that the Turkish electricity system is already on a successful transition to low-carbon technologies.

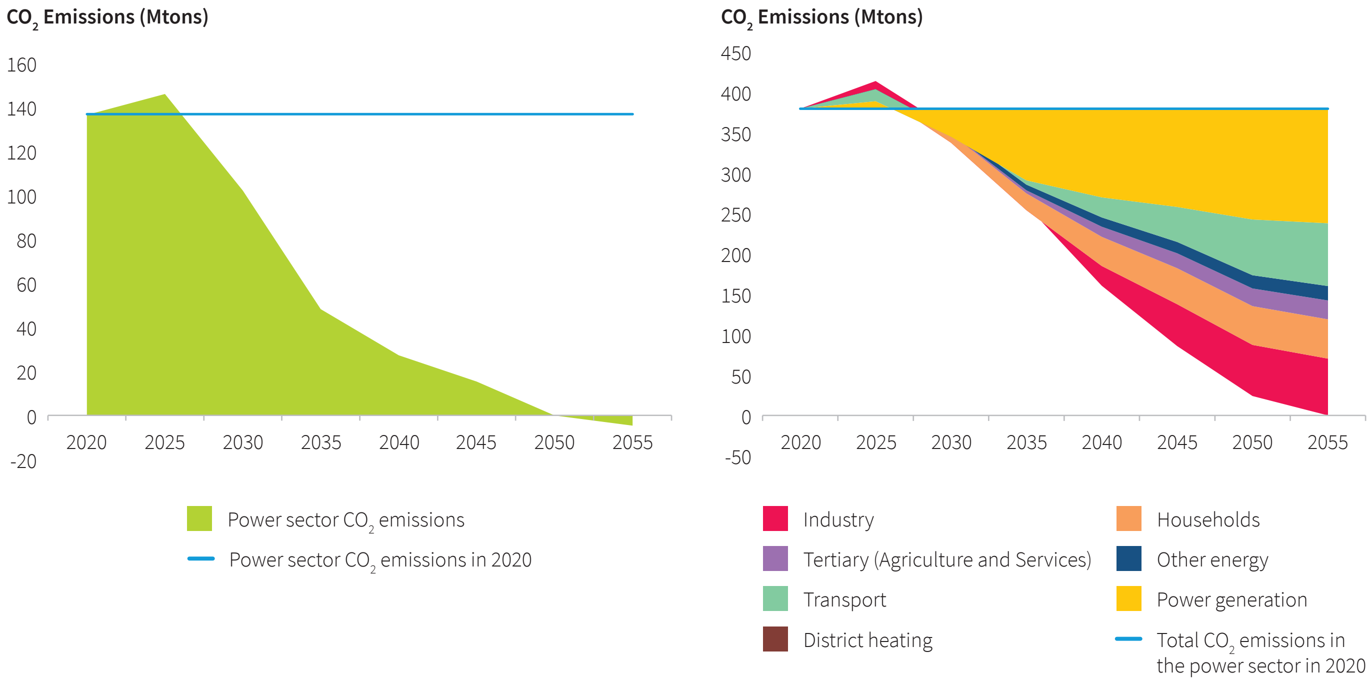
However, it should also be noted that electricity accounts for only 20% of total energy consumption in Türkiye, while the remaining share comes from the energy use in the buildings, transportation sector and manufacturing industry. All things considered, in order to mitigate the effects of climate change and ensure supply security, Türkiye needs to take decisive steps not only in the power sector but all other sectors as well.

The global fossil fuel crisis, which was triggered by the ongoing effects of Covid-19 pandemic and exacerbated by the Russian-Ukrainian conflict in 2022, further highlights the importance of energy transition. The crisis brought about a steep increase in energy prices throughout 2022. Shortages in primary energy sources led to cuts in the energy supply. High energy prices put households and business under pressure, and are nourishing the inflation. Therefore, 2022 has also demonstrated the social risk of relying on fossil fuels, which mostly need to be imported. Within this context, the crisis has increased awareness for the benefits of utilizing local renewable energy resources for energy affordability and energy supply security as well as environmental concerns. To combat climate change, Türkiye has made important progress in setting up new institutional frameworks, which needs to be followed by economy-wide transformation across all sectors and policy areas, focusing on the net-zero carbon emission commitment.

It is from this perspective that SHURA Energy Transition Center presents this study that explores the role of the power sector in the transition to a totally decarbonized Turkish energy system. This study assesses the evolution of energy demand across all sectors while considering energy efficiency improvements, additional demand from end-use electrification, and green hydrogen required to achieve net-zero carbon emissions. The transition pathway of the electricity system that supplies total demand is then examined, and includes an in-depth analyses of system security and costs.

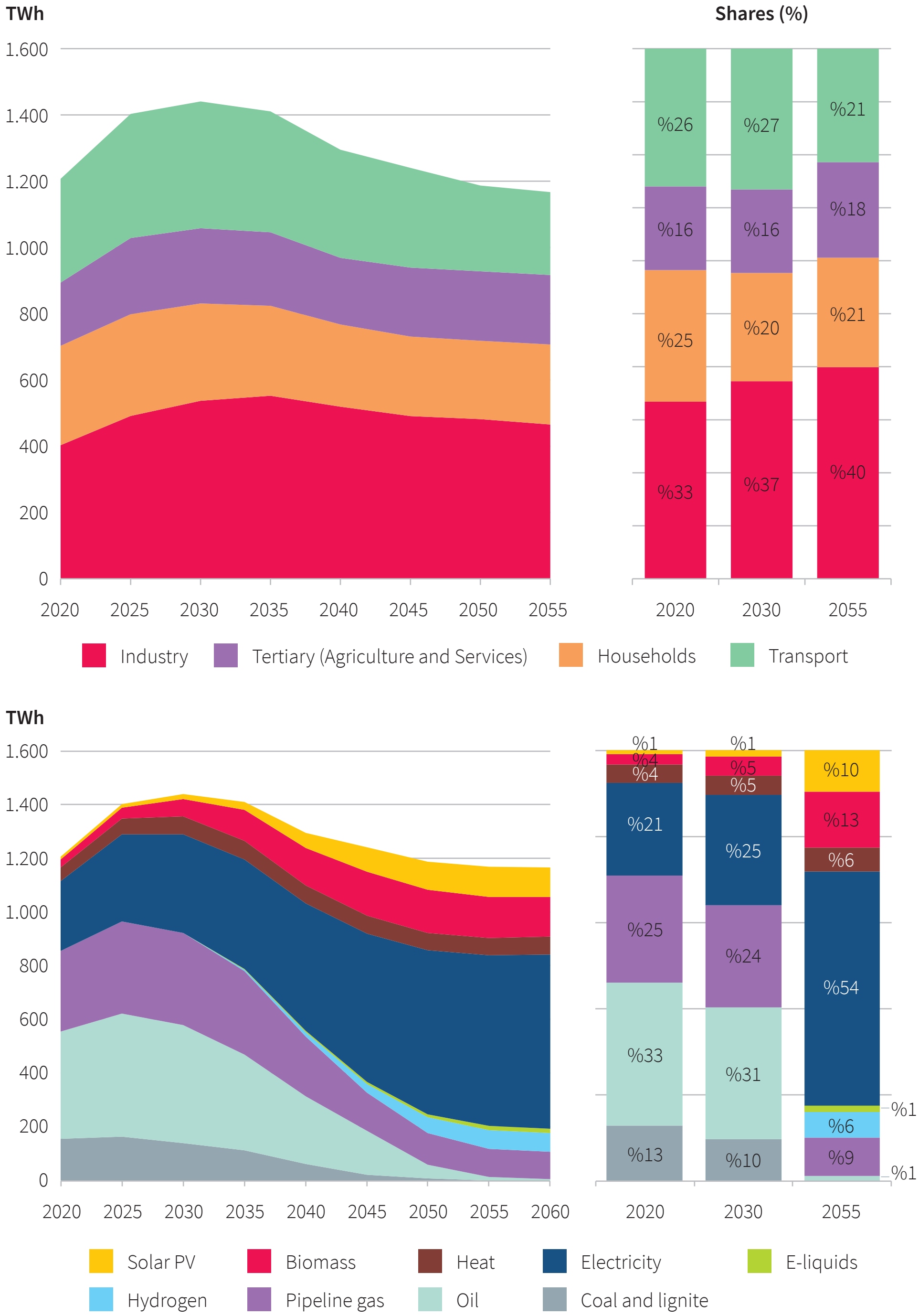
Türkiye's goal to reach net-zero carbon emissions by 2053 is achievable through the displacement of fossil fuels by renewable energy, improved energy efficiency and increased electrification in end-use sectors. The Net-Zero 2053 (NZ2053) scenario shows total carbon emissions peaking in 2025 and then declining by 37.2% in 2035 compared to 2025 levels (Figure 1-right). This early decline in emissions is driven mainly by the power sector (Figure 1-left), which rapidly phases down coal in its transition to renewables. Between 2020 and 2030, the operating hours are reduced for the most inefficient coal and lignite power plants, the pace of which is further accelerated after 2030 due to the implementation of a regulated coal phase out. After 2040, the electrification of the transport sector and introduction of e-fuels further reduces emissions. In the residential sector, the introduction of heat pumps significantly reduces cumulative emissions. Beyond 2050, the power sector contributes to negative emissions through the use of biomass coupled with carbon capture and storage (CCS). This helps counterbalance the residual emissions from other sectors and is an essential component to achieving economy-wide net-zero emissions.

Figure 1: *CO_2 emissions reductions from the power sector (left) and the total CO_2 emissions (right)*



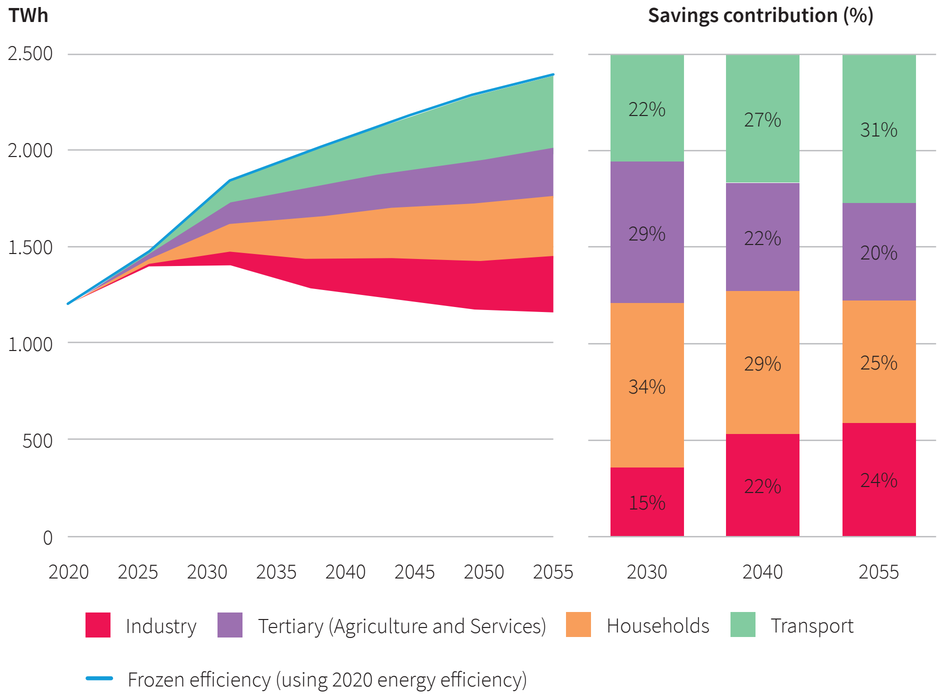
The macro-economic assumptions adopted in this analysis consider substantial economic growth of Türkiye over the entire projection period. Türkiye is assumed to retain its manufacturing capacity, while manufacturing will shift towards producing higher value-added and less energy intensive products. It is expected that construction grows in parallel with the population growth, the reduction in the number of people per residence and the infrastructure investment requirements, while the production of the construction materials will cater to the needs of the domestic market. It is foreseen that transport activity rises with increasing gross domestic product (GDP). **Türkiye's total energy demand continues to grow until 2030 due to increased economic activity. Despite the steady economic growth, energy demand in 2053 declines to 2020 levels thanks to the effects of electrification and energy efficiency improvements (Figure 2).**

Figure 2: *Total energy demand by sector (top) and by fuel type (bottom)*



Energy efficiency is one of the key drivers for decarbonization of the entire economy. In industry, final energy consumption is projected to peak by 2035 in line with the growing industrial production. Afterwards, energy demand in industry declines due to electrification and a shift to less energy intensive processes and manufacturing. One of the main pathways to reducing industrial energy demand is process improvements for waste heat recovery. In the model, additional process-wide improvements in several industries are considered, including the modification of clinker to cement ratios to reduce the energy and emission intensity of cement production. Other assumptions include the maximisation of recycling (secondary) production for all industries where possible. For the residential sector, energy savings are predominately enabled by building renovations that largely reduce heating and cooling demands. Additionally, new electronic appliances and cooling systems are assumed to be A+++-class of energy efficiency. In the model it is evaluated that the entire stock of existing buildings will need to undergo deep refurbishments by 2040. In transport, the shift to electric vehicles (EV) drives the greatest proportion of energy efficiency improvements. While approximately 80% of energy wasted in traditional combustion engines, battery electric vehicles are significantly more efficient, losing only about 10% of the electricity supplied (Kirk, 2022).

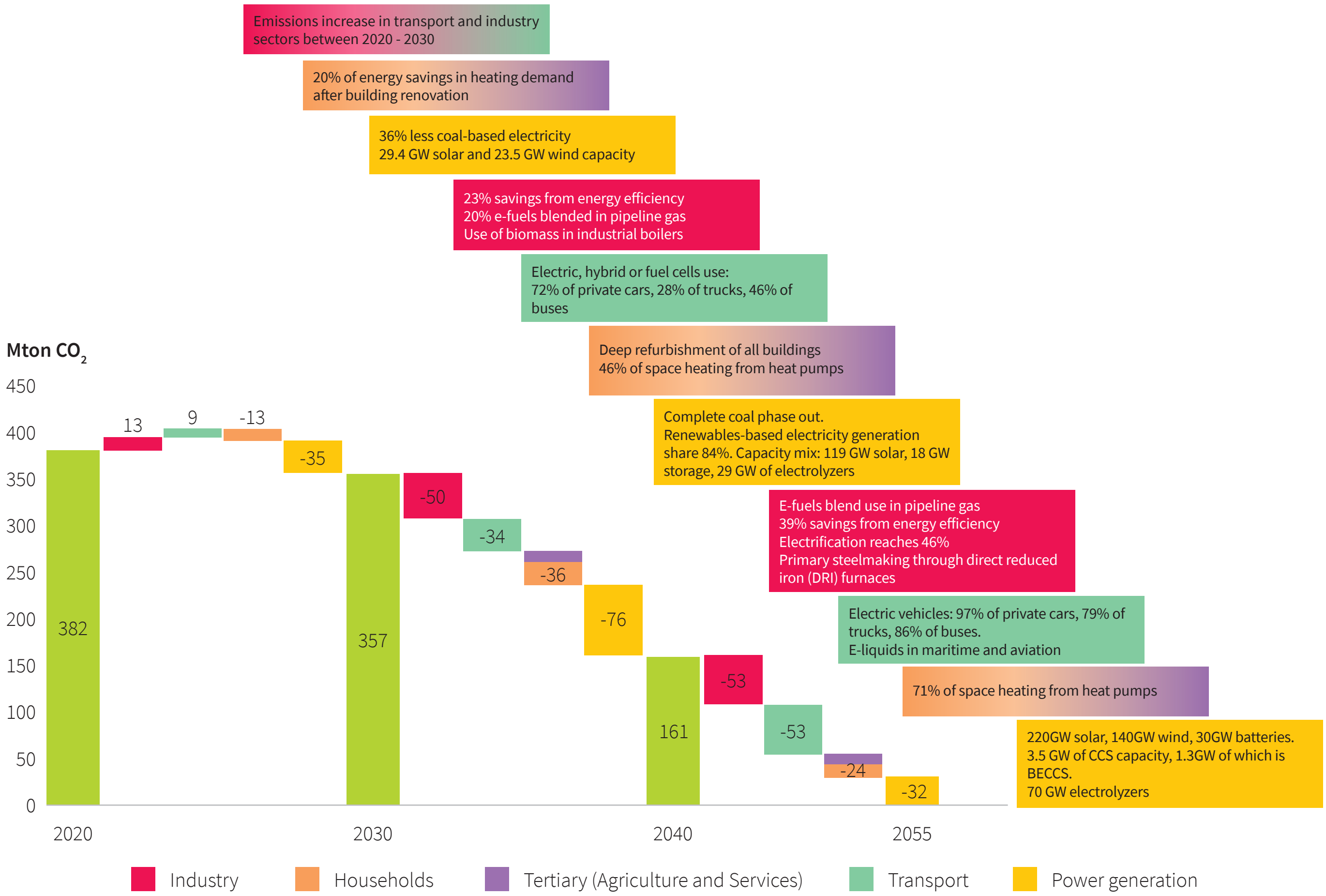
Figure 3: *Energy savings* by sector*



** Computed by freezing the efficiency level of 2020 for the same economic activity.*

Total emissions decrease relatively slowly, by 6.4%, until 2030 (Figure 4), after which emissions drop rapidly due to ceasing electricity production from coal and lignite power plants in the system by 2035. The expansion of renewable energy capacities largely covers increasing electricity demand, and together with the introduction of system flexibility options (i.e. energy storage), renewables displace fossil fuels as these resources are unable to compete on the whole-sale market. The full commissioning of the Akkuyu Nuclear Power Plant by 2030 also contributes to emissions reductions and gradual coal-phase out. By 2030, the power sector makes up the majority of the 24.6 million tons total net carbon reductions. Between 2030 and 2040, decarbonization occurs in all sectors. The power sector contributes to a total of 110 million tons CO_2 reduced between 2020 and 2040, which is almost half of the emission reductions achieved in that time period. After 2040, electrification of the transport and residential sectors increases in addition to the accelerated transition to e-fuels in the pipeline gas to achieve net-zero carbon emissions in 2053.

Figure 4: *NZ2053 scenario CO_2 emission reduction projections*

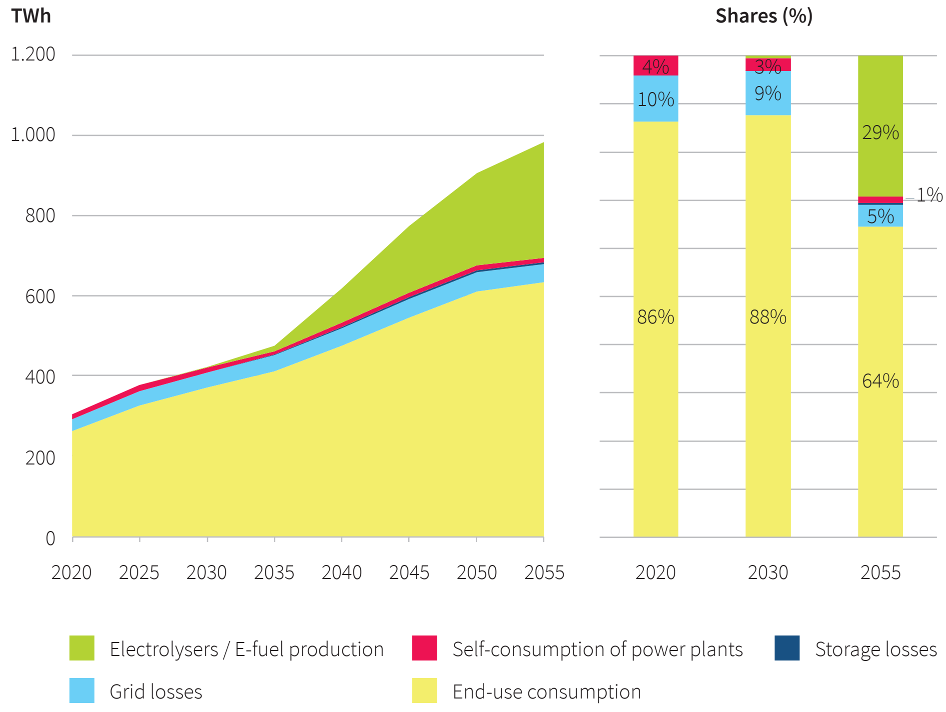


Achieving Türkiye's net-zero target would bring net economic benefits but will require a comprehensive set of public and private sector investments across the economy. The pathway towards a net-zero energy system for Türkiye does not rely on reduced consumption or stagnant economic growth. Rather, the Turkish economy is assumed to grow on average by 3.3% per year through to 2055. This relies on a comprehensive set of public and private sector investments that redesign Türkiye's electricity and transport systems in addition to building refurbishment, while also modernizing the industrial processes and construction. In addition to reducing greenhouse gas (GHG) emissions, these measures contribute to improved human and environmental health and welfare gains across Turkish society and drive the shift in moving Türkiye from a developing to a high-income economy.

A large portion of the investments considering the power sector will be directed into restructuring the electricity system to be based predominantly on renewables. Combined with renewable energy, the advantages imparted by energy efficiency gains in all sectors pave the way for reduced carbon and energy intensities of production. Türkiye's trade balance improves significantly, and energy import dependency drops from 69% in 2020 to just 9% in 2053.

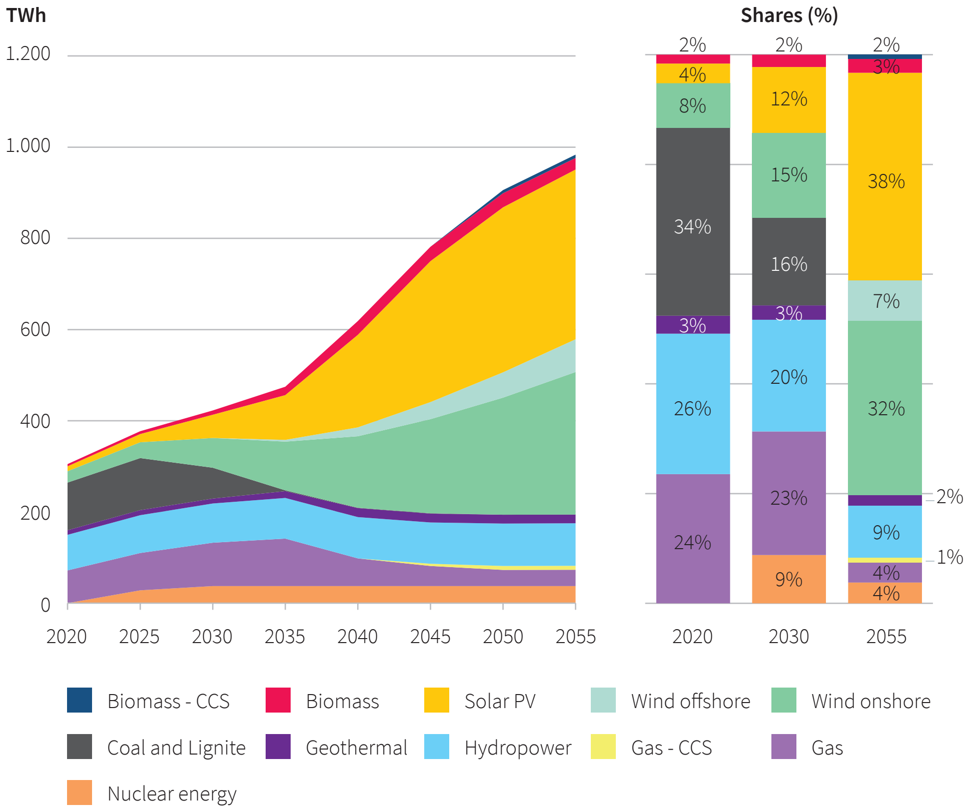
The electrification of end-use sectors and the domestic production of e-fuels results in a rapid increase in electricity demand. The share of electricity in total final energy demand (electrification ratio) is approximately 54% in 2053. Electrification is highest in the tertiary (agriculture and services) sector, where electricity supplies 61% of final energy in 2053 and is followed by the residential (60%), transport (58%) and industrial (46%) sectors. As end-use sectors transition from fossil fuels to electricity, ensuring that the electricity used is supplied by low-carbon or zero emission sources is paramount. Modelling results demonstrate that renewable energy technologies will be able to generate sufficient electricity for this purpose. In 2053, the electricity system will heavily rely on variable renewable energy resources (VRES) such as wind (including offshore) and solar, whose share in the total electricity generation grows to 77% (757 TWh). To balance their variable generation profiles, significant energy storage systems enable grid integration. The main storage systems considered in the model include pumped hydro, batteries, and electrolysers (Power-to-X systems), which increases the flexibility of the grid and ensure system stability. Demand side responses are provided in this analysis through electric vehicles and smart charging systems. Battery and pumped-hydro storage systems will be used primarily for daily balancing, while the usage of green hydrogen and/or e-fuels supply seasonal storage. By 2053, the total electricity demand (Figure 5) is expected to reach 982 TWh, of which 29% (287 TWh) will be used for the production of green hydrogen and e-fuels. The end-use final electricity demand is expected to be approximately 2.4 times more than the 2020 levels.

Figure 5: *Total electricity consumption*



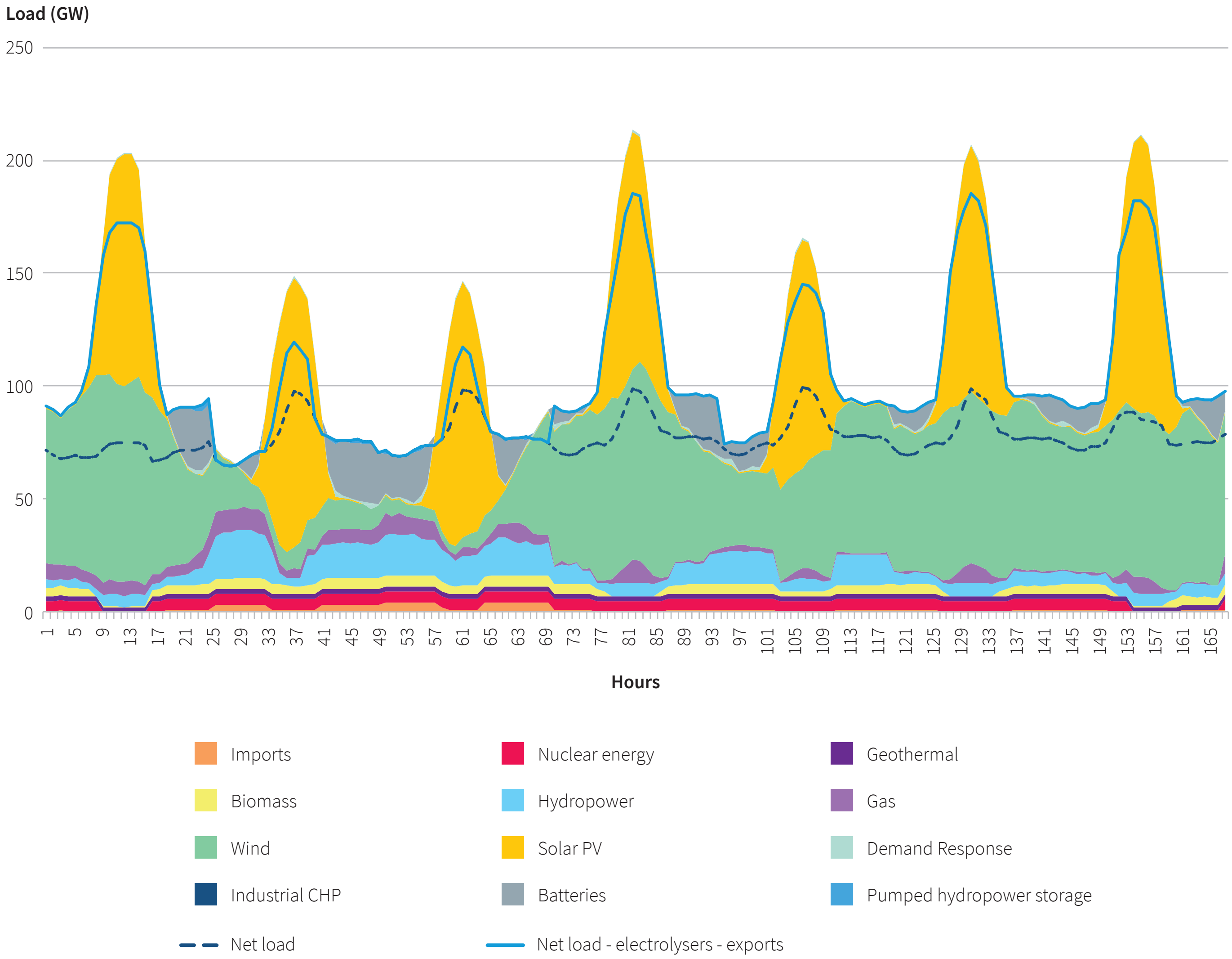
In the net-zero system of 2053, the share of the renewable energy of total electricity generation exceeds 90%. The development of Türkiye's offshore wind potential begins in 2030. The delay in offshore wind development is due mainly to current technology costs which affect the trend in the levelized cost of electricity (LCOE). On the other hand, onshore wind installed capacity reaches 38 GW by 2035. Thereafter, 20 GW is installed in each 5-year period, resulting in a total onshore wind capacity of 120 GW in 2055. Solar PV installed capacities reach 57 GW in 2035 and 220 GW in 2055. By 2053, some 33 GW of energy storage systems (pumped hydro and batteries) will ensure system stability and reliability. The capacity of the batteries deployed in the model reach 30 GW/120 GWh, corresponding to 4-hour discharge at maximum output. The electrolysers needed to produce green hydrogen will start being deployed in 2030 and reach 5.5 GW total capacity in 2035. In order to meet increasing demand for e-fuels, electrolyser deployment increases rapidly thereafter and totals 70 GW by 2053. Dispatchable generators total 92.5 GW in 2053, and guarantee system security and stability in cooperation with the flexibility provided by storage, transmission interconnections, and demand response. Electrolyers, which are expected to function in times of high renewables based electricity generation, add crucial additional system flexibility. E-fuels (e.g., synthetic methane, biogas and green hydrogen) are gradually phased into the natural gas network, and ultimately completely replace natural gas by 2053. Combined cycle gas turbine (CCGT) plants using e-fuels will then be operated as reserve capacity in the electricity system (Figure 6).

Figure 6: *Electricity generation by technology*



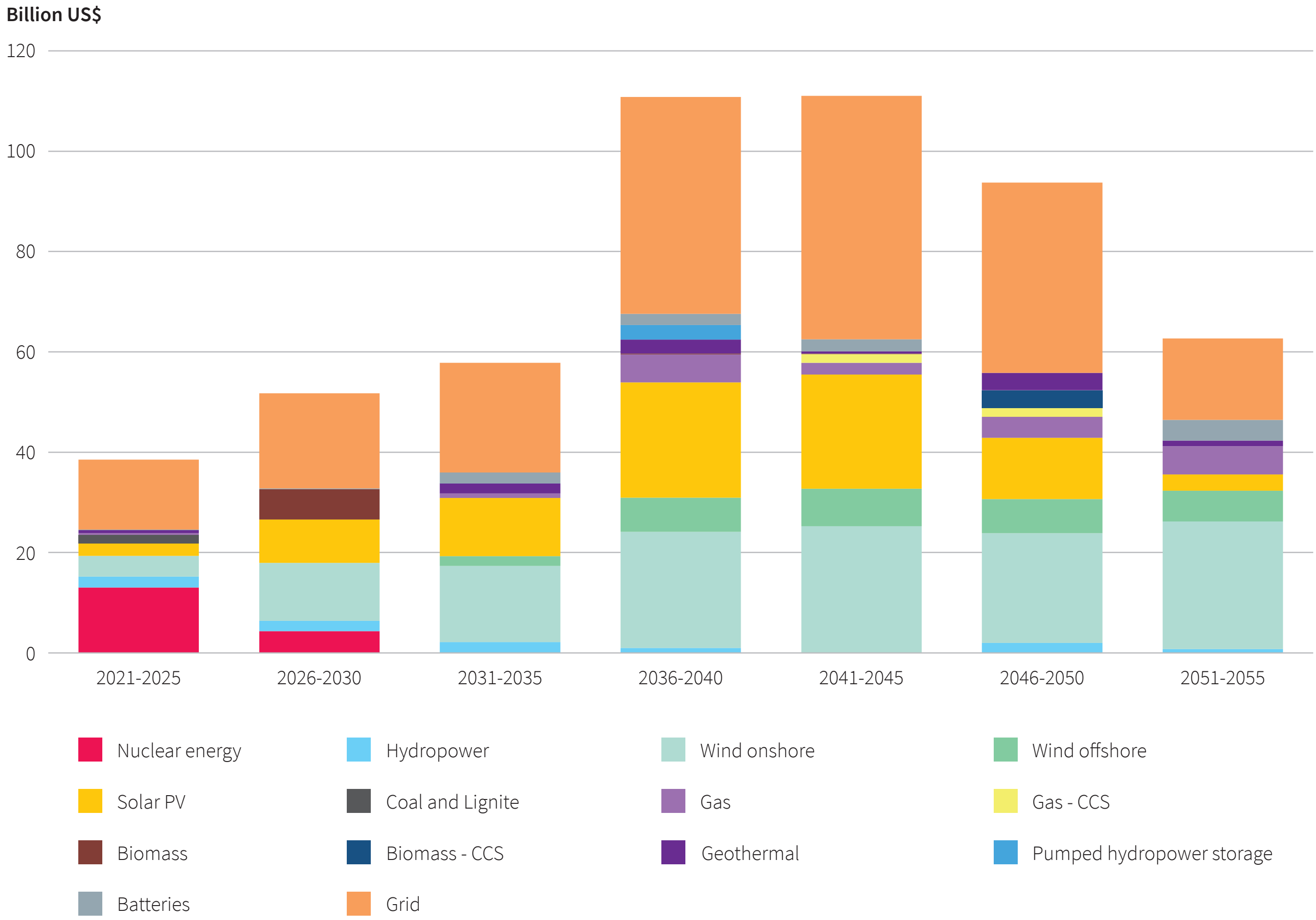
The Turkish power system in 2053 remains stable and reliable even with the vast amount of power generated by variable renewables. System reliability under various load conditions was tested on an hourly basis by the model (Figure 7). In addition to the energy storage systems, other dispatchable renewable generators (i.e., hydro, biomass and geothermal) keep the balance between supply and demand. Hourly simulations indicate that the system can deliver the demand requirements even under load stress conditions with the help of electrolysers and energy storage systems (i.e., pumped storage and batteries). Electrolysers are required to produce e-fuels and provide flexibility to the system. These units will operate flexibly at hours of highest availability of renewable energy, primarily during noon when the solar PV production is at highest. In the model, the demand side participation of the electric vehicles through smart charging provides a similar flexibility.

Figure 7: *Hourly electricity generation profile of a typical week*



The large expansion of new solar, wind and storage capacities create significant investment opportunities for the private sector. Investments increase especially after 2035 due to the growth in electricity demand driven by the electrification of demand across all sectors, while investments into grid infrastructure help manage the influx of variable renewables. Between 2020 and 2055, an annual average of 15 billion USD worth of investments is required. Of the 526 billion USD investment over the entire projection period, 62% is for installing new power plants and storage systems and the rest for grid development. Investment rates decline after 2050 as the growth in energy demand slows and the system nears net-zero (Figure 8).

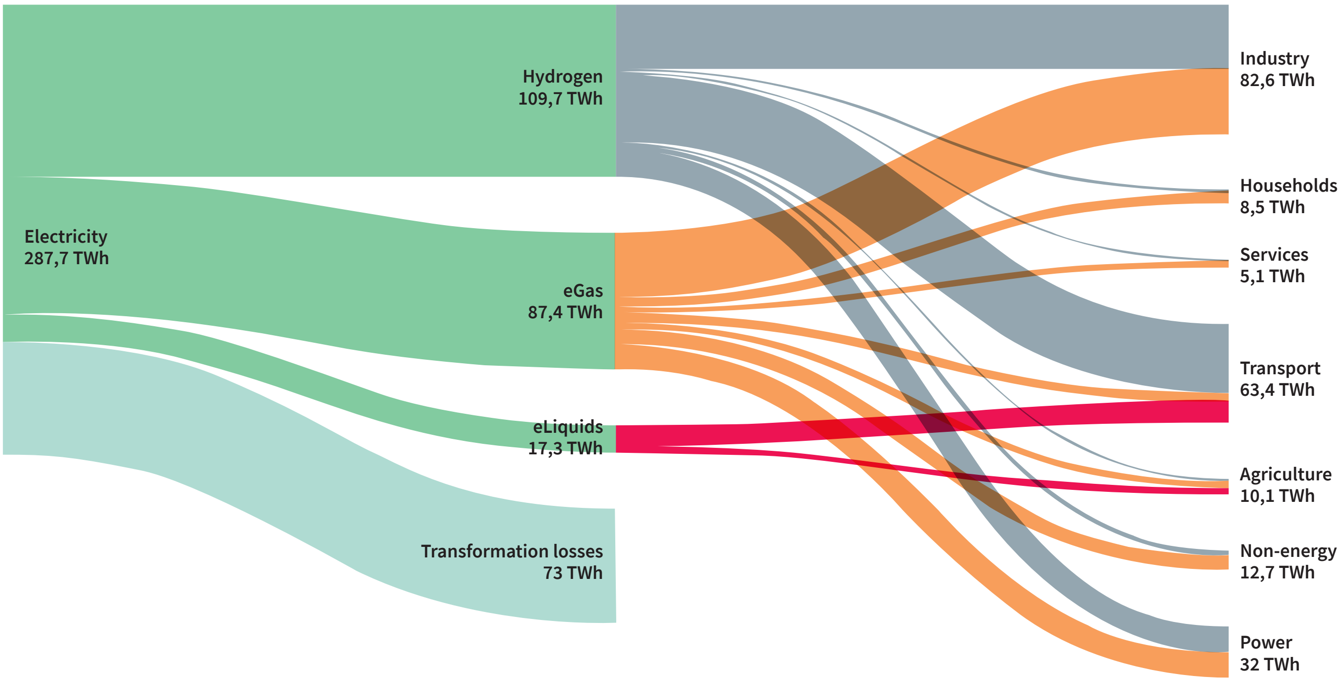
Figure 8: *Investments in the power sector (5-year periods)*



Indirect electrification through the use of green hydrogen and other e-fuels (Power-to-X) will play a crucial role in the decarbonization of the transport and industrial sectors given their current reliance on fossil-fuels. Power-to-X technologies are used especially in those sectors that depend on high temperature heat processes or where high energy densities are required. In the NZ2053 scenario, the shift to e-fuels in industry starts in 2035 with fossil-fuels completely phasing out in this sector by 2050. Correspondingly, Türkiye's gas network will also transition to e-fuel alternatives.

In transport, 71% of the passenger cars and 41% of the buses and trucks will either battery or plug-in hybrid electric vehicles (PHEV) by 2040. Between 2040 and 2045, all new passenger cars and vans will be either electric or fuel cell vehicles. In addition to this, e-fuels become necessary for transportation modes where electrification is not feasible, typically for travelling long distances. As such, green hydrogen is directed to around 10% of public road transport, 17% in Light Duty Vehicles (LDV) and 30% in Heavy Duty Vehicles (HDV) in 2053. Electrolysis-based e-liquids such as synthetic kerosene and ammonia are used in aviation and maritime transport respectively. The shares of e-fuels and green hydrogen in industry and transport are limited before 2030 but increase rapidly afterwards due to the expected technological advancements, drops in the technology costs and acceptance of the Power-to-X technologies both in in the world and Türkiye. In 2053, the share of green hydrogen and other e-fuels in total energy demand corresponds to approximately 15%.

Figure 9: *E-fuel production and sectoral consumption by type in 2053*



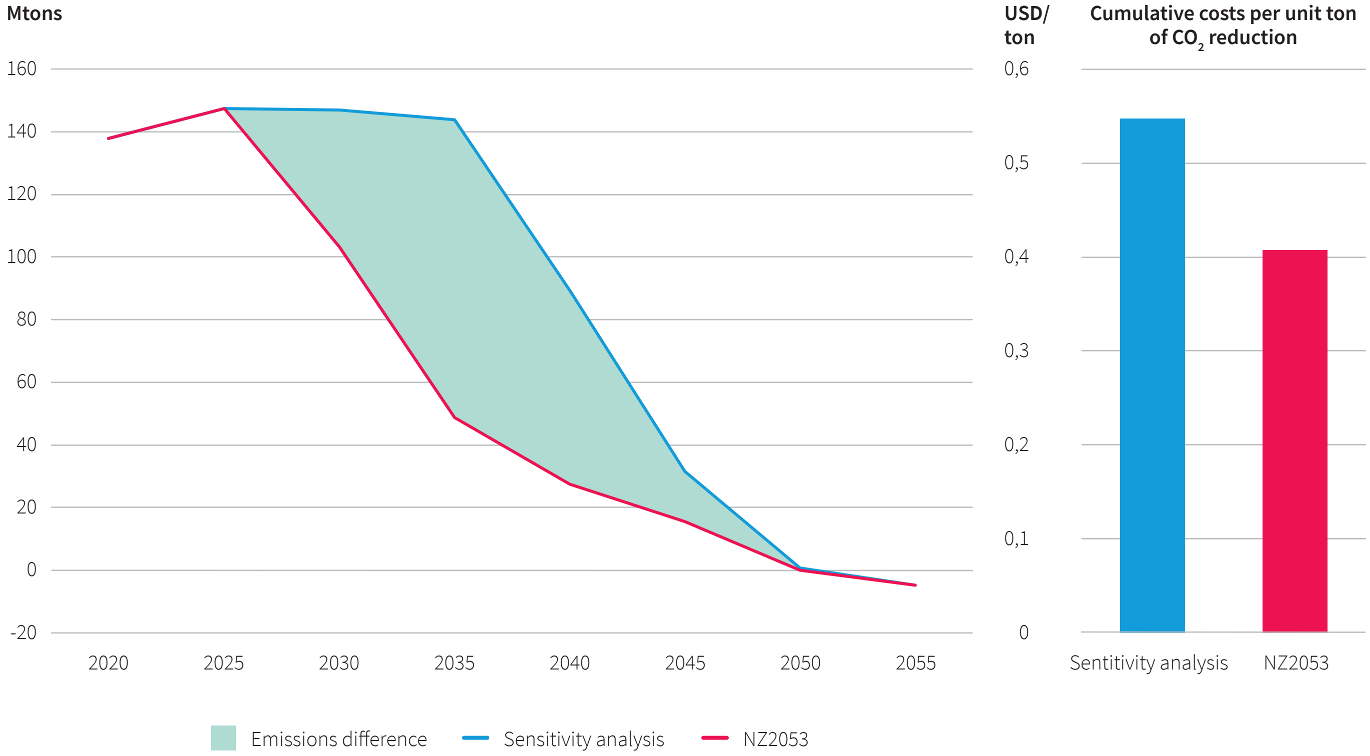
To fuel the indirect electrification requirements (considering hydrogen and e-fuel production), nearly 70 GW of electrolyser capacity is installed by 2053. The main advantages of having electrolyser capacity in the power system are that these units can utilize the excess amount of energy produced from solar PV and wind power plants, which would have otherwise been curtailed, to produce e-fuels and to keep the grid stable as the produced e-fuels can be utilised as a form of seasonal energy storage. In the model, the production of e-fuels is optimized simultaneously with the peak of renewable electricity generation. However, the production and then combustion of e-fuels involves significant conversion losses (approximately 50%); therefore, e-fuels should be used only where strictly necessary, but still can act as weekly or seasonal storage also for electricity.

Delaying immediate actions in decarbonizing the energy sector makes achieving Türkiye's net-zero target by 2053 significantly more challenging and poses considerably higher implementation risks. Within the scope of this work, a sensitivity analysis was conducted whereby the system achieves net zero by 2053, but the necessary changes are implemented with a delay. The sensitivity analysis demonstrates that running coal and lignite plants beyond 2035 increases cumulative carbon emissions while the continued presence of fossil fuels making

the transition more difficult, renewables deployment. By delaying action, an additional 59 GW wind and solar will need to be deployed over the last 13 years of the transition that would otherwise been distributed between 2020 and 2040 as observed in the NZ2053 scenario. Furthermore, continuing coal and lignite use until 2045 and then exercising a coal to gas switch results in an increase in natural gas imports and energy import expenditures over the projection period. When climate actions are delayed, the cumulative energy import costs between 2031-2055 are 20% higher than in the NZ2053 scenario. The continuing import dependency also increases the risk of exposure to fluctuations in the international fossil fuel prices. Additionally, further delaying the integration of renewable energy plants into the power system due to the existing fossil fuel power plants in the system, increases the total system costs. Furthermore, in order to reach net zero in the sensitivity analysis, over 200 GW of new renewable capacity, mostly solar and wind, will need to be deployed between 2040 and 2050, the implementation of which is nearly impossible considering supply of finance, labor and equipment.

Above all, delaying the transformation of the power system due to various impediments, increases Türkiye's cumulative emissions from the power sector by 46% and cumulative system costs per ton of CO_2 reduction approximately by 34% in 2053 (Figure 10).

Figure 10: *Comparison of the cumulative emissions and the cumulative system costs per unit ton of CO_2 reduced during the projection period*



Both the NZ2053 and the sensitivity analysis results show that it is imperative that the power sector reaches negative emissions between 2050 and 2055 to counterbalance the residual emissions persistent in the industry and transport sectors.

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About Istanbul Policy Center at the Sabancı University

Istanbul Policy Center (IPC) is a global policy research institution that specializes in key social and political issues ranging from democratization to climate change, transatlantic relations to conflict resolution and mediation. IPC organizes and conducts its research under three main clusters: The Istanbul Policy Center–Sabancı University–Stiftung Mercator Initiative, Democratization and Institutional Reform, and Conflict Resolution and Mediation. Since 2001, IPC has provided decision makers, opinion leaders, and other major stakeholders with objective analyses and innovative policy recommendations.

About European Climate Foundation

The European Climate Foundation (ECF) was established as a major philanthropic initiative to help Europe foster the development of a low-carbon society and play an even stronger international leadership role to mitigate climate change. The ECF seeks to address the “how” of the low-carbon transition in a non-ideological manner. In collaboration with its partners, the ECF contributes to the debate by highlighting key path dependencies and the implications of different options in this transition.

About Agora Energiewende

Agora Energiewende develops evidence-based and politically viable strategies for ensuring the success of the clean energy transition in Germany, Europe and the rest of the world. As a think tank and policy laboratory, Agora aims to share knowledge with stakeholders in the worlds of politics, business and academia while enabling a productive exchange of ideas. As a non-profit foundation primarily financed through philanthropic donations, Agora is not beholden to narrow corporate or political interests, but rather to its commitment to confronting climate change.

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