Increasing the Share of Renewables in Turkey's Power System:
Options for Transmission Expansion and Flexibility

EXECUTIVE SUMMARY

SHURA
Energy Transition Center

About SHURA Energy Transition Center

SHURA Energy Transition Centre founded by the European Climate Foundation (ECF), Agora Energiewende and Istanbul Policy Center (IPC) at Sabancı University (SU) contributes to decarbonization of the energy sector via an innovative energy transition platform. It caters the need for a sustainable and broadly recognized platform for discussions on policy, technological, and economic aspects of the Turkish energy sector. SHURA support the debate on the to a low-carbon Turkish energy system through energy efficiency and renewable energy by fact-based analysis and 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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The use of renewable energy resources, primarily wind and solar, is expected to grow significantly within Turkey's power system. There has been tremendous growth in the installed renewable electricity generation capacity in recent years and Turkey saw a record year in 2017. As deployment of renewable electricity generation technologies is on the eve of acceleration, there is a need to better understand how the rising share of wind and solar will affect Turkey's power system.

This evidence-based analysis is designed to highlight priority areas and inform energy planners, system operators, decision-makers and key market players on the consequences of higher shares of renewables and what they would mean for transmission investment and integration strategies in Turkey. This study – the first of its kind for Turkey – will help inform discussions about Turkey's transition to a low-carbon electricity system. Being one of the fastest growing economies and in view of the subsequent increase in Turkey's electricity demand, the analysis provides an important contribution to the energy security debate, proposing strategies how the current transmission system can integrate higher shares of renewables.

Turkey can generate 20% of its total electricity from wind and solar by 2026 without negatively impacting transmission system and planning.

Due to affordable technology costs, the wind and solar continue (defined together as variable renewable energy) are expected to continue. The analysis shows that Turkey can generate 20% of its total electricity from wind and solar by 2026 without negatively impacting transmission system and planning. Doubling the installed wind and solar capacity to 40 gigawatts (GW) is feasible without any additional investment in the transmission system compared to the Base Case scenario defined in this analysis. The total investment needed to expand the transmission grid and the additional transformer stations is estimated approximately the same as earmarked by Turkey's transmission system operator (TSO) Türkiye Elektrik İletişim A.Ş.'s (TEİAŞ) Ten-Year Network Development (TYNDP). The impact on redispatch and curtailment of electricity is found to be negligible. A wider distribution of solar and wind capacity across the country – based on demand, substation capacity and speed and irradiation – produces remarkable benefits for integration.

Generation from wind and solar are rapidly growing thanks to affordable technology costs and policies that utilise Turkey's excellent local resources. After a record year for adding renewables, this trend is expected to continue, as recent auctions for solar PV and wind have shown.

Added net renewables capacity (3.2 GW) was more than double that of non-renewables (1.5 GW).

In recent years, capacity additions for renewables have been marked by tremendous growth. Turkey saw a record year for renewables in 2017. Added net renewables capacity (3.2 GW) was more than double that of non-renewables (1.5 GW). At 1.79 GW, added solar photovoltaic (PV) capacity in 2017 was more than three times that of 2016, making Turkey one of the largest markets for solar PV in Europe. By the end of 2017, total installed wind capacity was nearly three times as high, at 6.9 GW.[1] Generation from wind and solar represents 7% of Turkey's total electricity output.[2] Almost 5 GW of (pre-)licenses for wind and solar projects were awarded by auction in 2017. This growth is likely to continue for a number of reasons.

[1] *Wind Europe (2018), Wind in Power 2017. Annual combined onshore and offshore wind energy statistics.*
[2] See http://www.emo.org.tr/genel/bizden_detay.php?kod=88369;
Enerji IQ (2018), Turkey's Energy Market Report, No: 2018 / 93 Year: 4, 13 March 2018.

The impressive decline in the costs of solar, wind and other renewable energy technologies has inaugurated a new era in low-carbon energy. Since 2012, global net capacity additions in renewables have surpassed those of all other technologies. In 2016, 161 GW of renewable energy capacity was installed, twice as much as net additions in coal and gas.[3] Turkey has benefited from these developments, as recent auctions for large-scale PV and wind have shown. Winning bids came in at USD 3.48 cents per kilowatt-hour (kWh) for wind and USD 6.99 cents/kWh for solar PV, far below Turkey's past feed-in tariffs. A majority of wind projects that received pre-licenses in 2017 will sell power on the market without a guaranteed price, and some will even pay the state-run grid operator TEİAŞ a per-kWh fee for feed-in rights.

There is a significant resource potential to scale up wind and solar generation in Turkey. Indeed, this is the time to combine this growing business case with the availability of abundant resources spread across the country. The prime locations for wind power generation along the Aegean coast have attracted much investment. For solar power, the south of the country offers many opportunities. What's more, in many other parts of the country where land is cheap or demand is nearby there's much potential for solar and wind.

Globally, Turkey has been one of the fastest growing economies. Its gross domestic product (GDP) per capita grew by 4.8% between 2010 and 2016,[4] the second fastest rate in the OECD. During the same period, its population grew by 1.6% per year, reaching more than 78 million in 2016. Beginning in 2010, total electricity demand increased 4.3% a year. Forecasts expect this trend to continue.

Total installed capacity reached more than 83 GW in 2017, up from 78.5 GW in 2016. Half of this total is renewable energy and the other half is fossil fuels. More than 70% of all electricity generation is supplied by fossil fuels. 29.3% of all electricity generation comes from renewables, mainly hydro and wind. Solar's share is a mere 1%. Turkey wants to meet its growing energy demand whilst reducing its dependence on energy imports, which currently make up 75% of Turkey's total supply. Renewable energy is a main pillar in overcoming this challenge.

Electricity generation from wind and solar is variable, that is, the output depends on the availability of wind and sunshine. This creates challenges for power system operators when it comes to meeting demand and delivering services. Global experience demonstrates that a share of 15% or more of variable renewable energy can be integrated into power systems without major changes in system planning and operation.

An energy system that is based on a higher share of renewable energy comes with multiple benefits: improved energy security, better trade balance, increased economic activity, new employment opportunities and a better environment.

An energy system that is based on a higher share of renewable energy comes with multiple benefits: improved energy security, better trade balance, increased economic activity, new employment opportunities and a better environment. Yet stakeholders and system operators often see growing shares of wind and solar as a challenge, one accompanied by additional costs and difficulties when it comes system reliability and flexibility.

Indeed, in recent years, experience in many countries around the world has shown that annual shares of solar and wind generation that reach 15% or more can be managed without major effort, provided operational aspects are taken into account and early planning occurs.

[3] *IRENA (2017):* Renewables Capacity Statistics 2017.
[4] At 2010 constant USD.

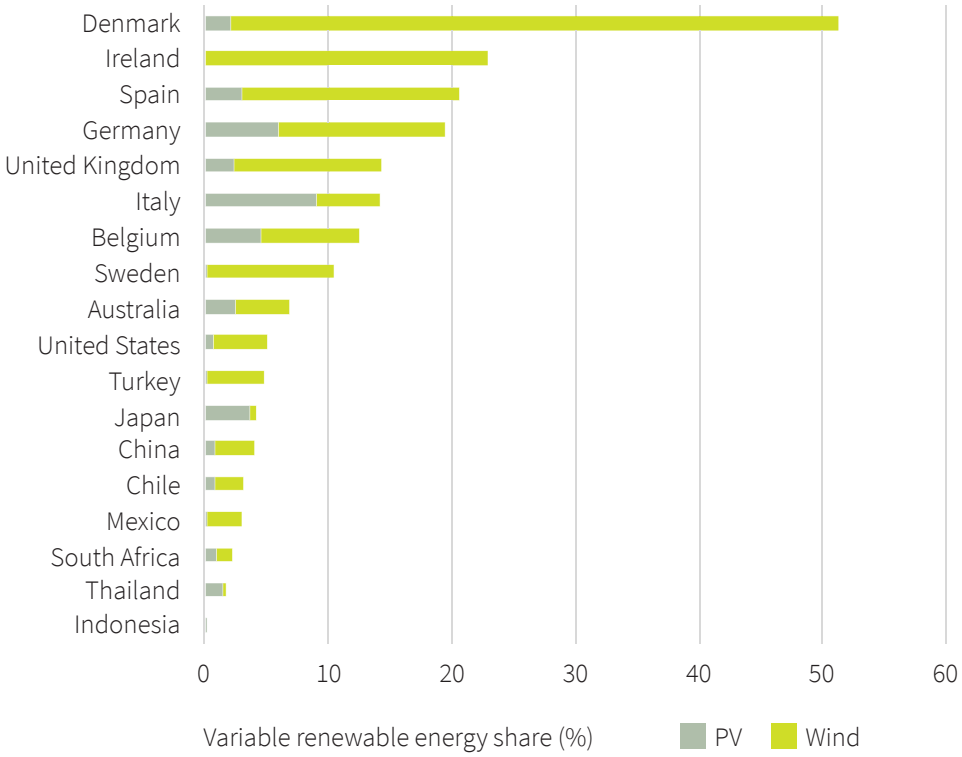


Figure 1: *Share of electricity generation from on/offshore wind and solar PV in selected countries, 2015*[5]

Global examples are showing that wind and solar shares of up to 25% can be successfully integrated without changing the power system. This can translate into more than 80% of demand at specific hours of the year. Systems in California, Germany and Spain have developed various flexibility options such as strengthening interconnector capacity with neighbouring systems, improving fossil fuel plant flexibility and allowing for limited curtailment in extreme cases. Some countries have also adapted their market design to address highly variable prices, low utilization rates of fossil plants and the associated investment challenges.

There is a need to better understand how the rising share of wind and solar energy will affect Turkey's power system. This study – a first of its kind for Turkey – will help inform discussions about Turkey's transition to a low-carbon energy system.

Country-specific assessments have become indispensable in understanding the challenges created by renewables and identifying suitable measures for efficient wind and solar. But such analysis has yet to be carried out for Turkey. This is essential to prepare policymakers, system operators, regulators and consumers for managing a clean-energy transition.

The study is designed to inform stakeholders in Turkey about the consequences of a greater share of renewables and what this would mean for transmission investment and integration strategies. It builds on a robust, innovative and in-depth simulation model.[6]

[5] *IEA (2017). World Energy Balances 2017 edition. OECD/IEA, Paris.*

[6] Due to complexity and data access, the distribution system is not part of this analysis. However, long-distance power flows do not have a significant effect on the distribution system. The challenge and cost of integrating renewables into the distribution grids will largely depend on local supply-and-demand ratios, as well as on smart planning, the monitoring and control of wind and solar feed-in.

This study, which covers the 2016–2026 period, considers three main scenarios that differ in their share of total installed wind and solar generation capacity: a Base Case scenario of 20 GW (in line with the existing TEİAŞ plan, which assumes 14 GW of wind and 6 GW of solar PV), a scenario where wind and solar capacity doubles (40 GW) and one where it triples (60 GW). Given the rapid cost decline of solar PV, an equal amount of wind and solar have been assumed for the doubling and tripling scenarios.[7] These capacity values do not necessarily reflect the most probable or desirable values. The idea is to create different scenarios in order that we may better identify challenges and system impact.

In the Base Case, the share of wind and solar reaches 12% by 2026. It increases to 21% in the Doubling and 31% in the Tripling scenarios. The total renewable energy share, including hydro, geothermal and biomass, is estimated at 35%, 44% and 53%, respectively.

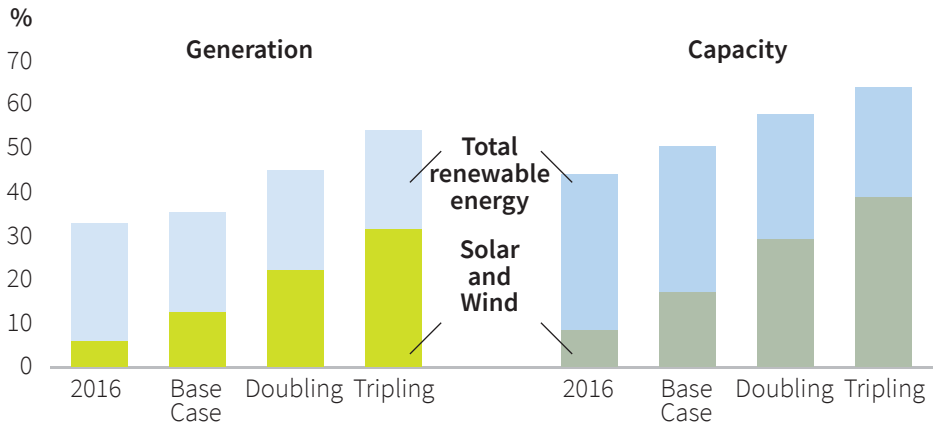
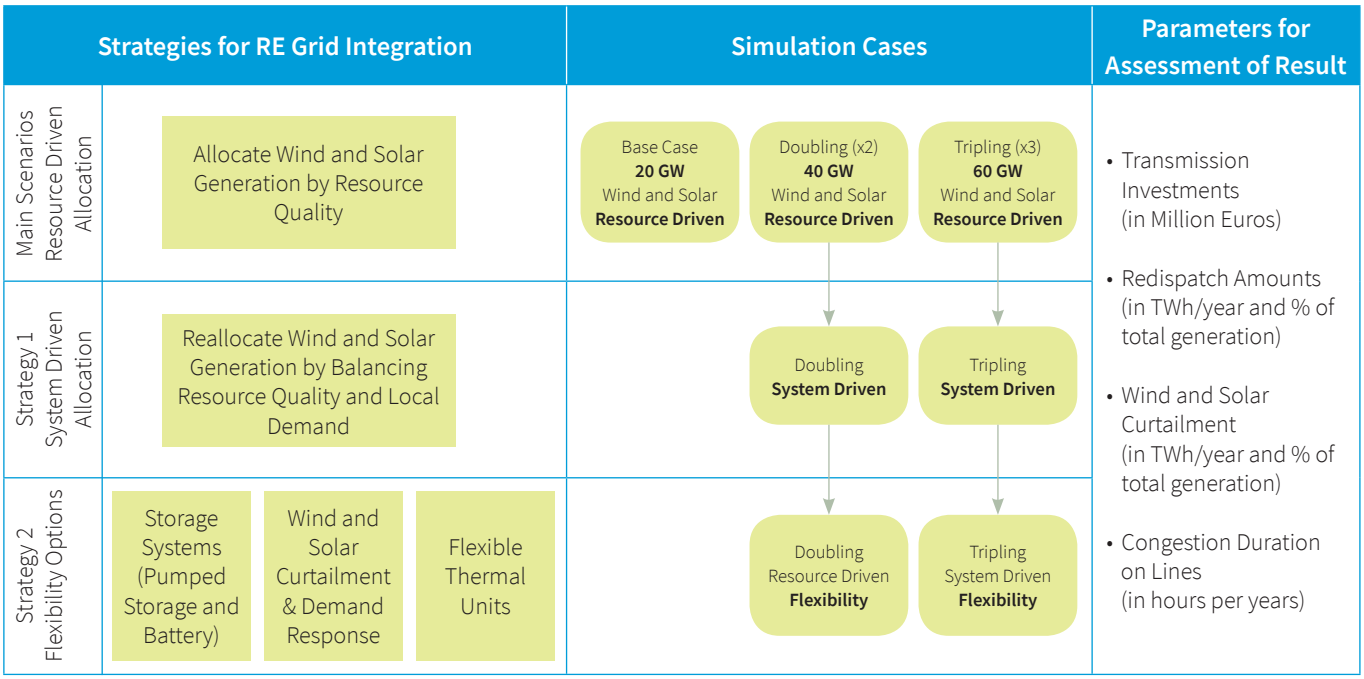


Figure 2: *Solar, wind and total renewable energy shares in the three scenarios, 2016–2026*

The effect of two grid integration strategies was assessed based on the scenarios: a *resource-driven allocation*, which locates wind and solar investment where the resource quality is best, and a *system-driven allocation*, which distributes solar and wind generation across Turkey in a balanced manner, taking into account demand centres as well as local grid capacity. The study then considers different flexibility options. All input data remain identical across the three scenarios and are based on real data and operational practices used by TEİAŞ as well as those used by current energy plans and government targets.

[7] Concentrated solar power does not feature prominently in the Turkey's context due to its high generation costs and was therefore not included in this analysis.



** Since there were only minor differences between results of system and resource driven assessment for scenario, the choice was made to assess based on resource driven allocation.*

Figure 3: *Scenario approach of this study*

Doubling the current plan of solar and wind capacity to 40 GW will not have a major impact on system planning and operation. It would be achievable without any additional costs and the impact on redispatch and curtailment would be negligible. The total investment needed to expand the transmission grid and add transformer stations is estimated at around EUR 390 million per year, roughly the same as that earmarked by TEİAŞ's TYNDP.

By 2026, Turkey's electricity generation is projected to reach 439 terawatt hours (TWh) per year, up from 272 TWh in 2016, for an annual growth of 5%.

For the Base Case scenario, the study follows the TYNDP of TEİAŞ for the 400 kilovolt (kV) and 154 kV systems. 8,900 km of new 400 kV lines, 10,700 km of new 154 kV lines and sixty-one 400 kV/154 kV transformer stations are identified. Investment costs are estimated to amount to EUR 390 million annually for 2016–2026. This represents a continuation of the investment average of the past 5 years. Most of the new investment will be needed along the Aegean Sea in West Anatolia, between Central Anatolia and Trakya, and in Southeast Anatolia.

Doubling the installed wind and solar capacities to 40 GW is feasible without additional investment in the transmission system.

Doubling the installed wind and solar capacities to 40 GW is feasible without additional investment in the transmission system. Minor additional investment may be needed in high capacity grid connection lines for large solar parks like those planned for the renewable energy resource area (RERA) system.

In the Base Case scenario, the redispatch share in total electricity generation would remain at the 2016 level, around 4.8%. Redispatch increases slightly but remains within the same bandwidth of 5% when total capacity doubles.[8] The need for the curtailment of wind and solar generation is negligible.[9] By comparison, Germany in 2016 had to curtail 3.3% of its wind and solar power generation (which provided nearly 20% of overall demand) due to delays in network expansion.[10]

[8] Generation redispatch, which changes the dispatch of plants to relieve demand, provides secure and reliable system operation, but it also creates additional costs.
[9] Depending on wind conditions and solar irradiation during extreme low-load public holiday periods, curtailment may be required for a few hours, but it will nevertheless be negligible, i.e. below 0.1% of annual wind and solar generation.
[10] *Bundesnetzagentur (2017): EEG 2016 in Zahlen.*

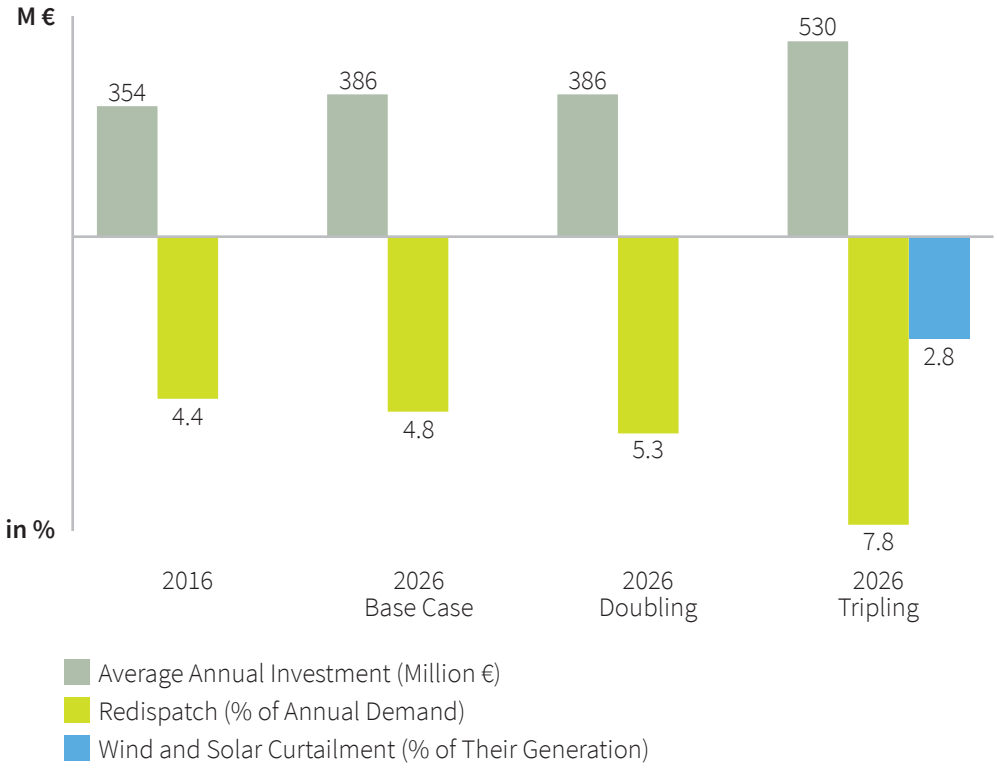


Figure 4. *Investment, redispatch and curtailment results for 2016 and for the main scenarios in 2026*

Tripling wind and solar capacity is also achievable with efficient implementation of the grid integration strategies. These include the selection of wind and solar generation sites based not only on resource quality but also on local demand, grid capacity, and increased system flexibility. A moderate increase of investment in the transmission grid to EUR 430 million annually can create a system that operates just as efficiently with limited redispatch and less than 1% of curtailment of solar and wind electricity.

Tripling installed capacity to 60 GW by 2026 would make solar and wind the largest source of electricity generation in Turkey with a total share of 31%.

Tripling installed capacity to 60 GW by 2026 would make solar and wind the largest source of electricity generation in Turkey with a total share of 31%. In this scenario, combined output from all types of renewables would represent half of Turkey's total electricity generation. A higher share of renewables would reduce the electricity provided by thermal generators. Assuming a market regime based on operational costs, plants using natural gas, lignite and imported coal would be most affected.

Without the use of grid integration strategies, achieving the Tripling scenario would require 30% more investment in transmission capacity and 20% more in transformer substations relative to the Base Case and the Doubling scenario. The annual required investment would thereby increase to EUR 530 million.[11]

The higher the share of wind and solar, the more rewarding this strategy is.

A wider distribution of solar and wind capacity across the country – based on local power demand and substation capacity as well as on wind speed and solar irradiation – produces remarkable benefits for integration (relocating approximately 50% of additional capacity). The higher the share of wind and solar, the more rewarding this strategy is. In the Tripling scenario, additional investment requirements in transmission capacity are two-thirds lower (2,750 km of extra lines as opposed to 8,300 km). Redispatch levels are lower as well – 6.6% instead of 7.8% – and the curtailment of wind and solar falls below 1% of total generation.

[11] This does not include grid connection costs, as these occur at different voltage levels and can be analysed properly only with a more detailed assessment of location and connection points at the distribution level. When comparing our scenarios, therefore, we decided to ignore the grid connections in, say, large YEKA PV parks.

The strategy of balancing wind and solar geographically is economically appealing as well. Due to the widespread availability of high-yielding wind and solar locations in Turkey, the increase of levelized electricity costs for a portfolio of more distributed wind and solar generation is, at less than 5%, negligible. This creates attractive investment opportunities for wind and solar in all parts of Turkey, which will benefit these regions and positively impact transmission system expansion and operation.

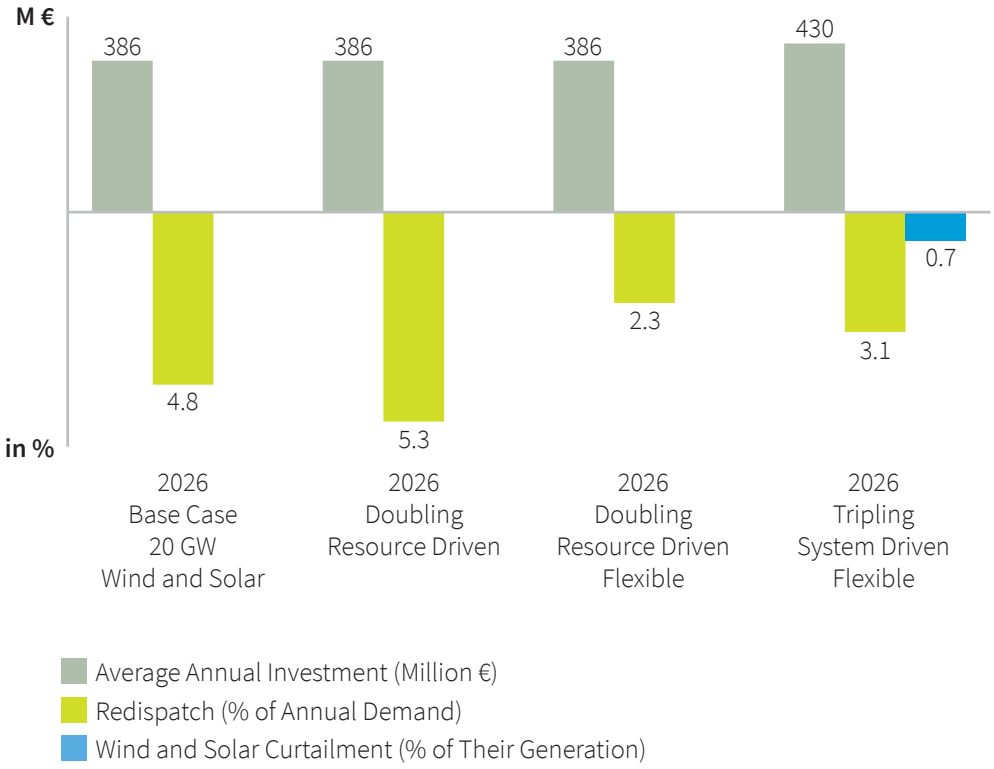


Figure 5. *Investment, redispatch and curtailment results for the main scenarios with integration strategies, 2026*

Introducing a portfolio of flexibility measures will further ease the challenge of integrating higher solar and wind shares. Flexibility can be offered by storage (2 GW pumped hydro and battery storage were modelled) and by more flexible thermal generation through modernized coal-fired plants and demand response mechanisms. In both doubling and tripling scenarios, redispatch levels would fall far below today's levels. The additional flexibility provided would have a positive albeit small effect on curtailment, with levels in the Tripling scenario well below 1% for both solar and wind.

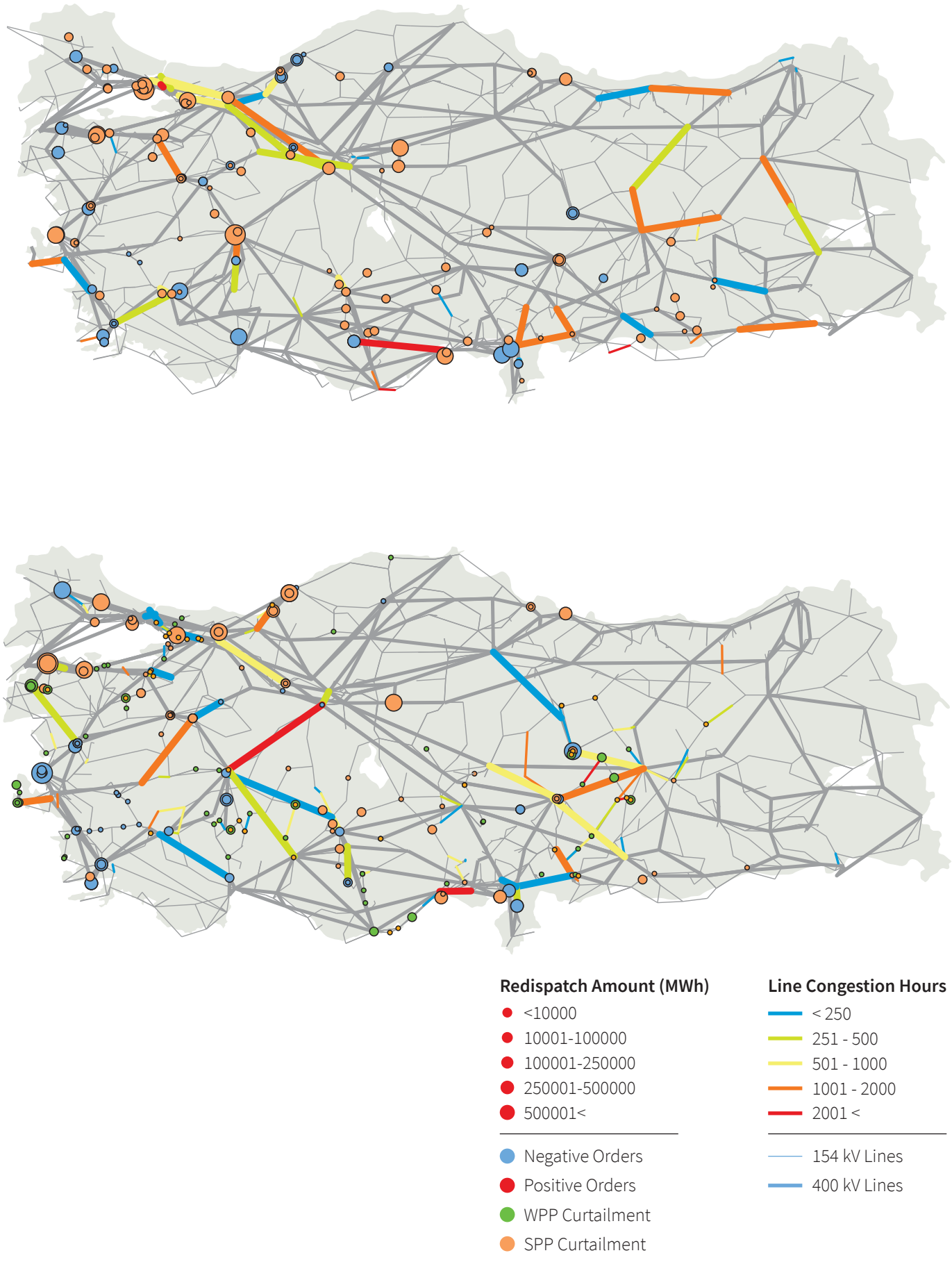


Figure 6. *Redispatch, congestion and curtailment map: Base Case (top) and Tripling (bottom) scenarios with resource-driven and flexibility strategies*

This first-of-its-kind study highlights the priority areas for energy planners and system operators to achieve wind and solar integration in Turkey's power system. Its findings provide the starting point of a clean-energy roadmap that takes into account the perspectives of all impacted stakeholders.

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This study shows that Turkey can generate 20% of its total electricity from wind and solar within less than a decade without any negative impact on transmission system and planning. Turkey, like many other countries across the globe, needs to prepare itself for a transition to a low-carbon energy system. Redefining how the electricity system is planned will be key. Data collection, transparency and management will gain momentum as demand and supply patterns change, variable resources like wind and solar spread and storage technologies are introduced. Planning is also crucial for system operators, who will have to rely on wind and solar generators' providing adequate information on power feed-in and system services.

Turkey can generate 20% of its total electricity from wind and solar within less than a decade without any negative impact on transmission system and planning.

Decoupling electricity demand from economic growth is of utmost importance because of its ability to limit power system costs. Yet as the system grows, additional generation will be required. Increasing the share of wind and solar will affect the need for flexible thermal power plants – something that system planners need to anticipate. Though many flexibility options are available, Turkey, if it is to minimize system costs, must aim at an optimal generation mix that takes into account technical capabilities, locational effects, environmental impact and associated expenses.

This study serves as a starting point for evidence-based planning to integrate wind and solar at a larger scale in Turkey's power systems.

Additional analysis will be required to undertake robust planning and to support policymakers as they set targets and introduce new regulations and incentive programs. Developing a national roadmap that prepares the power system for a higher share of renewable energy is an invaluable part of Turkey's future.

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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