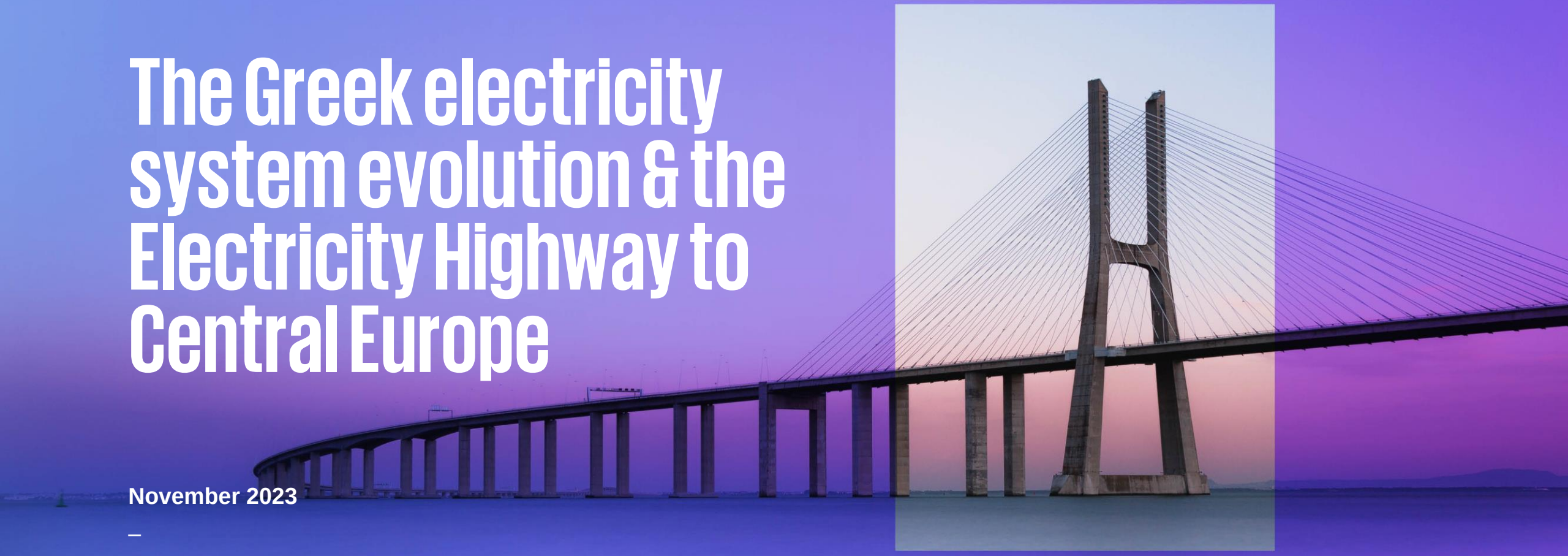
# The Greek electricity system evolution & the Electricity Highway to Central Europe



**November 2023**

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**KPMG Advisors Single Member S.A.** – Management Consulting – Strategy & Operations

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# Background to this study

The scope of this study is the long-term analysis of the Greek electricity market in order to **investigate the potential benefits from the operation of a new 9 GW green electricity corridor to Germany** for both the end-consumers and the Greek national economy.

For this purpose, a **30-year study horizon (2026-2055) was used** and three (3) scenarios were studied which follow, in general, the main provisions of the revised Greek National Energy and Climate Plan (NECP) that is currently under finalization by the Greek State, especially regarding the evolution of the system load demand (i.e. 65 TWh in 2030) and the RES penetration share (i.e. 80% RES share in 2030) as well as the permanent withdrawal of lignite units by the end of 2028. Appropriate adjustments and extrapolations have been done to various market and system parameters to formulate a realistic long-term electricity market simulation scenario for the entire study horizon based on our experience. The main assumptions of the three scenarios are as follows:

## Scenario 1

- **Four (4)** New CCGTs (Average UCAP ≈ 800 MW) operate during the entire study period
- BESS penetration according to NECP assumptions during the entire study period
- The 9-GW Interconnection to Central Europe is **NOT available**

## Scenario 2

- **Three (3)** New CCGTs (Average UCAP ≈ 800 MW) operate during the entire study period
- **No BESS** are considered during the entire study period
- The 9-GW Interconnection to Central Europe is **available**

## Scenario 3

- **Three (3)** New CCGTs (Average UCAP ≈ 800 MW) operate during the entire study period
- **Additional PV Capacity** with respect to Sc. 1 & 2 and **moderate BESS penetration** is considered to increase the annual utilization of the 9-GW Interconnection to Central Europe
- The 9-GW Interconnection to Central Europe is **available**

# Methodological Approach

The ultimate goal of this analysis is to estimate the total cost of electricity supply to be undertaken by the end-consumers along with the cost/benefit of the national economy associated with the cross-border electricity exchange in each of the three aforementioned scenarios. By comparing these figures in the three scenarios, **we can directly estimate the added benefit that the operation of a new 9 GW green electricity corridor to Germany can entail for both the end-consumers and the Greek national economy.**

In this context, the study is separated in two distinct steps, as follows:

## Detailed long-term simulation of the Greek wholesale electricity market

The scope of this simulation analysis is to perform a long-term forecasting of main wholesale market indicators (e.g. energy generation mix, market clearing prices, uplift account charges, etc.). It is underlined that all these market indicators are forecasted in the finest (hourly) time resolution and are then used in the extensive ex-post calculations that follow in the second step.

## Cost / Benefit analysis for end-consumers and the national economy

The said market indicators are used in order to estimate the total cost of electricity supply for the end-consumers along with the cost/benefit of the national economy associated with the cross-border electricity exchange for each of the three scenarios.

# Software Tool

In this study, the Greek wholesale electricity market was simulated for a future 30-year study period (2026-2055) with the integrated simulation tool "**Long-Term Scheduling extended" (LTSx)**. LTSx was developed by the Power Systems Lab of Aristotle University of Thessaloniki and is capable of realistically simulating the Greek wholesale electricity market in the long-term, by solving sequentially:

**01** Day-Ahead Market (DAM)

**02** Integrated Scheduling Process (ISP)

**03** Real-Time Balancing Energy Market (RTBEM)

The aforementioned optimization problems are processed and solved on a day-by-day basis using the appropriate temporal resolution:

- 1 hour for DAM
- 30-min for ISP
- 15-min for RTBEM

Each of these optimization models are **fully aligned with the regulatory and operational provisions of the current Greek wholesale electricity market**, as documented in the Day-Ahead Market & Intra-Day Market Trading Rulebook and Balancing Market Rulebook, as well as in the detailed technical decisions that have been published by the Greek Market Operator (HEnEx) and the Greek Transmission System Operator (IPTO).

The modeling environment used for the formulation and solution of the aforementioned core optimization models is the Generic Algebraic Modeling System (GAMS) along with the CPLEX solver

# In each scenario, the following components are calculated

## 01

### Wholesale market electricity procurement cost

- **Day-ahead market electricity procurement cost:** This is the electricity procurement cost undertaken by the Retailers for buying electricity directly from the day-ahead market. For the scope of this study, it has been considered that Retailers will use this option to cover their remaining needs after having concluded PPA contracts with RES producers.
- **RES PPA electricity procurement cost:** This is the electricity procurement cost undertaken by the Retailers for buying electricity directly from RES plants (mainly PV and wind stations). It has been considered that from the next 1-2 years onwards RES plants will be eager to conclude long-term PPA contracts with Retailers for providing them with their entire RES generation volumes. For the purposes of this study and following current practice, the weighted average PPA price of these contracts has been estimated equal to 60 €/MWh (close to the weighted average Levelized Cost of Electricity (LCOE) of the said RES technologies).
- **Uplift Account Charges (UAs):** These are additional charges that have to be undertaken by all Retailers to compensate for the transmission system losses costs (UA-1), the reserves provision costs (UA-2) and the balancing market financial neutrality costs (UA-3). The latter is used to allocate to Balance Responsible Parties (BRPs) any remaining balance after the calculation of the debits and credits calculated by the Greek Transmission System Operator (TSO) for the activated balancing energy for manual Frequency Restoration Reserve (FRR) and automatic FRR, the energy activated for purposes other than balancing and Imbalance Settlement.

## 02

### BESS out-of-the-market financial support

This refers to the out-of-the-market cost that has to be undertaken by the Retailers and, in turn, by the end-consumers to fully cover any “missing-money” problem of the BESS resources considered in each scenario. In other words, it is the average additional cost paid by the end-consumers throughout the study period to guarantee that the economic valuation of the new BESS resources will lead to a Project IRR equal to 8% and, therefore, these resources will not be loss-making in the long-term.

### New CCGT out-of-the-market financial support

Similarly to BESS resources, this refers to the out-of-the-market cost that has to be undertaken by the Retailers and, in turn, by the end-consumers to fully cover any “missing-money” problem of the new CCGT units considered in each scenario. In other words, it is the additional cost paid by the end-consumers to guarantee that the economic valuation of the new CCGT units over the 30-year period will lead to a Project IRR equal to 8% and, therefore, these resources will not be loss-making in the long-term.

## 03

### National economy deficit/surplus due to cross-border electricity exchange

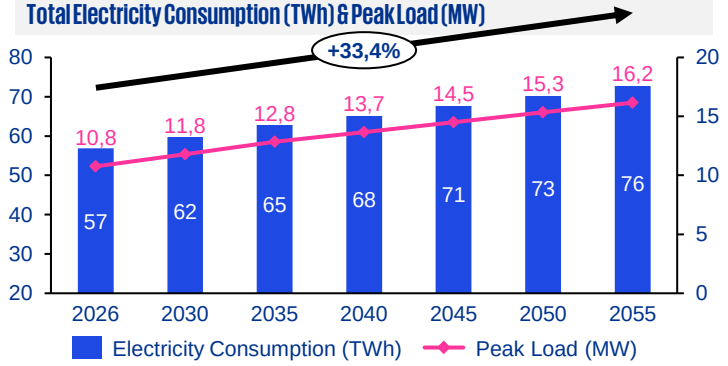
This cost component refers to the potential deficit/surplus arising from the cross-border electricity exchange. Specifically, the hourly imports/exports balance has been calculated for each hour of the study period on the basis of the analytical wholesale market simulation results and the associated national economy deficit/surplus was then calculated, considering that the national economy incurs a deficit during hours that the Greek power system is net-importer (calculated as: Hourly net-import volumes [MWh] x Hourly DAM price [€/MWh]) and, conversely, obtains a surplus during hours that the Greek power system is net-exporter (calculated as: Hourly net-export volumes [MWh] x Hourly DAM price [€/MWh]).

# Simulation scenarios definition and main assumptions

In this study, **three (3) simulation scenarios** have been defined as a combination of various parameters that affect the operation of the Greek interconnected power system during the period 2026-2055, such as RES and BESS installed capacity, CCGTs availability and interconnections' capacity. The scope of the formulated set of scenarios is to yield distinct market prices trajectories for the entire study period. In this context, Scenario 1 is considered as the Baseline Scenario. For all other scenarios, changes with respect to the Baseline scenario are **highlighted**.

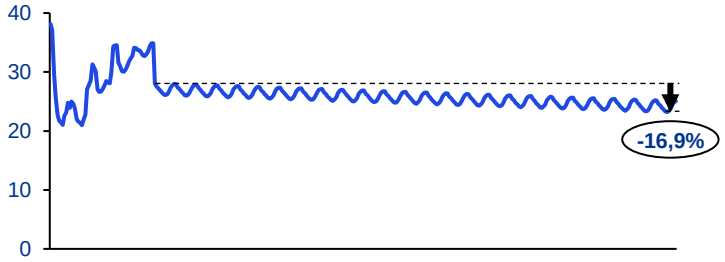
| Scen. ID | System load | Gas price | $CO_2$ emissions price | RES penetration | BESS penetration | # of New CCGT Units | Net imports |
|---|---|---|---|---|---|---|---|
| 1 | Base | Base | Base | Base | High | Four | Base |
| 2 | Base | Base | Base | Base | **Zero** | **Three** | **Base + 9 GW Line to Central Europe** |
| 3 | Base | Base | Base | **Base + Additional PV** | **Moderate** | **Three** | **Base + 9 GW Line to Central Europe** |

**Total Electricity Consumption (TWh) & Peak Load (MW)**



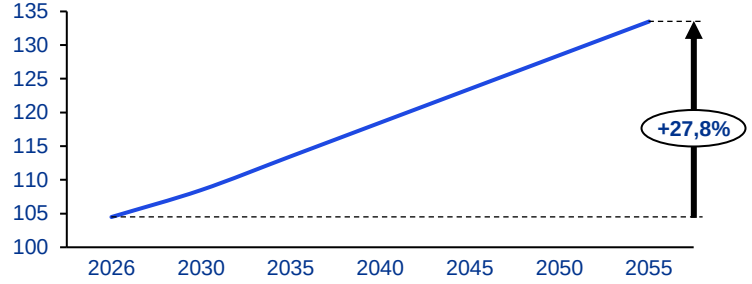

In the 30-year study horizon (2026-2055) all scenarios follow, in general, the main provisions of the revised Greek National Energy and Climate Plan (NECP). In 2023, the electricity load is projected to reach 51 TWh which is approx. 3% lower compared to the NECP. The study uses this updated forecast and applies a **gradual recovery in electricity consumption until 2027** so that to **align with NECP's projections from 2028 onwards**.

**Gas Supply Prices (€/MWh HHV)**




The assumptions used on the development of gas prices, the forward curves of Intercontinental Exchange (ICE) were used. According to the forecasts, the TTF prices will be at the range of 21€/MWh up to 38,1€/MWh **averaging on 26,1€/MWh** for the horizon examined in the study.

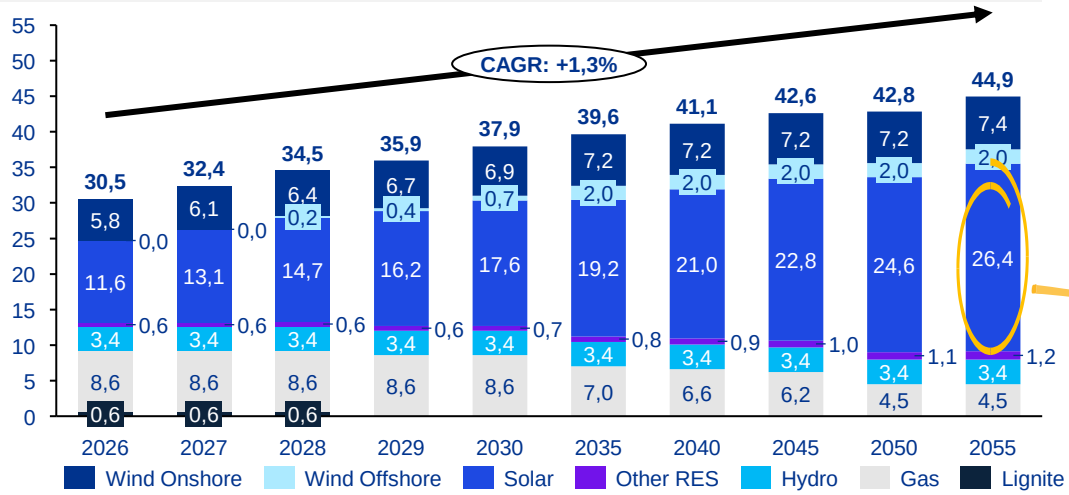
**ETS Prices (€/tn CO2)**



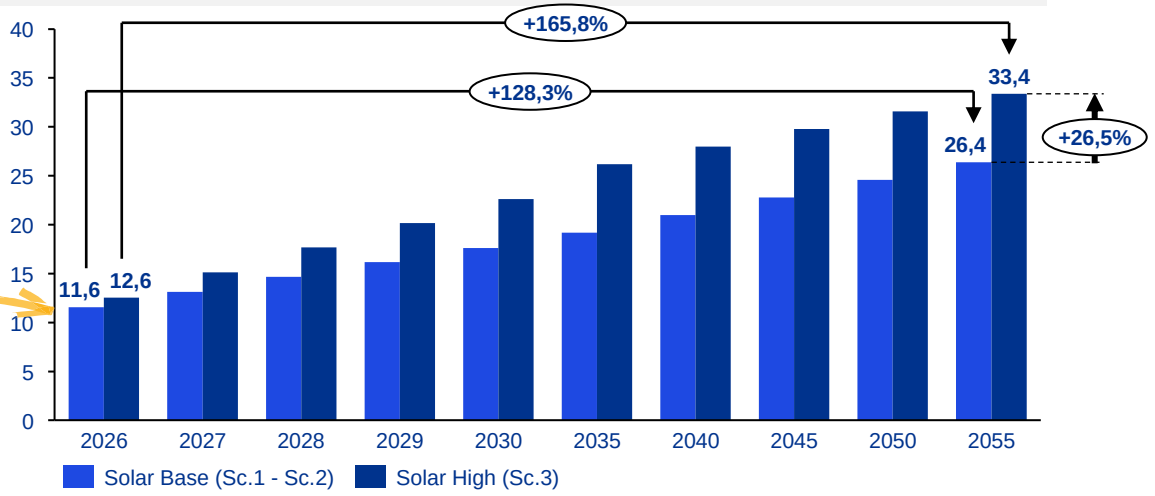

For ETS prices, the forecasts of both European Energy Exchange (EEX) and Intercontinental Exchange (ICE) were used leading to an increase of 27,8% from 2026 to 2055. The **average price is 119€/tn $CO_2$.**

# RES are expected to dominate the generation capacities starting from this decade

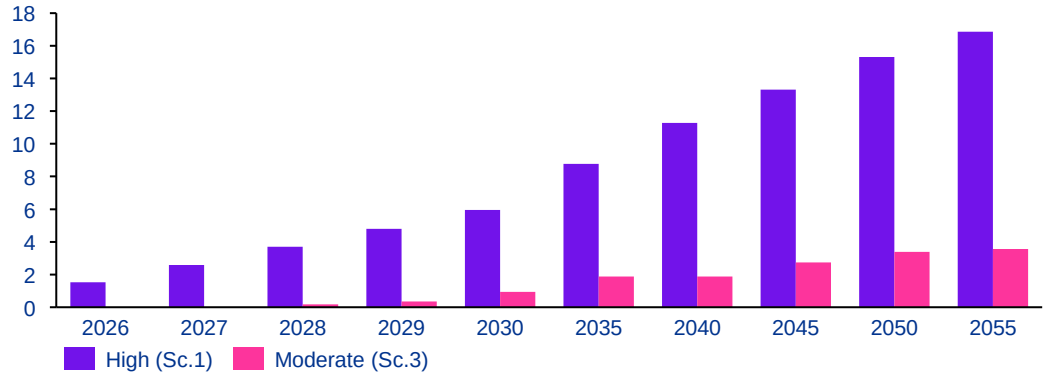
## Generation capacity (in GW)




## Solar capacity (in GW)

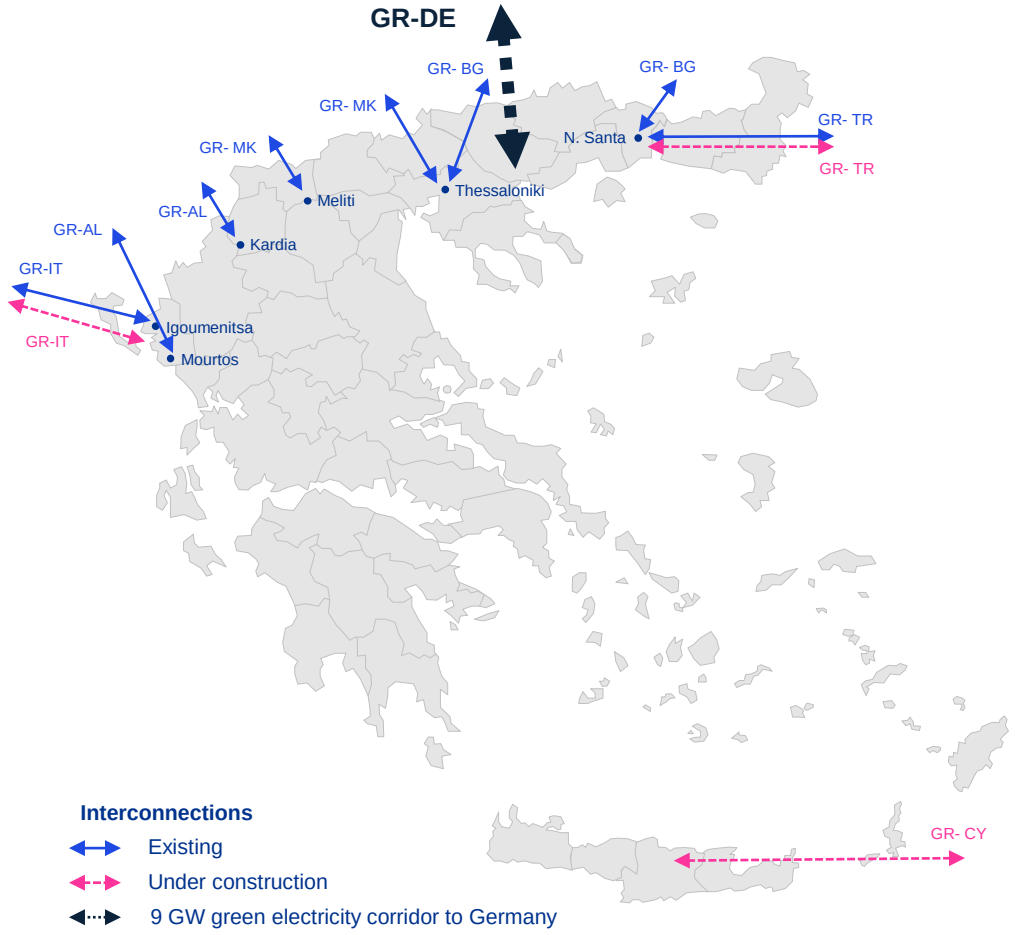



## BESS Penetration (in GW)




- Breakthroughs are expected to occur in the next decades in the field of power supply in Greece, as the RES share in power generation is expected to increase significantly and gradually replace the use of fossil fuels. Although in the 2019's NECP the lignite phase-out was scheduled by end 2023, the Russian-Ukrainian war changed the framework and with the very recent new climate law the new deadline for the lignite phase-out was extended to end 2028.
- The vast increase of RES is driven by on-shore wind and PVs, as these two categories represent 77% of RES total installed capacity mix in 2030 and 90% in 2055.
- Hydro plants' penetration is limited as the usable sites for their development are subject to saturation.
- High penetration of vRES require energy storage for sufficient take-up of the energy generated by such; additionally BESS provide flexibility and ancillary services to the System.

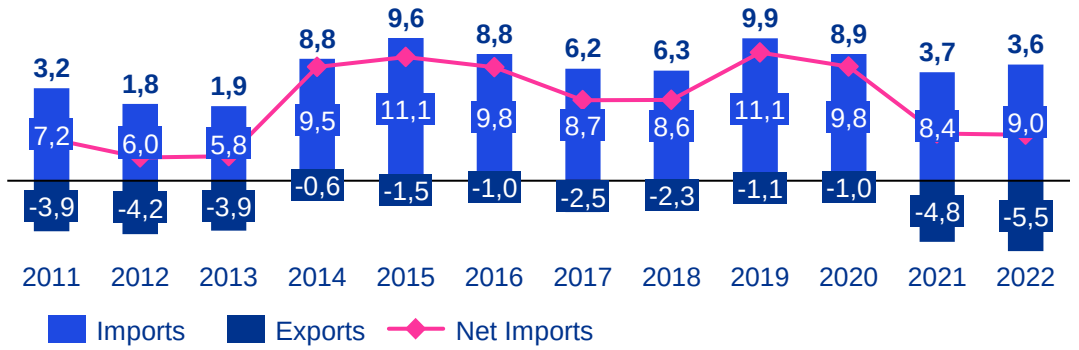
# The Greek Interconnection system developments are inline with ADMIE's plan




**Source:** IPTO

- The interconnections with the neighbor countries take place via 400kV AC lines (exception is Bistrica – AL which is 150kV), while the interconnection with Italy is made through an underwater DC connection.
- The interconnection of 130km between N. Santa and Maritsa (GR-BG 1.100MW) was completed in summer 2023.
- The interconnection of transmission systems Greece - Cyprus will take place with DC connections (1.000MW) and it is projected to be completed in 2028.
- The construction of the second interconnection to Italy (1.000MW) is considered from 2035 onwards
- The second interconnection to Turkey (600MW) is not considered in this study.
- **The 9 GW interconnection between Greece and Central Europe is assumed only in Scenarios 2 and 3.**

## Historical electricity imports and exports (in TWh)



# The 9GW link can exploit Greece's untapped RES potential and is aligned with EU strategic targets


— The development of an interconnection to central Europe could be the first electricity highway in the EU and part of the Priority Electricity Corridor of Central Eastern and South Eastern interconnections. Its development serves all EU energy targets:

- **Integration of markets and contribution** to the establishment of EU single market
- Intensified competition among electricity producers and traders, which will contribute to **reducing electricity costs and prices** in the long term
- **Expansion of the use of RES electricity** (through exports), contributing to the achievement of the EU's RES target
- Contribution to the **EU's security of supply** due to the replacement of Natural Gas imports with local RES production

— For the purposes of this study **SENEH route (South East-North Electricity Highway)** was used for the quantification of the total benefits; however, and since there are alternative routes that have been suggested during the last 2 years, the purpose of this study is not choose the exact path but rather **assess the benefits of an interconnection to Central Europe.**

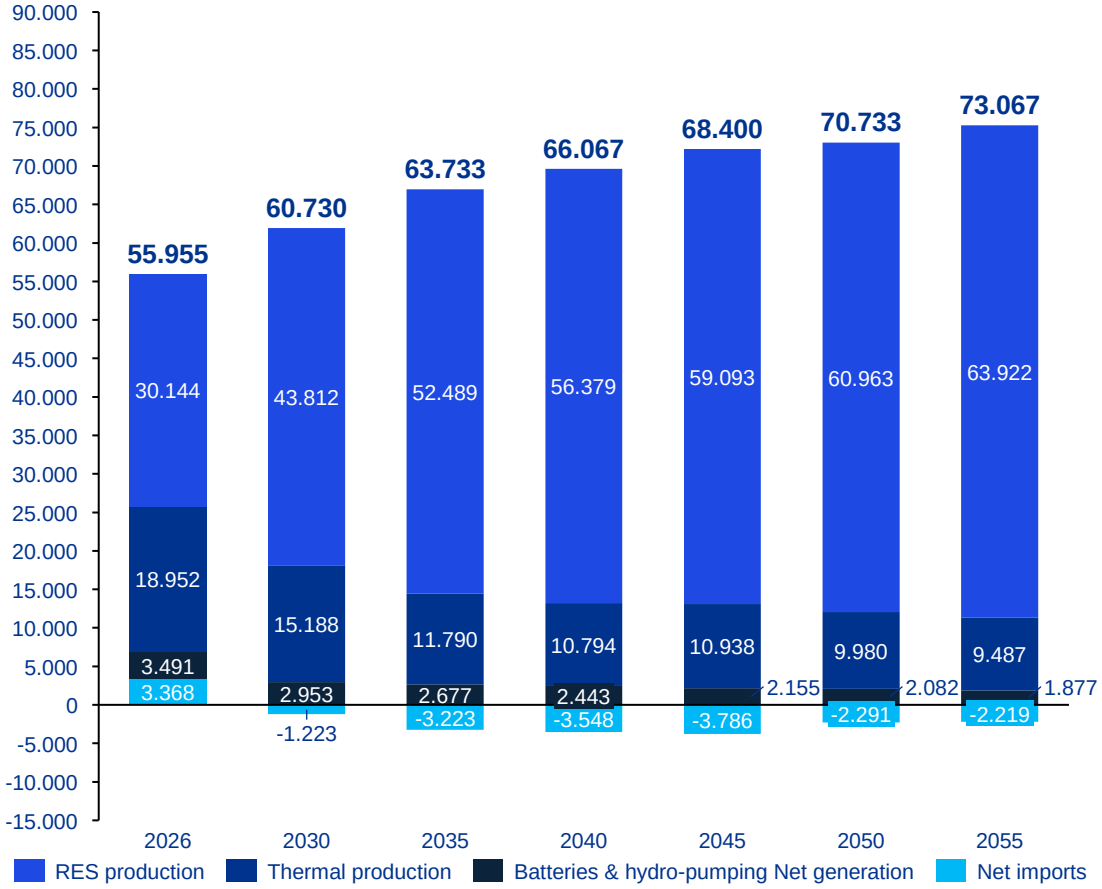
| SENEH Key Characteristics | |
|---|---|
| Route | Greece – Bulgaria – Romania – Hungary – Austria – Germany |
| Distance | 2.000 km |
| Investment | ~€ 2,8 to 4,5 billion[1,2] |

[1]**Note:** Indicative numbers estimated from the 2012-2013 PCI submission – numbers need to be updated and confirmed

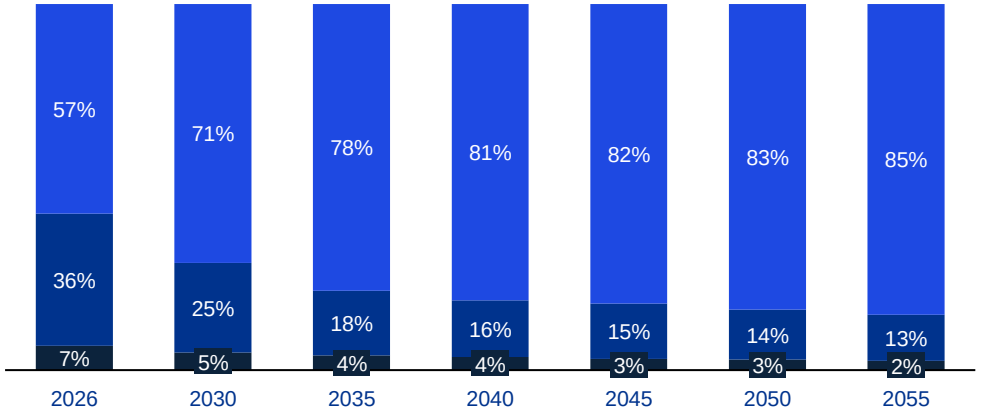
[2]**Note:** The alternative routes' investment cost is different as a result of the specific technical characteristics (distance, underwater/overhead lines, countries involved etc). The range of the investment is projected to reach even €8,0 billion in the case of Alternative Route 2

# In the baseline scenario, RES dominate in power generation while an important volume of exports can be noticed

## Energy Balance (GWh) – Scenario 1




## Net Generation Share per Technology[1] (%) – Scenario 1

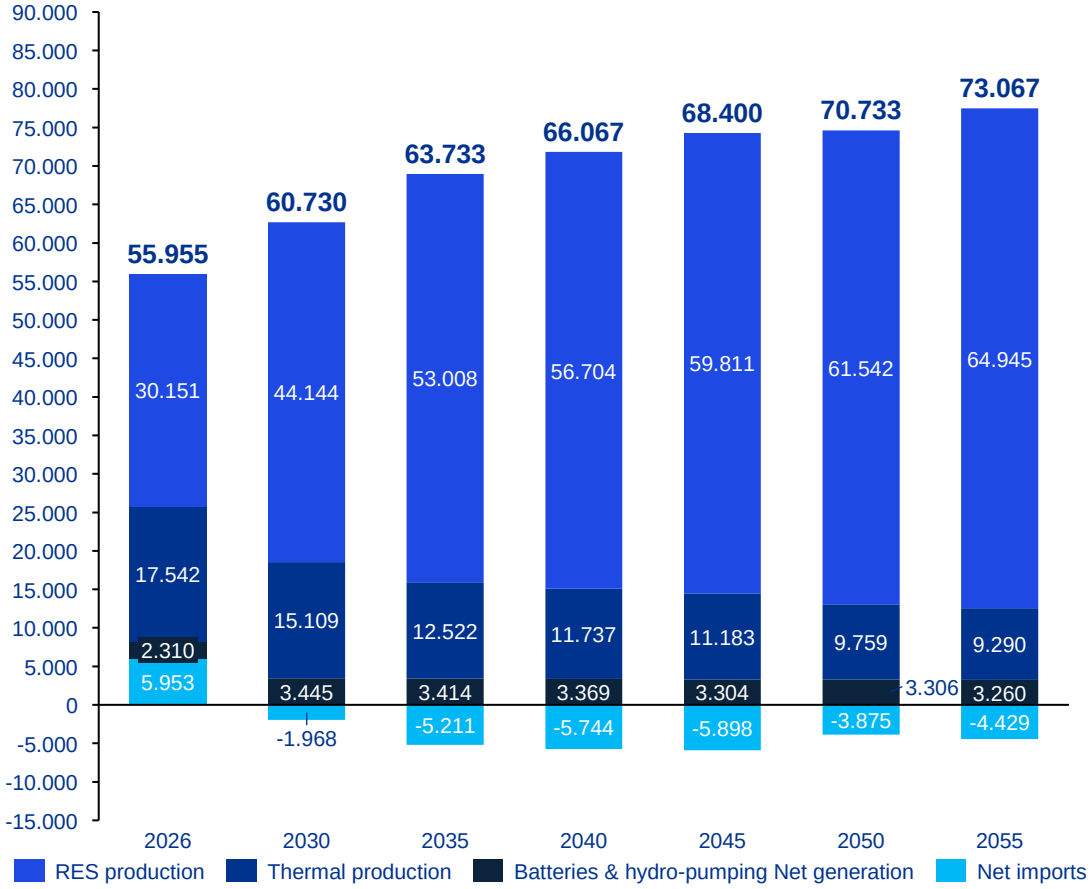



- In this scenario the new 9 GW interconnection line between Greece and Germany is not available.
- Four (4) new gas-fired units are considered to enter commercial operation in the Greek interconnected power system by the end of 2025.
- Battery Energy Storage Systems (BESS) capacity is considered to increase gradually from 2025 onwards following NECP provisions (≈ 6 GW in 2030).
- For the horizon 2026 to 2055 RES generation is the dominant generation asset averaging a 81,5% of the system load, followed by 18,1% of thermal generation and 3,7% of batteries and hydro-pumping injection.
- Net exports are projected to 67TWh in this scenario or 3,4% of system load.
- Total **RES curtailments reach 16TWh** throughout the period 2026-2055 or **1%** of the total RES production.

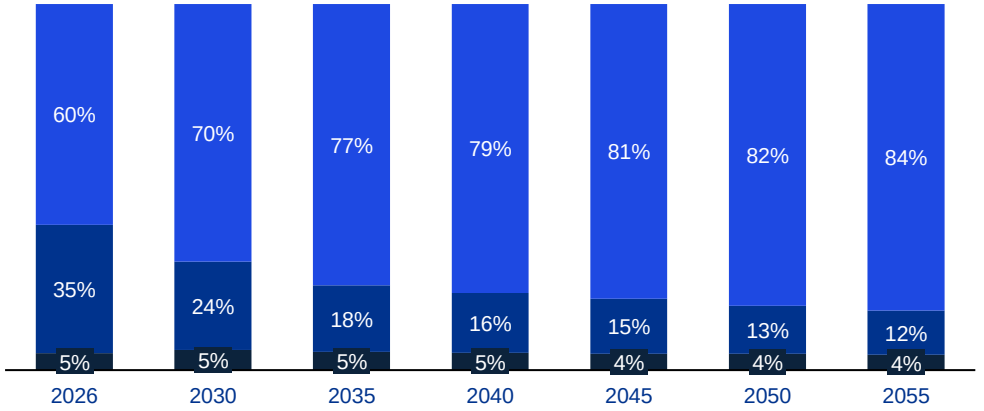
[1]**Note:** Net Generation share refers to the total generation per technology divided with the total generation excluding net imports

# The addition of the 9 GW Interconnection results to the increase of net exports

## Energy Balance (GWh) – Scenario 2




## Net Generation Share per Technology[1] (%) – Scenario 2




— The new 9 GW interconnection line between Greece and Germany is fully available for the entire study period.

— Additionally, 3 new CCGTs are assumed to provide the required flexibility in the system (instead of 4 in the baseline scenario).

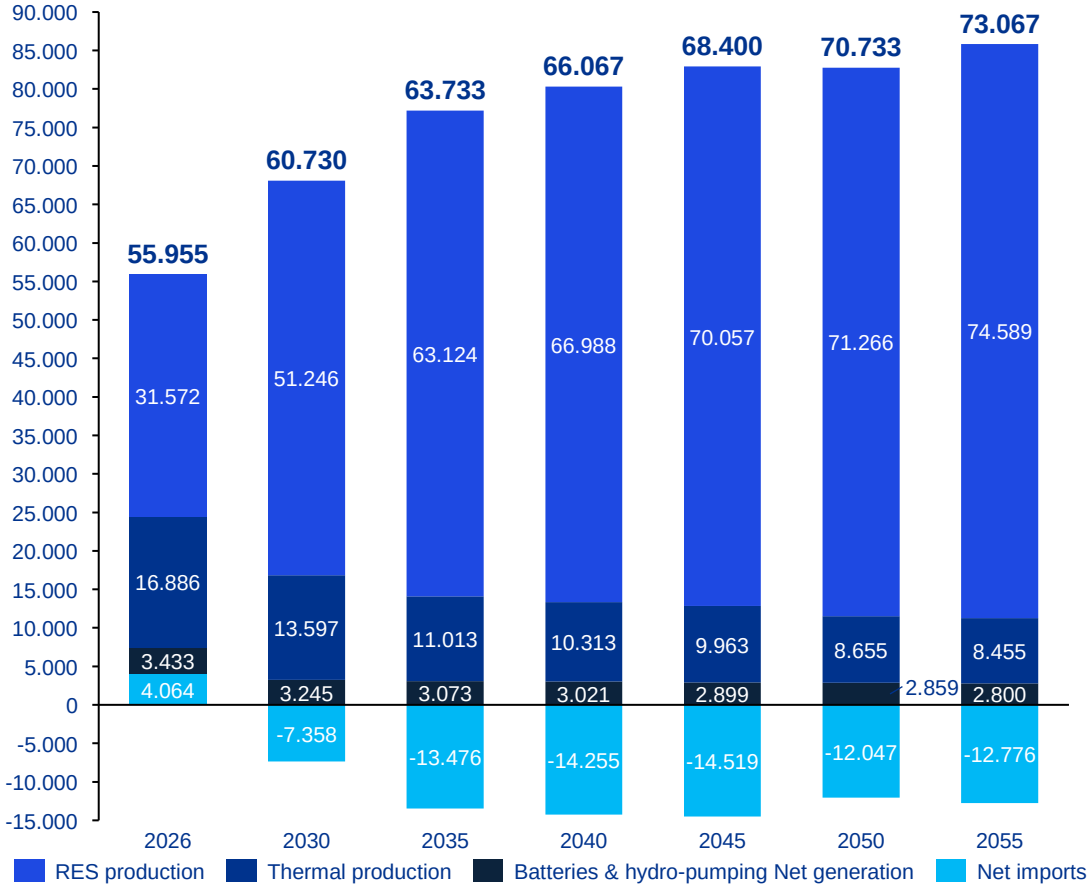
— A **64,8% increase of net exports** (vs Sc.1) as a result of the new interconnection is expected for 2026-2055 leading to a total of 111 TWh for the examined period.

— Although BESS capacities have not been considered in this scenario, **RES curtailments are zero** as a result of the increased exporting activity.

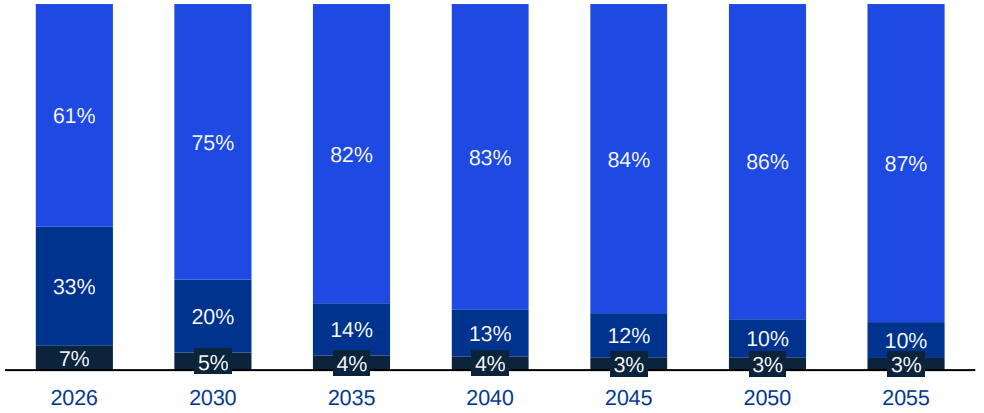
[1]**Note:** Net Generation share refers to the total generation per technology divided with the total generation excluding net imports

# The utilization of the corridor is further increased with the introduction of additional RES capacities

## Energy Balance (GWh) – Scenario 3




## Net Generation Share per Technology[1] (%) – Scenario 3




— The new 9 GW interconnection line between Greece and Germany is fully available for the entire study period.

— Additional RES capacity has been considered in order to increase the utilization rates of the new interconnection. In detail, +4GW of installed capacity in 2030 and +7GW from 2032 onwards (difference refers to the previous 2 scenarios).

— Moderate BESS penetration have been considered to support in the overall system balancing but also to moderate potential RES curtailments.

— As in the 2nd scenario, 3 new CCGTs are assumed to provide the required flexibility in the system (instead of 4 in the baseline scenario).

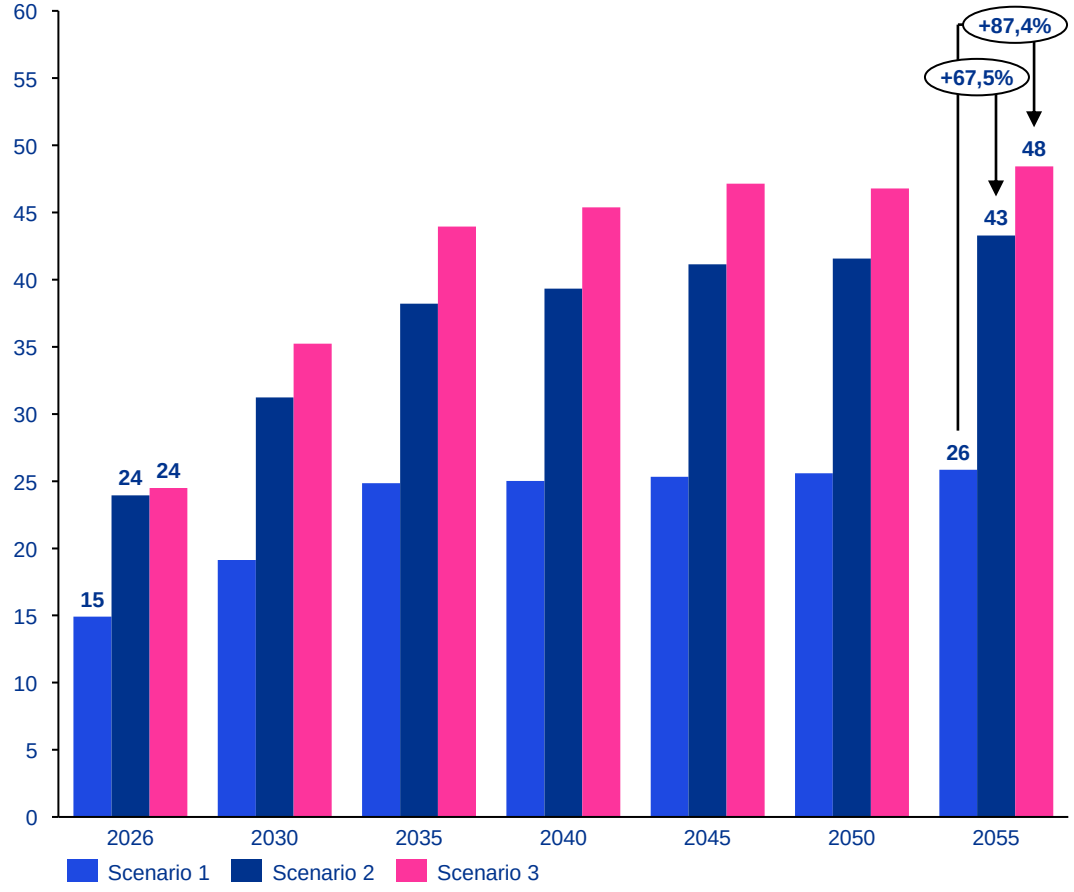
— **Exporting activity is expected** to skyrocket leading to a total of 337TWh net exports for the study horizon i.e. +402,2% vs Sc.1 and +204,7% vs Sc.2.

— Total **RES curtailments reach 5,8 TWh** throughout the period or **0,3%** of the total RES production.

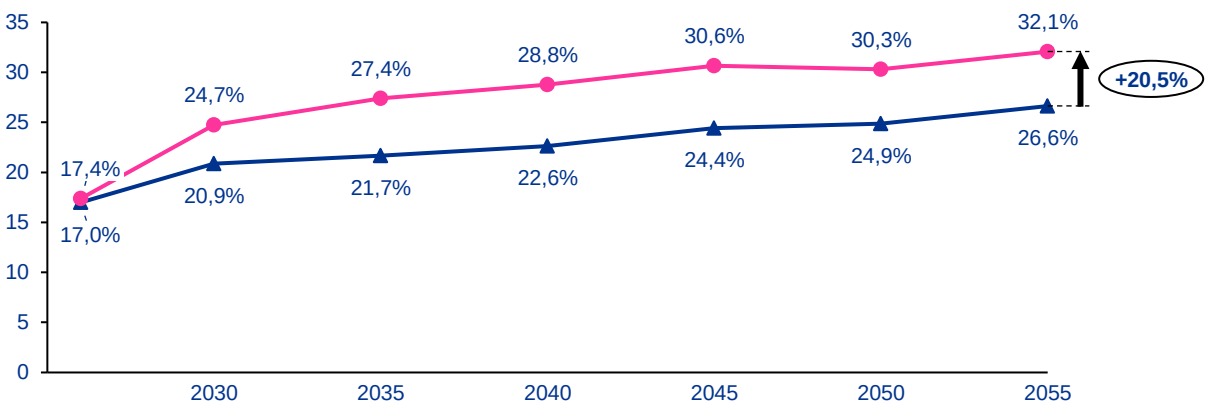
[1]**Note:** Net Generation share refers to the total generation per technology divided with the total generation excluding net imports

# The new interconnection is expected to exploit the full RES potential of Greece

## Transferred Annual Volumes[1] (in TWh)




## Utilization Factor of the 9-GW Interconnection (%)




— The development of the new 9 GW interconnection to Europe is expected to play a crucial role in the overall cross-border activity of Greece. In detail the simulation shows that:

- From Scenario 1 (no 9 GW corridor) to Scenario 2 a total of **+61,6%** transferred volumes are expected (from 695 TWh to 1.124 TWh)
- From Scenario 1 (no 9 GW corridor) to Scenario 3 a total of **+83,8%** transferred volumes are expected (from 695 TWh to 1.277 TWh)

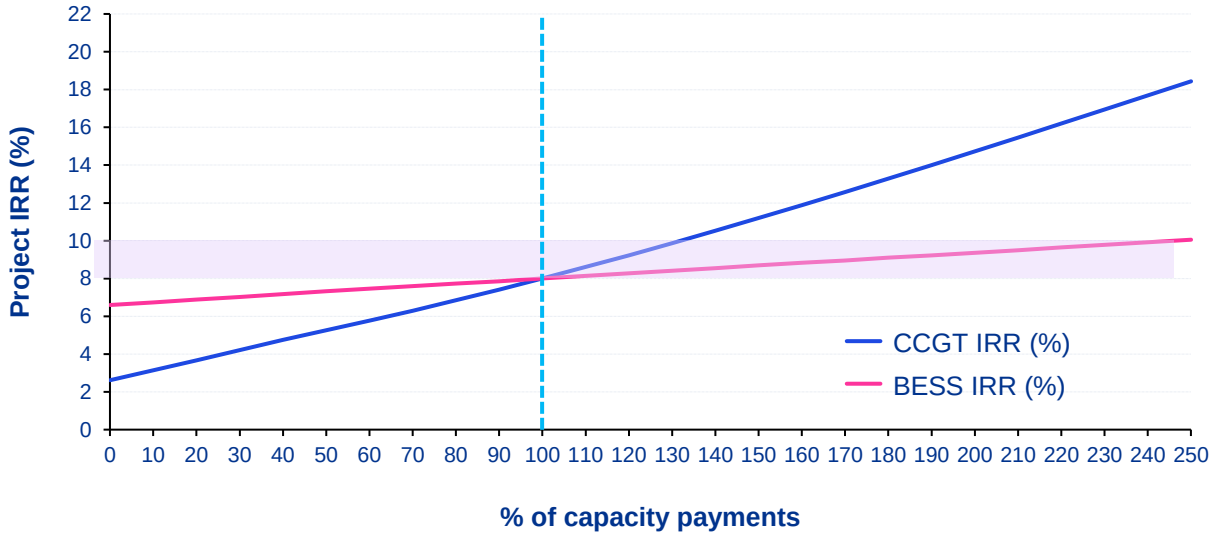
— Examining the extent to which the 9-GW Interconnection is utilized for imports and exports in Scenario 2, the simulation suggests that there is still enough room for increased utilization of the corridor. Consequently, in Scenario 3, with the higher penetration of RES, there is an opportunity for **even better utilization leading to an average +22,5%** throughout the examined period.

[1]**Note:** Refers to the total energy transferred i.e. imports and exports

# In order to achieve an acceptable financial performance, additional support will be needed for new CCGTs and BESS in Scenario 1

In all 3 scenarios, the economic valuation for the new BESS and CCGT capacities has been assessed. It has been assumed that an acceptable performance should reach an IRR of 8-10%, so for the purposes of this study we have estimated the required financial support schemes in order for a new unit to reach **an IRR of 8%.**

## IRR vs Capacity Payments for Scenario 1

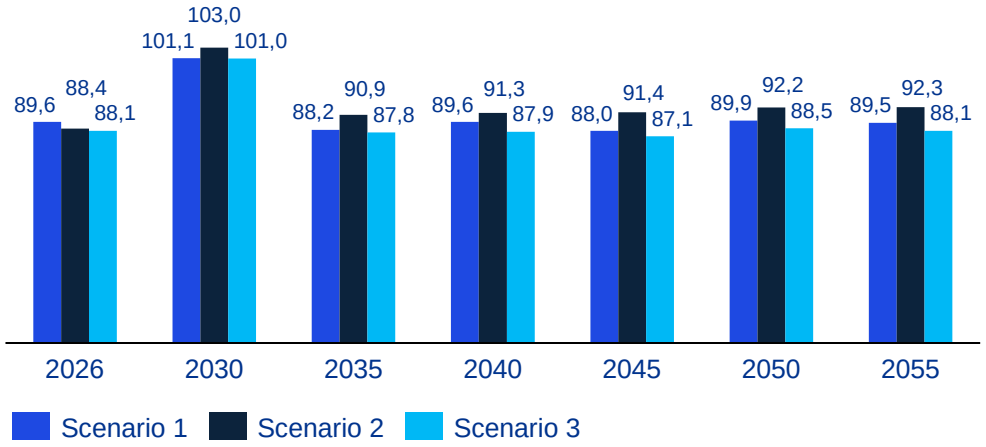



- After the elaboration of the detailed market simulation results, the economic valuation of the BESS and CCGT resources indicated that **in Scenario 1:**
  - Out-of-the-market financial support for the BESS resources should be equal to **11,700 €/MW-y** only for the capacities that are installed during the first two years of the study horizon i.e. 1.540MW in 2026 and additional 1.060MW in 2027 and for a total of a 10-year period (2026-2035) only.
  - The respective out-of-the-market financial support[1] for the new CCGT units should be equal to **44,850 €/MW-y** for the first 10-year period (2026-2035) only.
- In **Scenarios 2 and 3** the prevailing market operating conditions owing to the full availability of the new 9 GW green electricity corridor show that **no additional out-of-the-market financial support** (i.e. with zero capacity payments) is required since the projected project IRR is >8%[2].

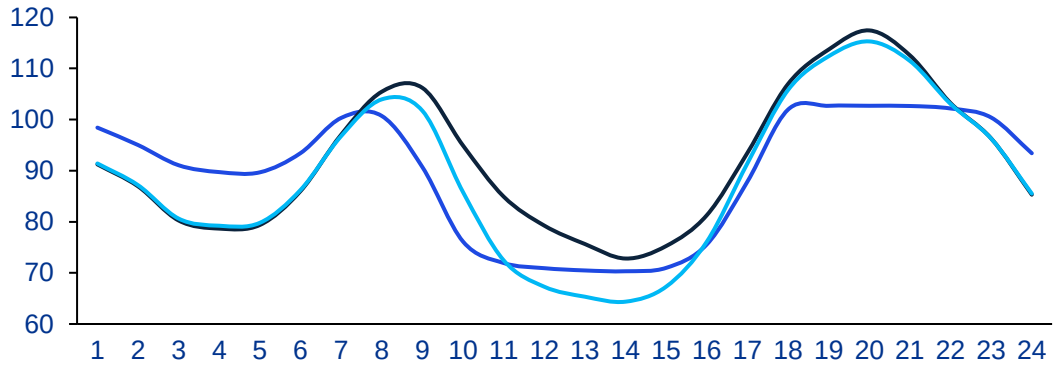
[1]**Note:** In a form of a Capacity Remuneration Mechanism [2]**Note:** BESS capacity is zero in Scenario 2

# DAM prices do not reveal significant differences on average, however interesting facts in the 24h price curve could be extracted

## DAM clearing prices(€/MWh)




## Average 24-hour DAM clearing prices (€/MWh)




## Sc.2

During the night hours where no PV generation exists (i.e. hours 1-6 and 23-24), the availability of the new corridor will allow higher volumes of low-cost imports to flow from Germany to Greece, which, in turn, will push the resulting DAM clearing price downwards compared to Sc. 1.

On the contrary, during the daylight hours, the RES overgeneration in Greece will be exported mainly through the new corridor to Germany, which is expected to minimize the associated RES curtailments and lead to substantial increase of the resulting DAM clearing prices during these hours.

## Sc.3

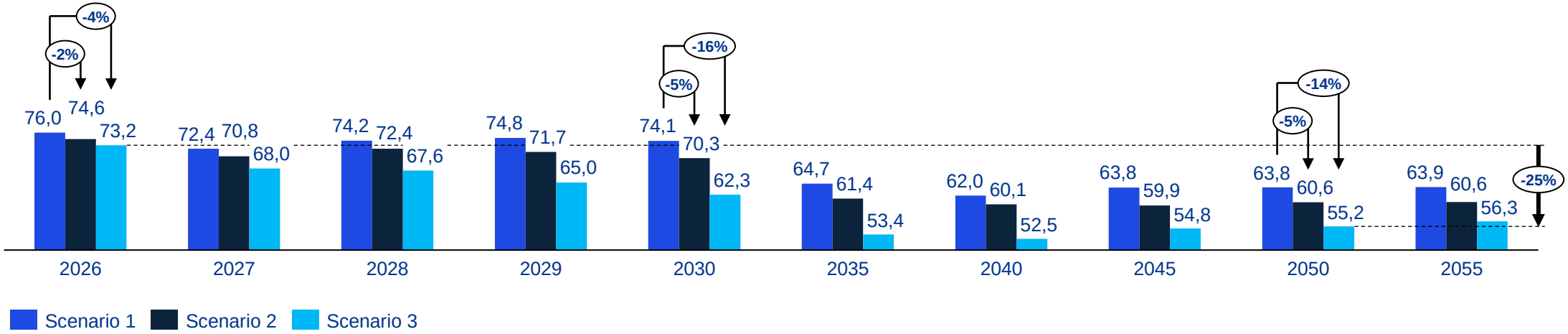
The consideration of higher PV installed capacity in Sc. 3 is expected to have a dual effect on the DAM clearing prices:

- During some daylight hours the additional PV injections will further increase exporting volumes from Greece to neighboring countries mainly through the new corridor, thus having a slightly upward effect on the DAM prices during these hours.
- During some other daylight hours though, the additional PV injections will be directed towards covering the domestic consumption, which will drive DAM clearing prices downwards, mainly during daylight hours in which the exporting capacity is already exhausted.

As a net result, annual average DAM clearing prices in Sc. 3 are projected to be lower compared to Sc. 2.

# The first positive outcome is that lower (final) electricity prices to consumers are projected

## Final Cost for Consumers (€/MWh)




— As we move from Scenario 1 to Scenarios 2 and 3, the RES production increases meaning higher quantities of renewable energy are contractualized through PPAs and, therefore, the blended electricity supply cost for consumers (expressed as the weighted average value of the respective DAM and PPA prices) decreases.

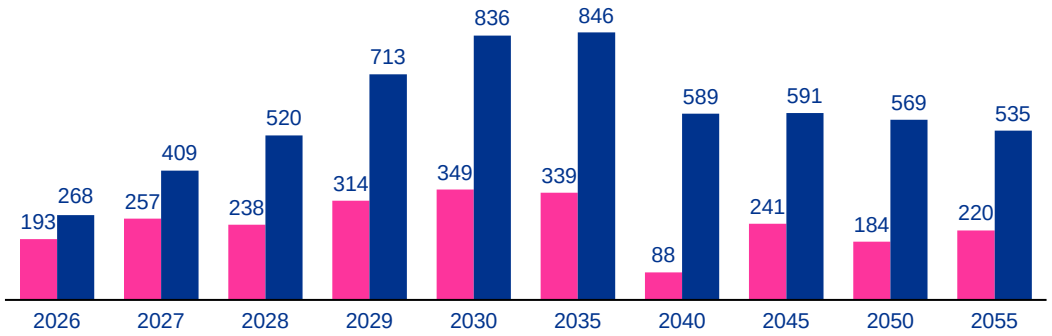
— Scenario 1 prices are also influenced by the out-of-market financial support for BESS and CCGTs as previously analyzed.

— As a result, the final prices to end-customers reach a -4,9% and a -13,3% compared to Scenario 1 on average throughout the examined period for Scenarios 2 and 3 respectively.

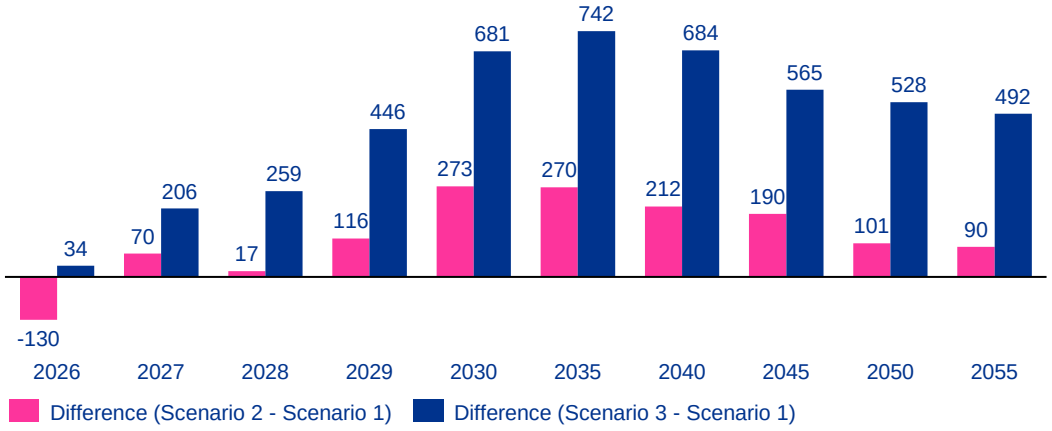
***Final Cost for Consumers*** *refers to the total electricity cost paid by end-consumers and is driven by the DAM Price, the quantities and prices contracted for PPAs, Uplift Accounts (UAs) as well as the Out-of-market financial support for BESS and CCGTs.*

# The second positive outcome is that significant economic benefits at national level arise from the development of such infrastructure

## Surplus for consumers due to lower electricity prices (mil. €)




## Additional surplus for the national economy (mil. €)




[1]**Note:** For the calculation of the respective NPVs, WACC was considered equal to 5,457%.

— The analysis shows that the development of the 9GW corridor to Germany will lead to a series of economic benefits:

- A **consumer surplus** effect as a result of lower prices (final cost of electricity)
- An **additional national economy** surplus to generators as a result of the increased exporting activity

— Comparing the 3 scenarios, the results show that there is a huge financial potential for both end-customers and generators. Depending on the level of RES deployment the total benefit for the Greek economy varies **from €6,2 bn to €17,5 bn**.

| | Sc.2 vs Sc.1 | Sc.3 vs Sc.1 |
|---|---|---|
| End-consumers' total electricity supply cost savings (NPV[1]) [€] | € 3,67 billion | € 9,43 billion |
| National economy surplus due to higher net exports (NPV) [€] | € 2,51 billion | € 8,11 billion |
| **Total benefit (NPV) [€]** | **€ 6,18 billion** | **€ 17,54 billion** |

— The mechanisms to achieve the required return on investment lie outside the scope of this study; however, it can be easily concluded that regardless of who will bear the burden of the extra cost (and to what extend), the added value that this Infrastructure project creates for the Greek economy exceeds the initial capital expenditure that is needed for its development.

Conclusions

# Final Remarks

## Energy System

Enables further RES projects and exploitation of RES potential for exports of massive amounts of RES energy. Additionally, increases security of supply and enhances system stability. At EU-level, such a project will help achieve the integration of the European energy market.

## Financial Incentives

This project creates a significant surplus for the Greek economy by lowering the overall consumers' prices but also through the increased exporting activity. Additionally, at EU-level by maximizing utilization of cheaper RES will minimize the overall cost. Additionally, the development of the interconnection will provide the required commercial viability to the new CCGTs and BESS, even without the need for out-of-market subsidies.

## Added value through the combination of technologies

The operation of the new 9GW corridor can further enhance RES penetration and combined with storage capacities maximize the total value for the consumers and the national economy.

**-3,7€/MWh to -9,9€/MWh**

Lower final electricity prices to end-consumers

**+70%**

Additional transferred energy through imports and exports

**€6 to €17,5**

billion is the expected value to be created to the Greek economy

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