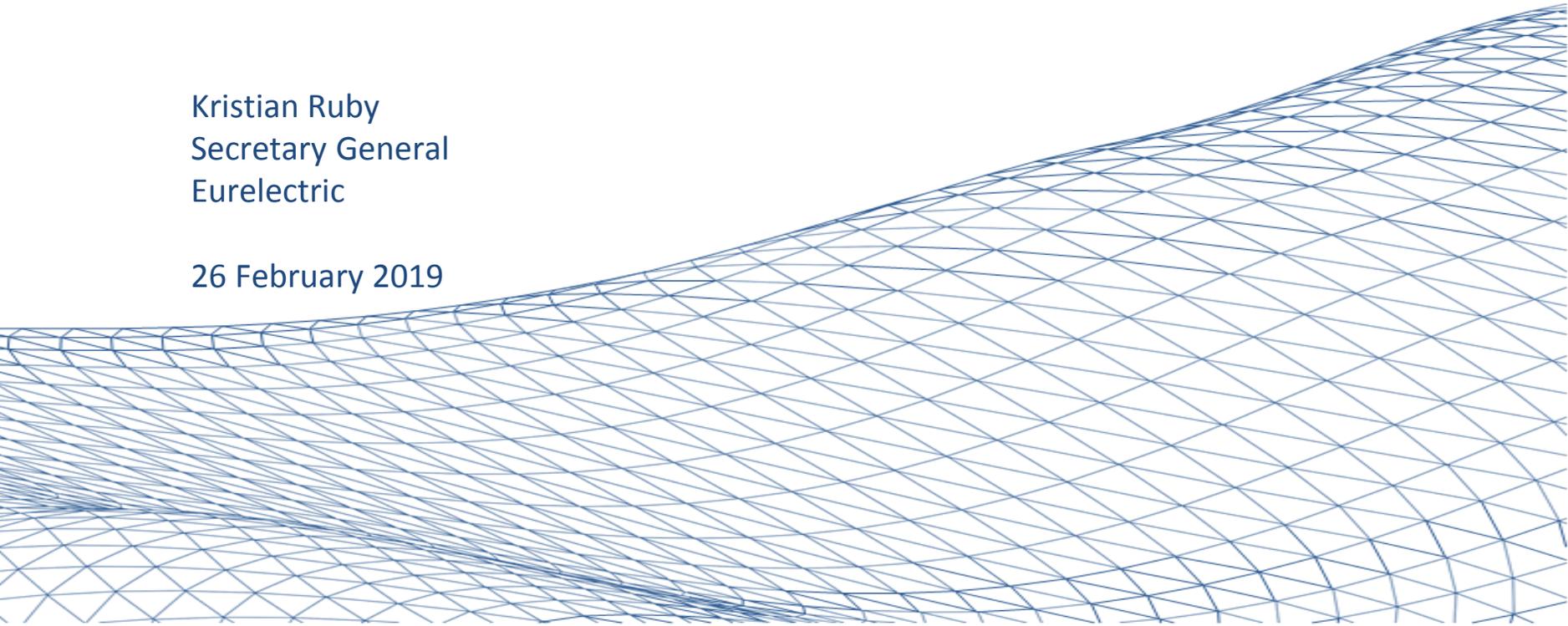


Decarbonization pathways

European Economy

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We have modelled 3 deep decarbonization scenarios based on electrification of key economic sectors



2015 – Baseline

2050 scenarios



EU economy decarbonization achieved vs. 1990^{1,2}

Direct electrification rate

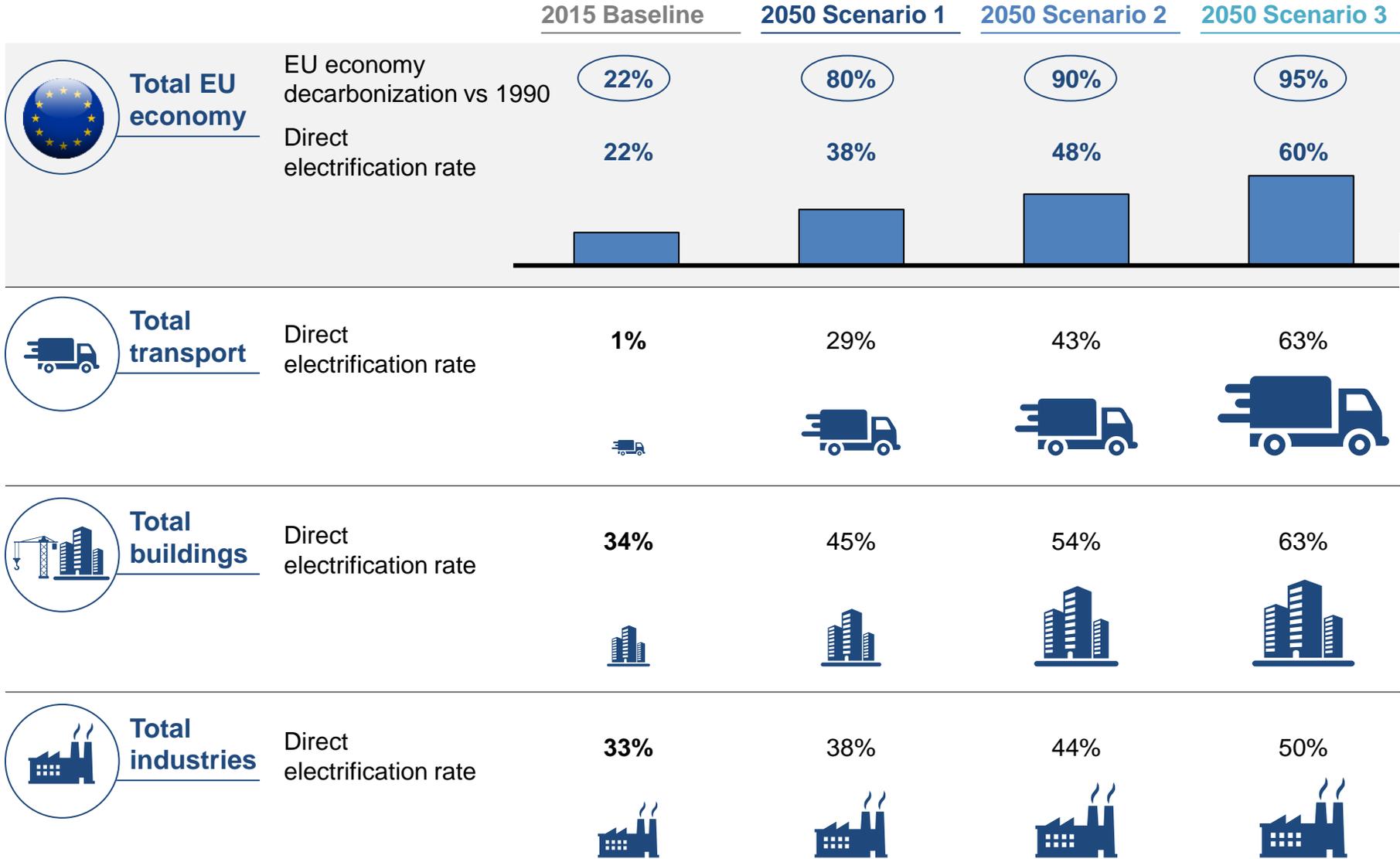


Cost breakthrough scenario in which we are driving towards full EU economy decarbonization. Assumes accelerated cost decline for renewables, nuclear, CCS and storage

¹ Emissions out of scope are expected to contribute proportionally to the decarbonization effort required in each scenario

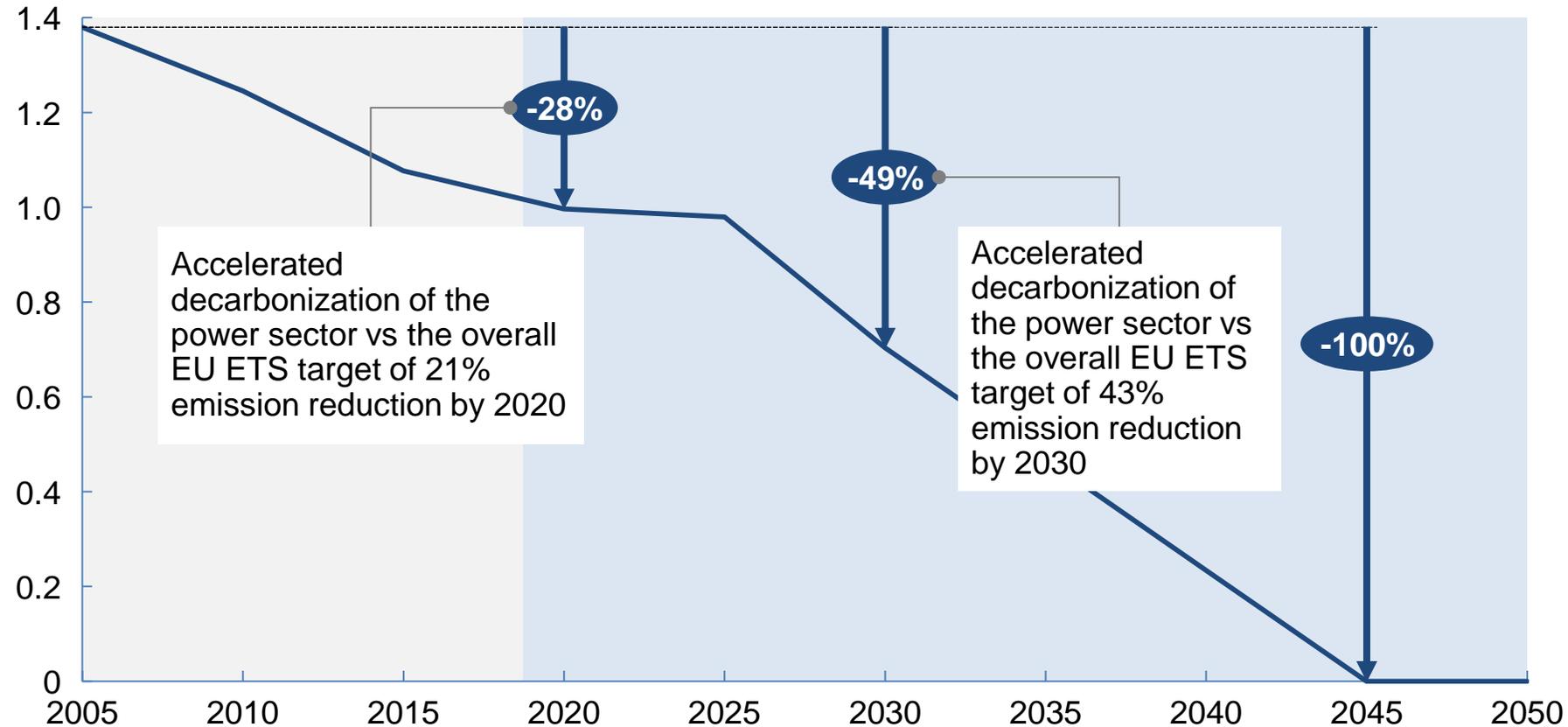
² Decarbonization will be different by sector depending on relative costs and available technologies, industry contributing least with below 80% of emission reduction in all scenarios

Direct electrification results by scenario



In all three scenarios, the European power sector is carbon neutral by 2045

CO₂ emissions from power sector in all scenarios, GT CO₂



By 2045 we envision a carbon neutral power sector that makes a significant contribution to decarbonization of the EU economy



High penetration of renewables and transmission build will be the main driving force of the European energy transition. Renewables will represent >80% of electricity supply driven by large untapped potential and rapidly declining cost



System reliability and flexibility needs provided by multiple sources in the power sector and from other industrial sectors. These include hydro, nuclear power and gas, and emerging sources deployed at scale such as demand side response, battery storage, hydrogen electrolysis and power-to-X



Changing role of fossil generation. Fossil electricity supply will be gradually phased out and represent only ~5% of total supply by 2045. However, gas will still represent ~15% of total installed capacity to contribute to system reliability, especially in regions that don't have access to hydro or nuclear



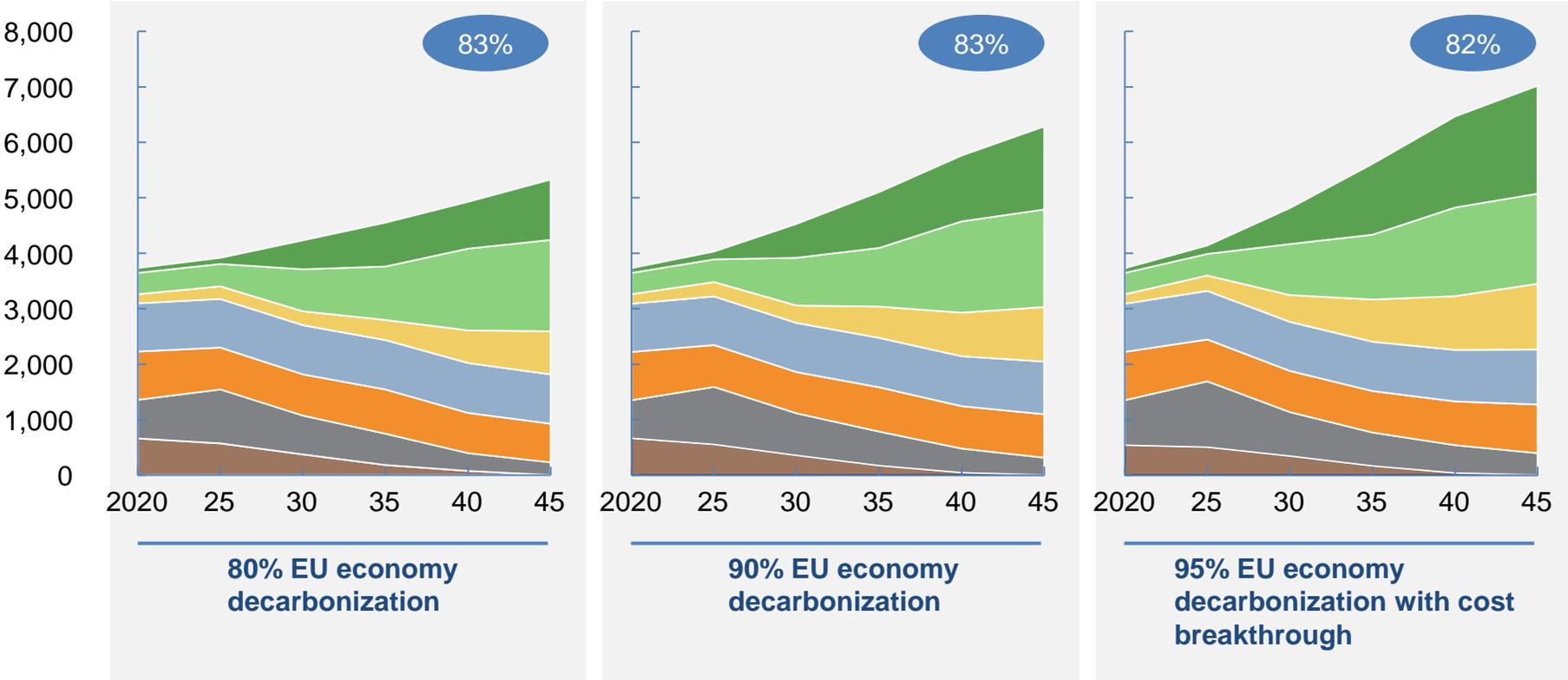
Decreasing costs of carbon neutral technologies and innovation to abate the last tons of CO2 emissions (e.g. CCS, negative emissions) coming from the marginal use of the remaining thermal capacity such as negative emissions and CCS technologies

In the least-cost, carbon neutral electricity system the bulk of electricity is provided by renewables and nuclear

Generation by fuel type, TWh

% Share renewables

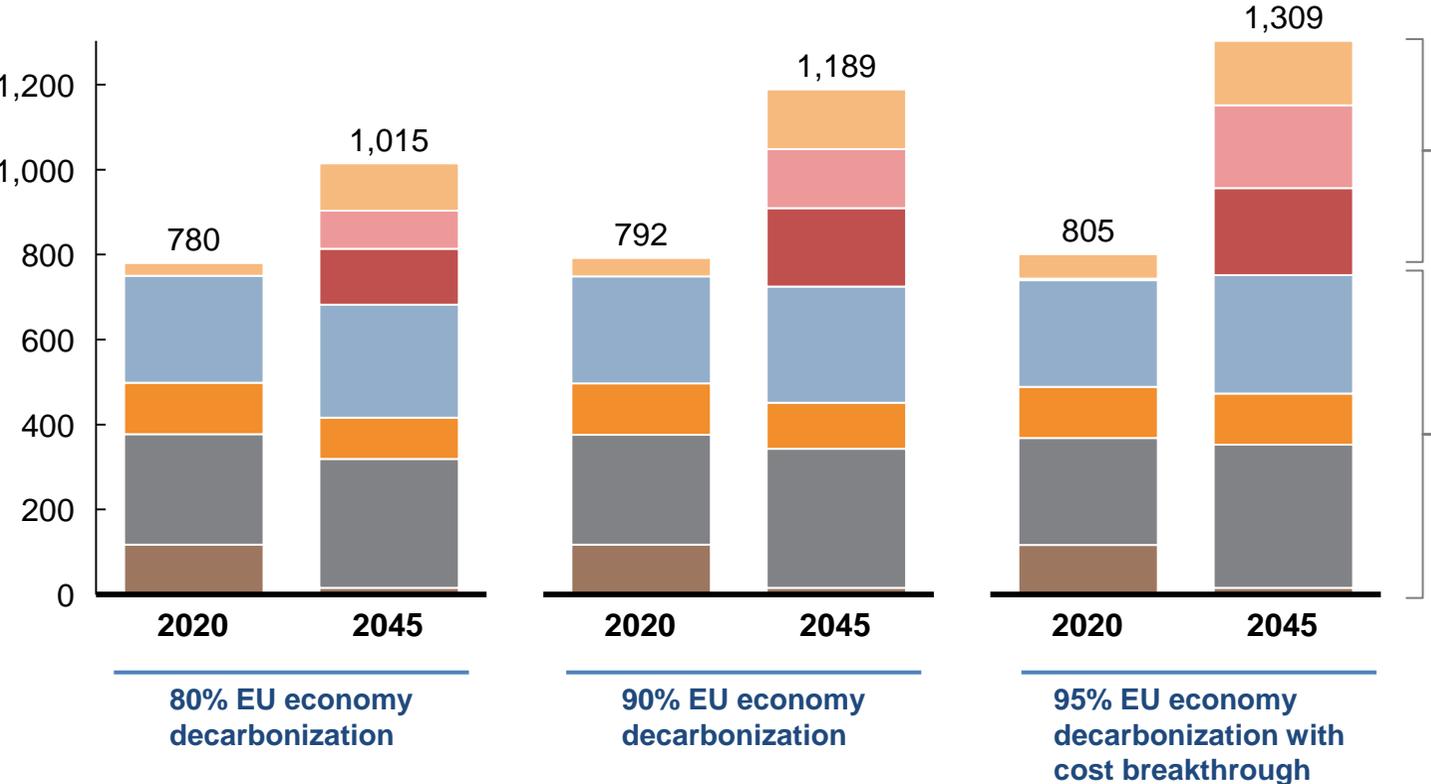
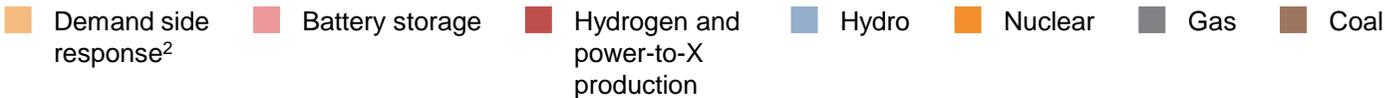
■ Offshore wind
 ■ Onshore wind
 ■ Solar
 ■ Hydro and other RES¹
 ■ Nuclear²
 ■ Gas and other non-RES³
 ■ Coal²



¹ Includes also small amounts of geothermal, biomass and biogas
² National policies on nuclear and coal phase out have been reflected
³ Up to 15% of gas capacity with CCS and other non-renewables

System flexibility is provided by several sources of dispatchable resources serving as back-up for days with low renewable generation

Dispatchable resources¹, GW

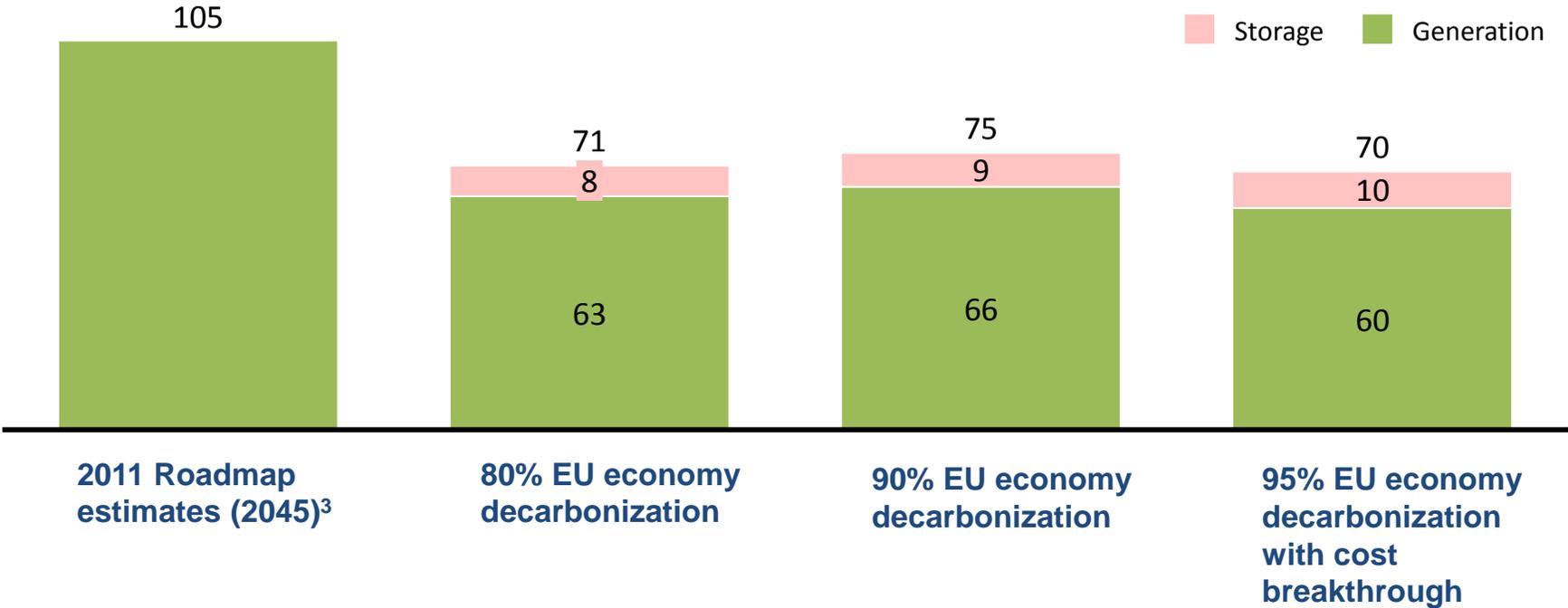


- New sources of flexibility**
 - Enable better utilization of other generators
 - Significant increase in capacity expected
- Traditional sources of flexibility**
 - Similar capacity needed in a high renewables, higher demand system as today
 - Provide electricity when renewables production is low and ability to leverage DSR has been exhausted
 - Hydro plays a unique role and can improve the overall dispatch and system economics

¹ District heating that is coupled with power sector is not included in this analysis
² DSR flexibility is provided by hour to hour load shifting in transportation, buildings and heating

Due to cost declines of renewables, decarbonization of the power sector now comes at a reduced cost

Cost of wholesale electric supply, 2045^{1,2}, EUR/MWh



A carbon neutral power supply by 2045 can be accomplished with generation costs of 70 – 75 EUR/MWh. Due to rapid cost declines and more options for flexibility in the system, the overall cost of decarbonization has decreased significantly since previous estimates and the pathway is now achievable

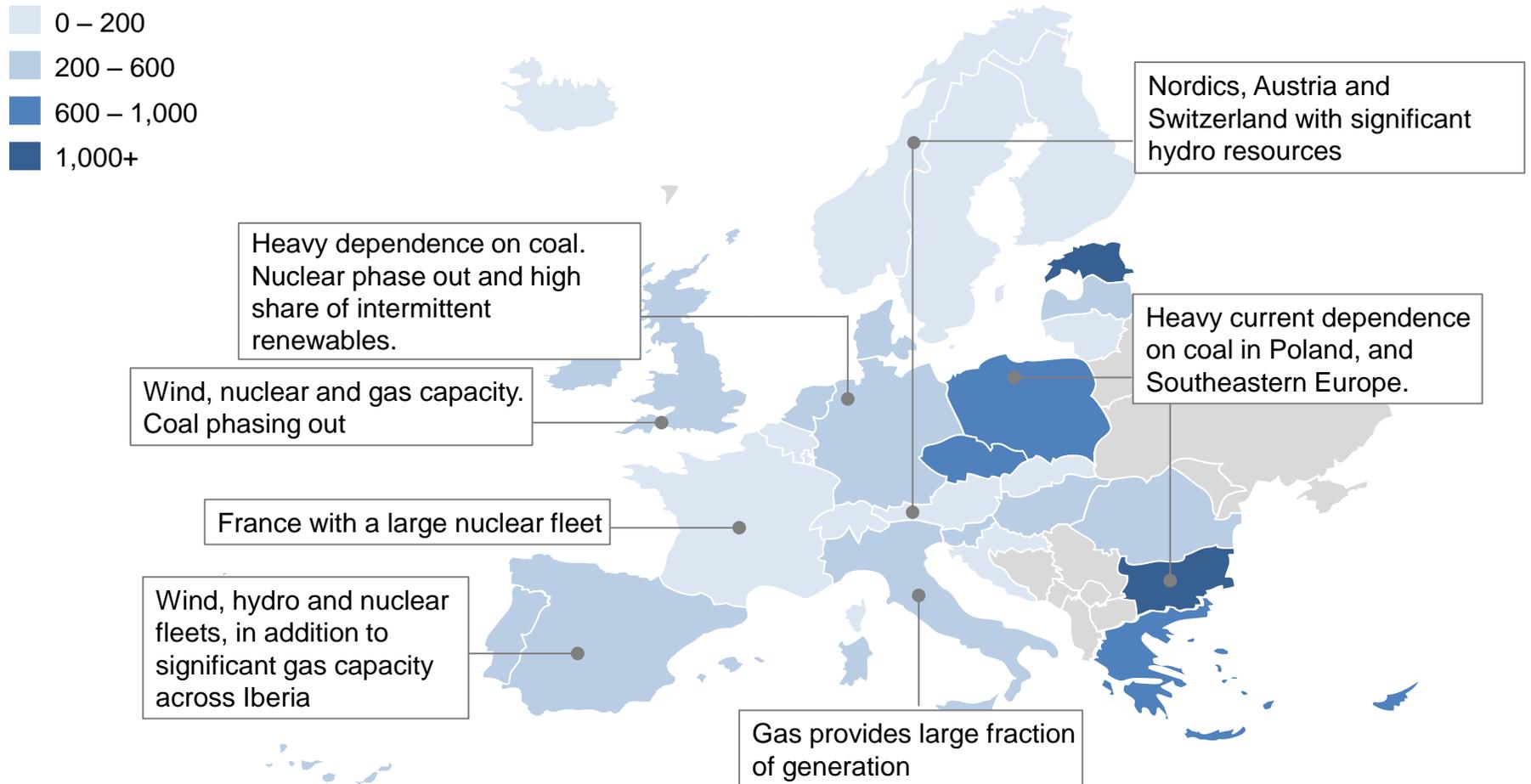
¹ Levelized cost approach approximates in-year revenue required to match cost; includes operating costs (e.g., fuel, variable O&M); additionally, capital expenditures (e.g., wind farms, battery storage, or CCS-retrofits) are amortized over the economic lifetime of the asset

² Real cost linked to 2016 price level

³ Generation includes Fixed Costs, and Variable and Fuel costs; Tax on fuels and ETS auction payments included for comparison against net zero carbon scenarios

European countries have different starting points in the energy transition

2015 carbon intensity of electricity¹, kg CO₂/MWh



¹ Refers to carbon intensity of domestic electricity production, i.e. does not take into account the carbon intensity of electricity mix consumed

A low cost, carbon neutral power sector must be supported by changing political, technological and market conditions



Political commitment to deep decarbonization across all sectors of the economy and regions. Continued efforts to integrate the European energy system



Active involvement of citizens e.g. through demand response and prosumers, and **increased social acceptance** for high renewables build out and new transmission lines



Synergies with other sectors. For example, P2X and H2 production enable decarbonization of other sectors while providing balancing capabilities to the power system. Existing gas pipeline infrastructure can be repurposed for power to gas and hydrogen transport and storage



Efficient market-based investment frameworks and adequate market design to trigger investments in a high renewables-based system. For example, resources must to a larger extent be valued based on their contribution to system reliability. Meaningful CO₂ price signals will also be required to sufficiently incentivize full decarbonization



A smarter and reinforced distribution grid that integrates new market participants (e.g. decentralized solar PV and local flexibility sources), and plays a significant role in consumer empowerment through managing local congestions and redispatch, security of supply and grid resilience issues



The path and investments required to reach full decarbonization differs by country as European regions have different existing electricity mix and resources available. To ensure just energy transition **support and dedicated EU funding will be required** for Member States that face a more difficult starting point in the electrification and energy transition journey.