Roadmap 2050: A practical guide to a prosperous, low-carbon Europe

Volume I: technical and economic assessment

Highlights - Draft

February, 2010

Roadmap 2050 project team

ECF (Philanthropic European climate foundation)	▪ Overall sponsor and funder ▪ Final report will be ECF branded
McKinsey & Company (Strategic consultancy)	▪ Overall content leadership, project management, data collection, analysis ▪ Reach out to industries, workshop facilitation
ECN (Energy research center)	▪ Support on assumptions for technologies (lead on nuclear) ▪ Policy development and recommendations based on analytics
KEMA (Technical grid consultancy)	▪ Grid design and investments, production capacity and costs associated with providing a plausible, secure electricity system for each of the pathways
Imperial College London	▪ In-depth modeling of system balancing requirements, reliability, optimization of transmission and back-up investment
The Centre (Political consultancy)	▪ Manage contact to EU-commission and parliament and ensure alignment with their needs. Participate in outreach to member states
Office of Metropolitan Architecture – R. Koolhaas	▪ Provide creative participation in the development of narrative. Provide conceptual framing and visual communication
ESC (European Strategy Centre)	▪ Design the report launch communication strategy ▪ Manage the launch of the report including holding presentations, meetings
RAP (Regulatory Assistance Project)	▪ Provide technical and policy input from their global experience
Oxford Economics (Macro-economic consultancy)	▪ Provide analysis of macro-economic impacts of decarbonization scenarios

Roadmap 2050 Core Working Group members

European Climate Foundation

	Core Working Group participants	Roles
Utilities	CEZ GROUP, edp, Electrabel GDF SUEZ, Enel, e.on, IBERDROLA, RWE, VATTENFALL	▪ The core working group provides input, supports the project development and reviews results and conclusions ▪ A series of technology workshops, in person full day meetings and bilateral calls were held ▪ Information shared can be quoted but not attributed to a specific participant. Confidential information was not disclosed ▪ The core working group is not accountable for the messages in the end report. The members will be acknowledged for providing input and support to the project
Transmission System Operators	ENERGINET.DK, nationalgrid, TenneT, Terna, entsoe	
Manufacturers	acciona, SIEMENS, Vestas	
NGOs	E3G, GERMANWATCH, WWF	

80% by 2050 only possible with *zero-carbon power supply*

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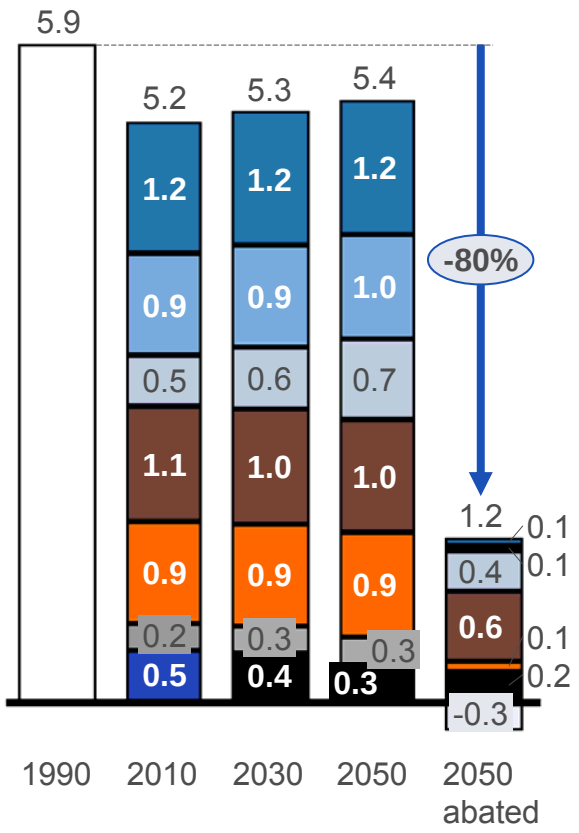
EU-27 total GHG emissions
$GtCO_2e$ per year



Sector	Abatement	Within sector[1, 2]	Fuel shift
Power	**95% to 100%**	>95%	
Road transport	**95%**	20%	75% (electric vehicles, biofuels and fuel cells)
Air & sea transport	**50%**	30%	20% (biofuels)
Industry	**40%**	35% (CCS[3])	5% (heat pumps)
Buildings	**95%**	45% (efficiency and new builds)	50% (heat pumps)
Waste	**100%**	100%	
Agriculture	**20%**	20%	
Forestry	**-0.25 $GtCO_2e$**	Carbon sinks	

1 Based on the McKinsey Global GHG Abatement Cost Curve
2 Large efficiency improvements already included in the baseline
3 CCS applied to 50% of industry (cement, chemistry, iron and steel, petroleum and gas, not applied to other industries)

SOURCE: Team analysis

Pathways must be reliable, technically feasible, have a positive impact on the economy…& be nearly zero carbon

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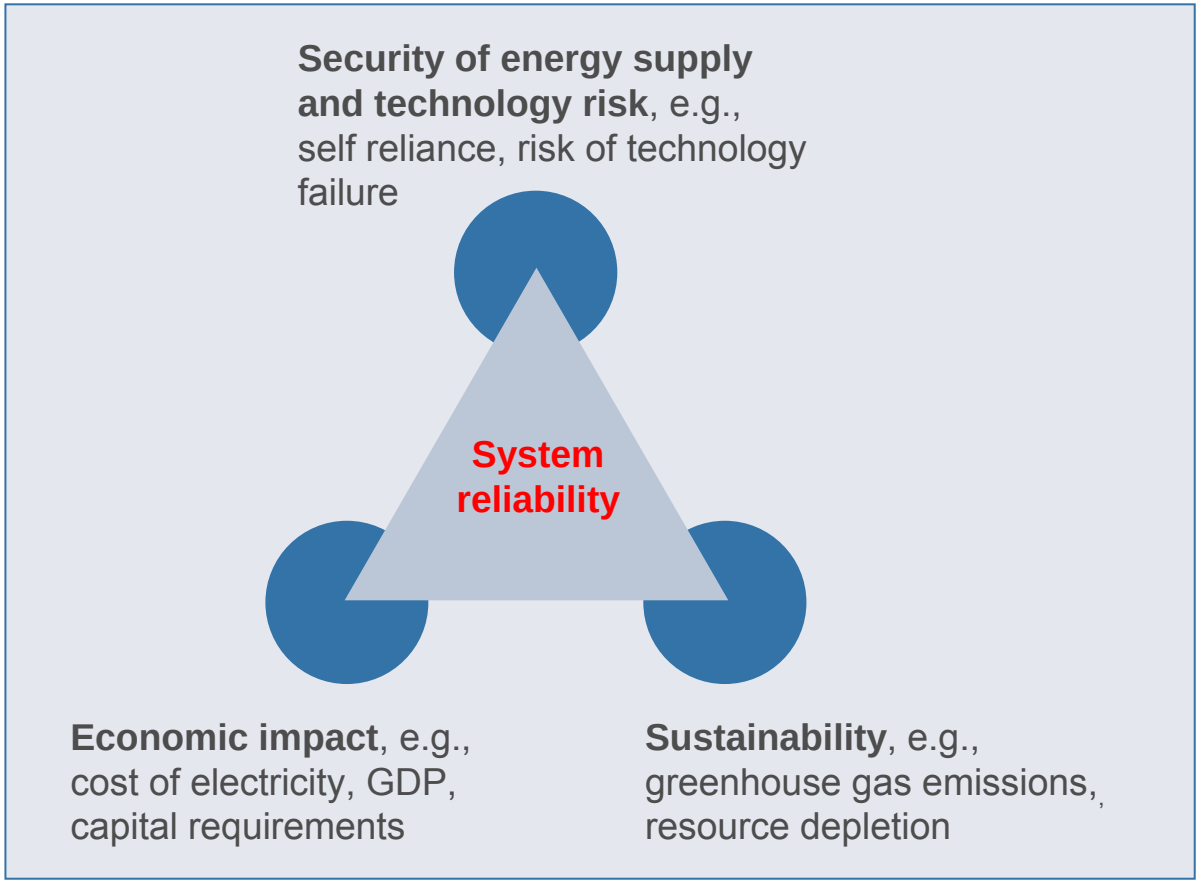
Assessment criteria

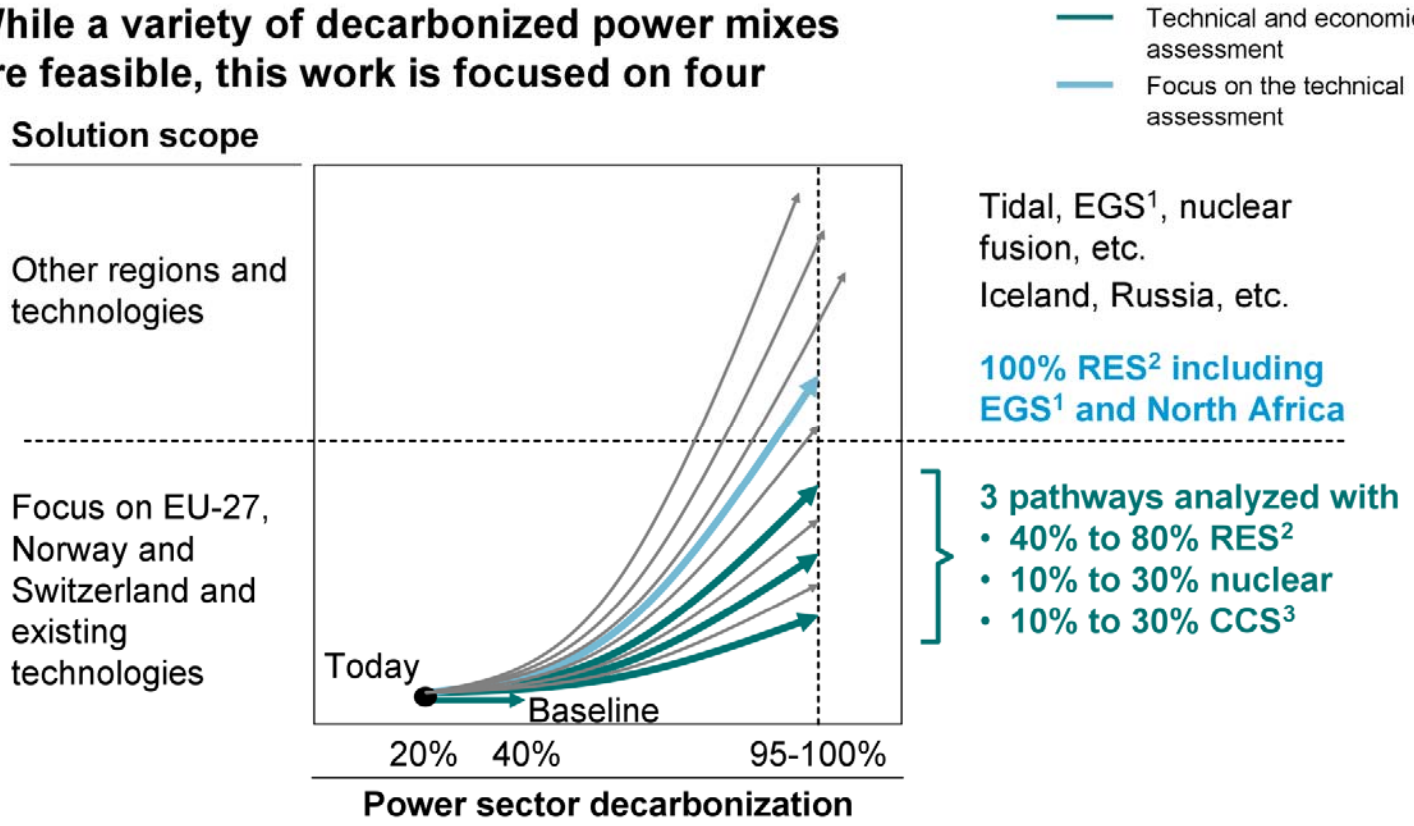


SOURCE: Team analysis

Pathways are based on domestic European resources, using existing technologies developed over time

EXHIBIT 1

While a variety of decarbonized power mixes are feasible, this work is focused on four



1 Enhanced Geothermal Systems 2 Renewable Energy Sources 3 Carbon Capture and Storage

SOURCE: Team analysis

All pathways can deliver power with roughly the same cost and reliability as the baseline with carbon price ≤ €50/tCO$_2$

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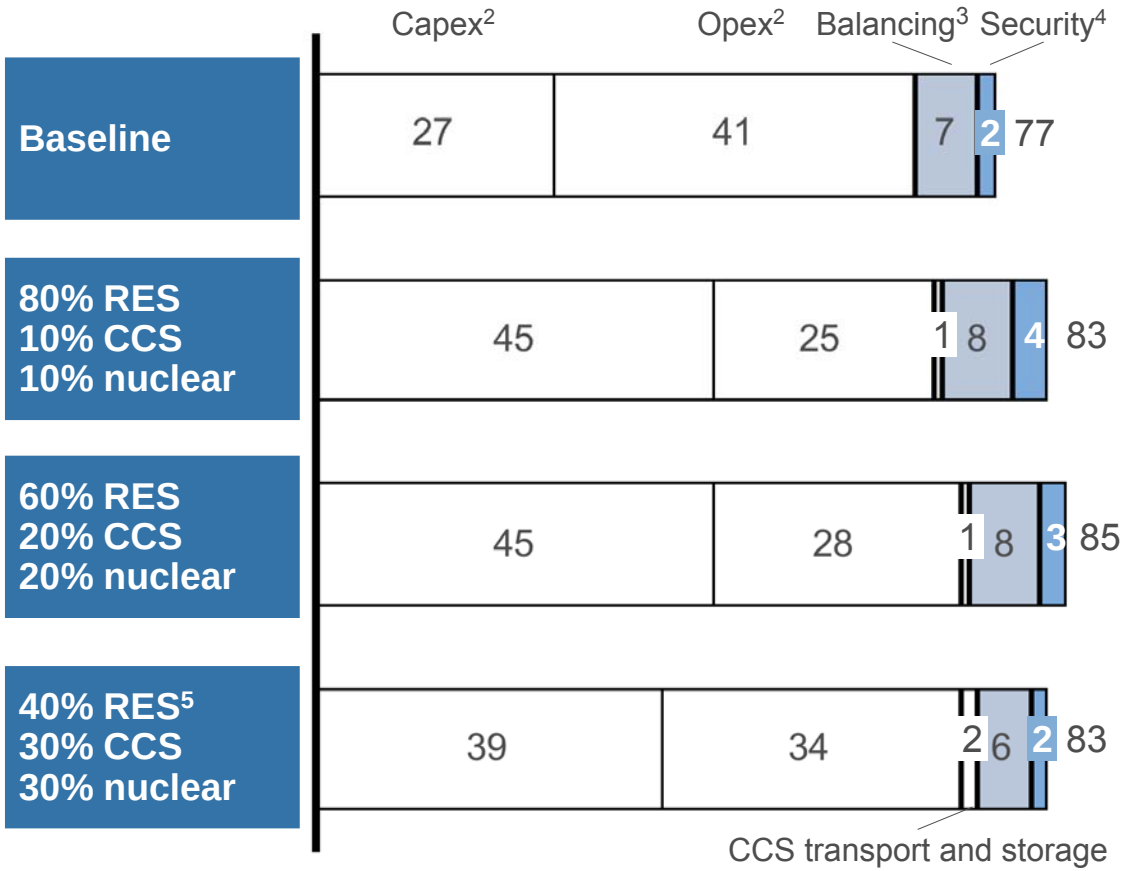
Average new built CoE from 2010 to 2050[1], EUR/MWh (real terms)



1 Weighted average based on the CoE in each 10-year time frame (2010, 2020, 2030, 2040, 2050)
2 Generation only
3 Cost related to non optimal plant use, system dispatch cost for secure operation, running backup plants, storage losses, reserve and response cost
4 Transmission and additional generation capex as well as fixed opex for transmission and backup
5 Grid not modeled by KEMA yet, impact estimated by interpolation from the other pathways

SOURCE: Team analysis

Confidence ranges for assumptions: likely outcomes are within 10-15% of each other across all pathways

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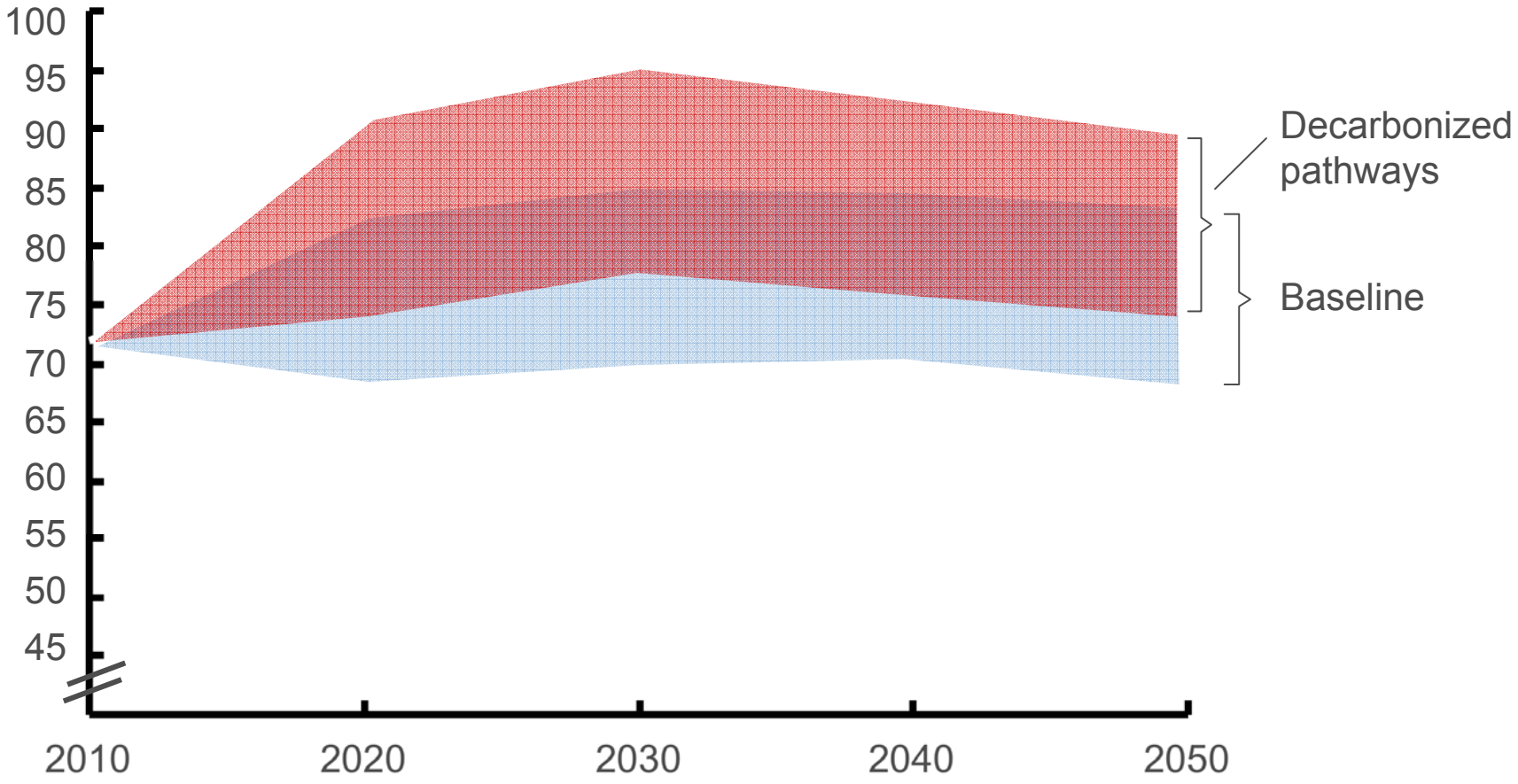
Likely ranges over time in the cost of electricity of new builds[1]
EUR/MWh (real terms)



NOTE This is excluding a price for CO2. A price of ~€50 per tCO2e would be equivalent to the range shown in the baseline
1 Based on a WACC of 7% (real after tax), computed by technology and weighted across technologies based on their production; including grid

SOURCE: Team analysis

Efficiency flattens demand growth, 'fuel shift' drives it back up to the same level as 'BaU', but far less energy intensive

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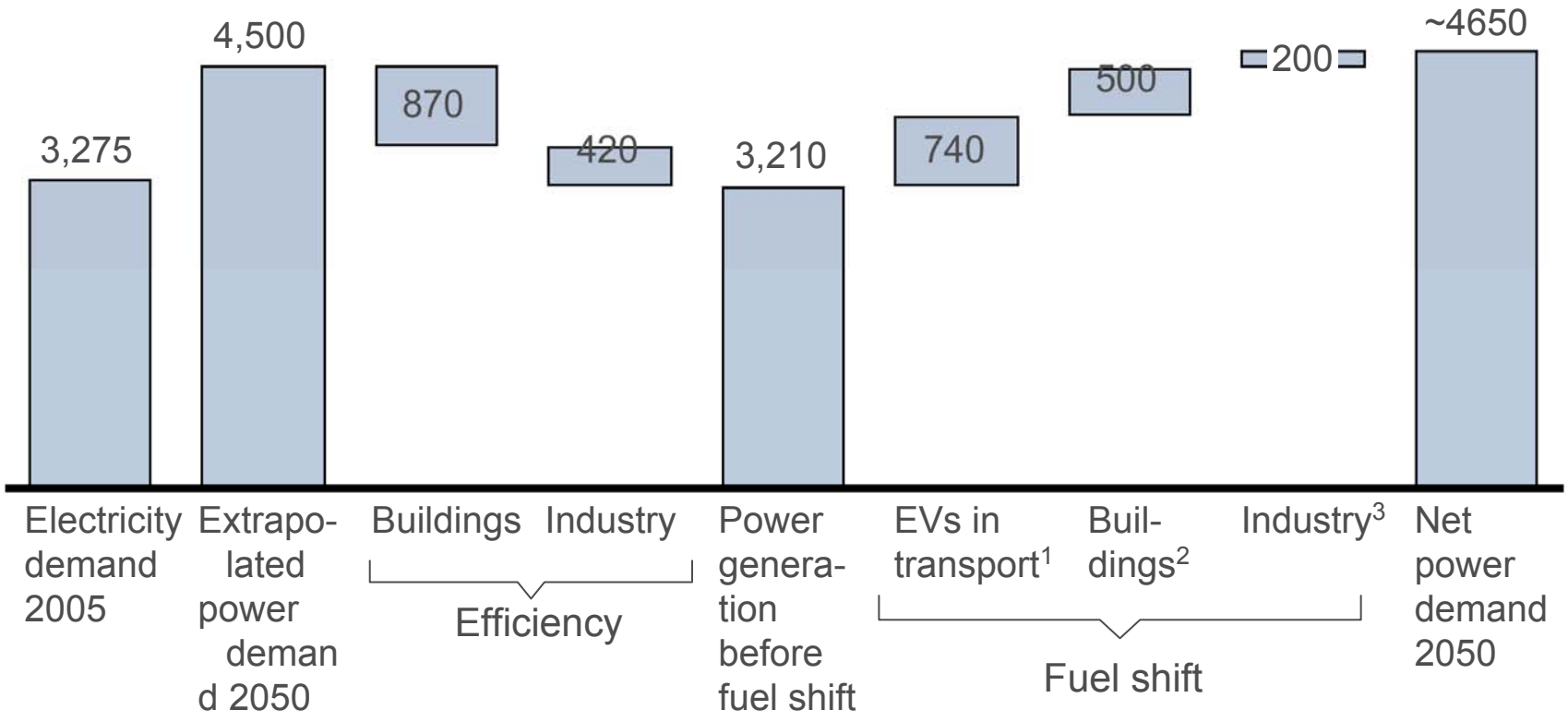
EU-27 power demand, TWh per year



1 Assumption: electrification of 100% LDVs and MDVs (partially plug-in hybrids); HDVs remain emitting ~10% while switching largely to biofuel or hydrogen fuel cells

2 Assumption: 90% of remaining primary energy demand converted to electricity usage in buildings for heating/cooling from heat pumps; assumed to be 4 times as efficient as primary fuel usage

3 Assumption: 10% fuel switch of remaining combustion primary energy demand converted to electricity in industry for heating from heat pumps; assumed to be 2.5 times as efficient as primary fuel usage

SOURCE: Team analysis

New inter-regional transfer capacity required (60% RES)

Interconnection	Capacity additional (existing) [GW]	Annual utilization [%]
UK&Ireland-France	8 (2)	75
UK&Ireland-Nordel	0 (0)	0
UK&Ireland-Benelux&Germany	3 (0)	83
France-Iberia	32 (1)	83
France-Benelux&Germany	14 (6)	78
France-Central-Europe	7 (3)	93
France-Italy&Malta	0 (3)	92
Nordel-Benelux&Germany	0 (3)	75
Nordel-Poland&Baltic	4 (1)	60
Benelux&Germany-Central-EU	0 (4)	74
Benelux&Germany-Poland&Baltic	9 (1)	81
Central-Europe-Poland &Baltic	0 (2)	77
Central-South East EU	1 (2)	80
Central-Europe-Italy	0 (5)	58
South East EU-Italy	9 (1)	79
Total	**87 (34)**	

SOURCE: Team analysis

Increased interconnectivity across regions exploits natural counter-cyclicality of primary European RE resources

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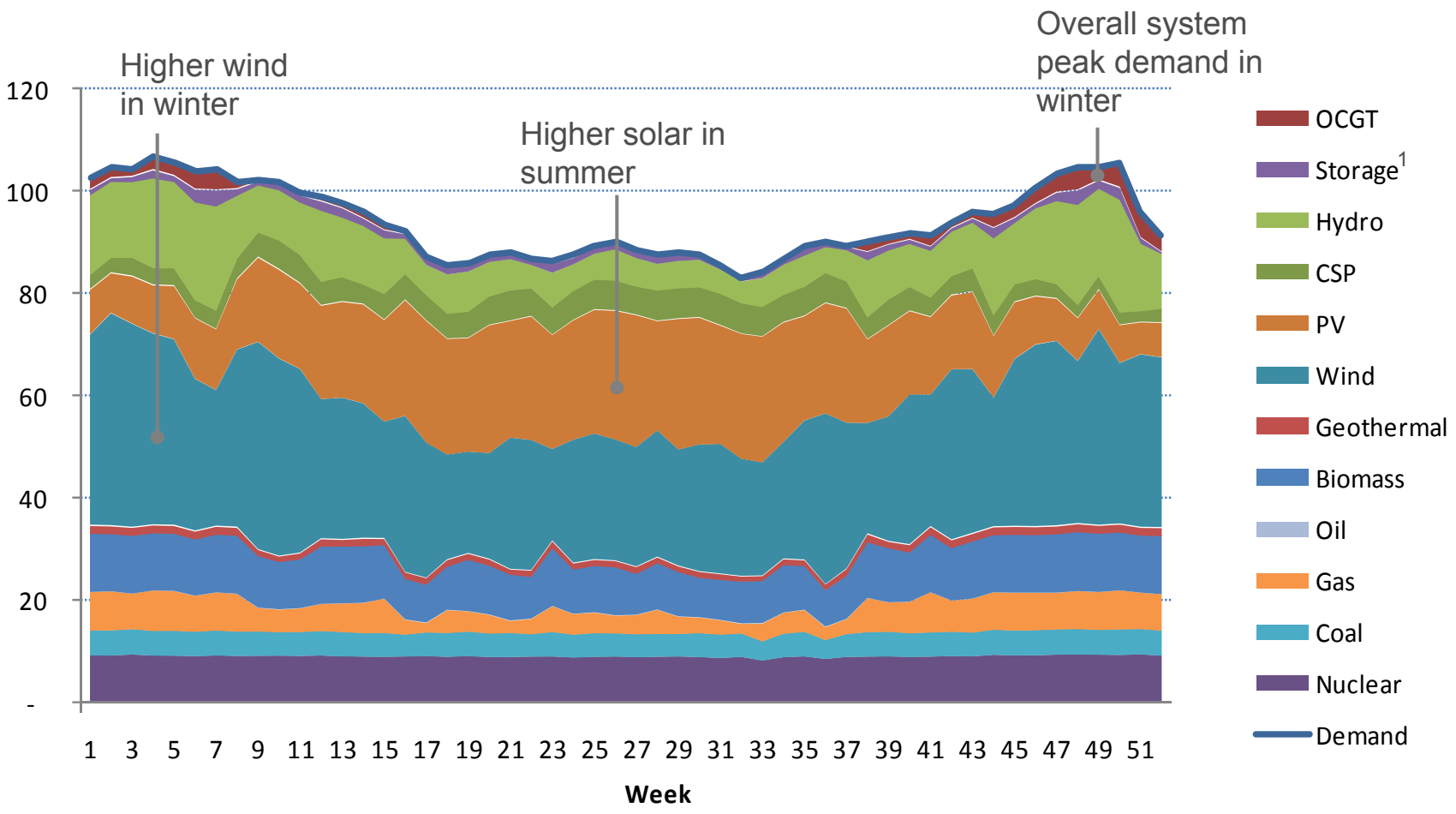
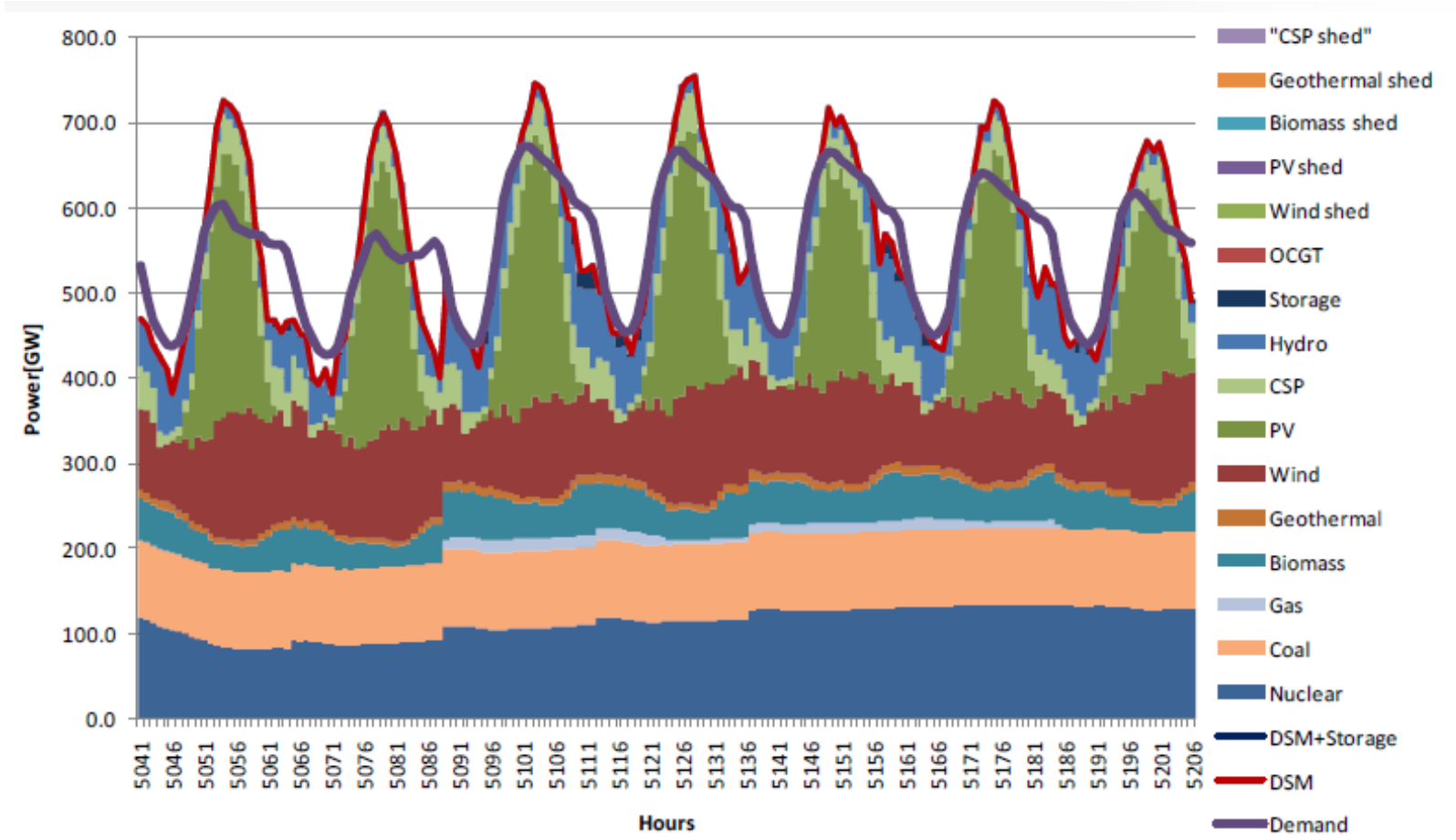
Overview of yearly energy balance, 80% RES pathway, TWh per week



1 Storage included in the model relates to the existing hydro storage available across the regions

SOURCE: Team analysis

Increased demand flexibility through 'smart' grid investments is a cost-effective alternative to curtailing low-carbon sources



SOURCE: Team analysis

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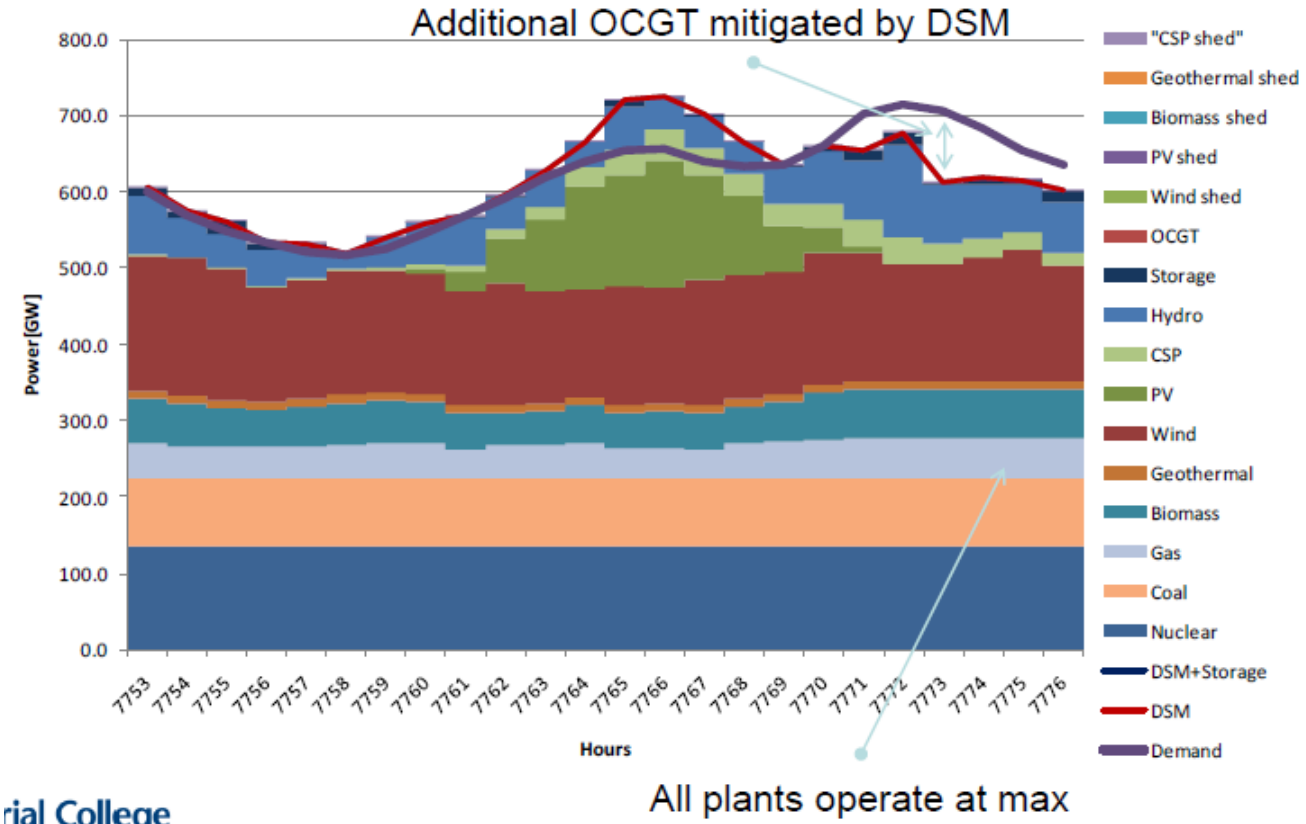
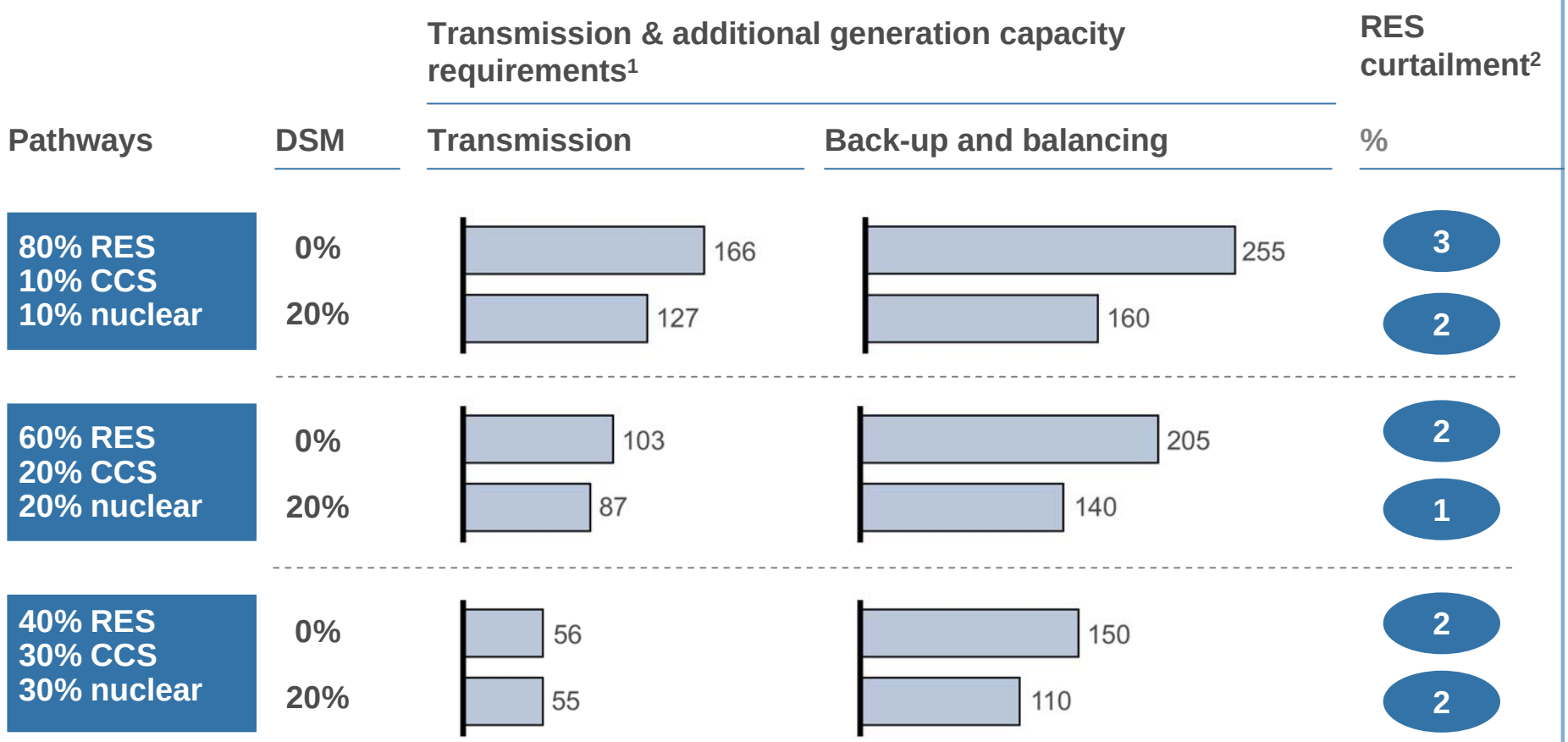


- DSM also reduces the need for additional OCGT plants
- The graph shows how the original demand line (purple) is shifted to earlier during the day (red line) when more power is available to match supply

SOURCE: Team analysis

Demand flexibility reduces grid and related investments, minimizes low-carbon resource curtailment, minimizes cost

2050, GW



SOURCE: Team analysis

Back-Up

SOURCE: Team analysis

The study methodology is uniquely robust on the crucial question of system reliability – 'keeping the lights on'

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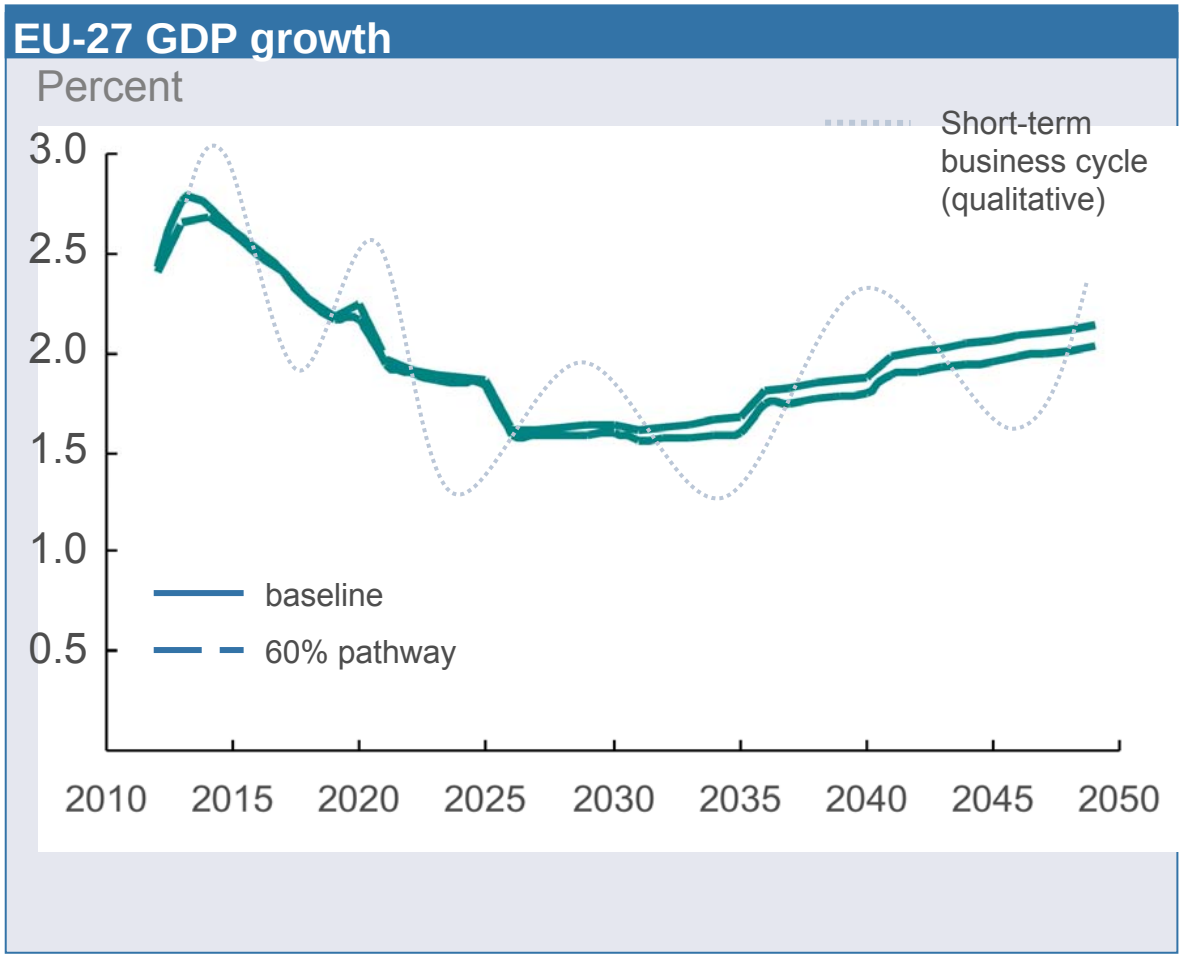
Capacity used (GW), modeling results of Monday Jan 16, 03.00 CET

Centre of gravity

x Load on a winter night, 03.00 CET

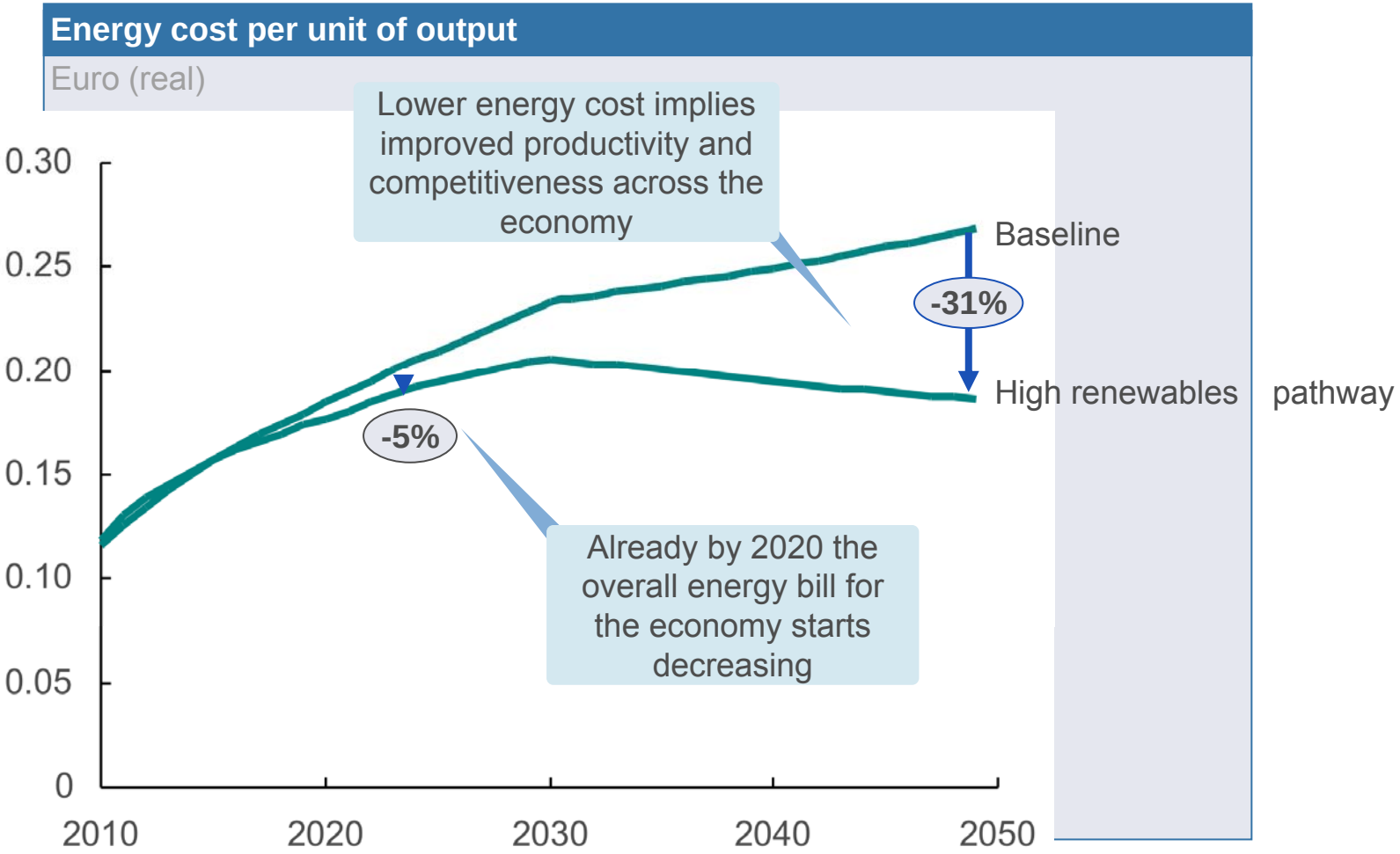
SOURCE: Imperial College London; Kema

Despite slightly higher initial unit costs for power, impact on overall economic performance is neutral to positive



SOURCE: Team analysis

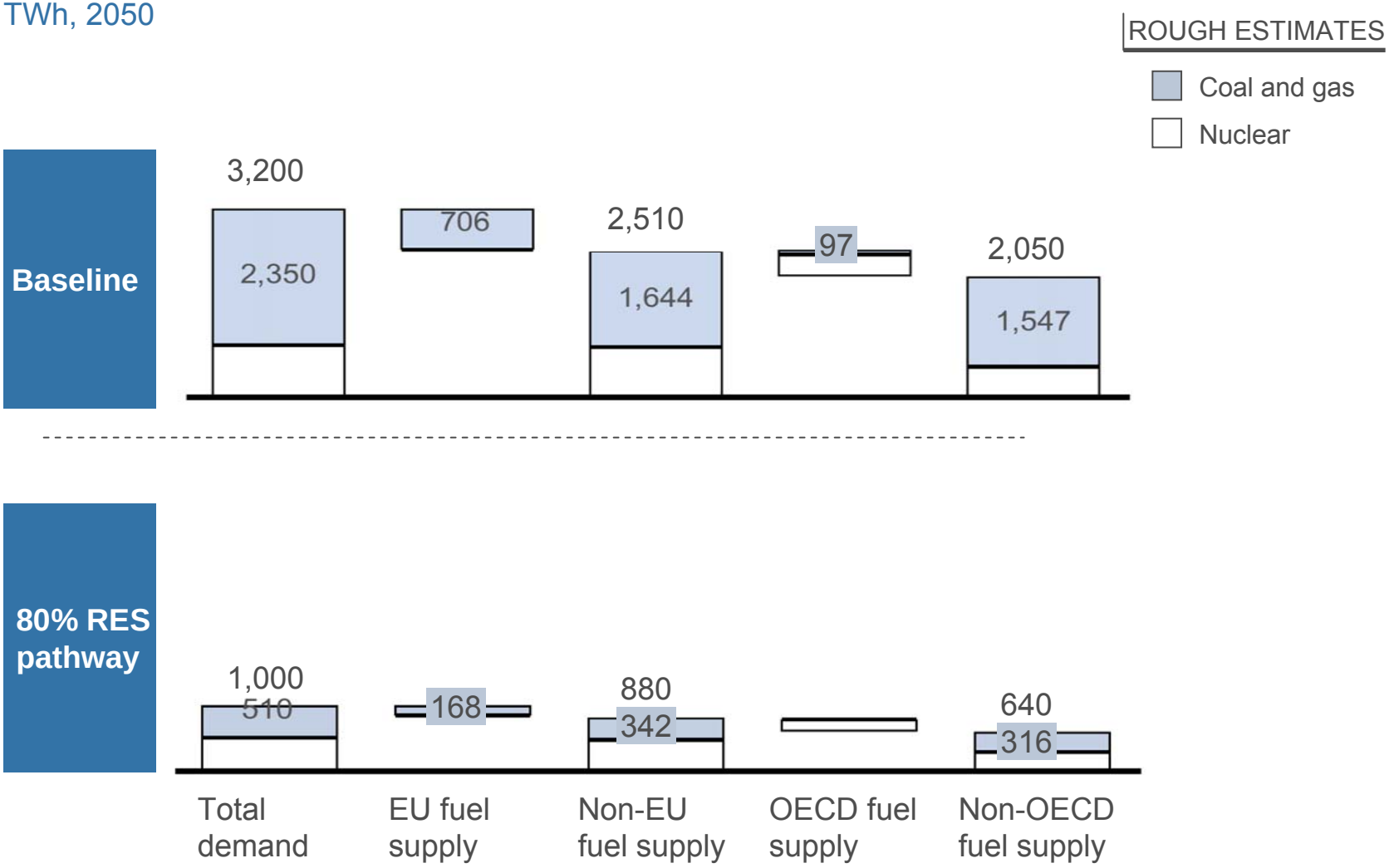
The low-carbon economy, based on decarbonized power, spends ≈ 30% less on energy and is thus more competitive



SOURCE: Team analysis

In the “high RES” pathways, European imports of coal and gas decline from 35% of final consumption to 7%

TWh, 2050



Availabilities 2050: biomass: 90% EU-27, 10% Non-OECD; nuclear: 2% EU-27, 43% OECD, 55% Non-OECD; coal: 50% EU-27; 10% OECD, 40% Non-OECD; gas: 16% EU-27, 0% OECD, 84% Non-OECD

SOURCE: IEA WEO 2009; World Nuclear Association; team analysis

Critical market 'pull' for low-carbon resources is driven by steady, timely retirement of existing high-carbon assets

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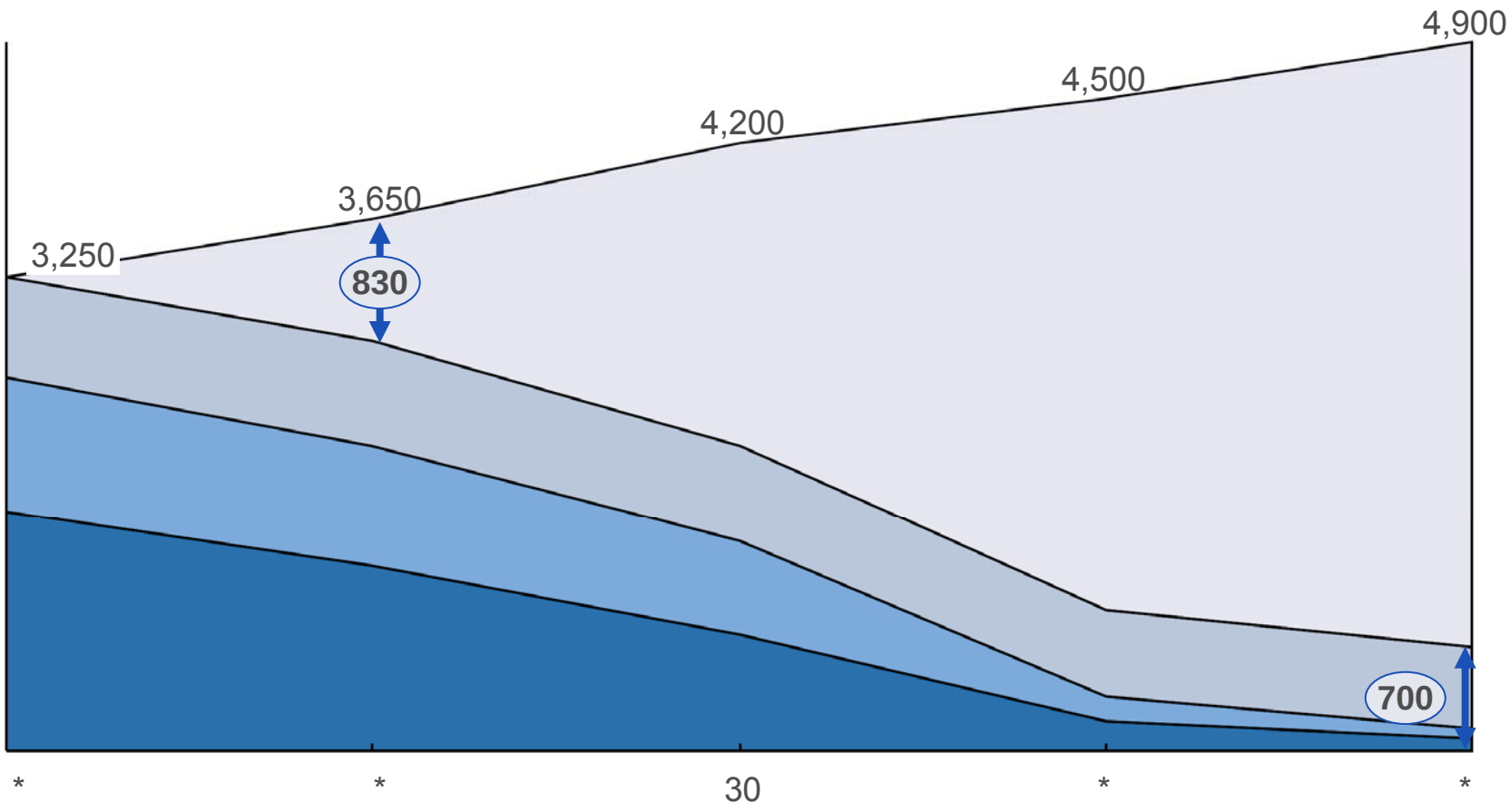
Power supply by existing and currently planned power plants and forecasted power demand, TWh



SOURCE: Team analysis