Energy solutions for a changing world

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

A project of the European Climate Foundation

Presentation to the U.S. Department of Energy
Electricity Advisory Committee
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The objective was to develop a fact based report - supported by key stakeholders and feeding directly into EU decision making

Key deliverables

- A set of **plausible and visionary emissions pathways with an 80% reduction** across the EU-27 below 1990 levels by 2050
- Deep dive on **the decarbonization of the power sector**
- Implications **on strategic options** for the EU
- A related **set of policy options** highlighting potential decisions for the next 5 years

Overarching objective

Develop a **fact based report** to support the European Commission and Member State policy-makers to chart an energy strategy for 2010-2014 consistent with the EU's 2050 climate and energy security commitments

Political agenda

Post-Copenhagen **political agenda for the new European Commission**

- **November 2010**
  - Commission to present European Infrastructure Package
- **2011**
  - Commission to present Communication on 2050 Energy Strategy
  - Commission to present Energy Action Plan 2011-2014

Roadmap 2050 project team

ROADMAP 2050 PARTNERS

	ECF (Philanthropic European climate foundation)	▪ Overall sponsor and funder
Volume 1	McKinsey & Company (Strategic consultancy)	▪ Overall content analysis, project management, data collection ▪ Reach out to industries, workshop facilitation
Volume 1	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
Volume 1	Imperial College London	▪ In-depth modeling of system balancing requirements, reliability, optimization of transmission and back-up investment
Volume 1	Oxford Economics (Macro-economic consultancy)	▪ Provide analysis of macro-economic impacts of decarbonization scenarios
Volume 2	E3G	▪ Coauthor of policy volume 2 ▪ Policy insights based on the analytics
Volume 2	ECN (Energy research Center of the Netherlands)	▪ Support on assumptions for technologies ▪ Policy development and recommendations based on analytics
Volume 3	Office for Metropolitan Architecture	▪ Provide creative participation in the development of narrative. Provide conceptual framing and visual communication ▪ Spatial planning and visualization of the grid

Key stakeholders are involved by providing input and reviewing results

Core Working Group participants

Utilities
- CEZ GROUP
- edp
- RWE
- Enel
- e.on
- IBERDROLA
- VATTENFALL

Transmission System Operators
- ENERGINET/DK
- nationalgrid
- tennet
- Terna
- entsoe

Manufacturers
- acciona
- Siem ens
- Vestas

NGOs
- E3G
- GERMANWATCH
- WWF

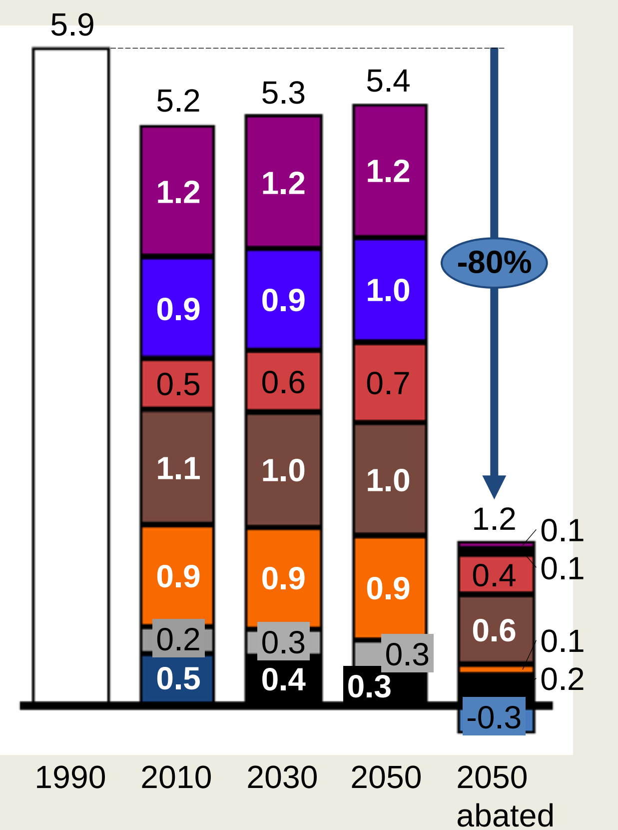
Further outreach

Plus 40 more companies, NGOs and research institutes

- NUON
- EWEA
- First Solar
- DESERTEC
- Q.CELLS
- SCHOTT solar

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

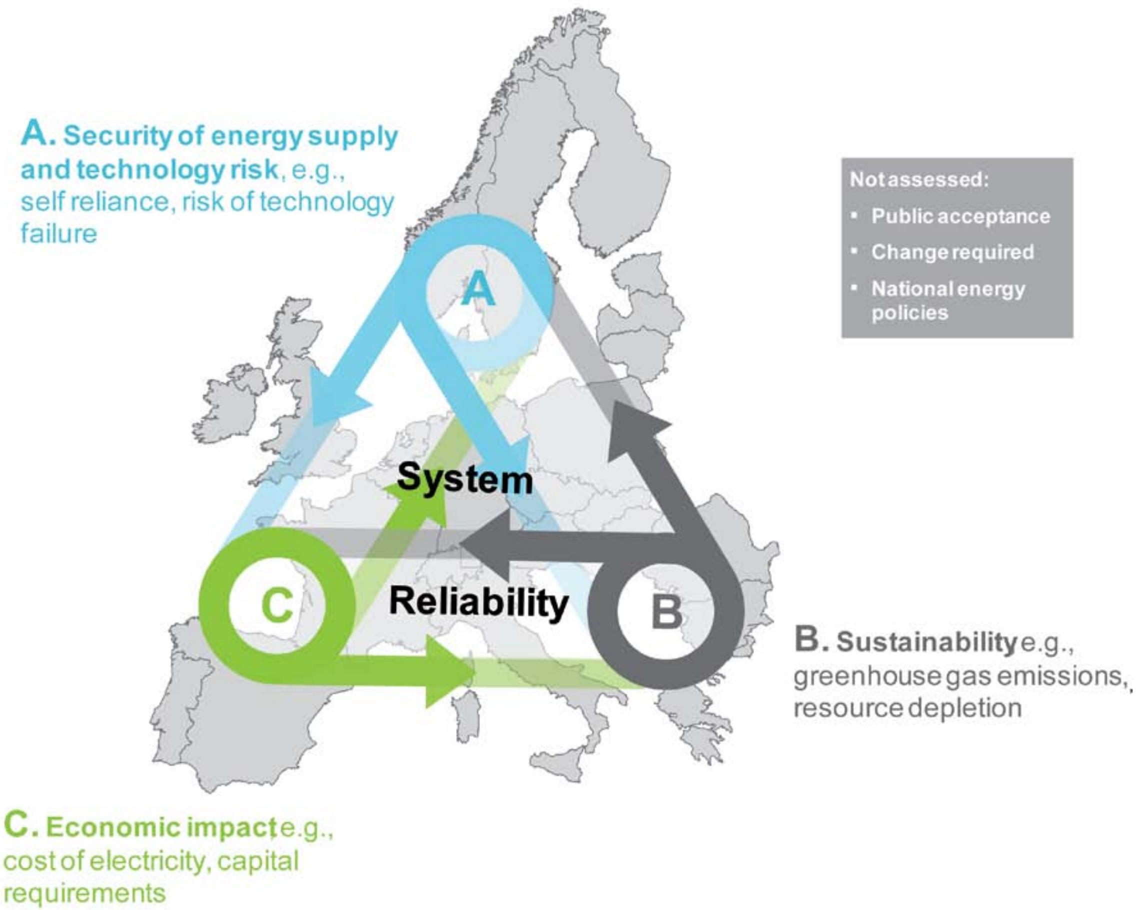
EU-27 total GHG emissions
$GtCO_2e$ per year



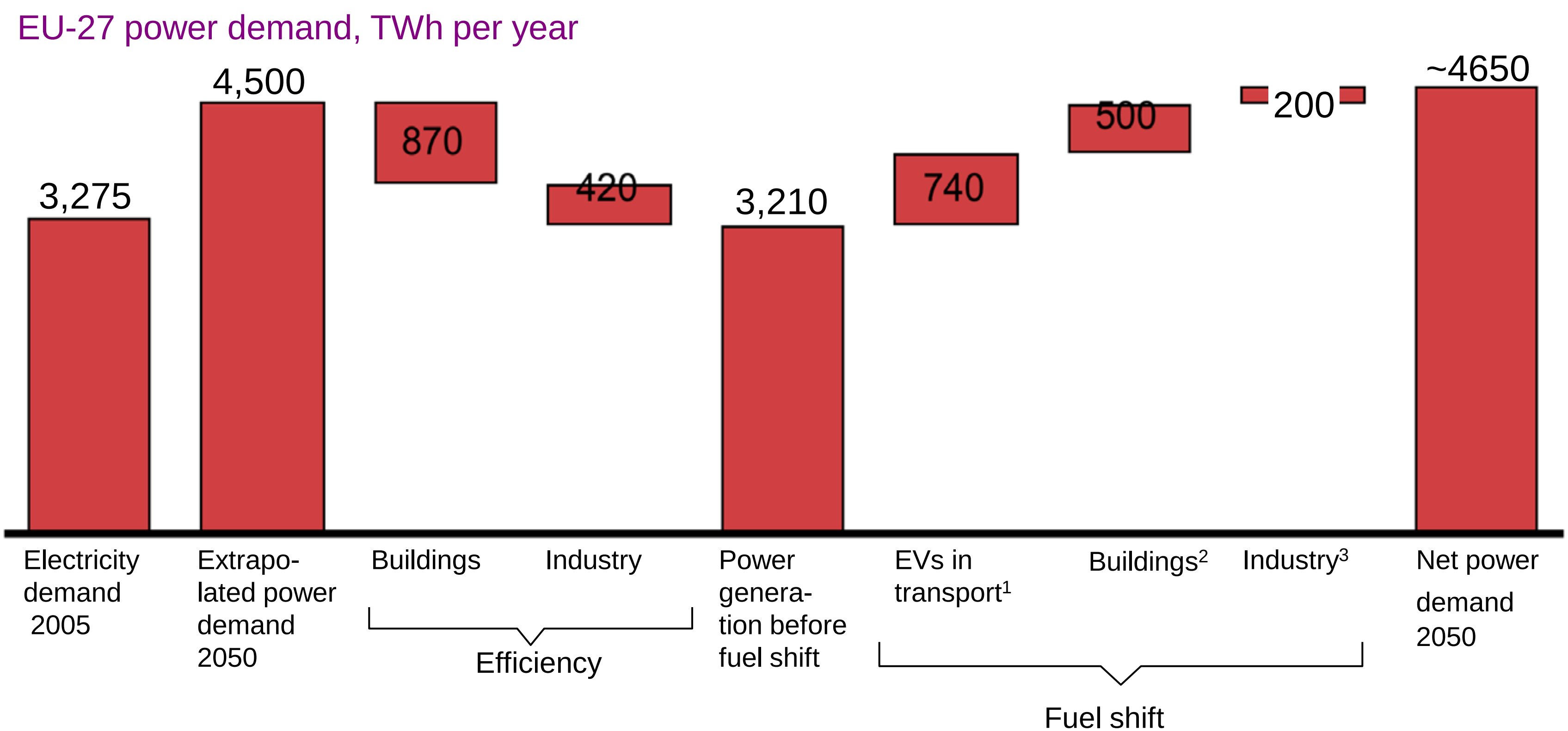
Sector	Abatement	Within sector[1, 2]	Fuel shift
Power	**95% to 100%**	>95%	
Road transport	**95%**	20%	75% (electric vehicles, biofuels and fuel cells)
Air & sea transport	**50%**	30%	20% (biofuels)
Industry	**40%**	35% (CCS[3])	5% (heat pumps)
Buildings	**95%**	45% (efficiency and new builds)	50% (heat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

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



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



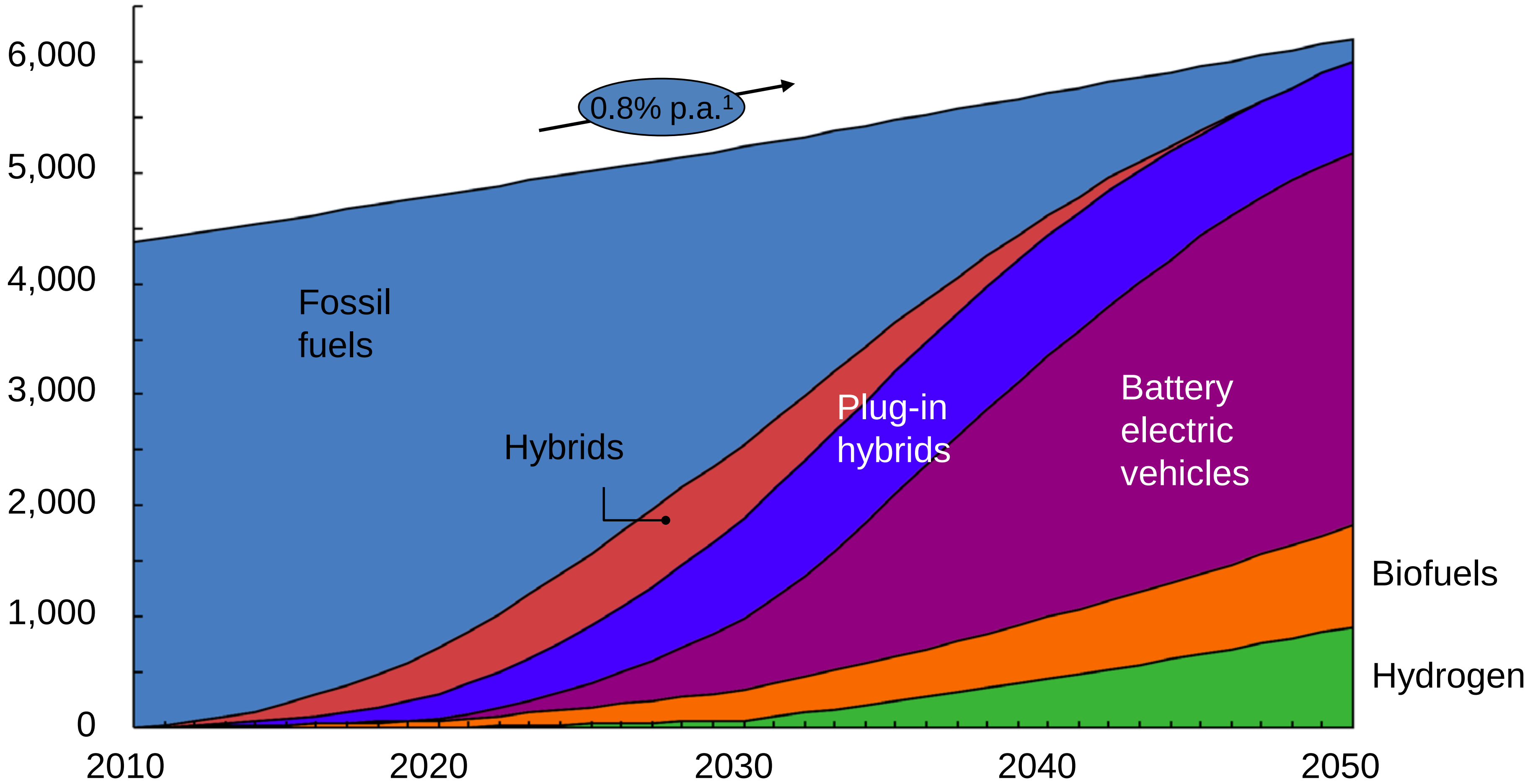
1 Assumption: electrification of 100% LDVs and MDVs (partially plug-in hybrids); HDVs remain emitting ~10% while switching largely to biofuel or hydrogen fuel cells

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

The decarbonized pathways assume a mix of electric vehicles, biofuels and fuel cell vehicles

Billions of Km driven[1] by type of energy sources



1 Kilometers for heavy trucks normalized for a factor 4 higher fuel consumption per km

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Decarbonization pathways

40% RES[1]
30% Nuclear
30% CCS

- RES share close to currently legally committed by the EU and the IEA baseline
- Sensitivities on a high nuclear share and a high thermal / CCS share are included

60% RES
20% Nuclear
20% CCS

80% RES
10% Nuclear
10% CCS

- RES mix based on current deployment (minimum), aim for a broad mix of technologies and theoretical deployment (maximum)
- Equal shares for nuclear and thermal / CCS

Additional sensitivities

- Fuel prices (coal, gas, uranium)
- Cost of capital
- Learning rates
- Grid solutions
- Electricity demand
- 100% RES supply

1 Renewable energy sources

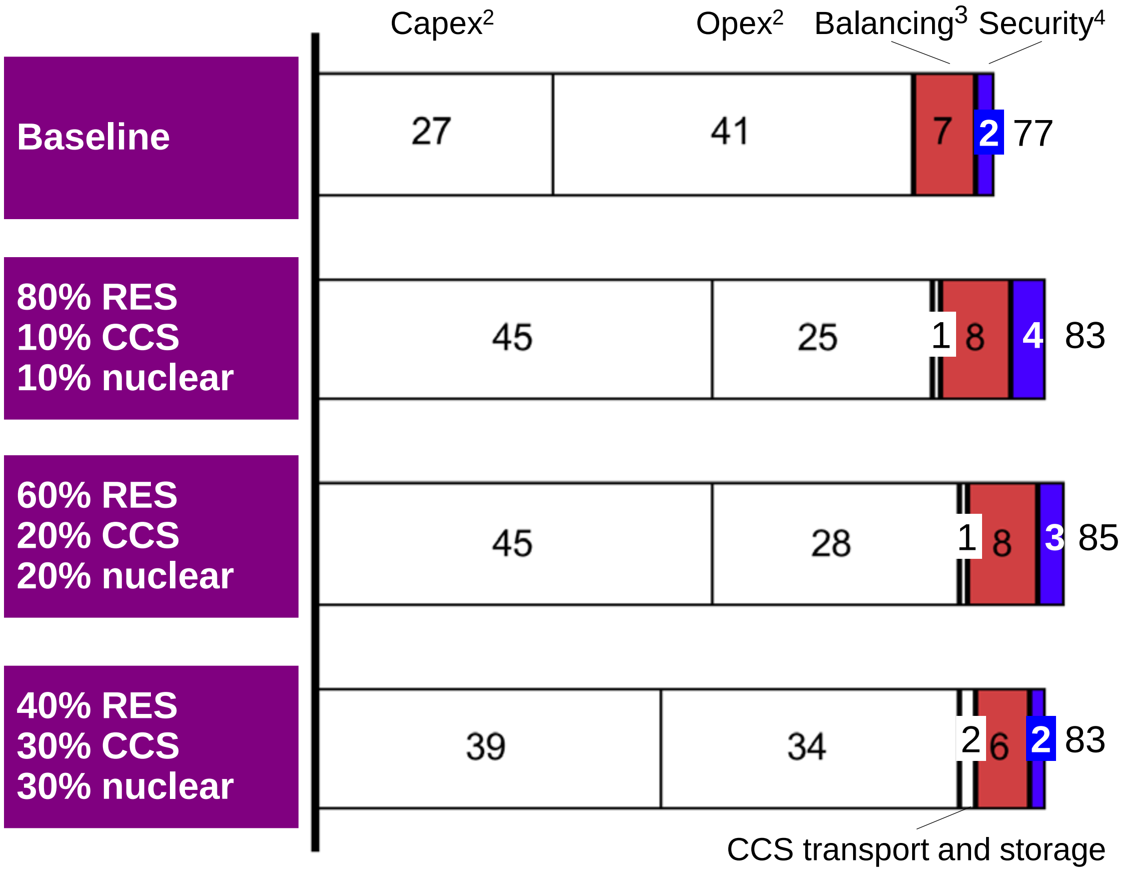
Share of production by technology in 2050 as defined

In percentage of production

	Coal	Coal CCS	Coal CCS retrofit [1]	Gas	Gas CCS	Gas CCS retro-fit	Nu-clear	Wind: On-shore	Wind: Off-shore	Solar: PV	Solar: CSP	Bio-mass	Geo-thermal	Large Hydro
80% RES 10% CCS 10% nuclear	0	3	2	0	5	0	10	15	15	19	5	12	2	12
60% RES 20% CCS 20% nuclear	0	7	3	0	10	0	20	11	10	12	5	8	2	12
40% RES 30% CCS 30% nuclear	0	10	5	0	15	0	30	9	2	4	3	8	2	12
(Baseline) 34% RES 49% coal/gas 17% nuclear	21	0	0	28	0	0	17	9	2	1	1	8	1	12

1 Only on “CCS ready” plants
2 5% from Europe and 15% from North Africa

All pathways can deliver power with roughly the same cost and reliability as the baseline with carbon price ≤ €50/tCO_2



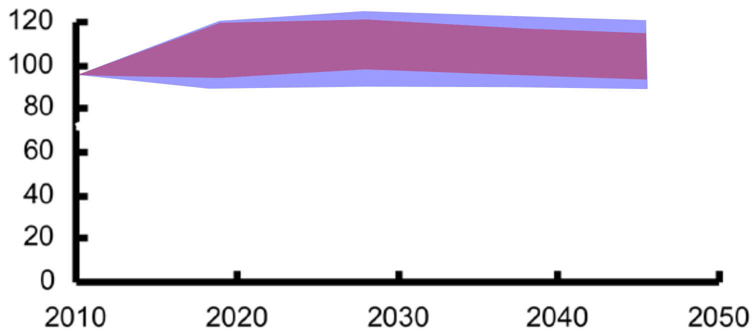
Average new built CoE from 2010 to 2050[1], EUR/MWh (real terms)

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

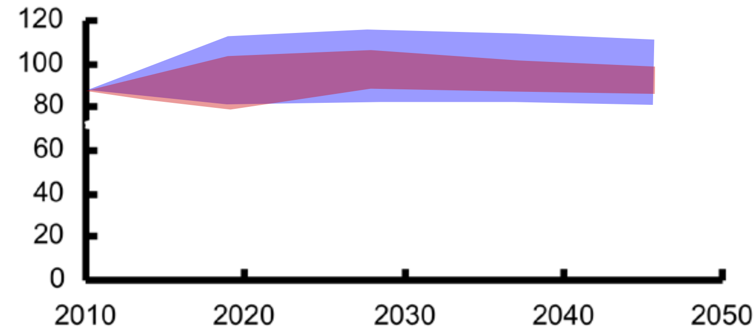
Confidence ranges for assumptions: likely outcomes are within 10-15% of each other across all pathways

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

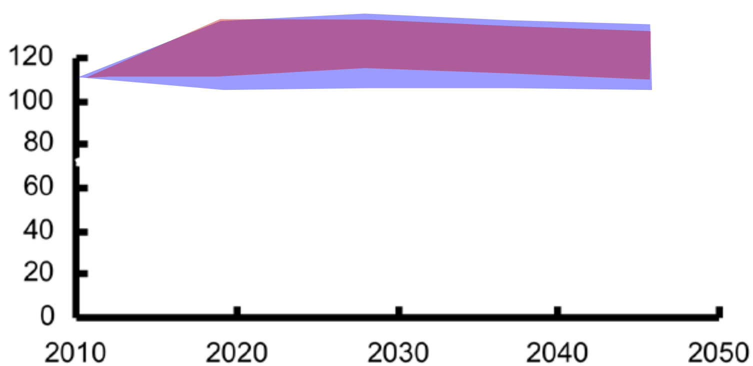
Baseline and average of decarbonized pathways



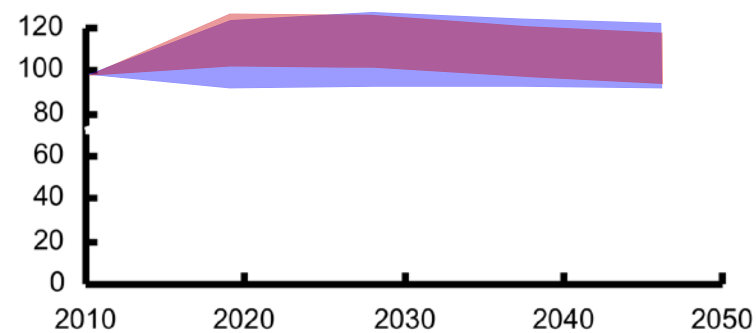
Baseline and 40% RES pathway



Baseline and 60% RES pathway



Baseline and 80% RES pathway

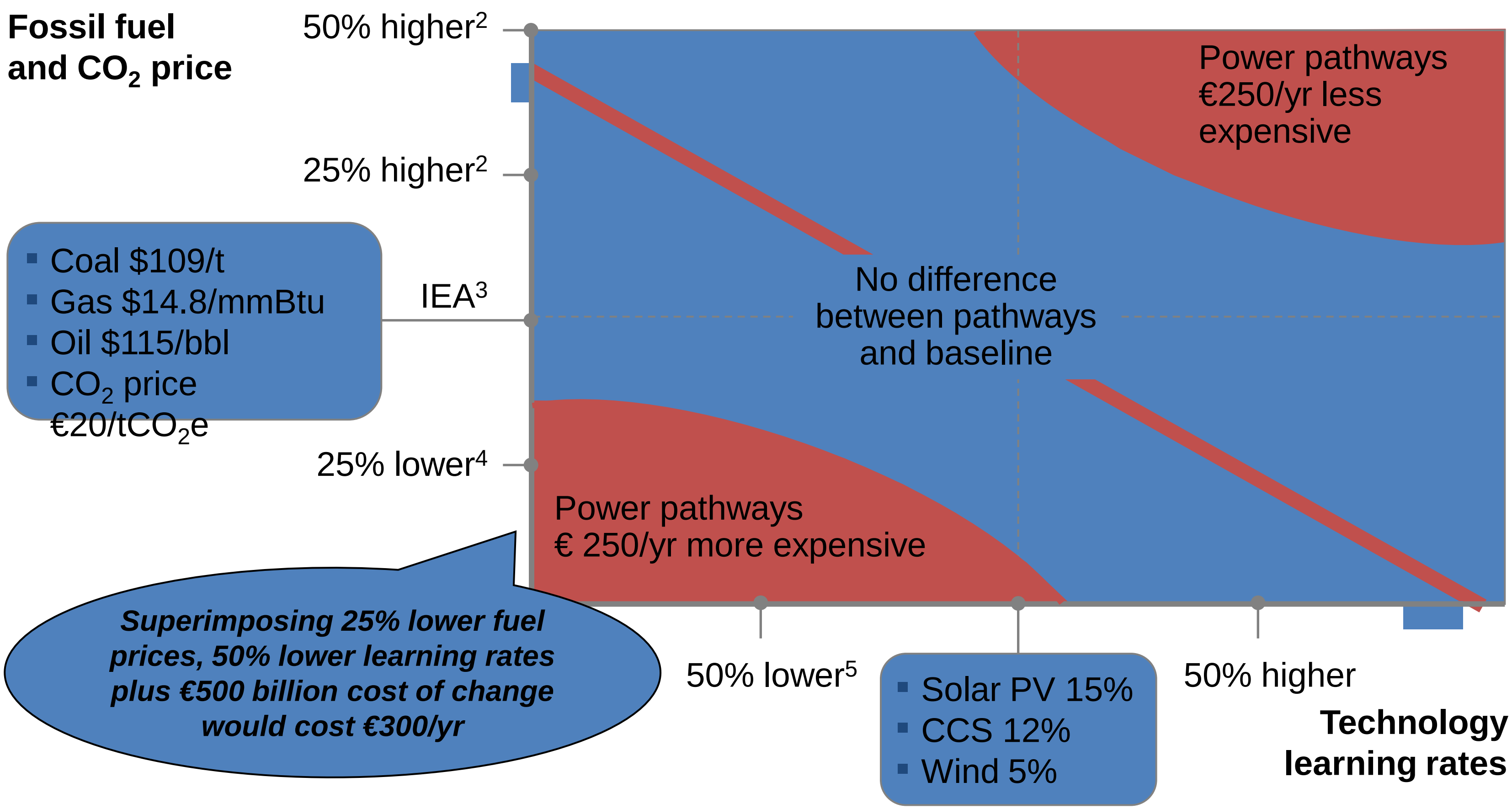


NOTE This is excluding a price for CO_2. A price of ~€50 per tCO_2e would be equivalent to the range shown in the baseline

1 Based on a WACC of 7% (real after tax), computed by technology and weighted across technologies based on their production; including grid

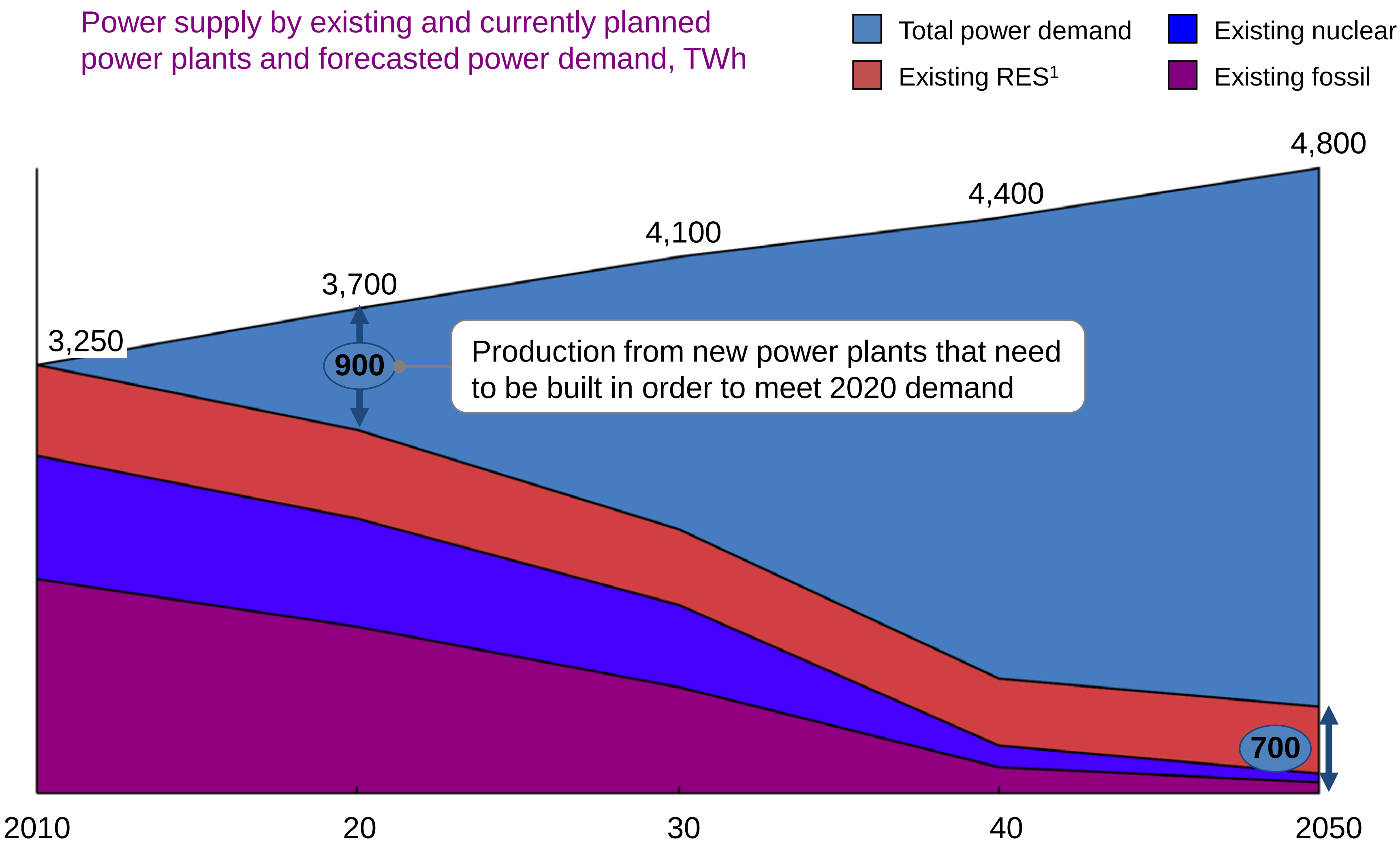
The cost of the decarbonized pathways and the baseline are likely to differ less than € 250 per year per household

Cost impact of the decarbonized power pathways per year per household[1]



1 Assuming all power costs get passed through to households
2 CO_2 price assumed of € 40/tCO_2e
3 IEA WEO 2009 ‘450 Scenario’ assumptions for 2030, kept constant up to 2050
4 No carbon price
5 For all technologies, learning rate defined as capex improvement per doubling of cumulative installed capacity

Most of the non-hydro capacity will be retired by 2040



1 Existing RES mainly hydro; remains in operation until 2050

Power generation technologies that are at least in late stage development are included

Power generation technologies included in the pathways

Type of generation		Generation technologies
RES	Non-intermittent	Large hydro Geothermal Biomass dedicated Solar CSP with storage
	Intermittent	Wind onshore Wind offshore Solar PV Hydro run of river
Fossil		Coal conventional Coal CCS Coal CCS retrofit Gas conventional Gas CCS Gas CCS retrofit Oil
Nuclear		Nuclear III

Regional clustering of EU-27 countries (including Switzerland and Norway)

Nordic
- Denmark
- Finland
- Sweden
- (Norway)

Poland and Baltic
- Estonia
- Latvia
- Lithuania
- Poland

Benelux and Germany
- Belgium
- Germany
- Luxembourg
- Netherlands

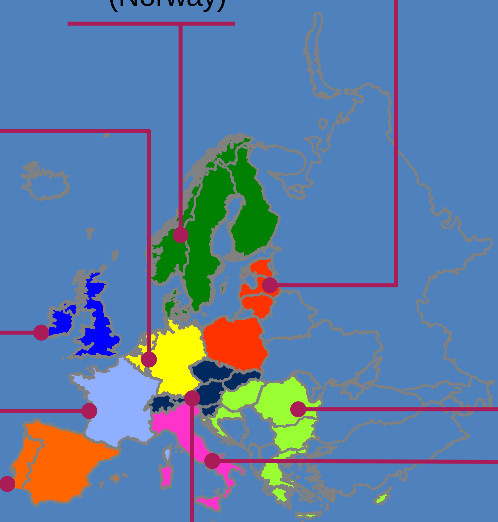
South East Europe
- Bulgaria
- Cyprus
- Greece
- Hungary
- Romania

UK and Ireland

France

Italy & Malta

Iberia
- Portugal
- Spain



Central Europe
- Austria
- Czech Republic
- Slovakia
- Slovenia
- (Switzerland)

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

● Centre of gravity

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)**	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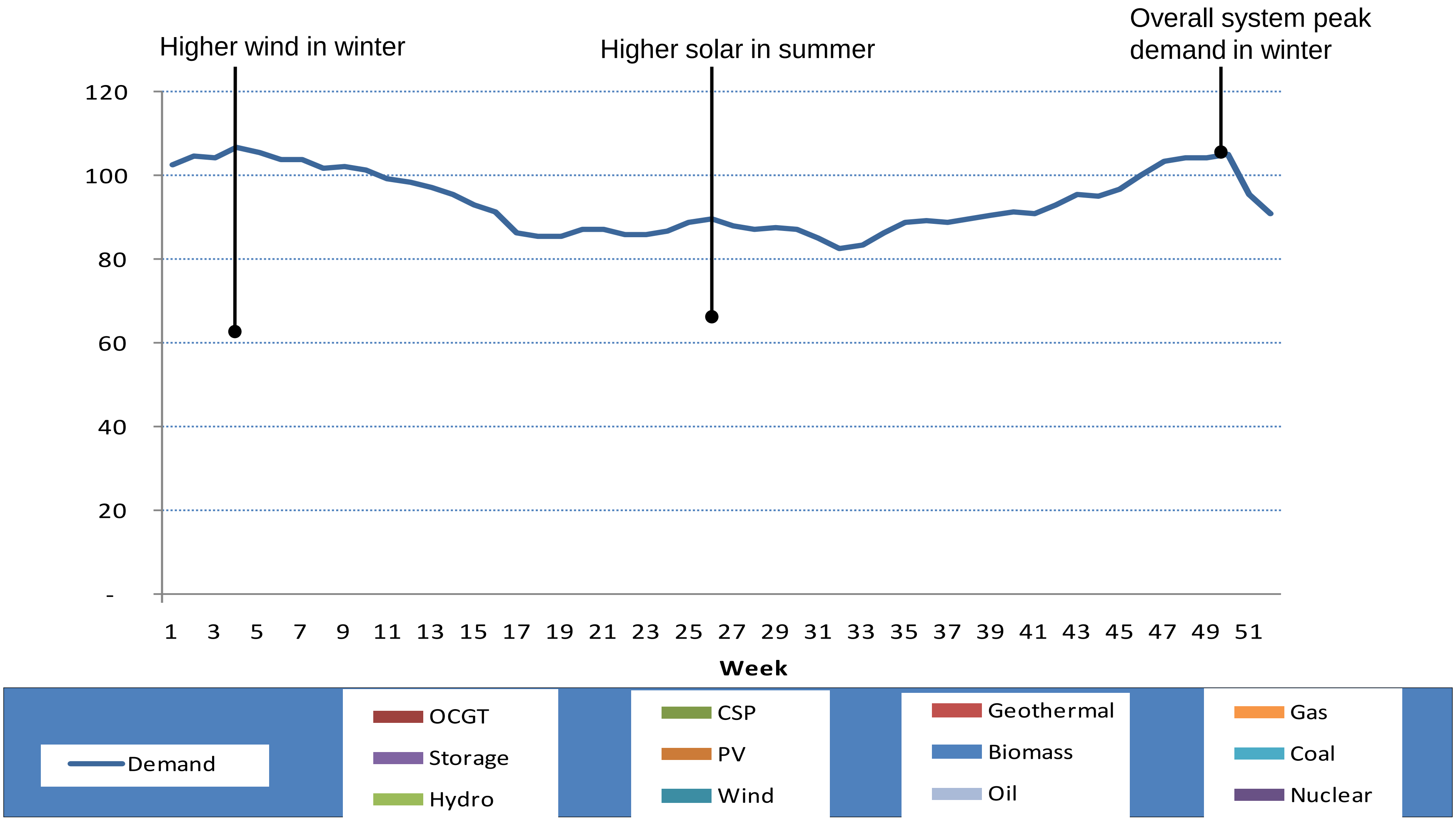
ESTONIA
EU Grid Passports & Balloons

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

Overview of yearly energy balance, 60% RES pathway, TWh per week



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

Map of
ENEROPA
Boundaries:
Biomassburg
C.C.S.R. (Carbon Capture & Storage Republic)
Enhanced Geothermalia
Geothermalia
Hydropia
Isles of Wind
Solaria
Tidal States
Vrania
NORTH HYDROPIA
ISLES OF WIND
TIDAL STATES
GEOTHERMALIA
C.C.S.R.
VRANIA
ENHANCED GEOTHERMALIA
EAST HYDROPIA
CENTRAL HYDROPIA
BIOMASSBURG
WEST HYDROPIA
SOLARIA
Scale 1 : 20000000
Meridian of Greenwich
Eneropa
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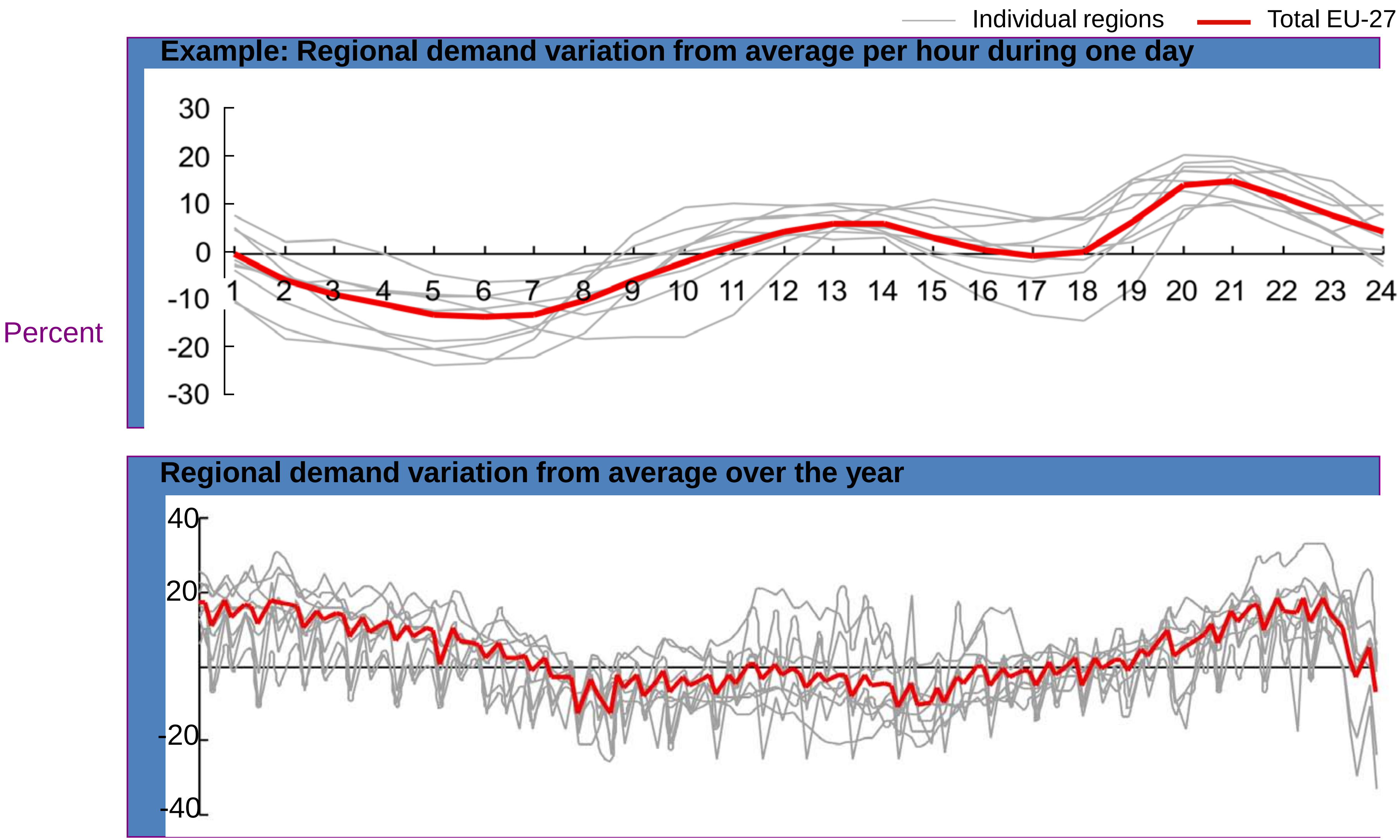
Increased transmission cancels out both daily and seasonal fluctuations



NOTE Excluding additional seasonality demand from heat pumps and extreme weather cases

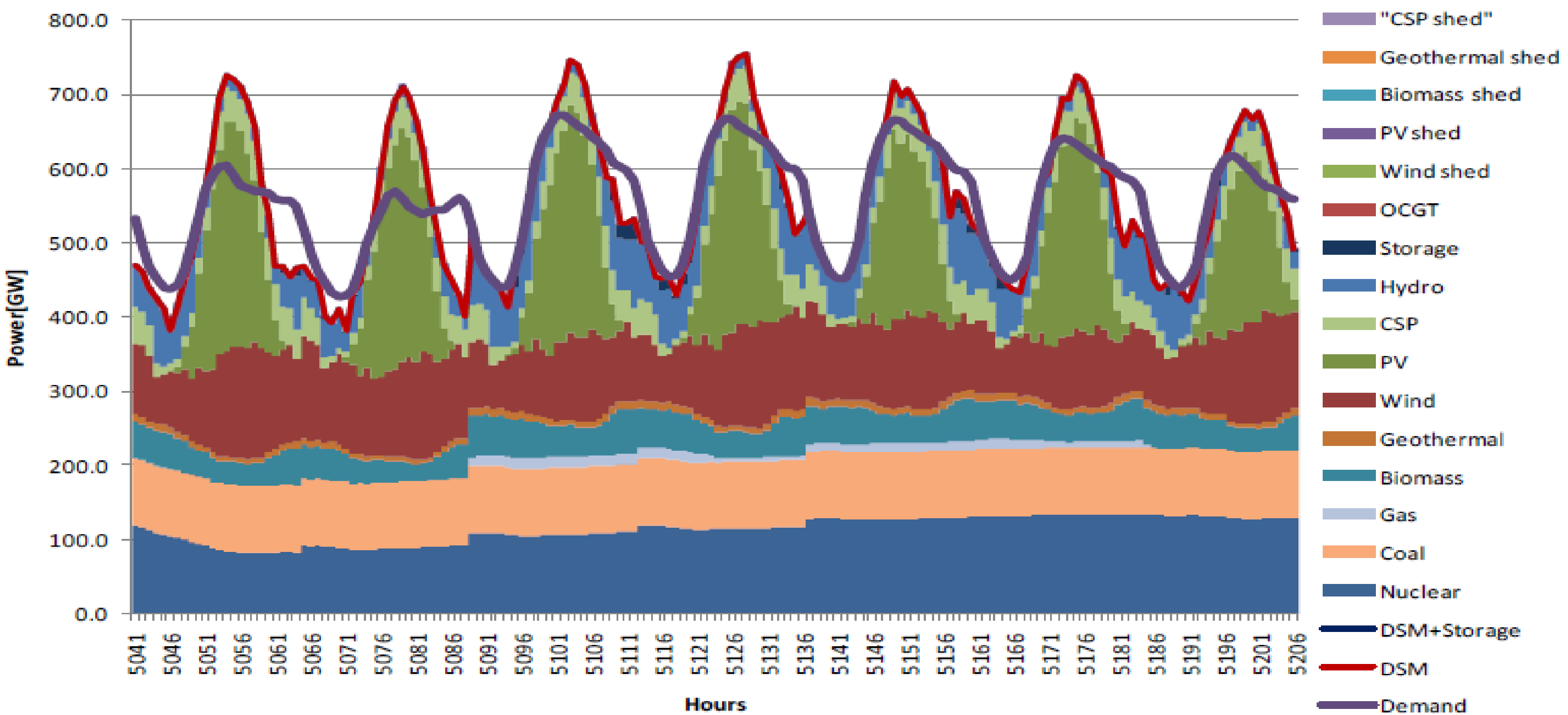
Reserve sharing between regions reduces total reserve requirements by ~40%

Maximal reserve requirement[1], GW

Region	Baseline	80% RES	60% RES	40% RES
UK & Ireland	8	42	28	15
France	2	31	21	9
Iberia	7	40	27	10
Nordic	3	20	15	10
Benelux & Germany	13	44	28	10
Central-Europe	2	29	20	8
Poland & Baltic	2	18	12	5
South East Europe	2	18	12	4
Italy & Malta	2	40	27	10
Total EU27	42	281	191	80
Benefit of reserve sharing	20	98	66	32
Total with reserve sharing between regions	22	183	125	48
	-47%	-35%	-35%	-40%

1 Reserve refers to reserve required at four hour ahead of real-time. This is required to manage the larger changes in generation (due to plant outages and expected uncertainty in intermittent output) expected over that four hour period that could require starting additional (or switching off) generation

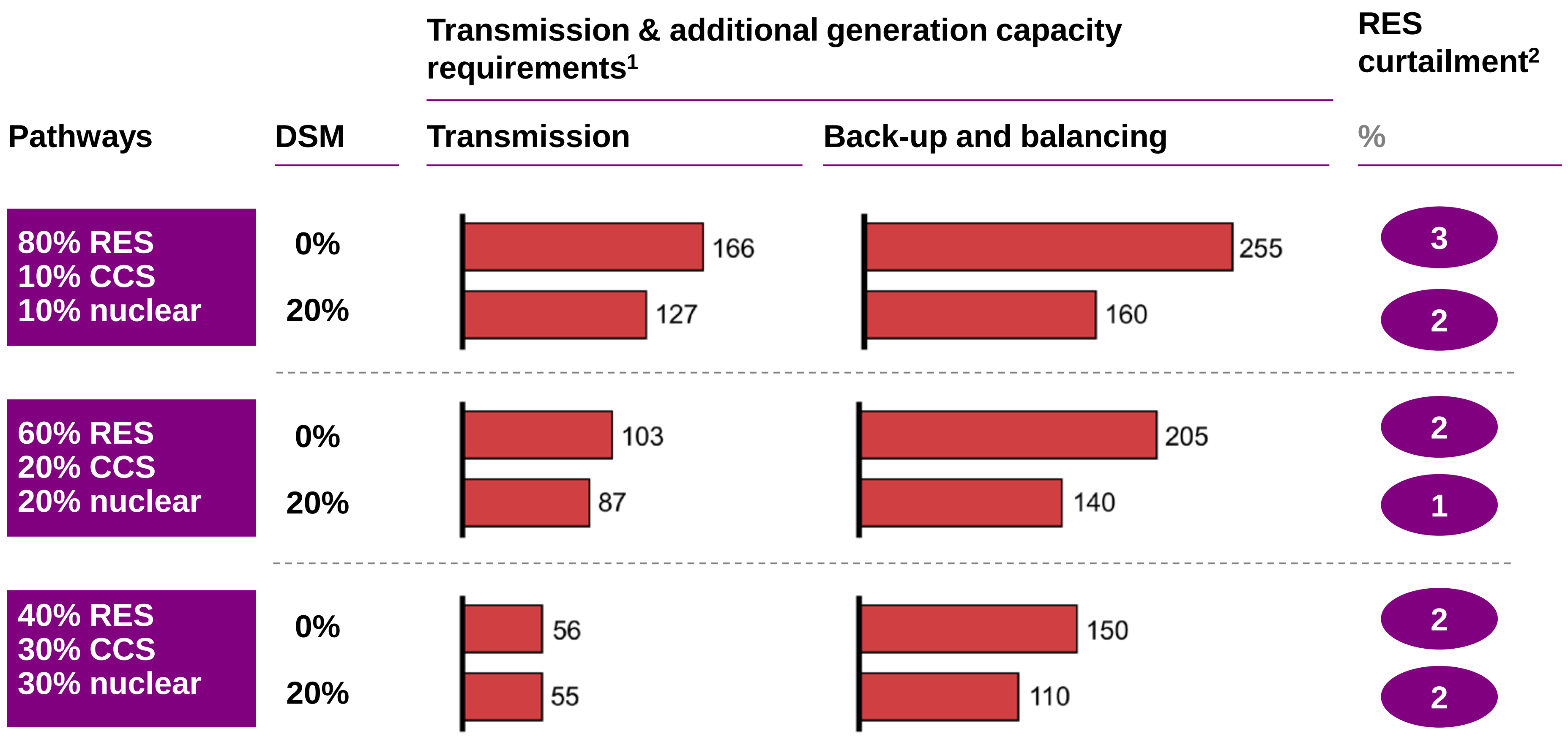
Increased demand flexibility through 'smart' grid investments is a cost-effective alternative to curtailing low-carbon sources



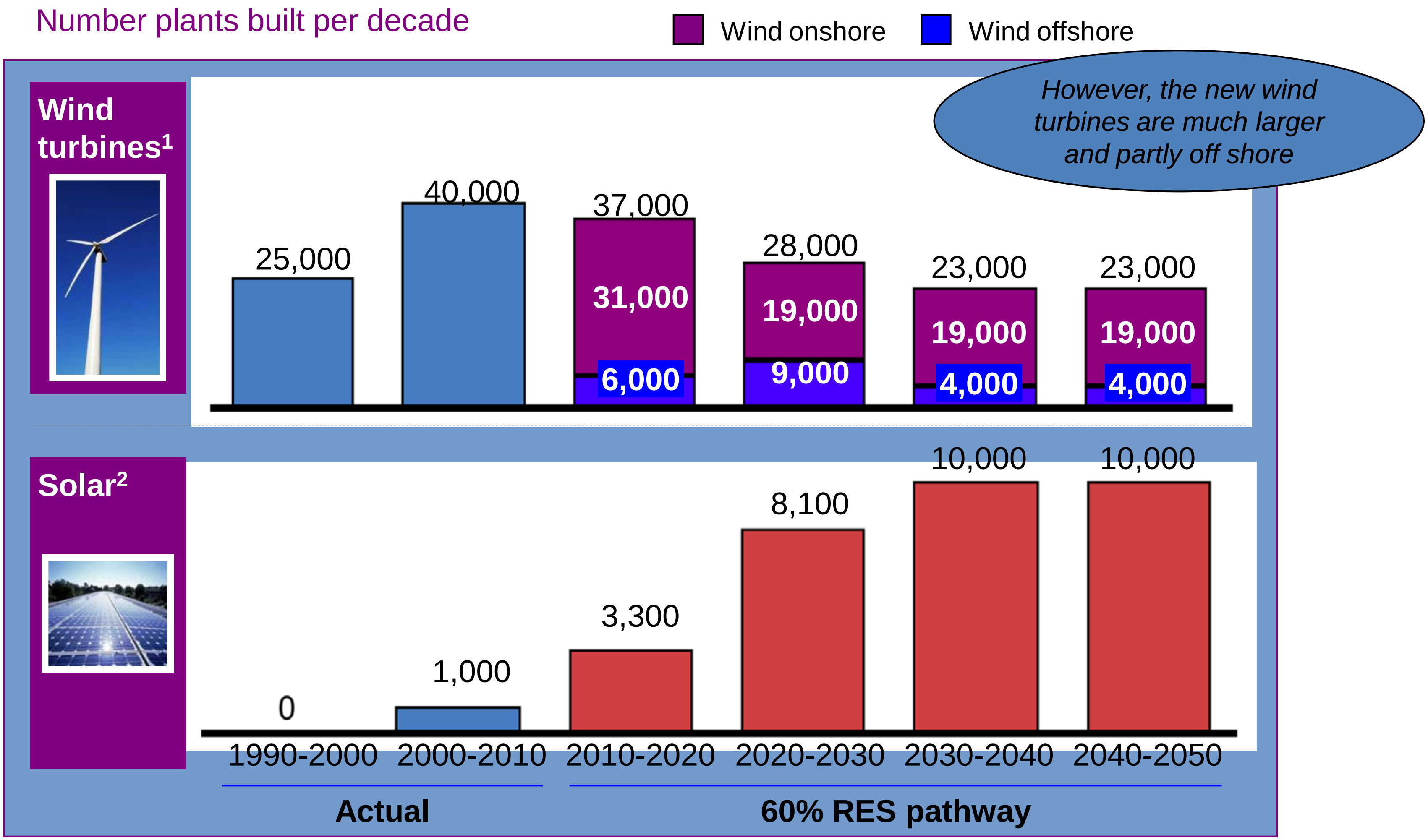
- DR also reduces the need for additional OCGT plants
- The graph shows how the original demand line (purple) is shifted to earlier during the day (red line) when more power is available to match supply

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

2050, GW



More balance between wind & solar investment as PV technology matures



1 1990 to 2010 actual data taken from BTM Consult ApS; average size of new wind turbines for wind onshore: 2.5 MW until 2020 and 3.0 MW thereafter; for wind offshore: 5.0 MW until 2020, 7 MW 2020 to 2030 and 10 MW thereafter

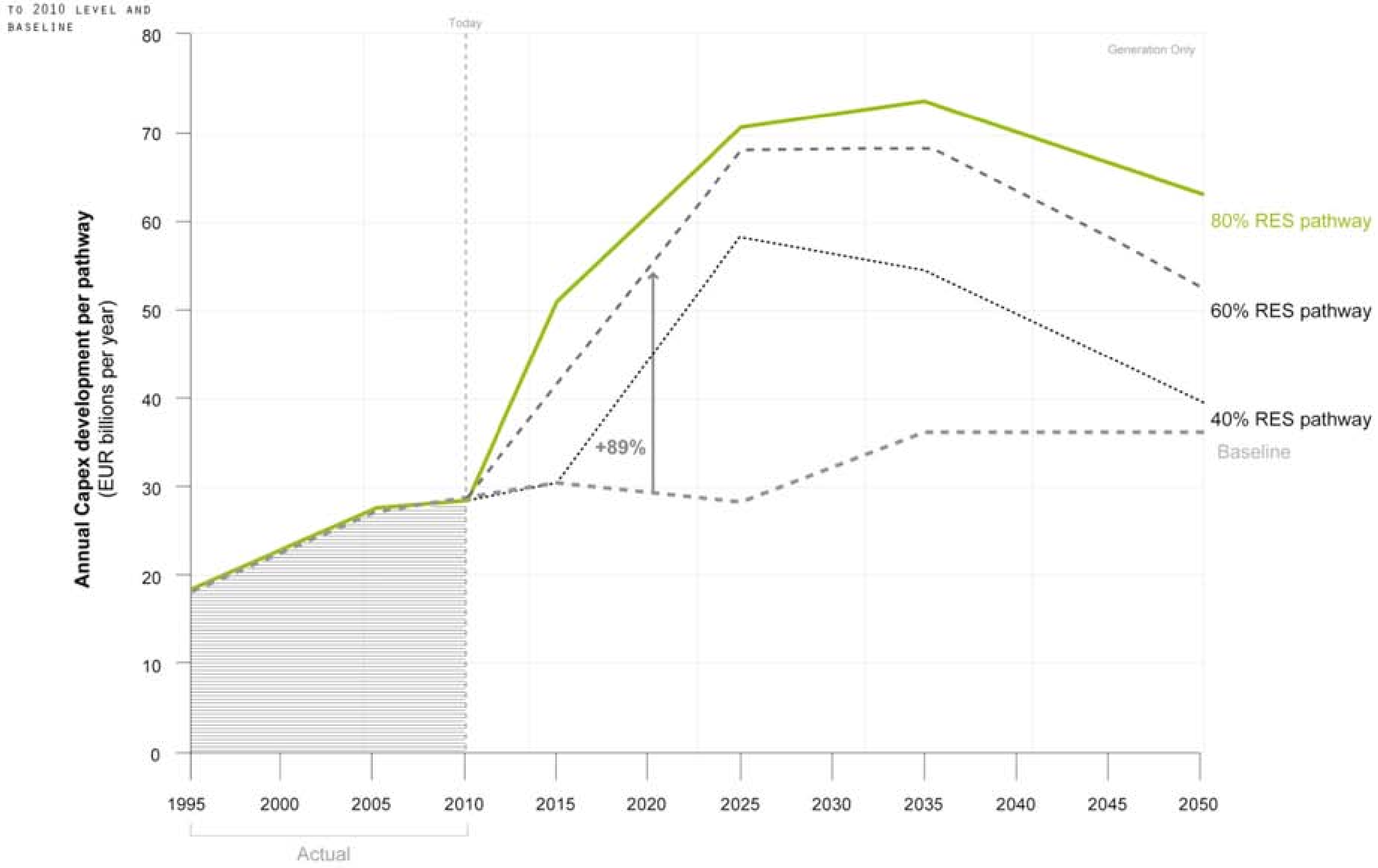
2 Average size of 20 MW per plant; buildup of 500 plants between 2005 and 2010 which leads to 1,000 plants for 2000 to 2010

3 In line with assumption of maximum annual growth per technology of 20%

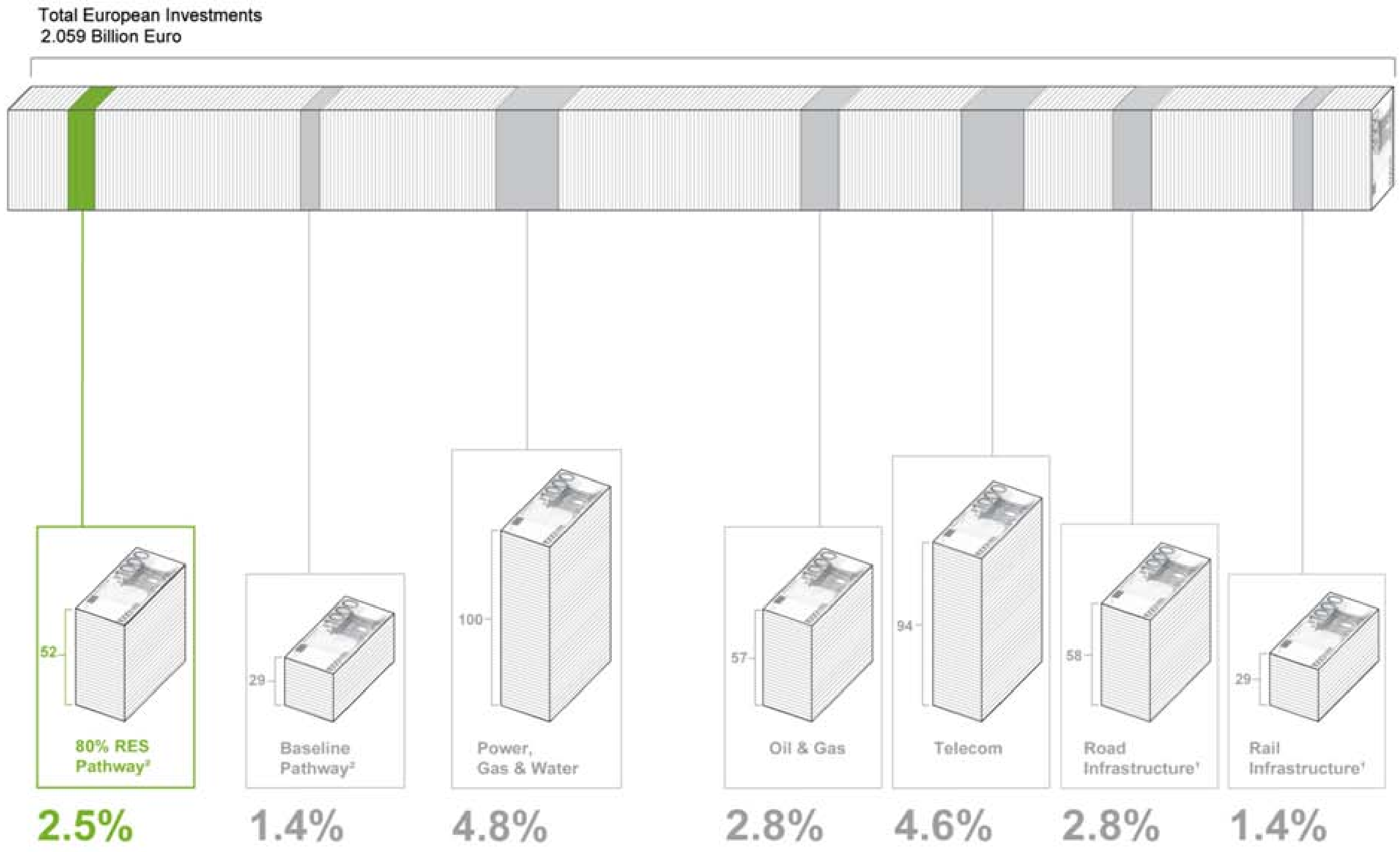
A doubling of capex would be required over the next 15 years

Annual capex development per pathway, € billions per year

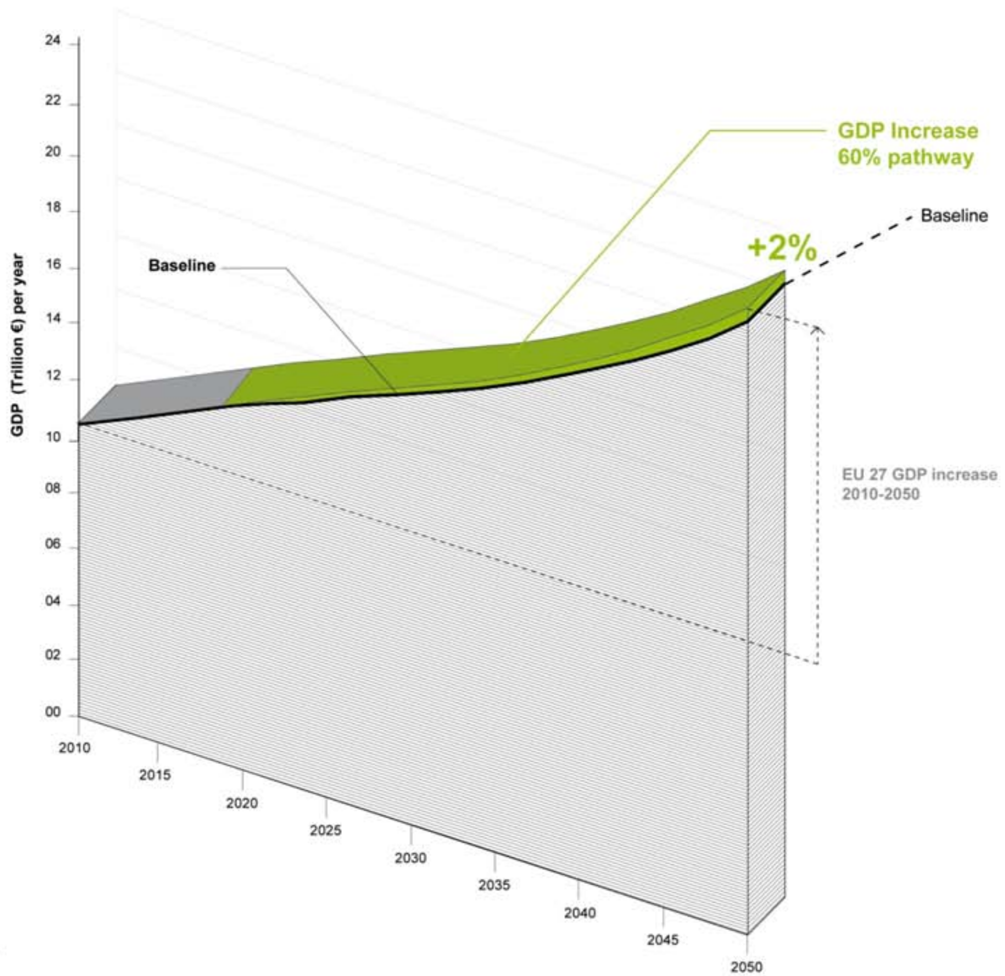
GENERATION ONLY



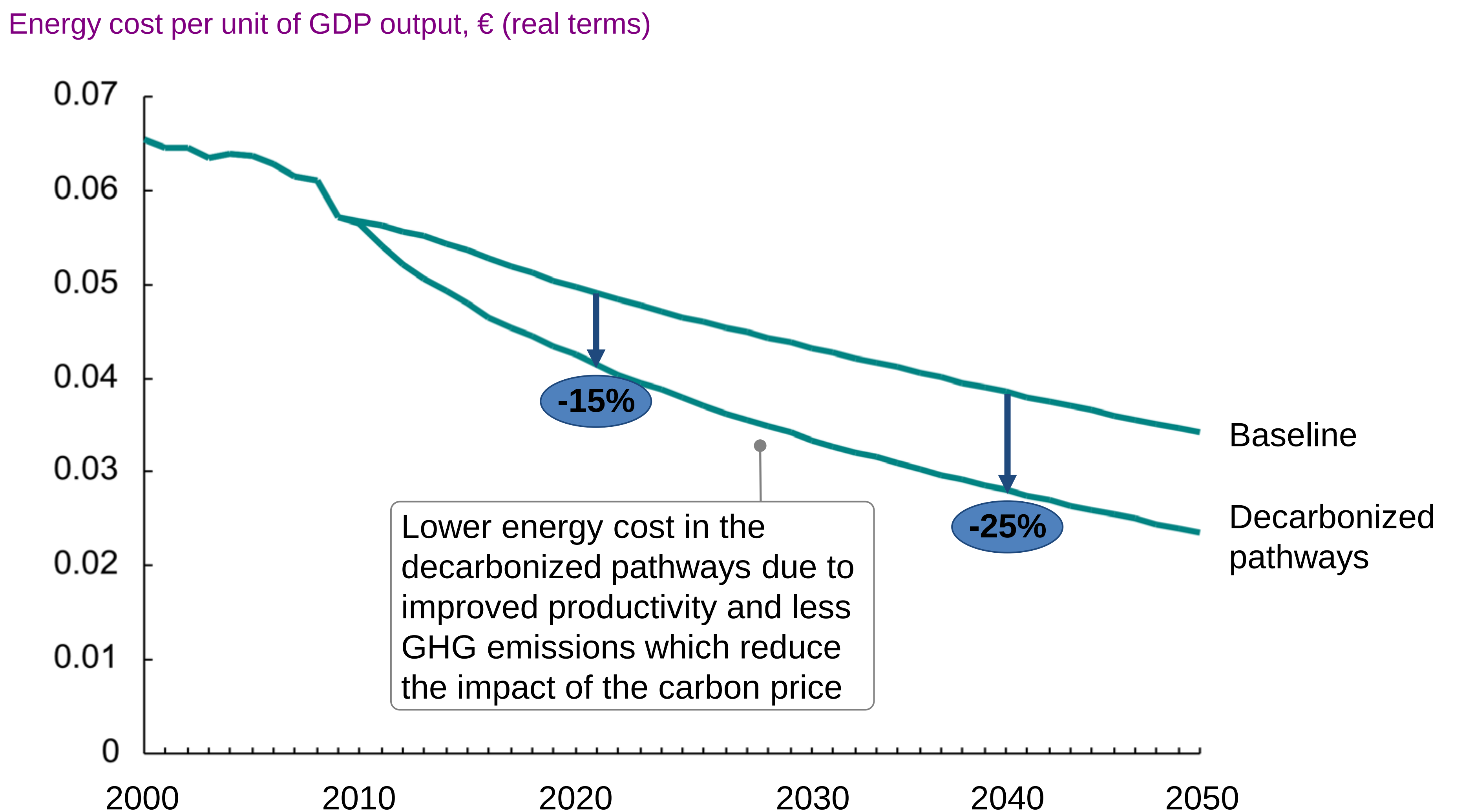
Annual capital compared to total EU capital investment



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

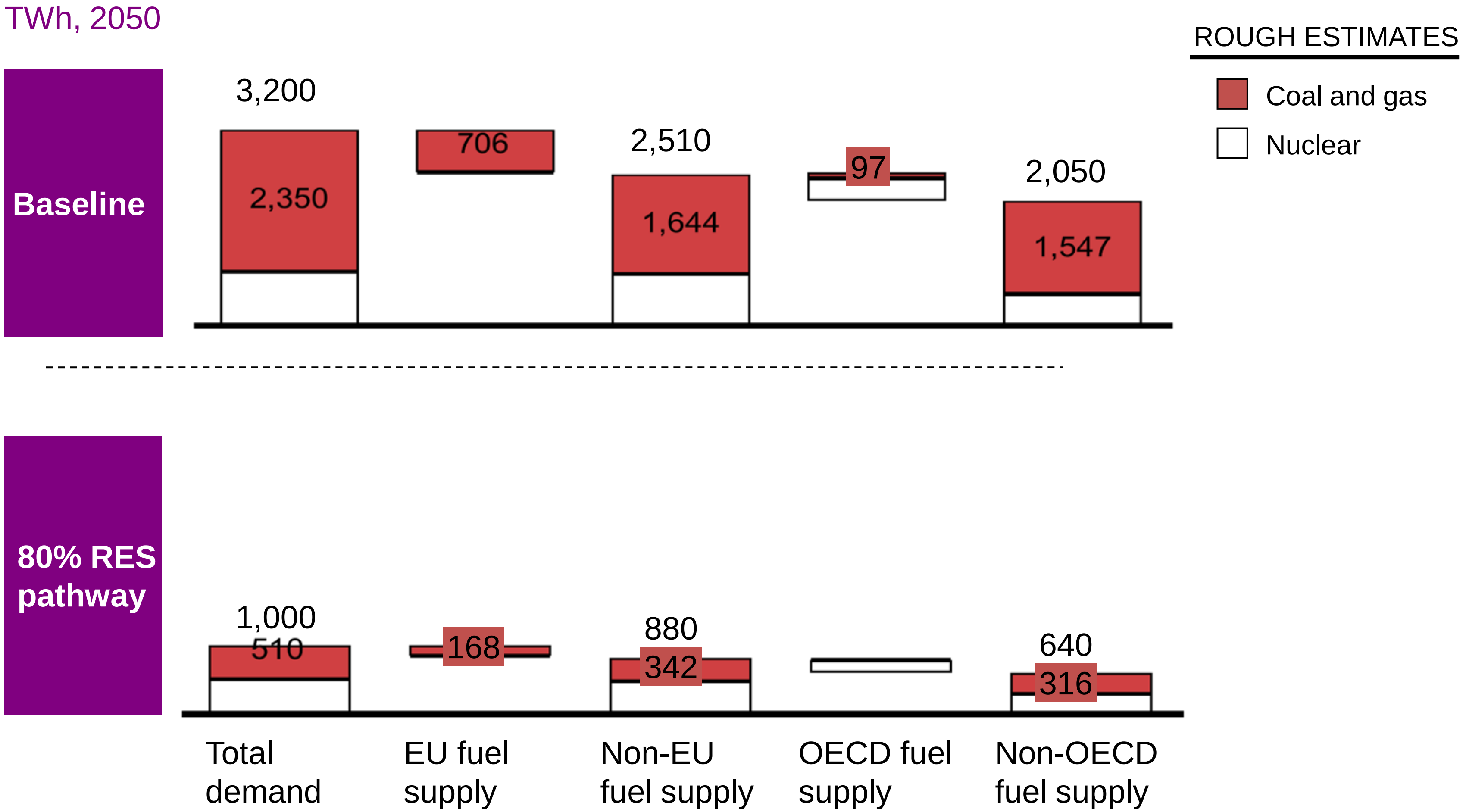


Energy cost decreases in the baseline, but even more so in the decarbonized pathways



NOTE: Energy prices are a weighted average of prices faced by consumers weighted by the shares of consumption of different fuels

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

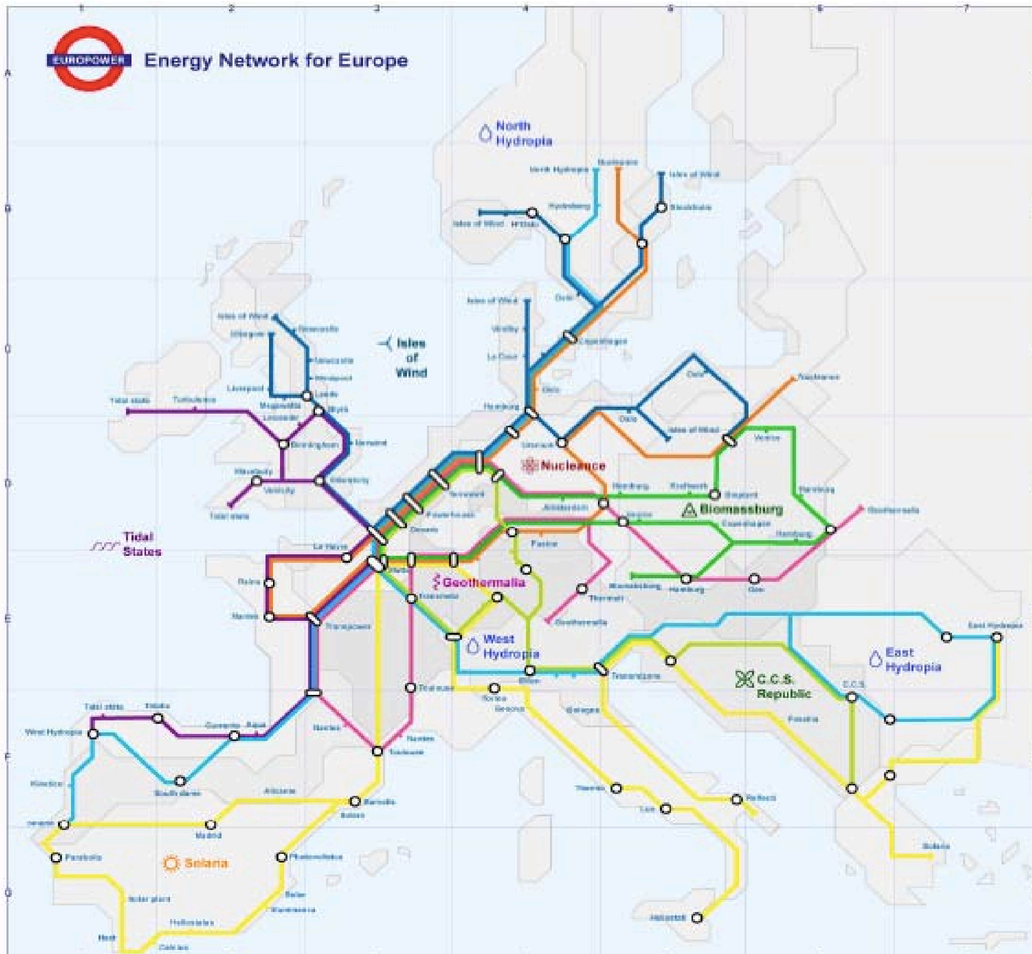


Availabilities 2050: biomass: 90% EU-27, 10% Non-OECD; nuclear: 2% EU-27, 43% OECD, 55% Non-OECD; coal: 50% EU-27; 10% OECD, 40% Non-OECD; gas: 16% EU-27, 0% OECD, 84% Non-OECD

Key emerging challenges for the EU

- Step change in energy efficiency
- Technology commercialisation
- Creating strategic EU power network (wide-area integration + demand-side activation)
- The future of ETS, complementary measures and market reform

What real energy security looks like…



About RAP

The Regulatory Assistance Project (RAP) is a global, non-profit team of experts that focuses on the long-term economic and environmental sustainability of the power and natural gas sectors. RAP has deep expertise in regulatory and market policies that:

- Promote economic efficiency
- Protect the environment
- Ensure system reliability
- Allocate system benefits fairly among all consumers

Learn more about RAP at www.raponline.org

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