ROADMAP 2050

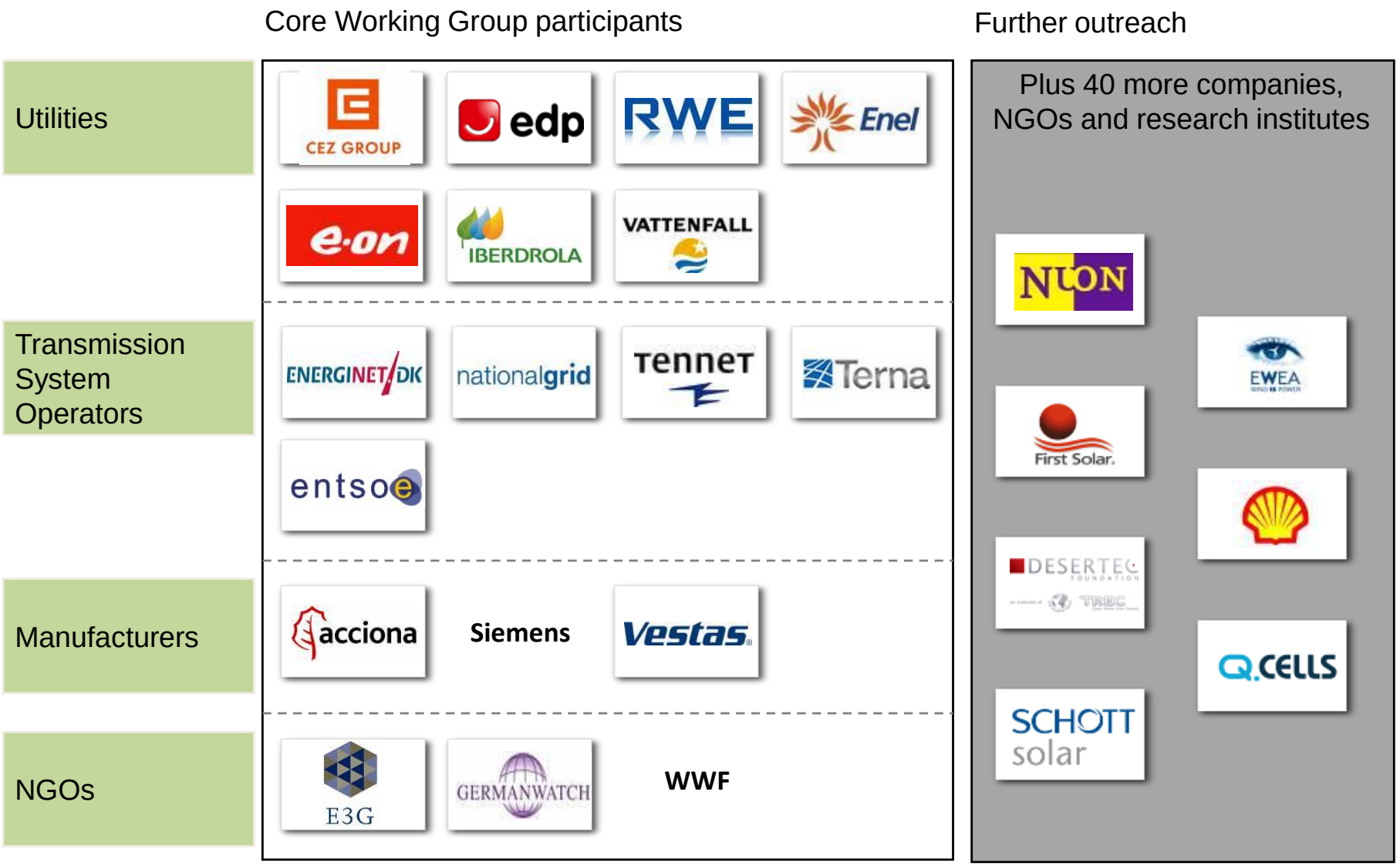
A Practical Guide to a Prosperous, Low-Carbon Europe

The mission of Roadmap 2050 is to provide a practical, independent and objective analysis of pathways to achieve a low-carbon economy in Europe, in line with the energy security, environmental and economic goals of the European Union.

ROADMAP 2050 PARTNERS

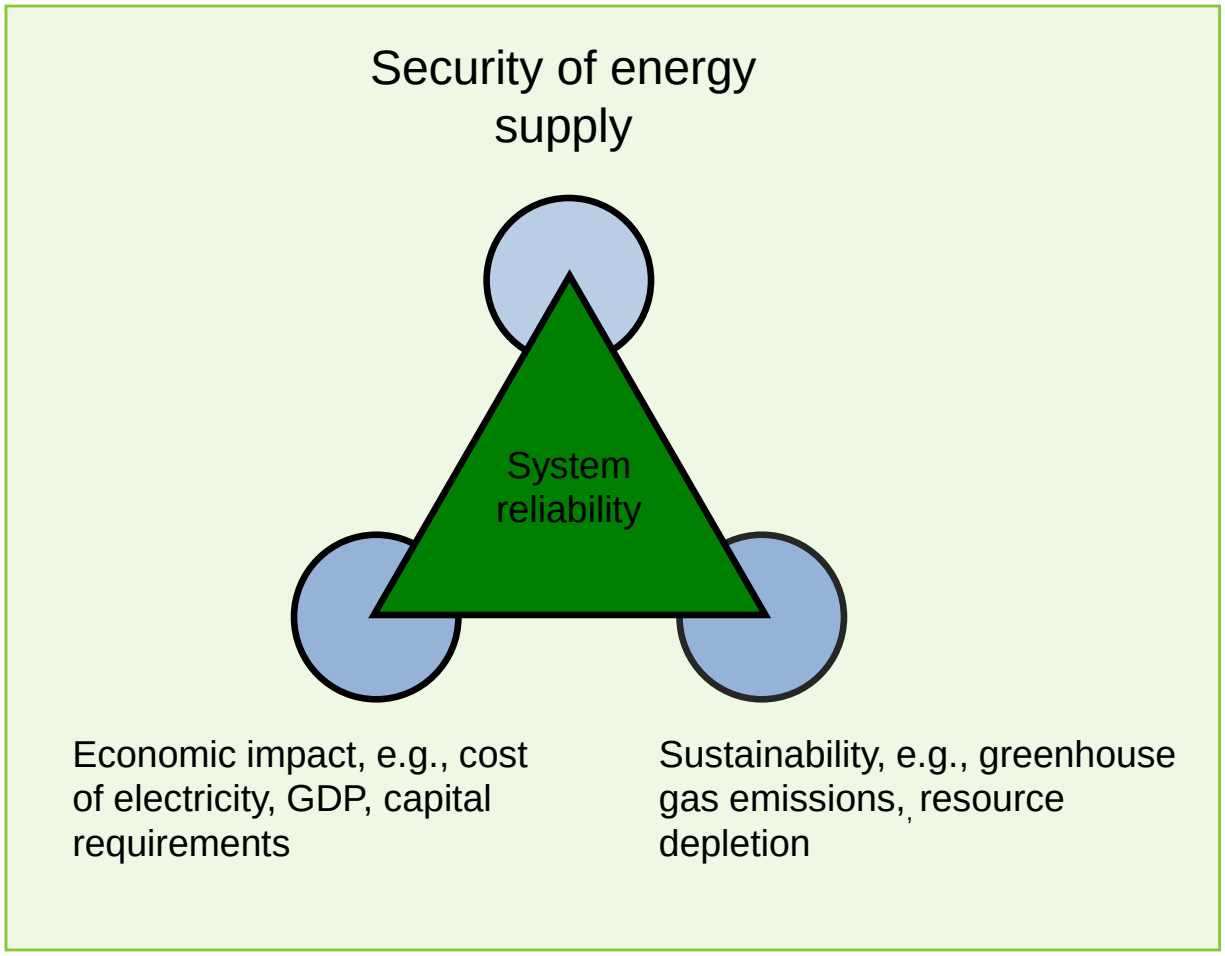
	ECF (Philanthropic European climate foundation)	■ Overall sponsor and funder
Volume 1	McKinsey & Company (Strategic consultancy)	■ Overall content analysis, project management, data collection ■ Reach out to industries, workshop facilitation
Volume 1	KEMA (Technical grid consultancy)	■ Grid design and 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

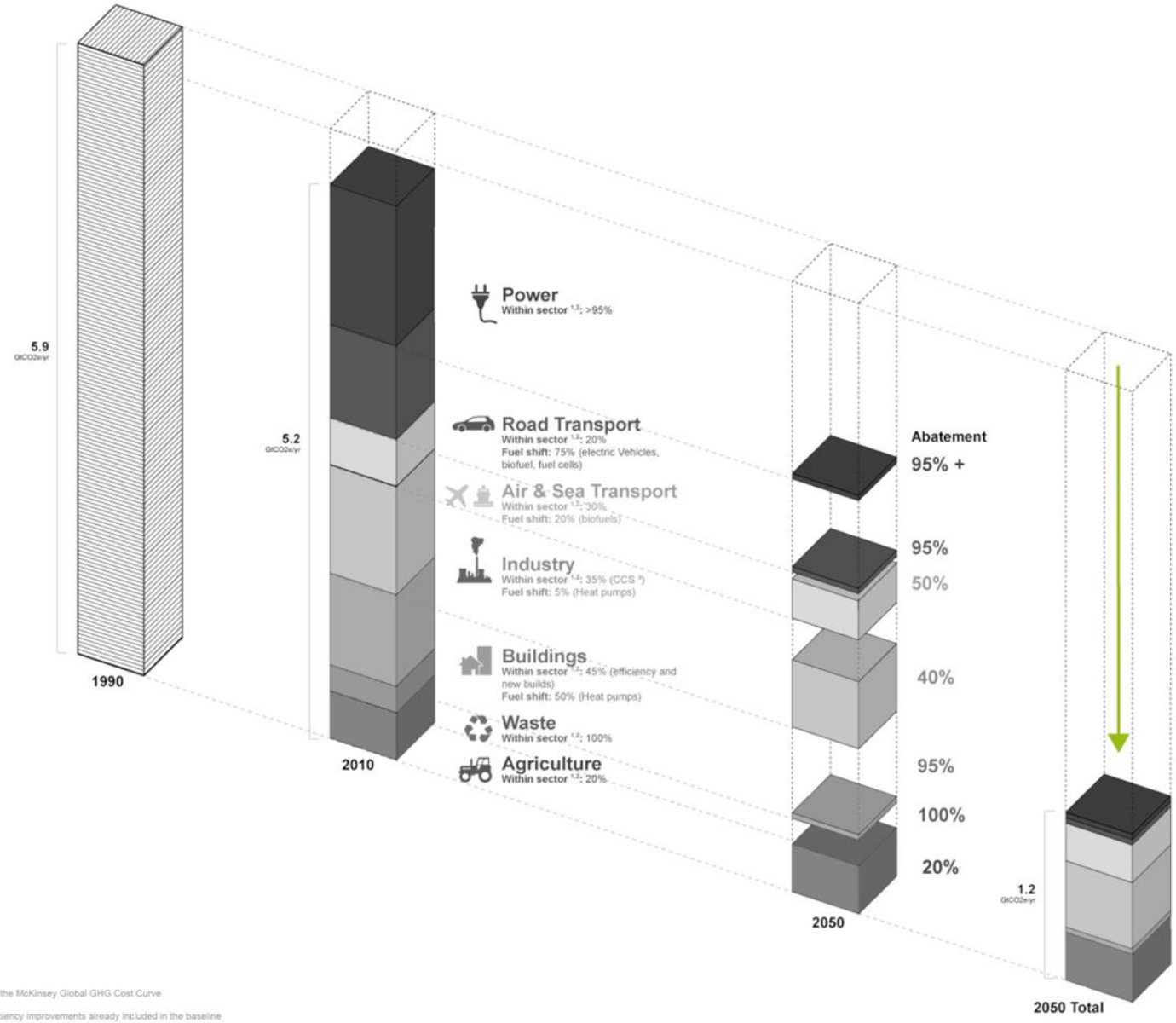


THE DECARBONIZATION PATHWAYS SHOULD BE SUSTAINABLE, TECHNICALLY FEASIBLE AND HAVE POSITIVE IMPACT ON THE ECONOMY

Assessment criteria



80% CO2 EMISSION REDUCTION



THE 80% CO2 REDUCTION OVERALL IMPLIES 90-95% REDUCTION IN POWER, ROAD TRANSPORT AND BUILDINGS. THIS COULD BE ACHIEVED BY MAXIMUM ABATEMENT WITHIN AND ACROSS SECTORS. NOTE: THIS LEVEL OF DECARBONIZATION IS DEPENDENT ON ACHIEVING AGGRESSIVE 2% YEAR ON YEAR ENERGY EFFICIENCY SAVINGS, WITHOUT WHICH THIS LEVEL OF ABATEMENT IS NOT POSSIBLE IN THIS MODEL.

1 Based on the McKinsey Global GHG Cost Curve

2 Large efficiency improvements already included in the baseline

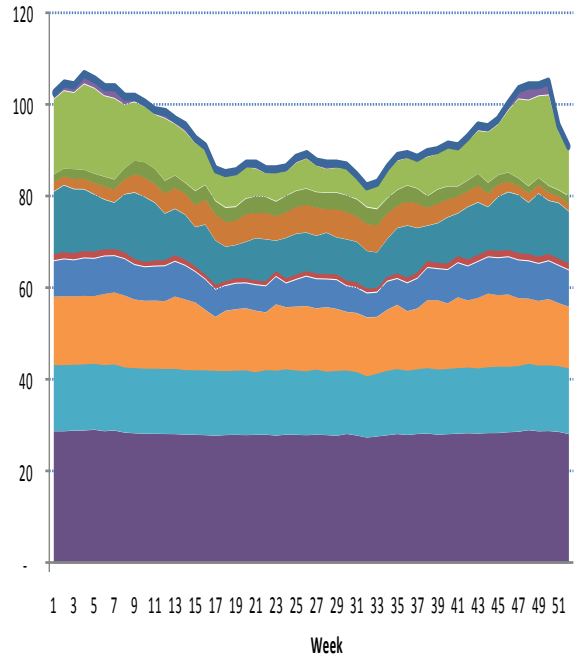
3 CCS applied to 50% of industry (cement, chemistry, iron and steel, petroleum and gas, not applied to other industries)

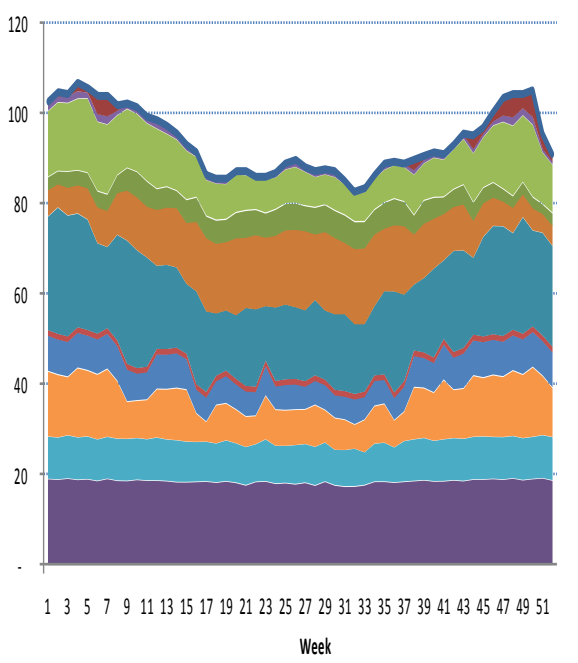
SOURCE: McKinsey Global GHG Abatement Cost Curve; IEA WEO 2009; US EPA; EEA; Roadmap 2050 Technical Analysis

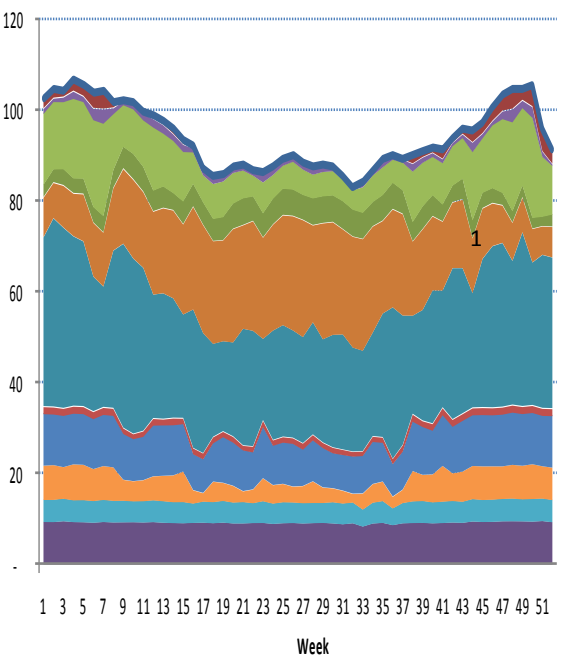
THREE SPECIFIC PATHWAYS MODELLED INCLUDING BOTH GENERATION AND GRID COSTS

Energy production mix over the year, TWh per week

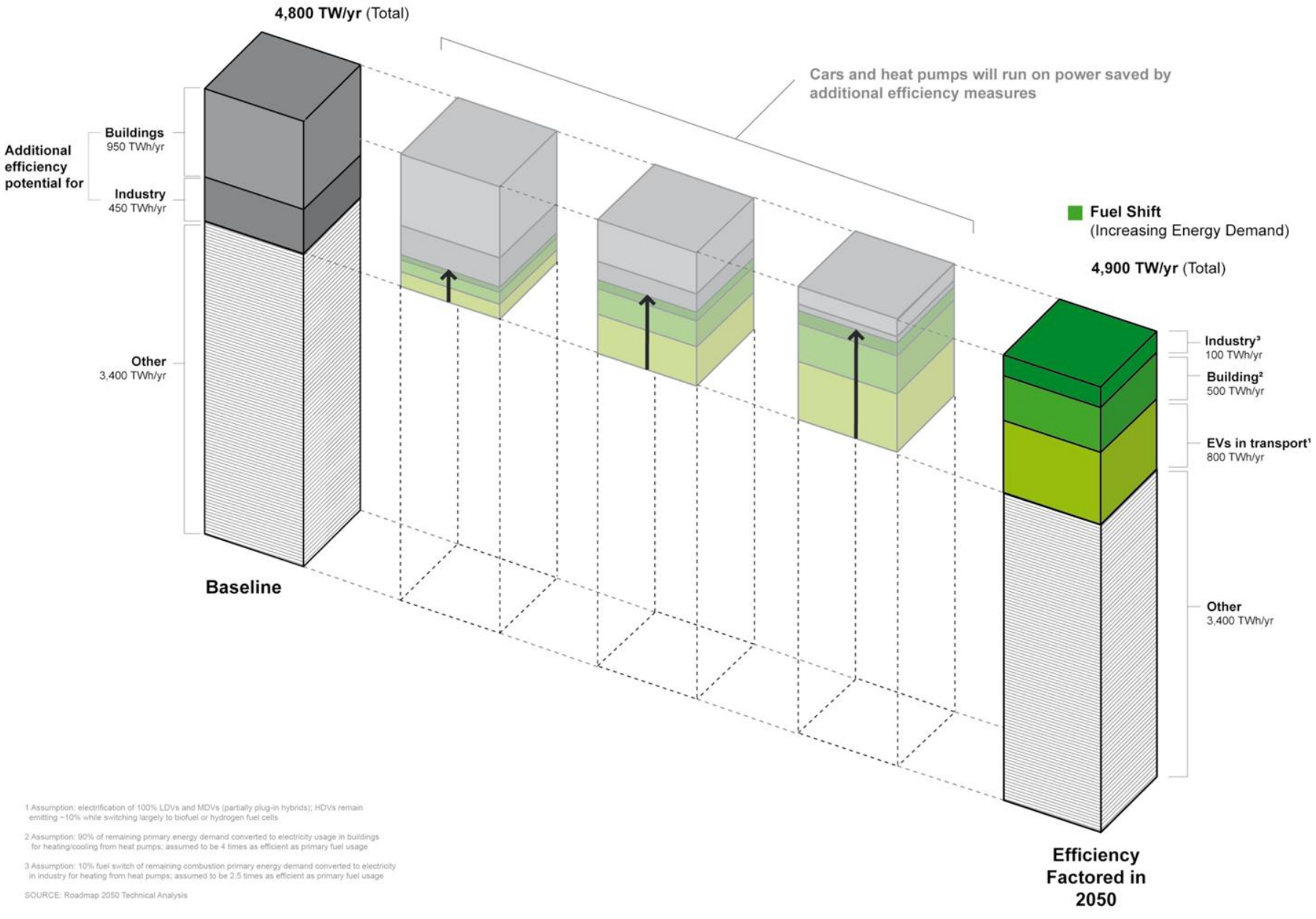
40% RES 30% CCS 30% nuclear	60% RES 20% CCS 20% nuclear	80% RES 10% CCS 10% nuclear







ENERGY EFFICIENCY & FUEL SHIFT BALANCE DEMAND



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

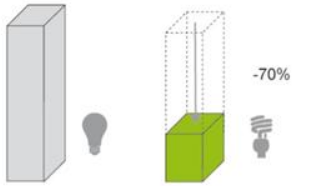
2 Assumption: 90% of remaining primary energy demand converted to electricity usage in buildings for heating/cooling from heat pumps; assumed to be 4 times as efficient as primary fuel usage

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: Roadmap 2050 Technical Analysis

ADDED EFFICIENCY BENEFITS

REDUCE ENERGY CONSUMPTION[1]

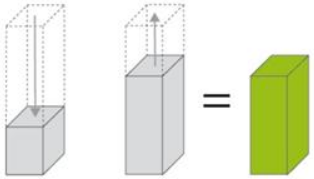


Incandescent light bulb

Low-energy bulb

THE OVERALL ABILITY OF THE EU TO DECARBONISE IS DEPENDENT ON ACHIEVING AGGRESSIVE ENERGY EFFICIENCY SAVINGS.

OFFSET INCREASING ENERGY DEMAND



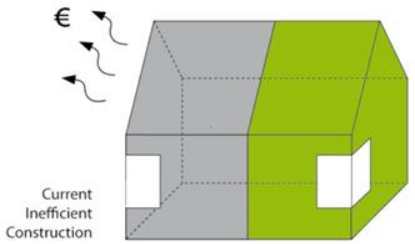
Efficiency Reduction

Demand Increase

2050 Demand + Efficiency

WITHOUT ENERGY EFFICIENCY SAVINGS, ENERGY DEMAND WILL INCREASE AND IT WILL BE HARDER AND MORE EXPENSIVE TO MEET THAT DEMAND.

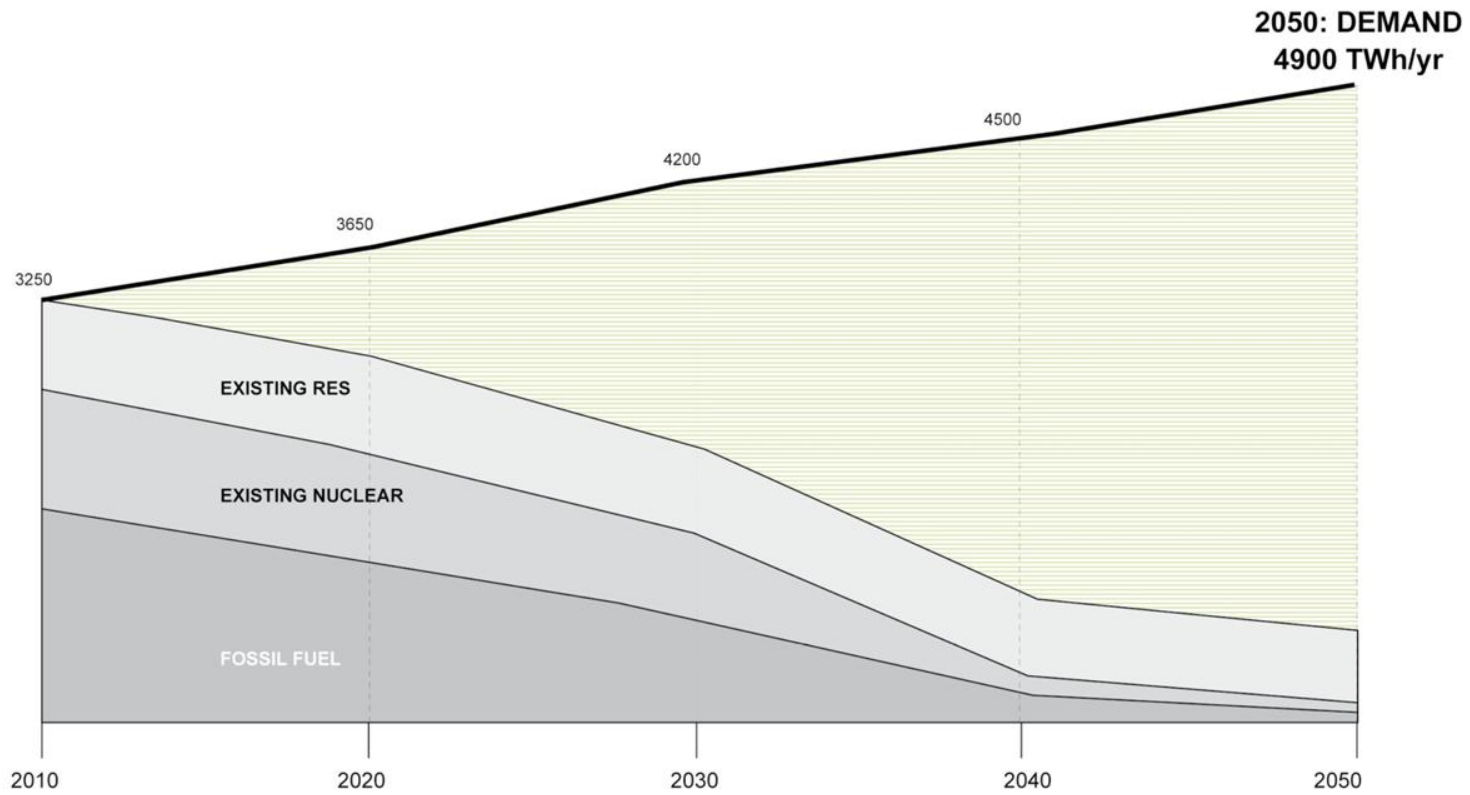
INCREASE ENERGY EFFICIENCY SAVINGS[2]



ENERGY EFFICIENCY SAVINGS SHOULD BE PURSUED URGENTLY. THEY CAN BE MADE NOW, AND THE MAJORITY ARE CHEAPER THAN BUILDING NEW. THIS IS HAS A SPECIFIC IMPACT ON CO2 EMISSIONS IF IT IS UNABATED FOSSIL GENERATION THAT IS BEING BUILT TO MEET DEMAND THAT COULD HAVE BEEN MET BY ENERGY SAVINGS.

1) Compact fluorescent lamps (CFLs) use about 70% less electricity to produce the same light as a normal bulb, cutting greenhouse gas by over 50%. SOURCE: www.bbc.co.uk/bloom
2) SOURCE: Roadmap 2050 Technical Analysis
3) Buildings are responsible for 40% of energy consumption and 36% of EU CO2 emissions. Energy performance of buildings is key to achieve the EU Climate & Energy objectives SOURCE: www.ec.europa.eu/energy/efficiency

ELECTRICITY DEMAND 2050
(EU27 PLUS NORWAY & SWITZERLAND)

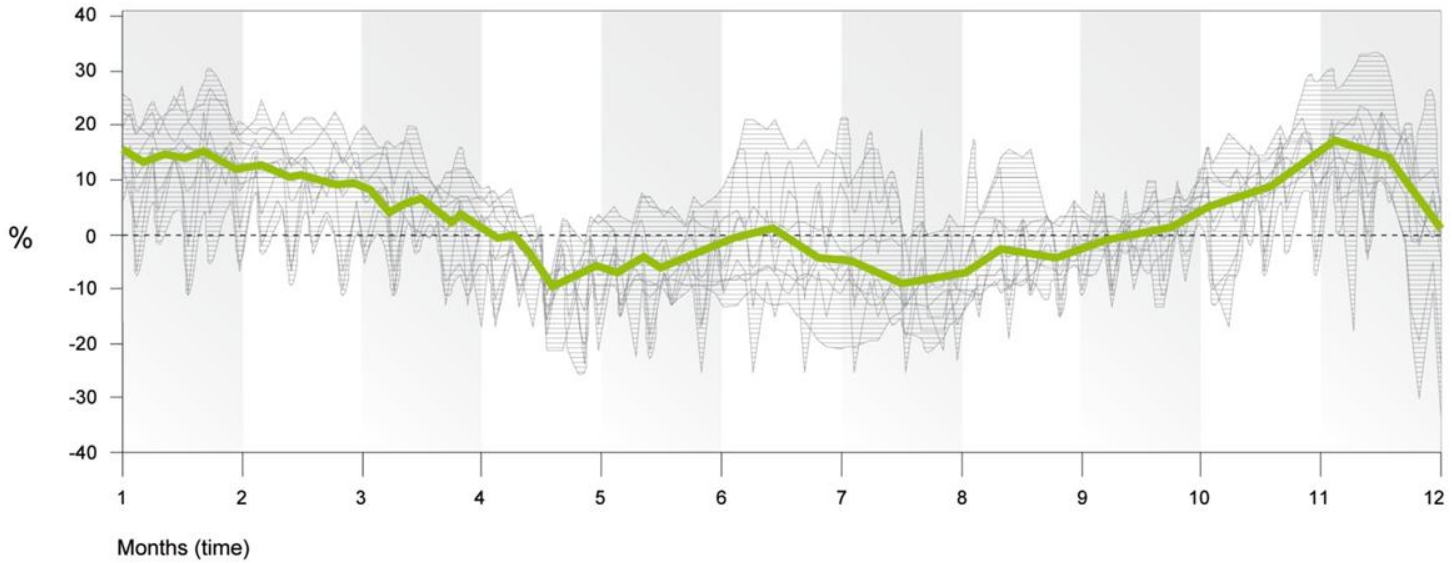


Note Existing capacity includes new builds until 2010

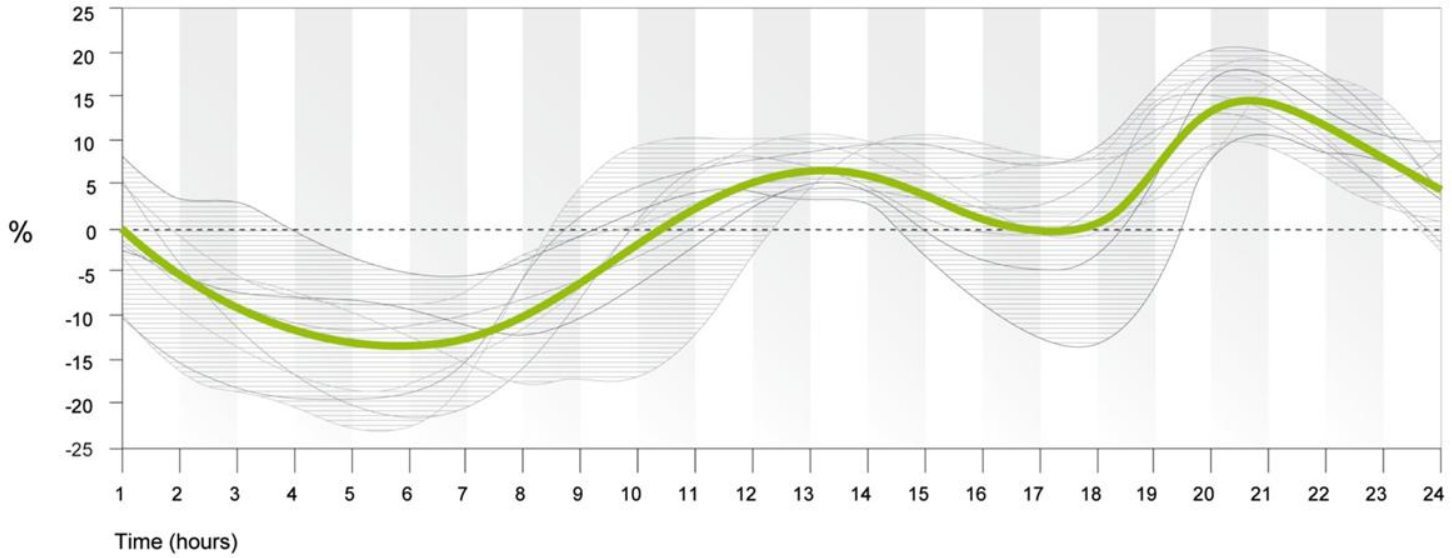
SOURCE: Roadmap 2050 Technical Analysis
(McKinsey Power Generation Model)

COMBINING REGIONAL DEMAND CURVES REDUCES VOLATILITY

Regional demand variation from average over the year

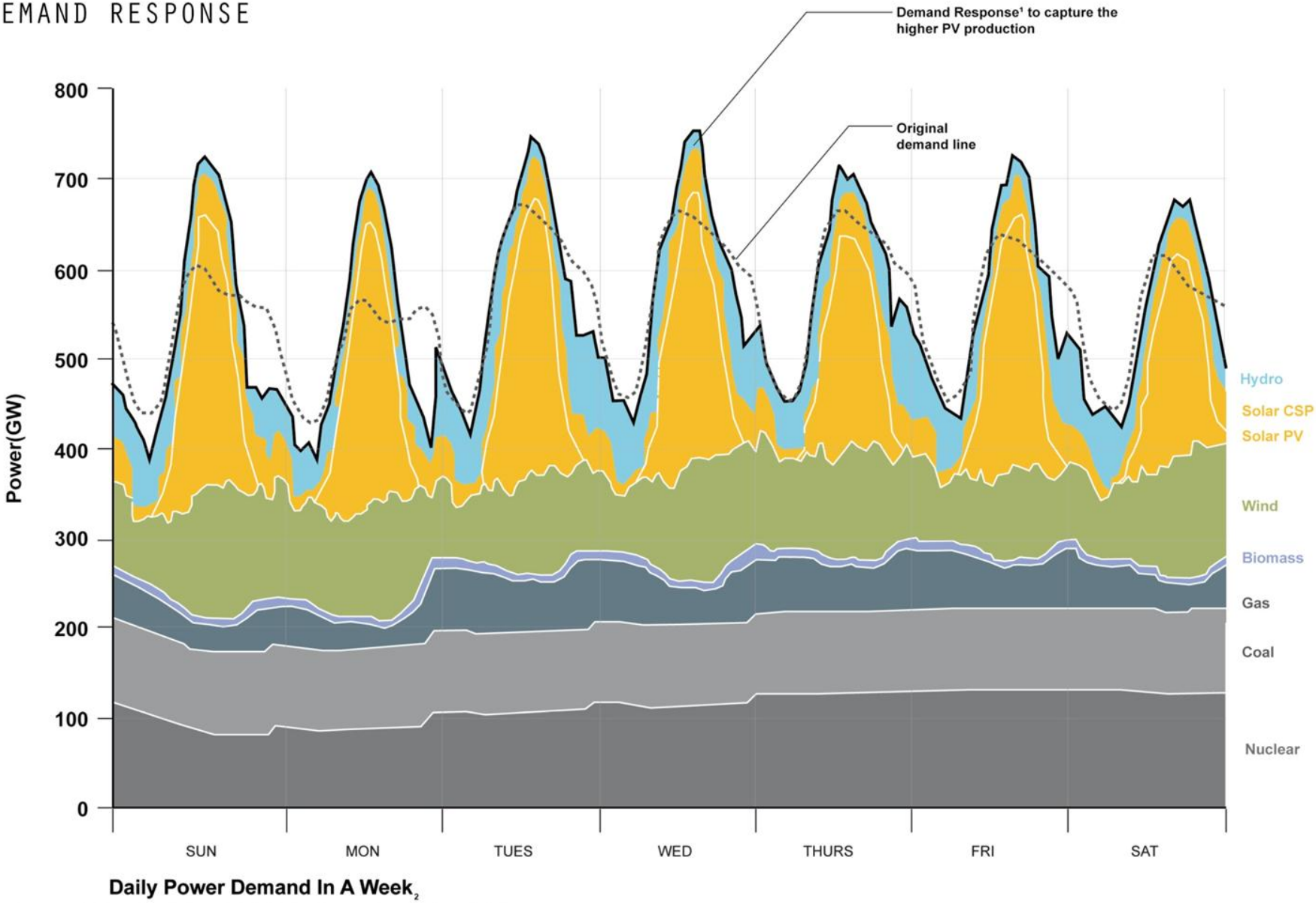


Regional demand variation from average per hour on weekend day



SOURCE: Roadmap 2050 Technical Analysis

DEMAND RESPONSE



Daily Power Demand In A Week[2]

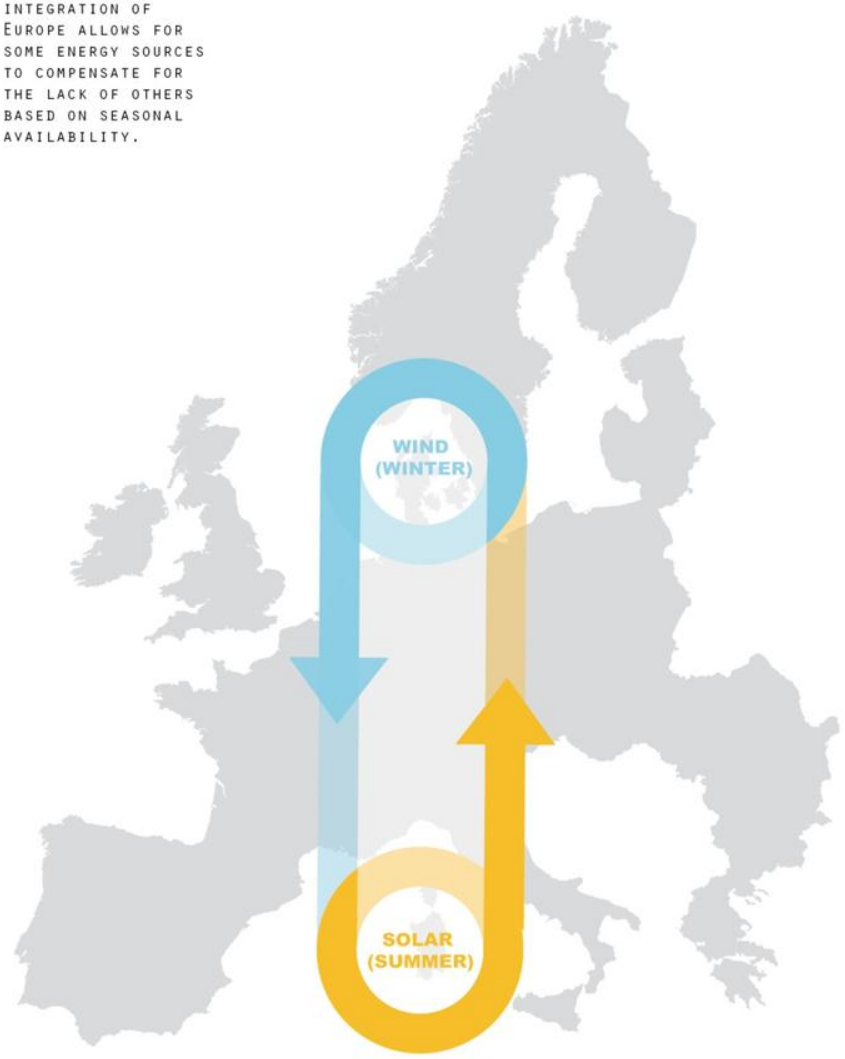
"Demand response as used in this paper refers to changing a customer's electricity demand in response to dispatch instructions or price signals through communications technologies. In the Volume 1 analysis, it is assumed that any such changes retained the total energy consumed within the day, that is, moved or shifted demand rather than reduced total daily consumption"

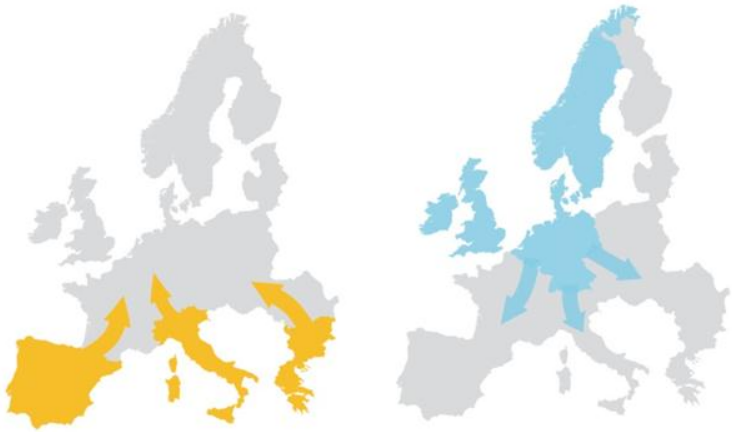
1) The graph shows how the original demand line (dashed) is shifted to a higher level (black line) by DR to capture the higher PV production
2) 60% RES, 20% DR, Week 32 - Sunny week

SOURCE: Roadmap 2050 Technical Analysis

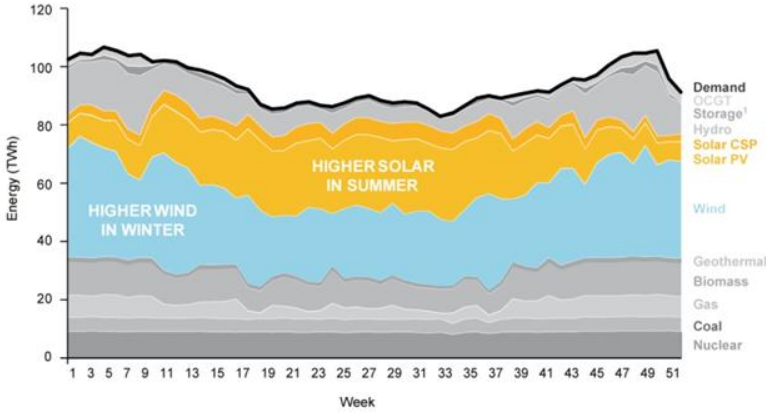
RES DIVERSITY CONTRIBUTES TO CONSISTENT SUPPLY

Over the course of the year, the integration of Europe allows for some energy sources to compensate for the lack of others based on seasonal availability.





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: Imperial College, KEMA, Roadmap 2050 Technical Analysis

INTER-REGIONAL TRANSMISSION REQUIREMENTS

Compared to current transmission infrastructure, the requirements for transmission capacity between the regions defined in the technical report are significant.

2010
Existing Capacity

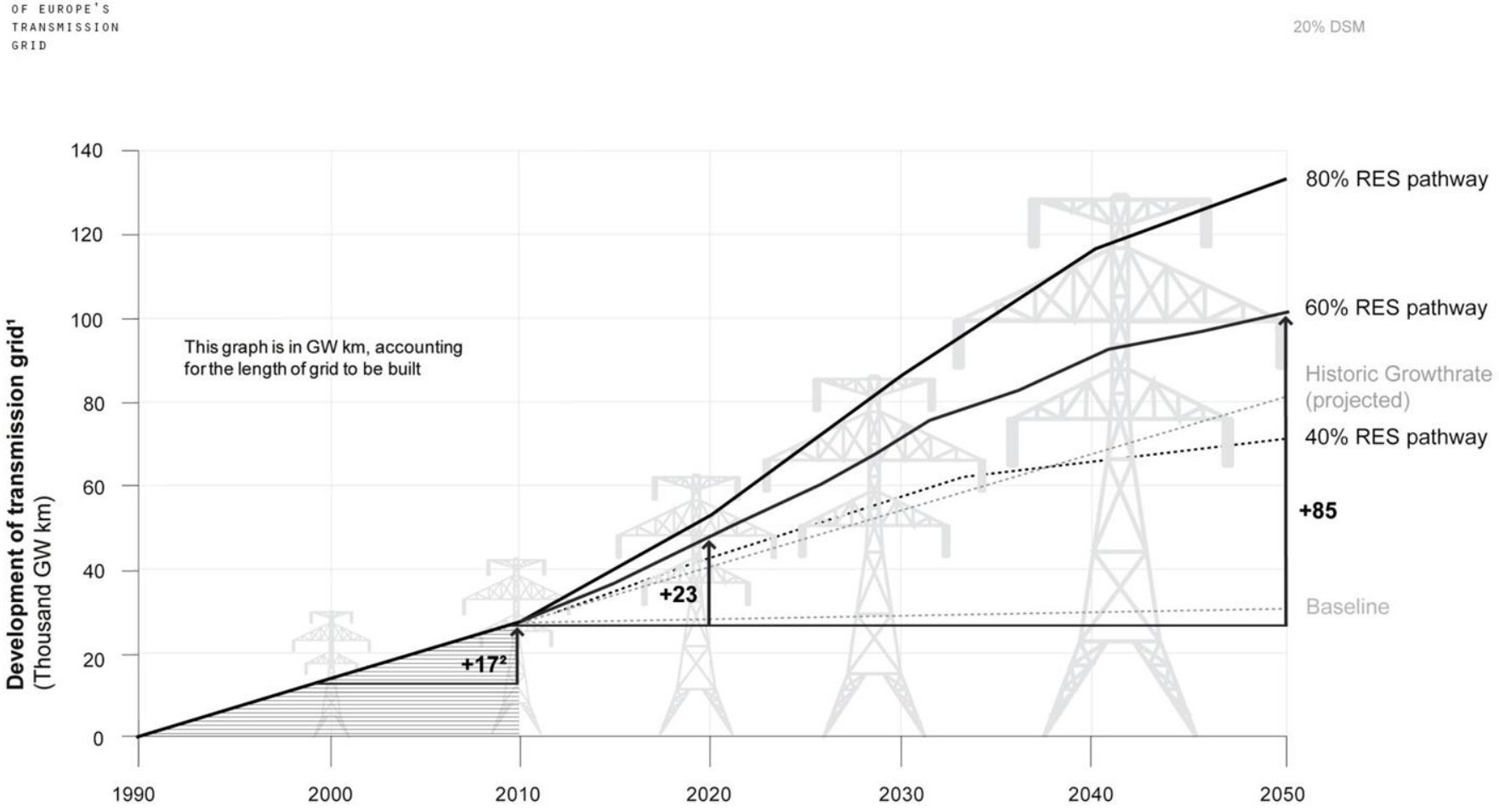
2050
Total Transmission Requirements
Assuming 80% RES & 20% DR[1]

1GW
10GW
20GW

1 Demand response as used in this paper refers to changing a customer's electricity demand in response to dispatch instructions or price signals through communications technologies. In the Volume 1 analysis, it is assumed that any such changes retained the total energy consumed within the day, that is, moved or shifted demand rather than reduced total daily consumption
NOTE: Iberia-France link is challenging and maybe reduced by different solar/wind mix.
SOURCE: Roadmap 2050 Technical Analysis

INCREASE IN GRID CAPACITY

THE ROADMAP REQUIRES SIGNIFICANT DEVELOPMENT OF EUROPE'S TRANSMISSION GRID

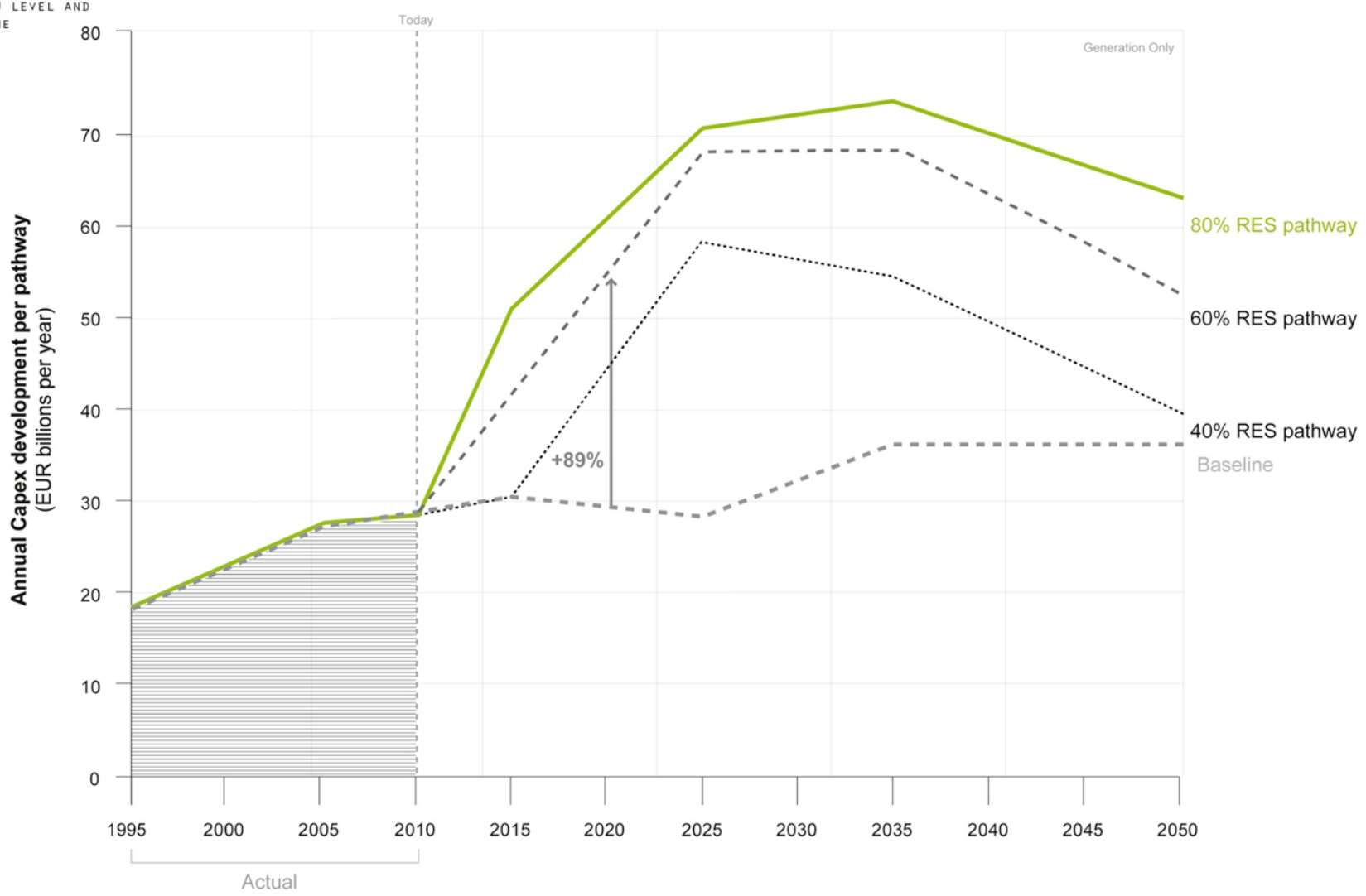


1 Development of grid is assumed to be driven by the penetration of intermittent power sources (solar PV, wind onshore and wind offshore)
2 This assumes a linear build up of grid capacity in thousand GW km between 1990 and 2010, starting at zero, although some grid has been built even before 1990, i.e. UK-France and much of the Central European interconnections

SOURCE: Roadmap 2050 Technical Analysis

ANNUAL CAPEX DEVELOPMENT

In the 60% RES pathway, annual capex requirements increase by 89% until 2020 compared to 2010 level and baseline

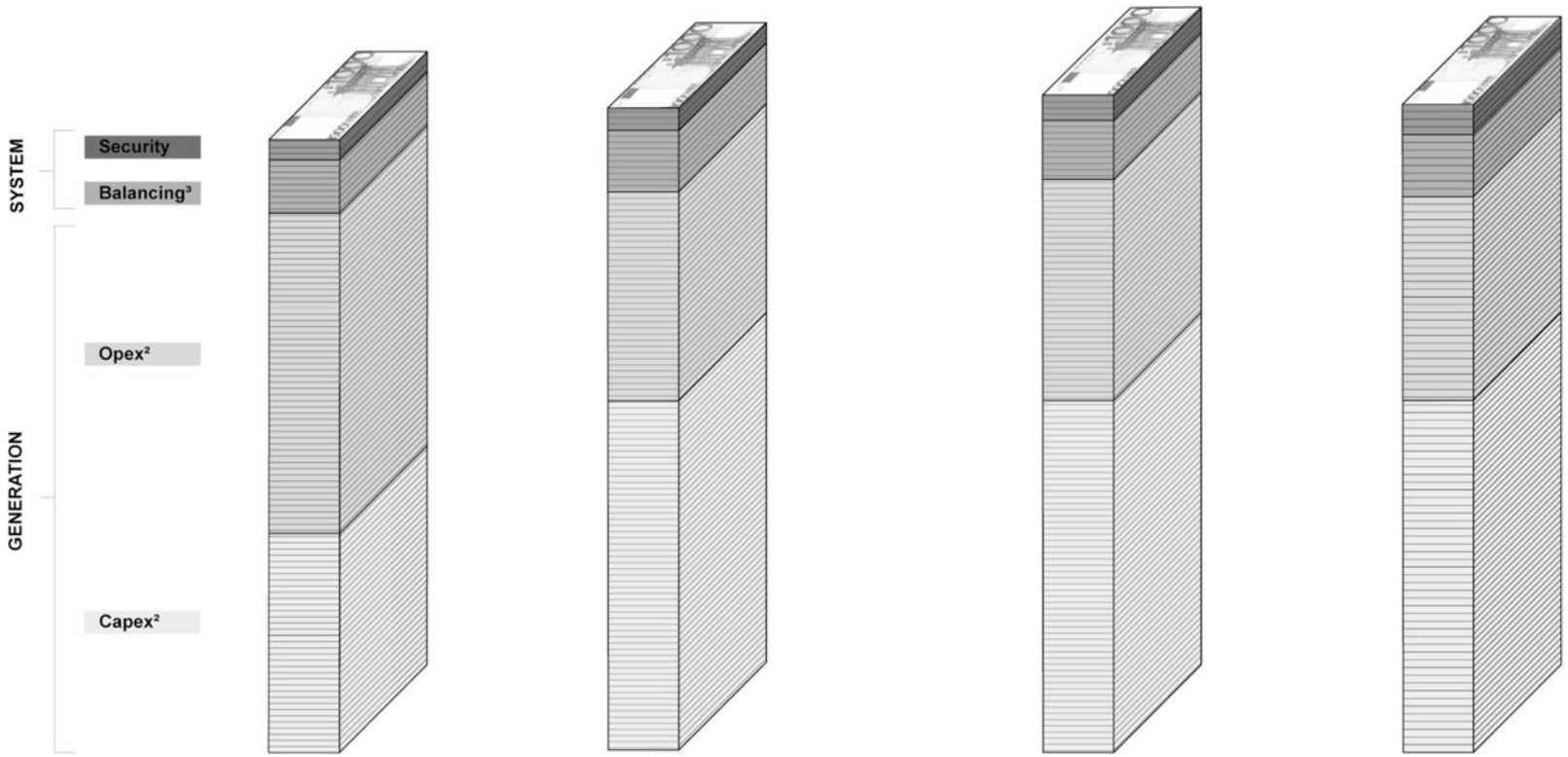


A doubling of capital spend would be required over the next 15 years
SOURCE: Roadmap 2050 Technical Analysis

COST OF ELECTRICITY

THE HIGHER CAPITAL COST IS OFFSET BY A LOWER OPERATIONAL COST.

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

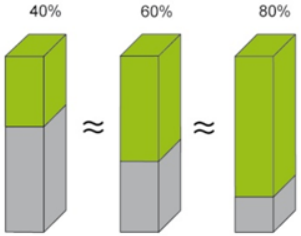


1 Weighted average based on the CoE in each 10-year time frame (2010, 2020, 2030, 2040, 2050)
2 Generation only
3 Cost related to non optimal plant use, system dispatch cost for secure operation, running backup plants, storage losses, reserve and response cost
4 Transmission and additional generation capex as well as fixed opex for transmission and backup

SOURCE: Roadmap 2050 Technical Analysis

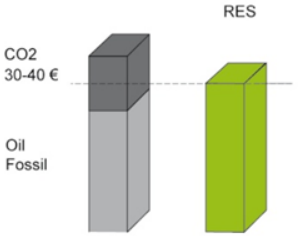
COST OF ELECTRICITY

COSTS TO CONSUMER ARE NEARLY THE SAME



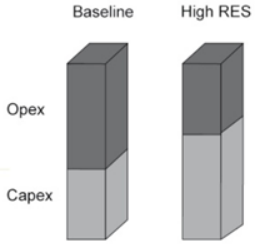
The key finding from aggregating CAPEX, OPEX, back-up and balancing costs and grid costs over the next four decades is that all three of the decarbonised pathways cost nearly/approximately the same to the consumer.

FACTORING IN A CO2 PRICE



When a CO2 price of 30-40 Euros or more is included, the price of the decarbonized pathways is the same as the baseline pathway.

HIGH RES PATHWAYS MEAN LOWER OPEX



Decarbonized pathways are characterised by higher capital expenditure and lower operating expenditure and the opposite is true in the baseline. Inevitably those pathways with higher fossil fuel dependence are more sensitive to fuel price shocks or significant increases in fuel prices. The decarbonized pathways are more sensitive to increases in weighted costs of capital and to delays in achieving expected learning rates for pre-commercial technologies.

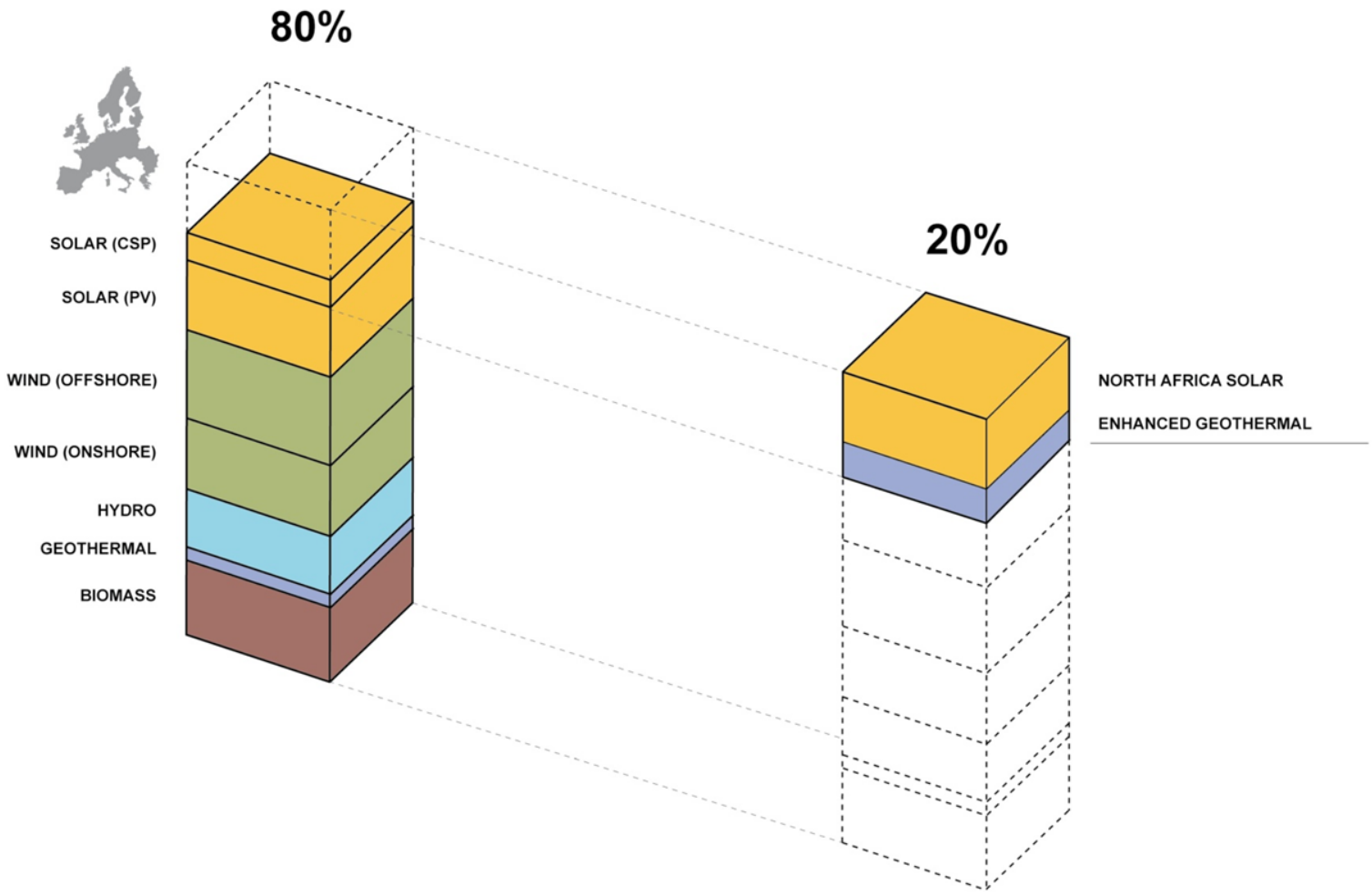
COST IS NOT A BARRIER TO DECARBONIZED PATHWAYS

We did not expect to see these results - we can conclude that critical policy decisions can be made on issues other than on the higher capital of decarbonized resources and that the transmission costs associated with high renewables penetrations are not a significant cost barrier.

SOURCE: Roadmap 2050 Technical Analysis

100% PATHWAY

ADDITIONAL CAPACITY IS REQUIRED TO REACH THE 100% RENEWABLE ENERGY PATHWAY THIS IS ACHIEVED THROUGH THE INTRODUCTION OF BREAKTHROUGH TECHNOLOGIES + SOLAR FROM N. AFRICA



SOURCE: : Roadmap 2050 Technical Analysis, Desertec

BENEFITS OF NORTH AFRICAN SOLAR

Both the EU-27 and North Africa will benefit from their introduction into the European Energy grid.

EU-27:

Consistent source of renewable electrical power

100% Renewable energy supply

NORTH AFRICA:

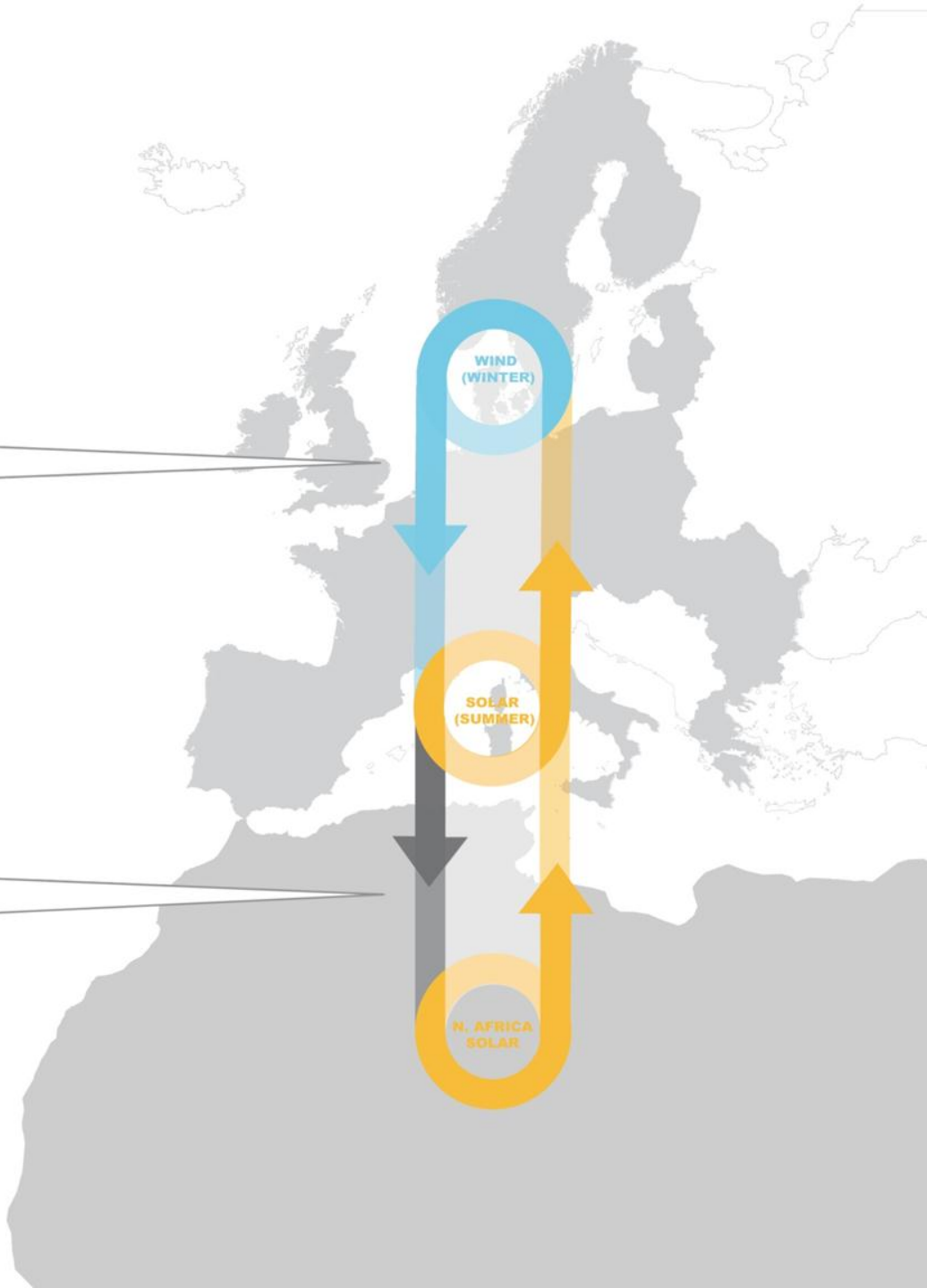
Consistent source of renewable electrical power

Water from solar powered desalination

Revenue source that will not run out

New jobs

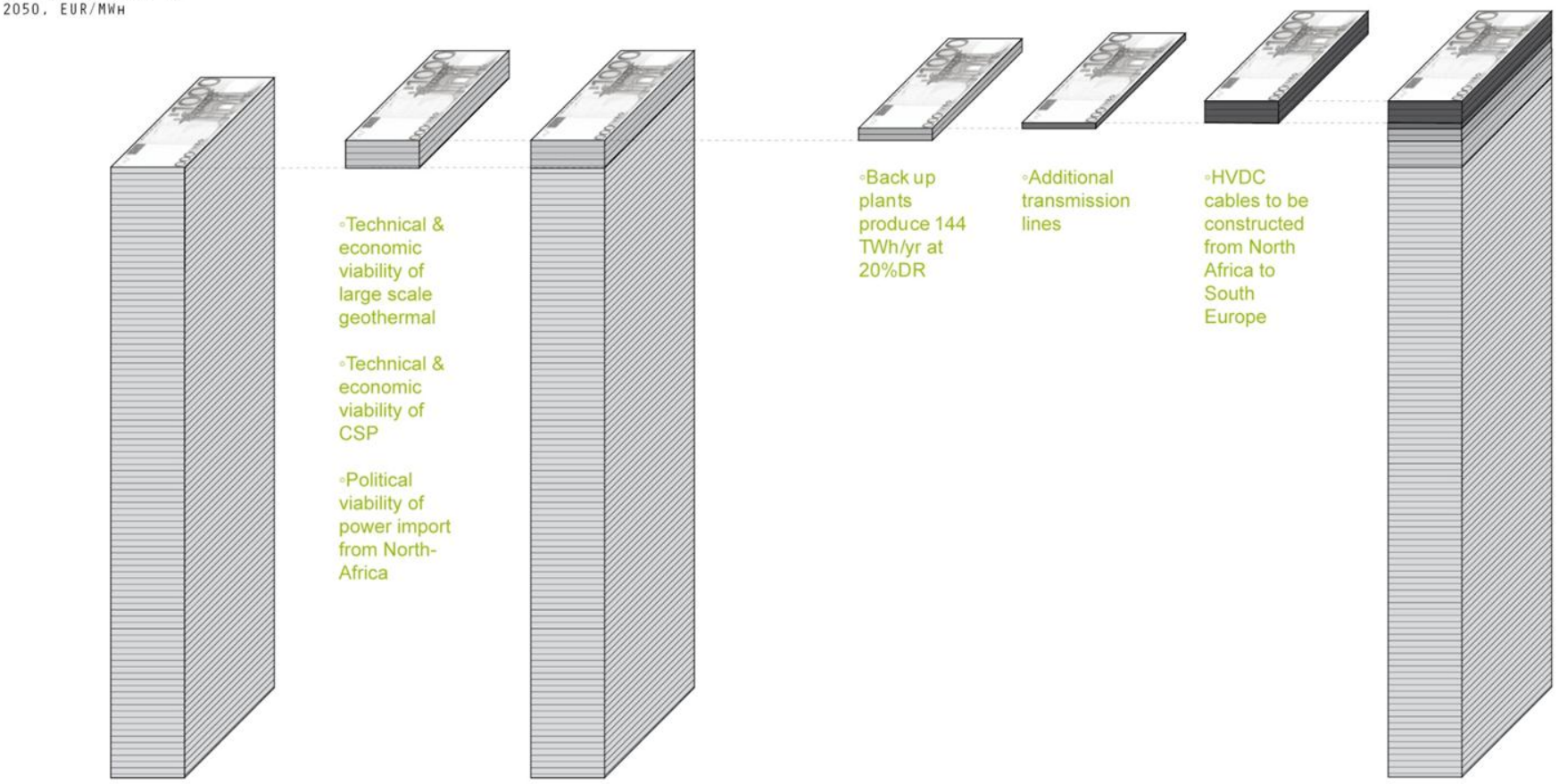
Agriculture from new desalination water supply



100% RES PATHWAY CoE (COST OF ELECTRICITY)

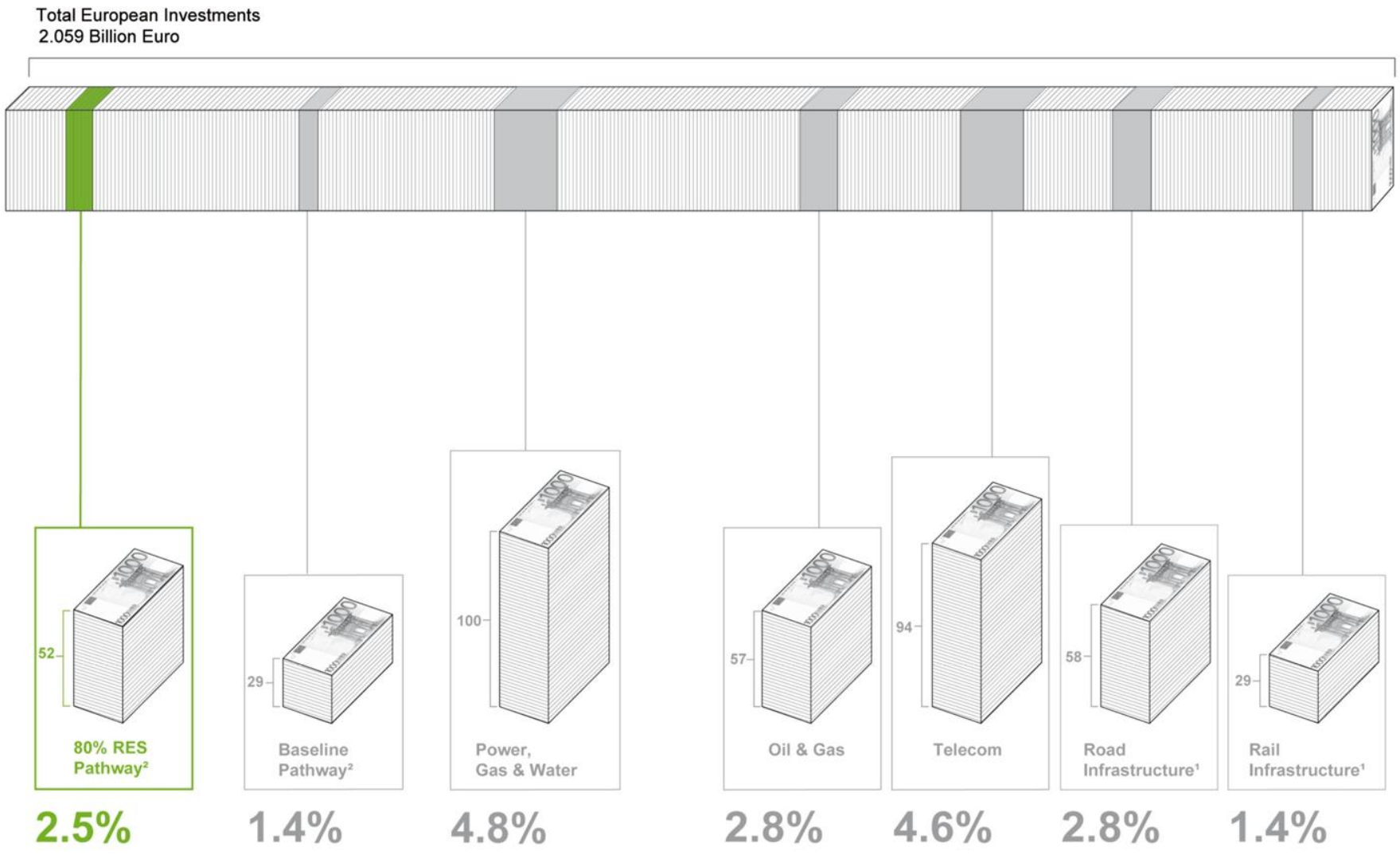
A 100% RES PATHWAY COULD BE ABOUT 10% MORE COSTLY AND RELIES ON 15% IMPORT OF POWER FROM NORTH AFRICA

AVERAGE CoE OF NEW BUILDS FROM 2010 TO 2050, EUR/MWH



1) Coal (5%), gas (5%) and nuclear power (10%) replaced by 15% solar CSP from North-Africa (~700-800 TWh (similar as Desertec) and 5% enhanced geothermal (assumed to be spread over the region relative to the estimated potential). CSP CoE assumes 25% improved irradiation compared to Iberia.
SOURCE: Roadmap 2050 Technical Analysis, Desertec

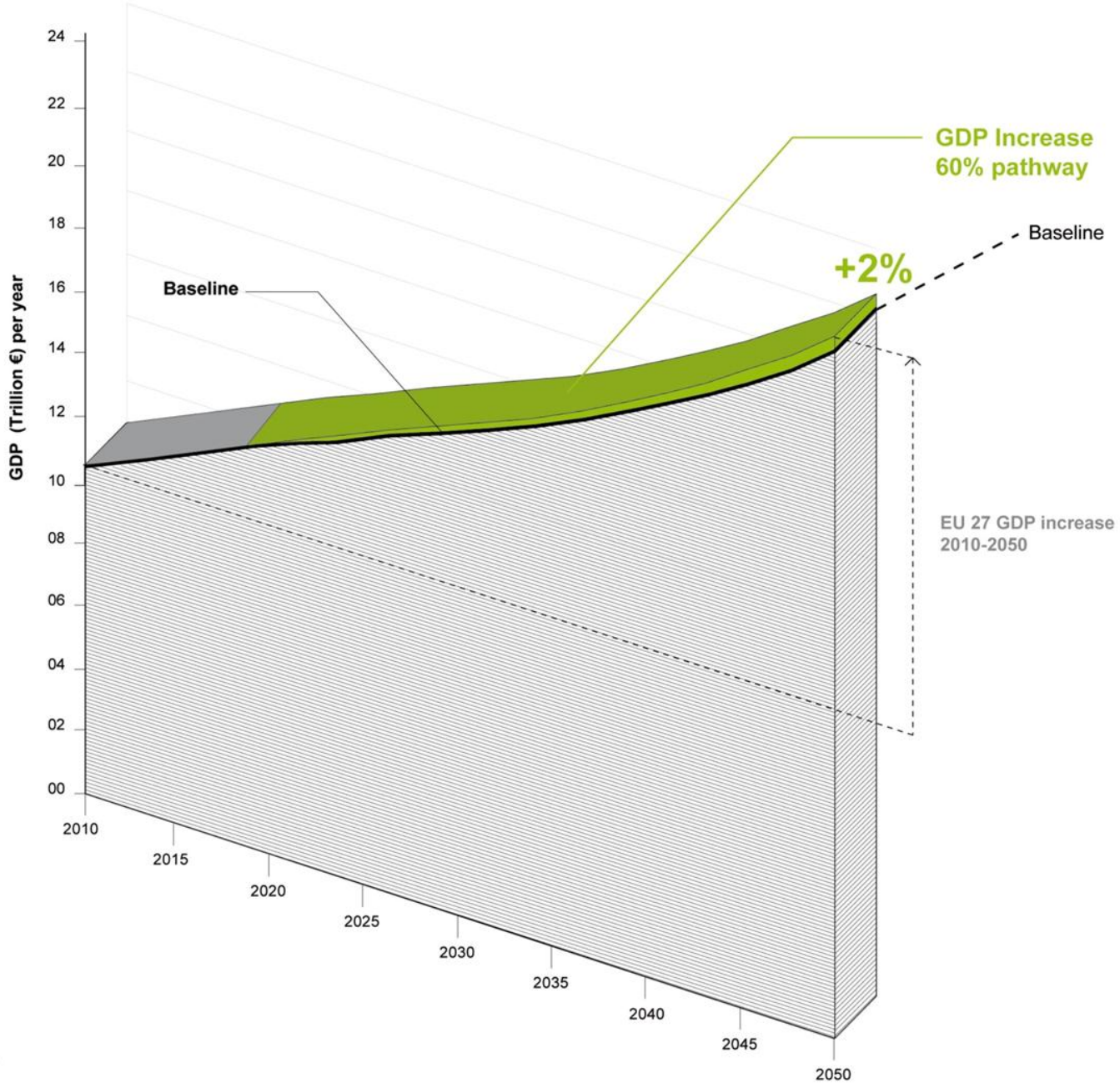
ANNUAL COST COMPARED TO EU SPENDING



1 Forecast for 2010 capex requirement not available for road and rail infrastructure investments; 2007 actual data is used instead
2 Average yearly capex requirement from 2011 to 2020

SOURCE: Roadmap 2050 Technical Analysis

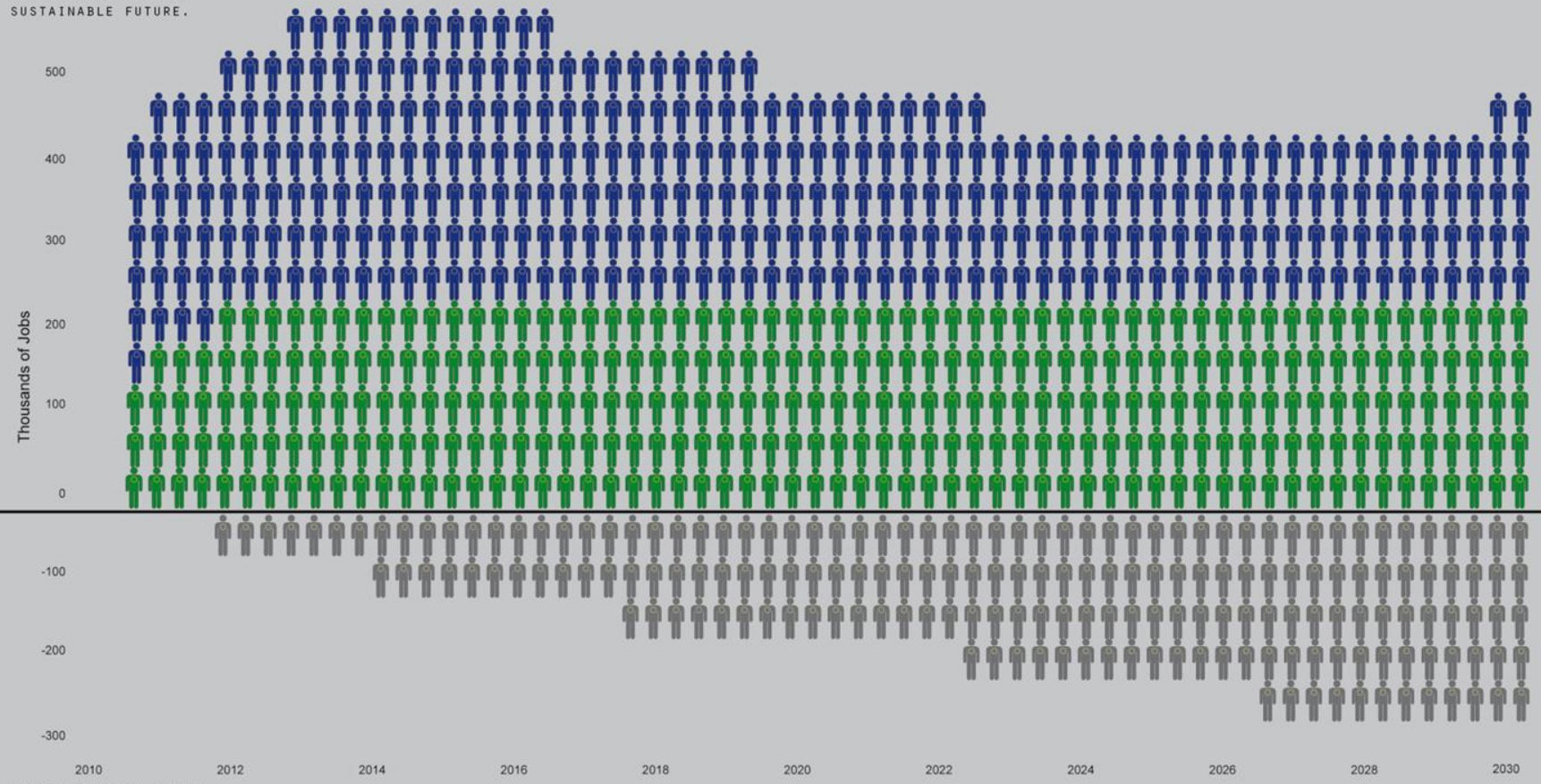
LONG-TERM EU27 GDP



SOURCE: Roadmap 2050 Technical Analysis

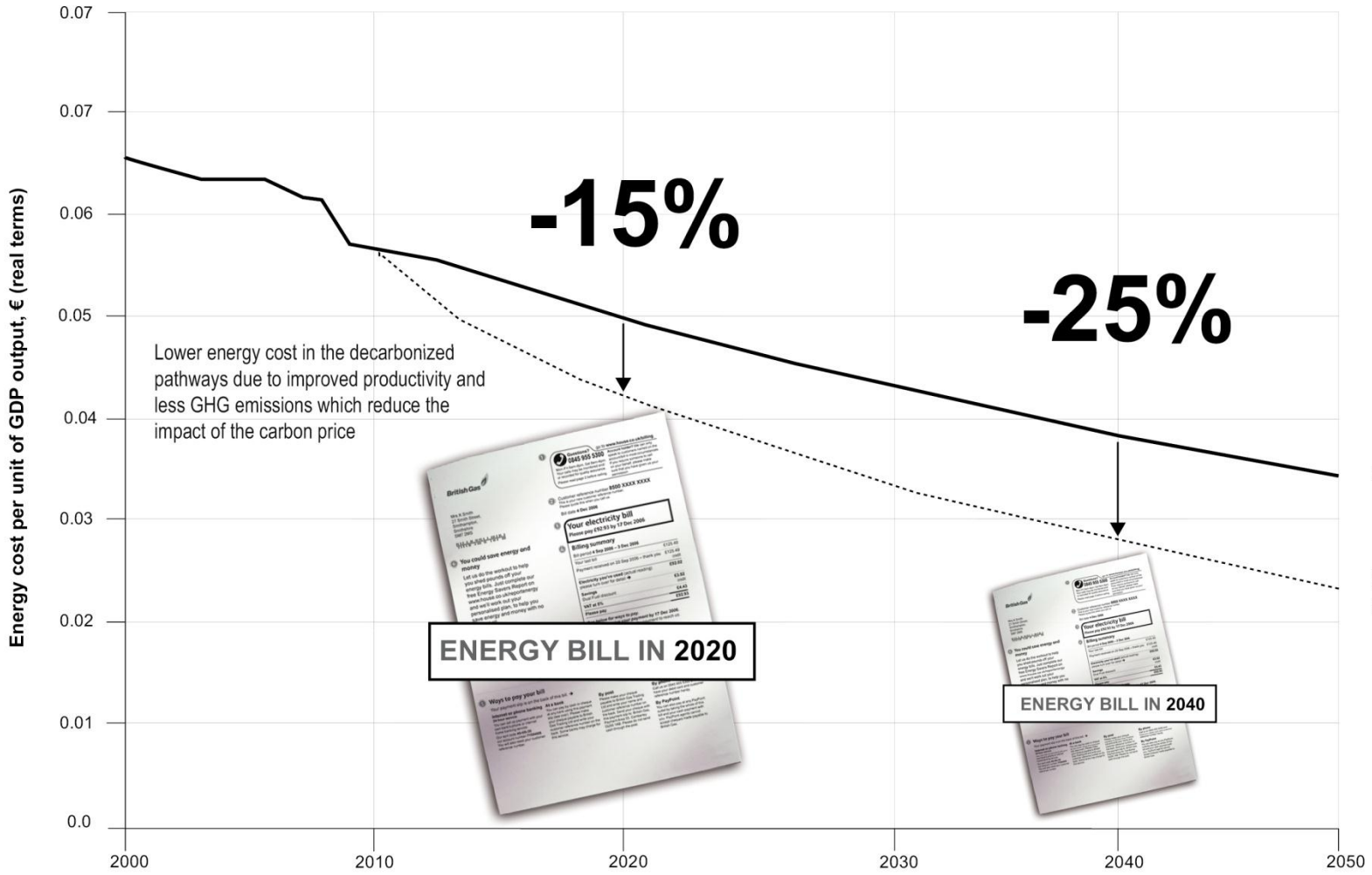
EU JOB CREATION

Jobs are expected to increase with investment in research and development and commitment to building of renewable technologies. Jobs created in the Low-carbon power sector along with production and development in product efficiency will contribute significantly to net job creation and an economically sustainable future.



SOURCE: Roadmap 2050 Technical Analysis
NOTE: Efficiency and fuel shift investment includes all efficiency levers from McKinsey cost curves (excluding what already in the baseline), further penetration of heatpumps in residential and industry and the slow penetration of EVs

DECARBONIZING THE ECONOMY SAVES MONEY

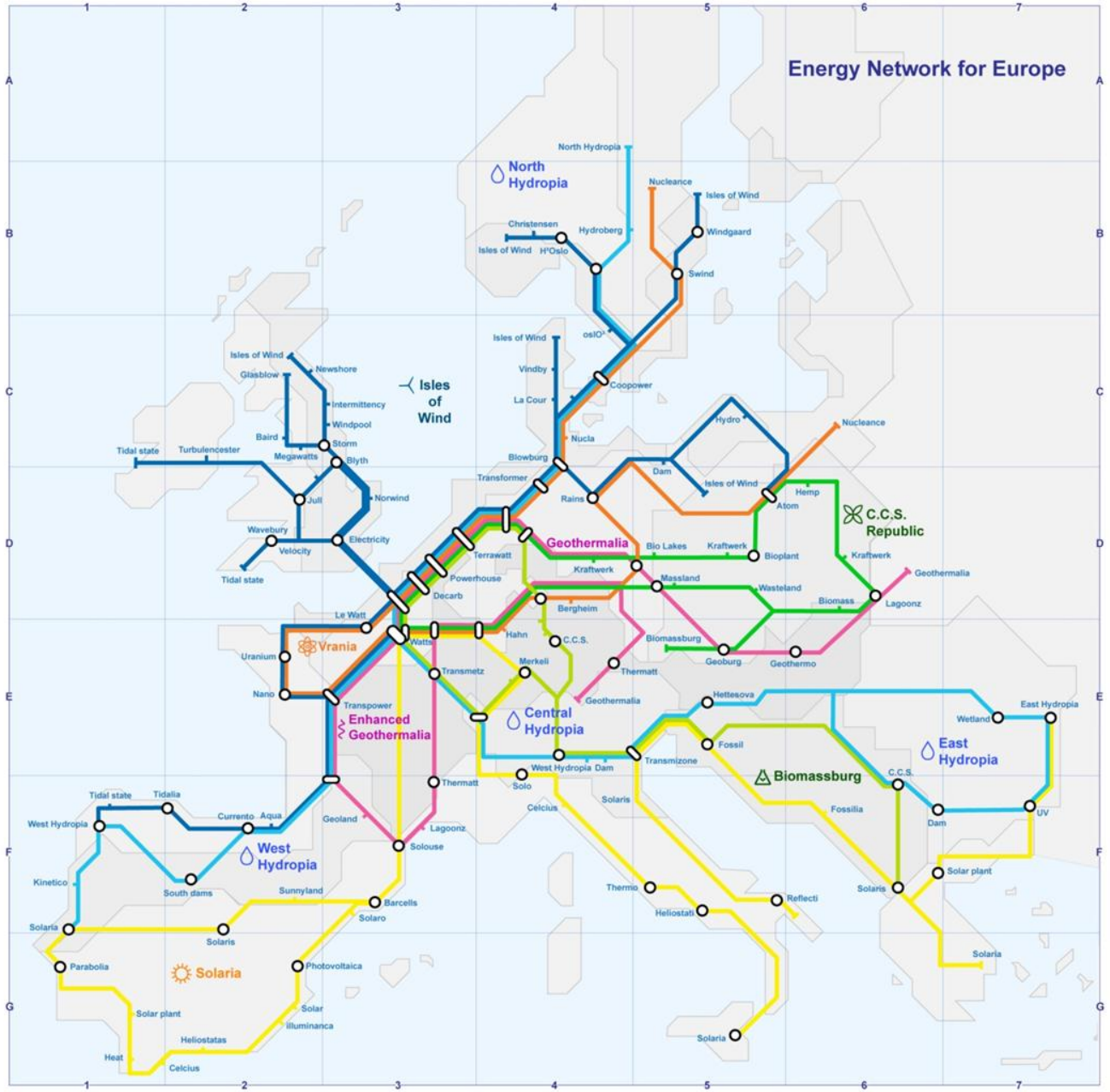


NOTE: Energy prices are a weighted average of prices faced by consumers weighted by the shares of consumption of different fuels

SOURCE: Roadmap 2050 Technical Analysis

EU ENERGY NETWORK

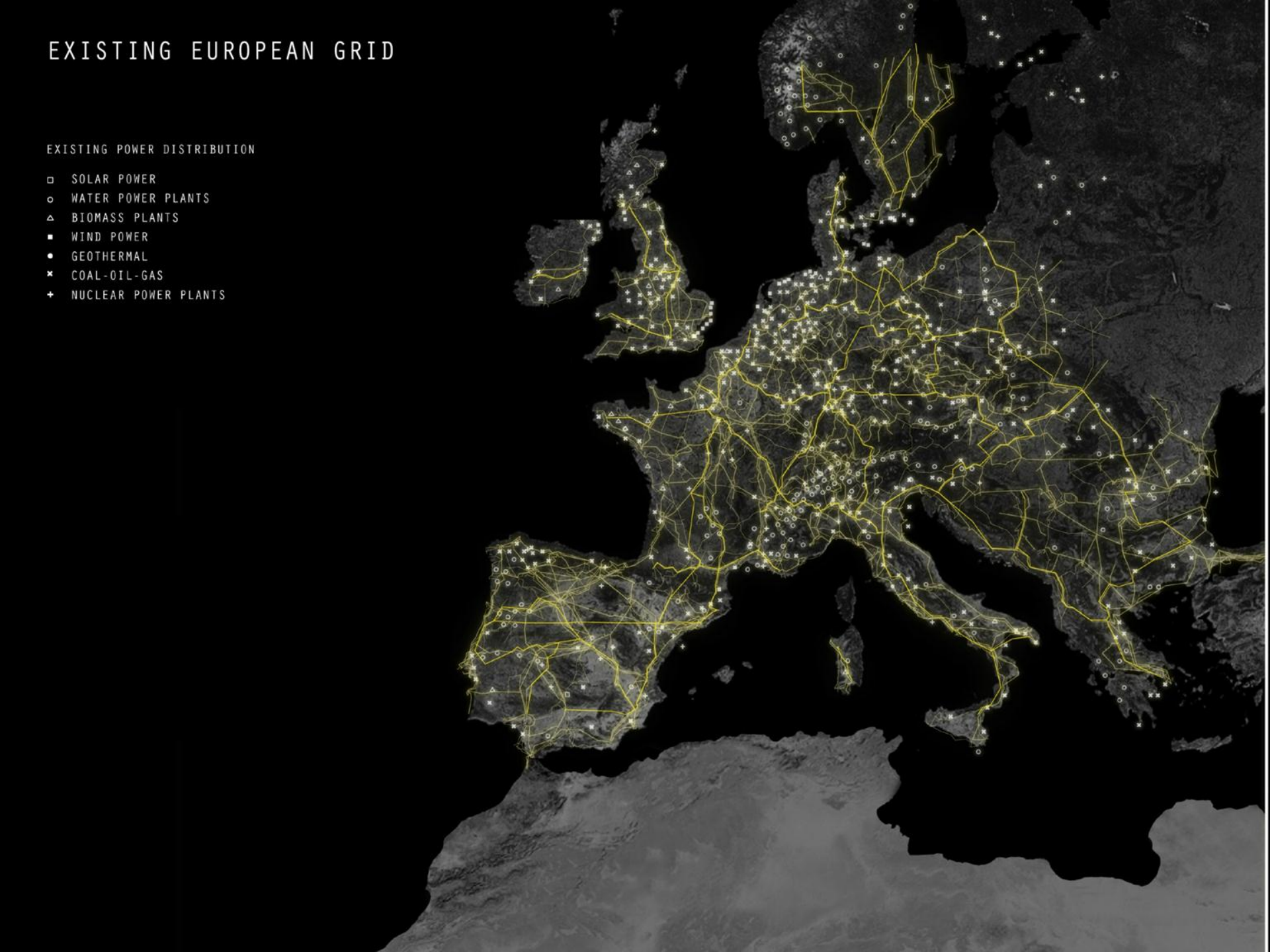
Diagrammatic representation of integrated European power grid.



Key to Lines

Interchange station	Power station	
		Hydropower
		Wind Power
		Geothermal
		Nuclear
		Solar Power
		C.C.S.
		Biomass

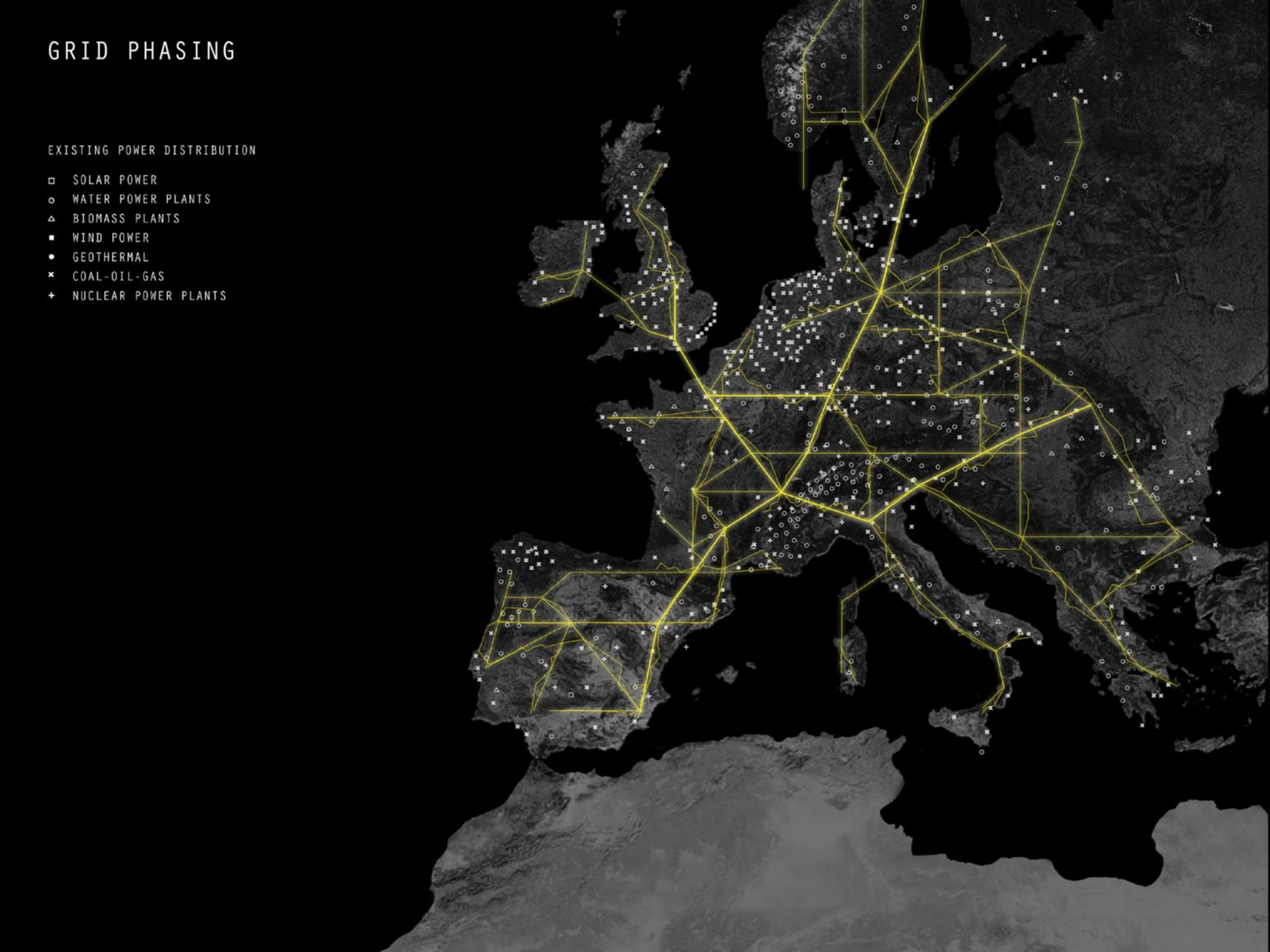
EXISTING EUROPEAN GRID



GRID PHASING

EXISTING POWER DISTRIBUTION

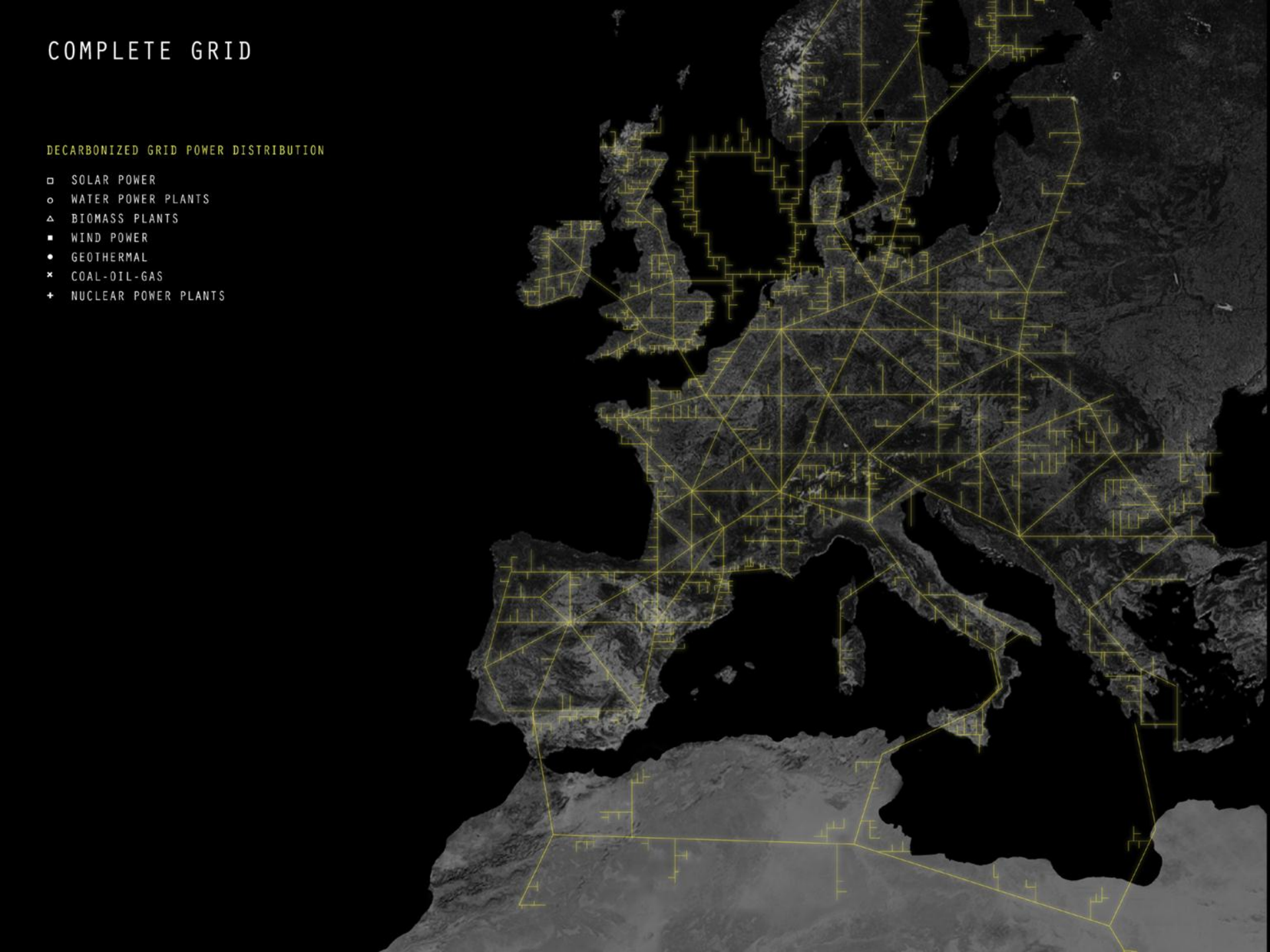
- SOLAR POWER
- WATER POWER PLANTS
- BIOMASS PLANTS
- WIND POWER
- GEOTHERMAL
- COAL-OIL-GAS
- NUCLEAR POWER PLANTS



COMPLETE GRID

DECARBONIZED GRID POWER DISTRIBUTION

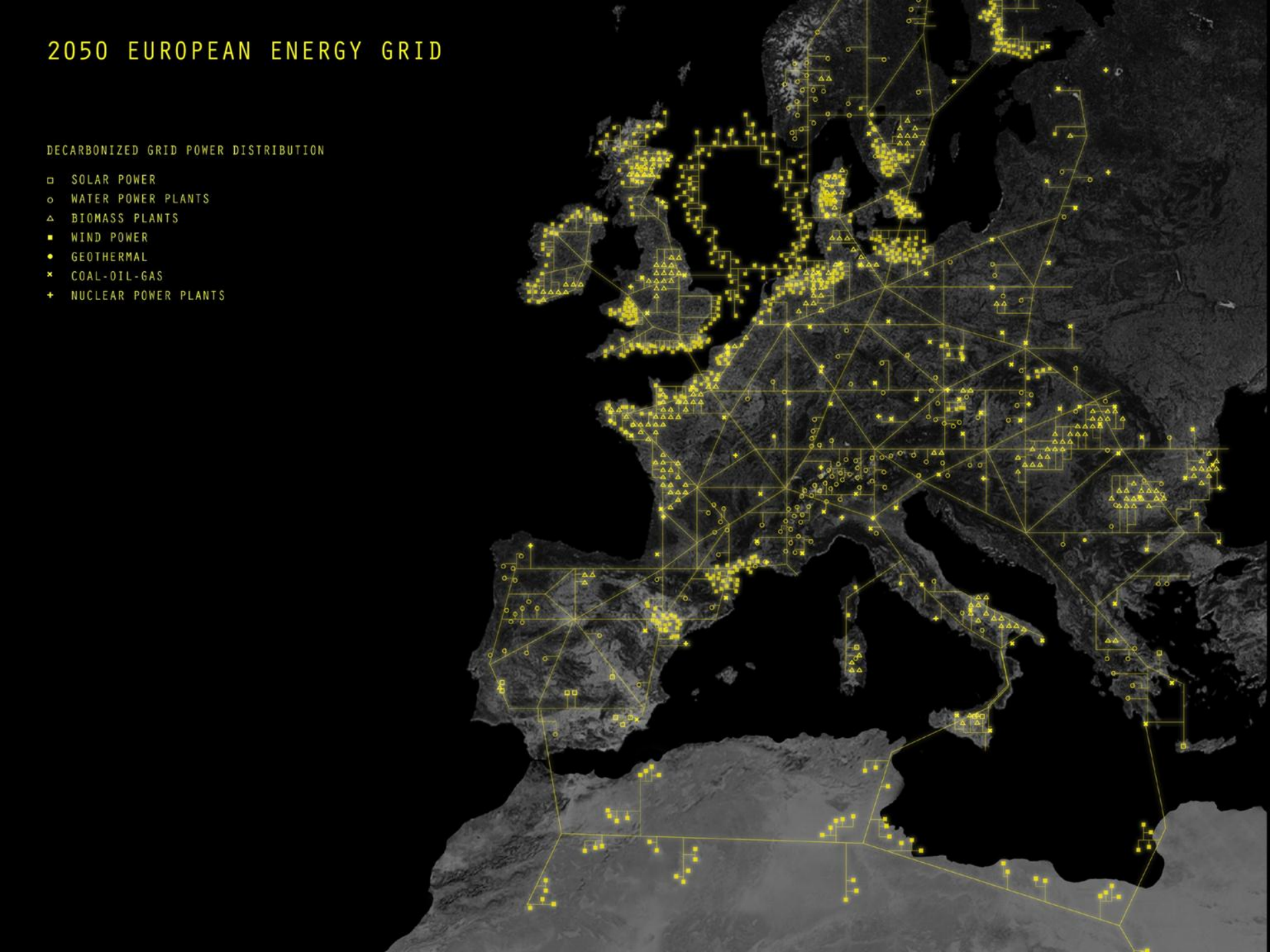
- □ SOLAR POWER
- ○ WATER POWER PLANTS
- △ BIOMASS PLANTS
- ■ WIND POWER
- ● GEOTHERMAL
- × COAL-OIL-GAS
- \+ NUCLEAR POWER PLANTS



2050 EUROPEAN ENERGY GRID

DECARBONIZED GRID POWER DISTRIBUTION

- □ SOLAR POWER
- ○ WATER POWER PLANTS
- △ BIOMASS PLANTS
- ▪ WIND POWER
- ● GEOTHERMAL
- × COAL-OIL-GAS
- \+ NUCLEAR POWER PLANTS



EU 2050

Wind Farm

Nuclear Power Plant

Tidal Power

Biomass Plant

EVs in transport

C.C.S Plant

Energy Network

Solar Farm

Technology Breakthrough

Solar Rooftops

THE NEW ENERGY GRID CAN BE COMBINED WITH TRANSPORT AND DATA LINKS TO PROVIDE AN EFFICIENT POST-CARBON DISTRIBUTION SYSTEM