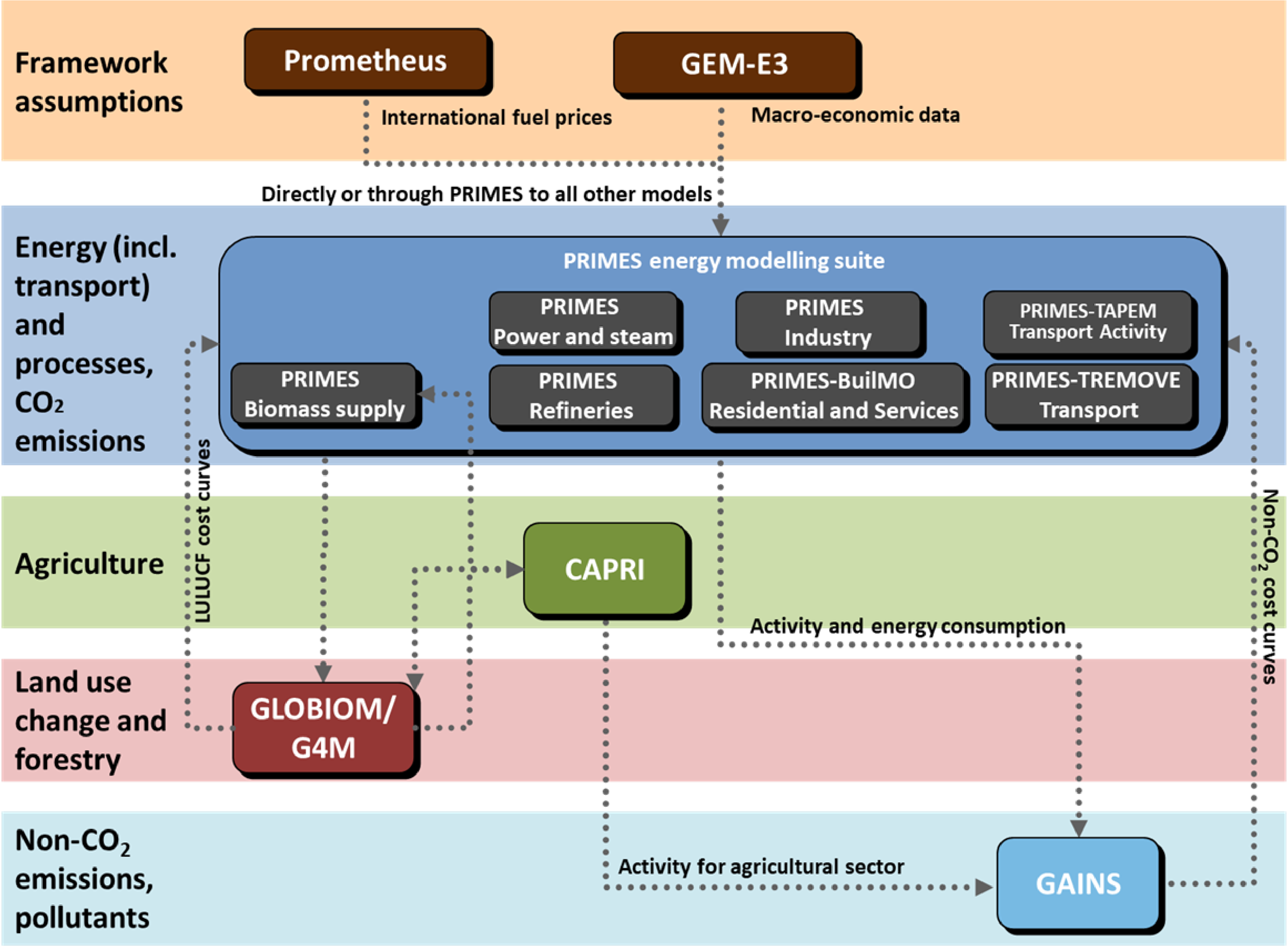
MODELLING OF THE EU LONG-TERM STRATEGY TOWARDS A CARBON NEUTRAL ENERGY SYSTEM

A. De Vita, Prof. P. Capros, G. Zazias, et al.

Dresden, 12 April, 2019

The presentation reflects purely personal opinions

Modelling suite for EU long-term strategy



Framework assumptions

Prometheus

GEM-E3

International fuel prices

Macro-economic data

Directly or through PRIMES to all other models

Energy (incl. transport) and processes, CO₂ emissions

PRIMES energy modelling suite

PRIMES Power and steam

PRIMES Industry

PRIMES-TAPEM Transport Activity

PRIMES Biomass supply

PRIMES Refineries

PRIMES-BuilMO Residential and Services

PRIMES-TREMOVE Transport

LULUCF cost curves

Non-CO_2 cost curves

Agriculture

CAPRI

Activity and energy consumption

Land use change and forestry

GLOBIOM/ G4M

Non-CO_2 emissions, pollutants

Activity for agricultural sector

GAINS

E³M-lab

EuroCARE

International Institute for Applied Systems Analysis
www.iiasa.ac.at
IIASA

E³M - Lab

PRIMES energy system model

AIM:

- **Simulate structural changes and long-term transitions**

Model structure:

- **Modular system:** one module per sector
- **Microeconomic foundation with engineering representations**

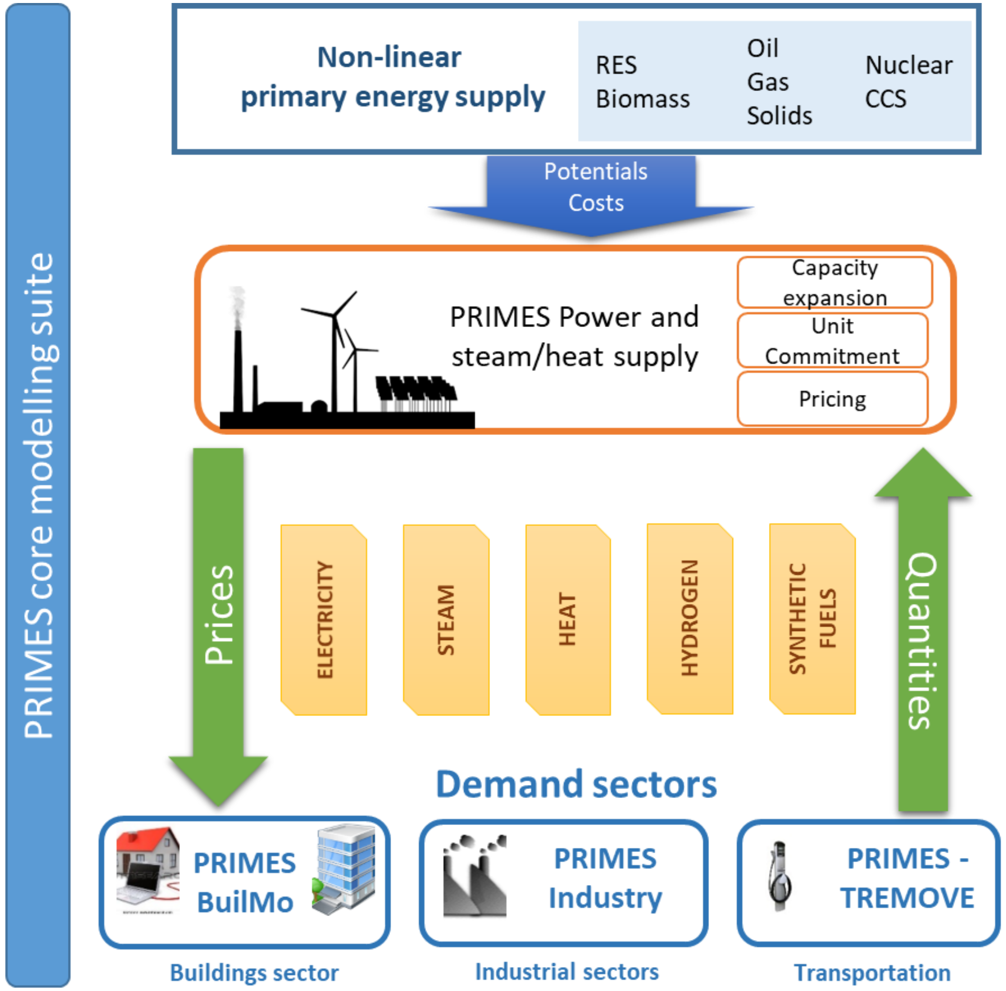
Focus:

- **Market-related mechanisms**
- Representation of **policy instruments for market, energy and emissions**, for policy impact assessment

Technology database:

- Energy technology database has a standard format and is open access

PRIMES Overview

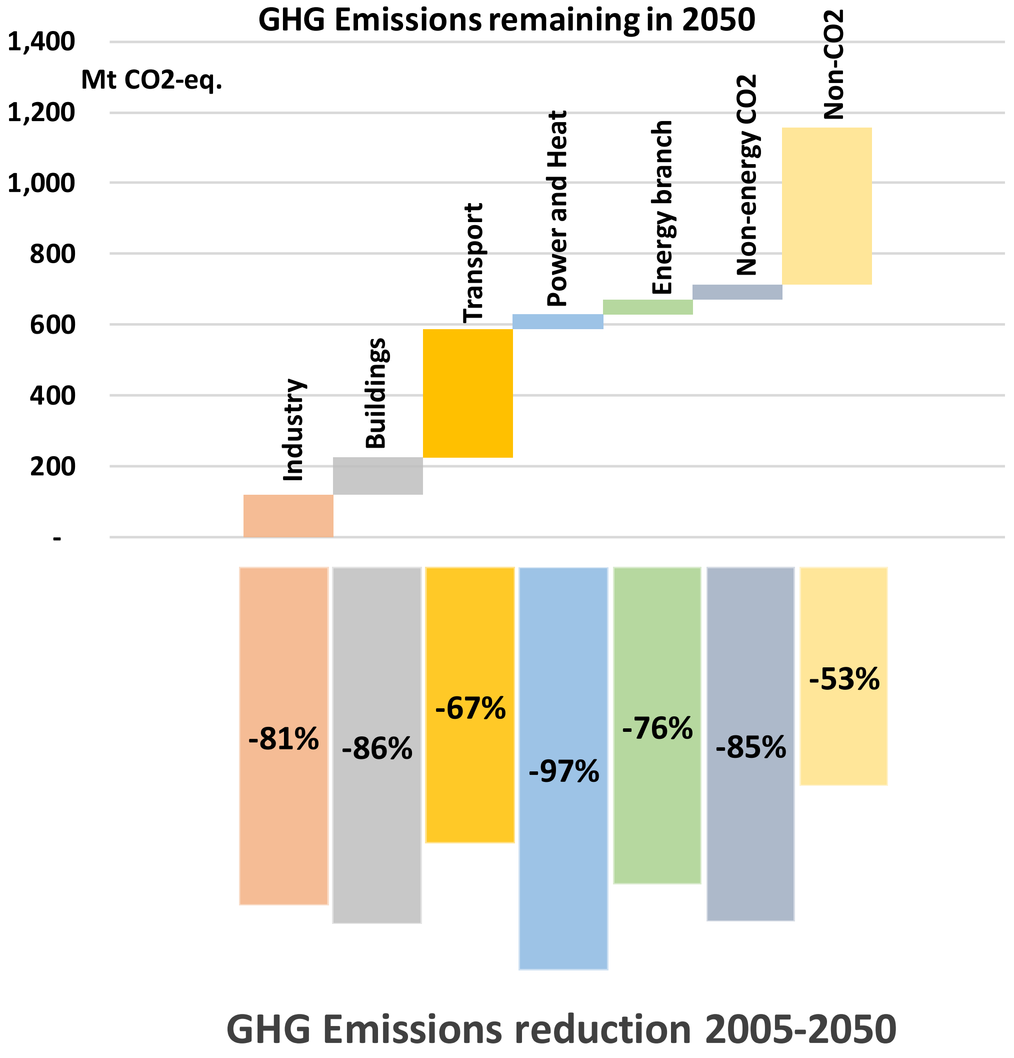


Temporal resolution: to 2070, in 5-year time steps
Geographic resolution: 28 EU MS + 10 European non-EU countries
Mathematically: concatenation of mixed-complementarity problems with equilibrium conditions and overall constraints (e.g. carbon constraint with associated shadow carbon value) - EPEC

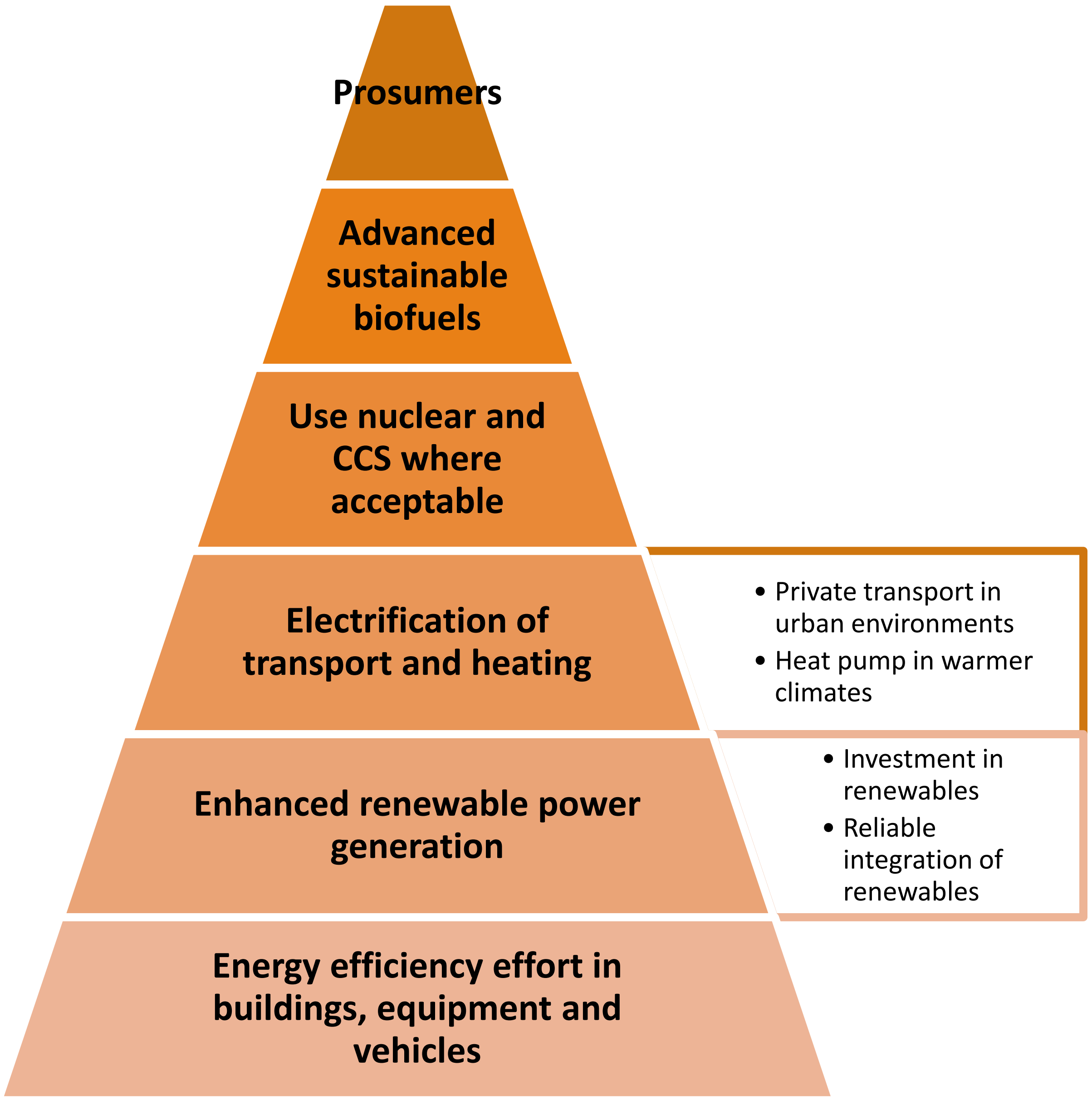
Going from 2°C to 1.5°C

- In 2050, 1100 Mt GHG (-80% compared to 1990 levels) are consistent with a 2°C trajectory
- By 2050, the remaining GHG (in a EUCO scenario) are 58% due to energy, of which:
  - 31% in transport
  - 20% in stationary use
  - Power and heat and energy branch account for 9%
- The challenge is to bring emissions close to zero
  - ~80-85% in 2050 in a 2°C context
  - ~92-94% in 2050 in a 1.5°C context
- **Is it possible?**
- **How? When? At which cost?**

Remaining emissions in 2°C



No-regret options



Prosumers

Advanced sustainable biofuels

Use nuclear and CCS where acceptable

Electrification of transport and heating

- Private transport in urban environments
- Heat pump in warmer climates

Enhanced renewable power generation

- Investment in renewables
- Reliable integration of renewables

Energy efficiency effort in buildings, equipment and vehicles

Disruptive options

A. Reduce energy demand in all sectors **beyond conventional energy savings**, e.g. circular economy, sharing of vehicles, materials sequestering CO_2

B. Changes in the way users **use energy**, e.g. extreme electrification in industry and transport, direct use of distributed hydrogen

C. Changes in the **production and nature of energy commodities**, e.g.:

   i. e.g. mix hydrogen and biogas in gas distribution

   ii. replace fossil gas by renewable gas

   iii. fossil liquids by synthetic fuels (electro-fuels from hydrogen and captured or biogenic CO_2)

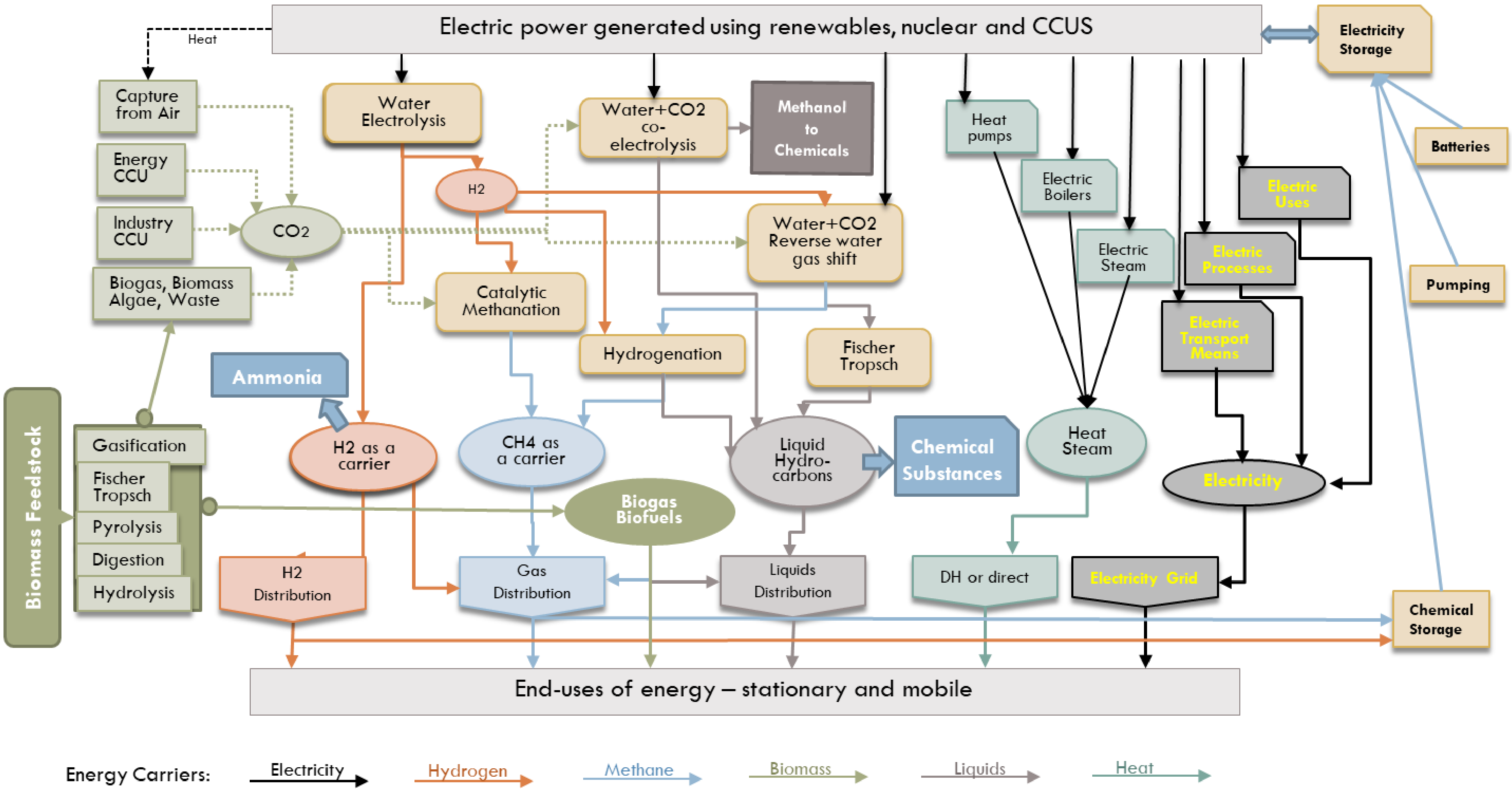
D. Use and storage of **CO_2**

   i. establish circuits of CO_2 capturing

   ii. use and sequestering in storage areas, materials and/or fuels, e.g. CO_2 captured in industrial processes used in ammonia or petrochemicals, replacing reforming of fossil fuels, biomass CCS and CO_2 capture from the air

E3M - Lab

ALTERNATIVE PATHWAYS-ILLUSTRATION



Electric power generated using renewables, nuclear and CCUS

Heat

Capture from Air

Energy CCU

Industry CCU

Biogas, Biomass Algae, Waste

CO_2

Water Electrolysis

H2

Water+CO2 co-electrolysis

Methanol to Chemicals

Water+CO2 Reverse water gas shift

Catalytic Methanation

Hydrogenation

Fischer Tropsch

Ammonia

H2 as a carrier

CH4 as a carrier

Liquid Hydro-carbons

Chemical Substances

Biogas Biofuels

Biomass Feedstock

Gasification

Fischer Tropsch

Pyrolysis

Digestion

Hydrolysis

H2 Distribution

Gas Distribution

Liquids Distribution

Heat pumps

Electric Boilers

Electric Steam

Heat Steam

DH or direct

Electric Uses

Electric Processes

Electric Transport Means

Electricity

Electricity Grid

Electricity Storage

Batteries

Pumping

Chemical Storage

End-uses of energy – stationary and mobile

Energy Carriers: Electricity → Hydrogen → Methane → Biomass → Liquids → Heat →

E3M - Lab

Pros and cons

	Max Efficiency & Circular Economy	Maximum Electrification	Hydrogen as a carrier	Clean e-gas and e-liquids
PROS	Environment-friendly Reduces costs Relaxes investment and resource constraints in the supply side Positive economic and jobs impacts	High efficiency in end-use Convenience-cleanness Can be self-produced Implies relatively small growth of demand for electricity	Can cover all end-uses including transport Chemical storage of electricity Less expensive and less electricity intensive than e-fuels	Use of existing infrastructure Convenience in end-use: no disruption in transport Chemical storage of electricity Competition among carriers
CONS	Uncertainty about investment by individuals Uncertainty about needed disruptive changes in industry and circular economy Difficulty in inducing large modal shifts in transport Low demand growth discourages investment in technology progress	Not fully applicable in all end-uses, including in transport Lack of competition in the supply of energy carriers as lack of choice for consumers Without chemical storage electricity storage cannot be seasonal	New infrastructure for distribution and storage Uncertainty about economies of scale of electrolyzers Blue hydrogen is attractive but depends on geological storage Not fully convenient in some energy uses Uncertain success of learning-by-doing for fuel cells	CO_2 capture from air and biogenic not yet mature Uncertainty about future costs of e-fuels, need for very significant learning and economies of scale of the industry producing e-fuels Too high increase of total power generation challenging the potential of resources

Key features

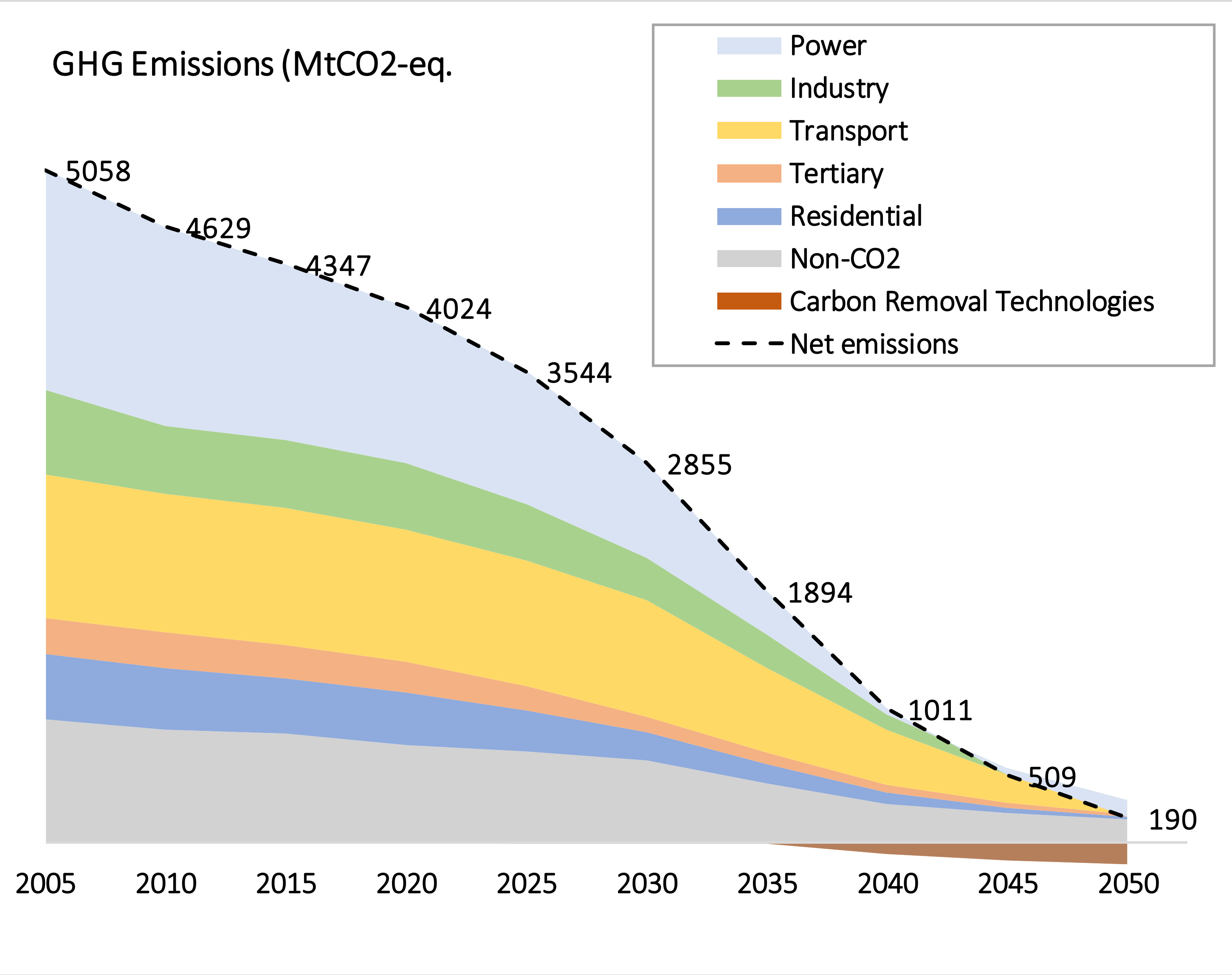
Scenarios	Targets for 2030	GHG target 2050	Main feature	Transport sector
Baseline	Achieved	No	BaU after 2030	BaU after 2030
ELEC		-80% at least	Max electrification	CO_2 -60% at least
H2			Max hydrogen	
P2X			E-fuels GHG free	
EE			Max Energy Efficiency	
CIRC			Circular economy, bio-energy	
COMBO		-88% at least	Combination of ELEC, H2, P2X and EE	CO_2 -75% at least
1.5TECH		-95%	Same as COMBO but more ambitious decarbonisation	Min. use of fossils
1.5LIFE			Same as COMBO, plus CIRC, and more ambitious decarbonisation	

Emissions for 1.5°C

- **Including LULUCF** emission sink, the 1.5°C scenarios achieve **carbon neutrality** of the EU by 2050 and beyond

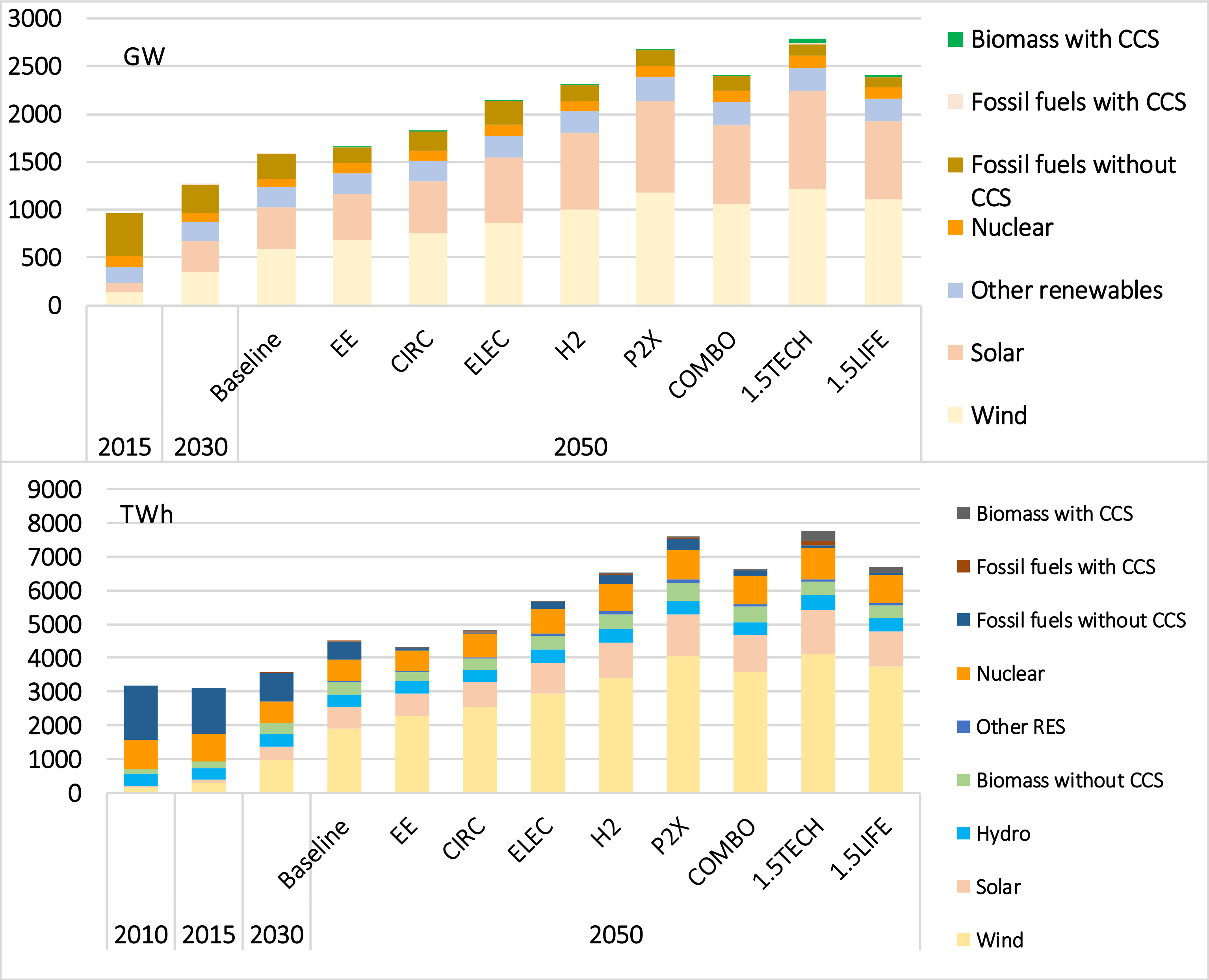
- The carbon removal technologies are BioCCS and CCU for sequestration in materials

- **Negative emissions**, albeit small in magnitude, compensate for remaining GHG emissions in 2050, notably as non-CO_2 emissions in agriculture and few fossils in energy demand sectors and small remaining industrial-process emissions



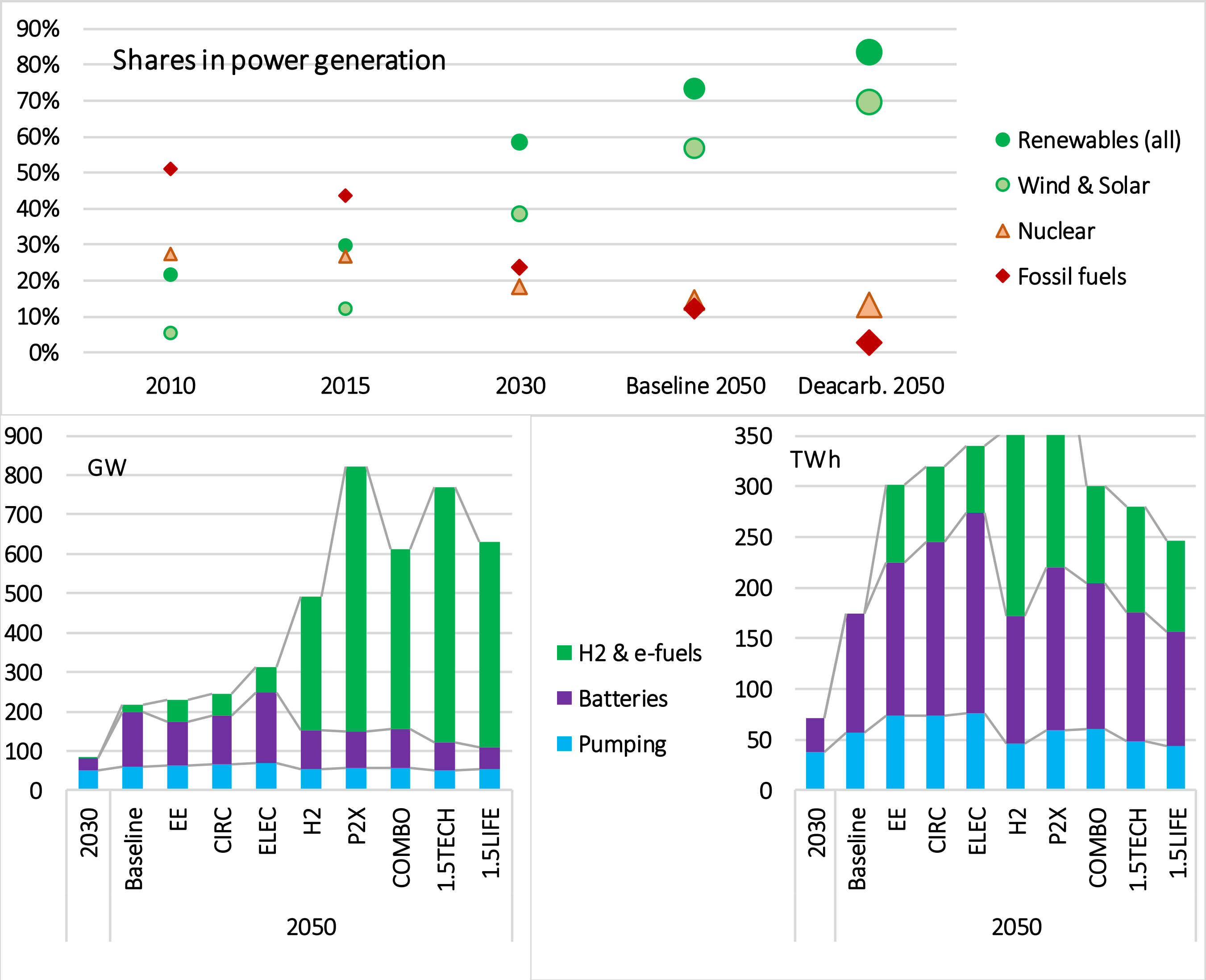
Capacity and mix of power generation

- The energy efficiency scenarios imply a minimum increase in the volume of power generation despite electrification. Among the scenarios focusing on the supply sector, the maximum electricity scenario is the most efficient regarding total electricity generation.
- The e-fuel scenarios imply a considerable increase in total power generation, up to almost a doubling of total volume.
- Both solar and wind deploy massively in all strategy scenarios. Sensitivity analysis showed that ensuring sufficient RES supply in the e-fuel scenarios require unobstructed access to remotely located RES from all places in the EU grid.



RES and Storage

- All decarbonisation scenarios foresee huge deployment of RES in the power sector (>80% in 2050) with variable RES getting a share above 70% in 2050.
- Storage occupies an increasing place in ensuring flexibility in the system; thus, high development of electricity storage capacities in all strategy scenarios.
- Batteries alone are not sufficient, although the scenarios assume maximum integration of batteries in mobility, **batteries in dispersed RES applications and demand-response.**
- The system will require significant capacities of **multi-day and seasonal storage**, which are possible via chemical storage, primarily based on hydrogen.
- The consumption of e-fuels in final demand provide considerably important **indirect storage** (not shown in the figures) thanks to the fuel storage facilities in fuel distribution.
- The simulations show that the system reaches **economic optimality** when maximizing hydrogen and e-fuel consumption at times of high variable RES, with lowest marginal system costs, due to the excess of RES.



CONCLUDING REMARKS

- Tremendous changes are required in the system:
  - Central role of electricity
  - Significant increase in power generation (mainly from RES)
  - No-regret option to enhance energy efficiency
  - Self-production using RES by consumers, demand response and intelligent systems are no-regret developments
  - A major uncertainty regards costs of hydrogen and e-fuels.
- Significant challenges:
  - Development of technologies (e.g. Electrolyzers, e-fuels)
  - Uptake of technologies
  - Private investments (e.g. for energy efficiency)
  - Market design and organization