Models? Not crystal balls!
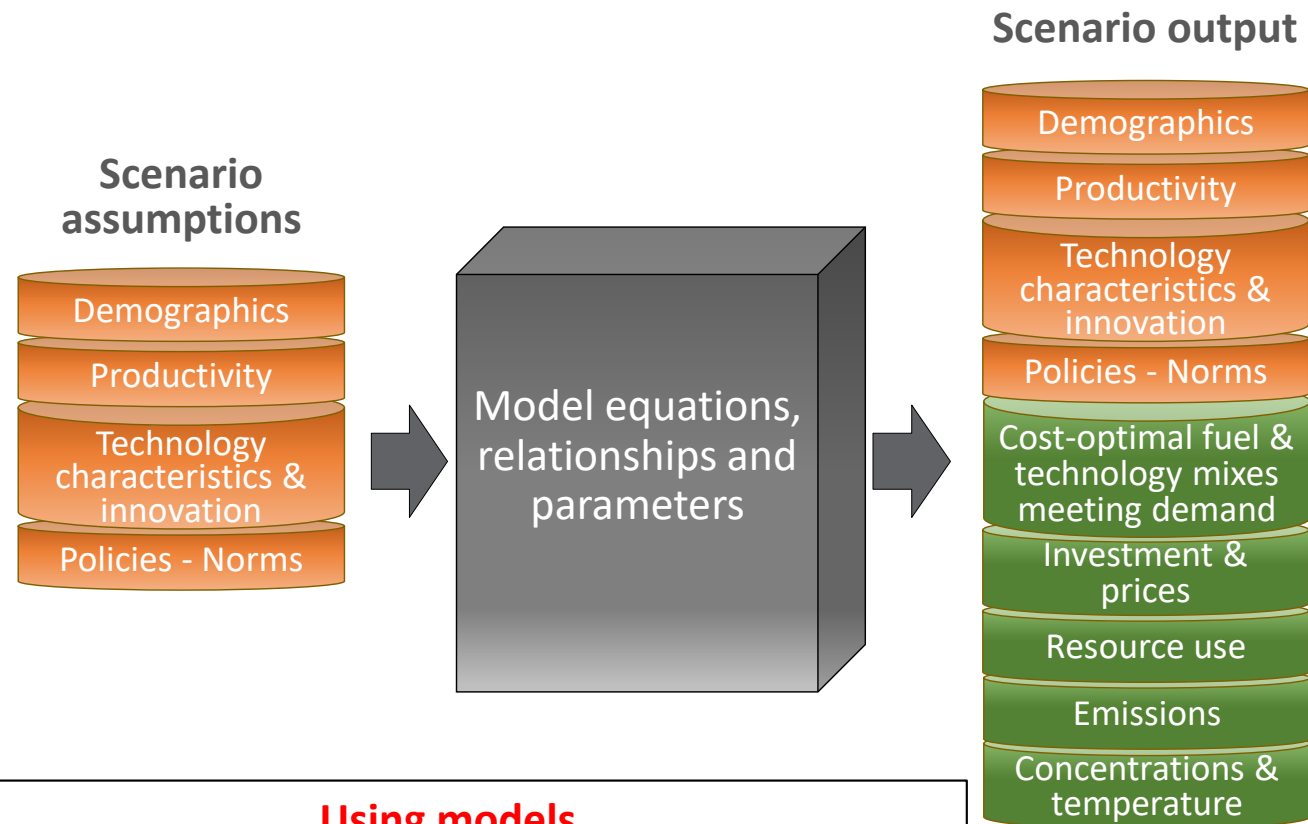## Processing data and assumptions

- Energy models are simplified mathematical representations of real-world systems and relationships, calibrated with historical data

- Assumptions required to parameterize models
  - Integral part of the model design
  - Future rates of technological development
  - Socio-economics
  - Policy changes

- The model solves the mathematical relationships, given the input assumptions

- Scenarios explore different assumptions about inputs

- Policies can be defined through changes to model assumptions or specific policy goals

Scenario assumptions

Demographics

Productivity

Technology characteristics & innovation

Policies - Norms

Model equations, relationships and parameters

Scenario output

Demographics

Productivity

Technology characteristics & innovation

Policies - Norms

Cost-optimal fuel & technology mixes meeting demand

Investment & prices

Resource use

Emissions

Concentrations & temperature

Using models

Models **can** inform policy makers on the implications of proposed domestic or international policies

Models **cannot** determine the "best" technology or policy options

2

Essence of energy systems modeling

- Energy is not an end in itself

- Energy is a 'complex system'
  - account for technologies, infrastructures, costs, variability of demand, technology limitations, policy constraints, security of supply, among others
  - ensure that demand is always met in an efficient way (and now also sustainably)
  - identify the most important drivers of the system with a quantification of their inter-relations
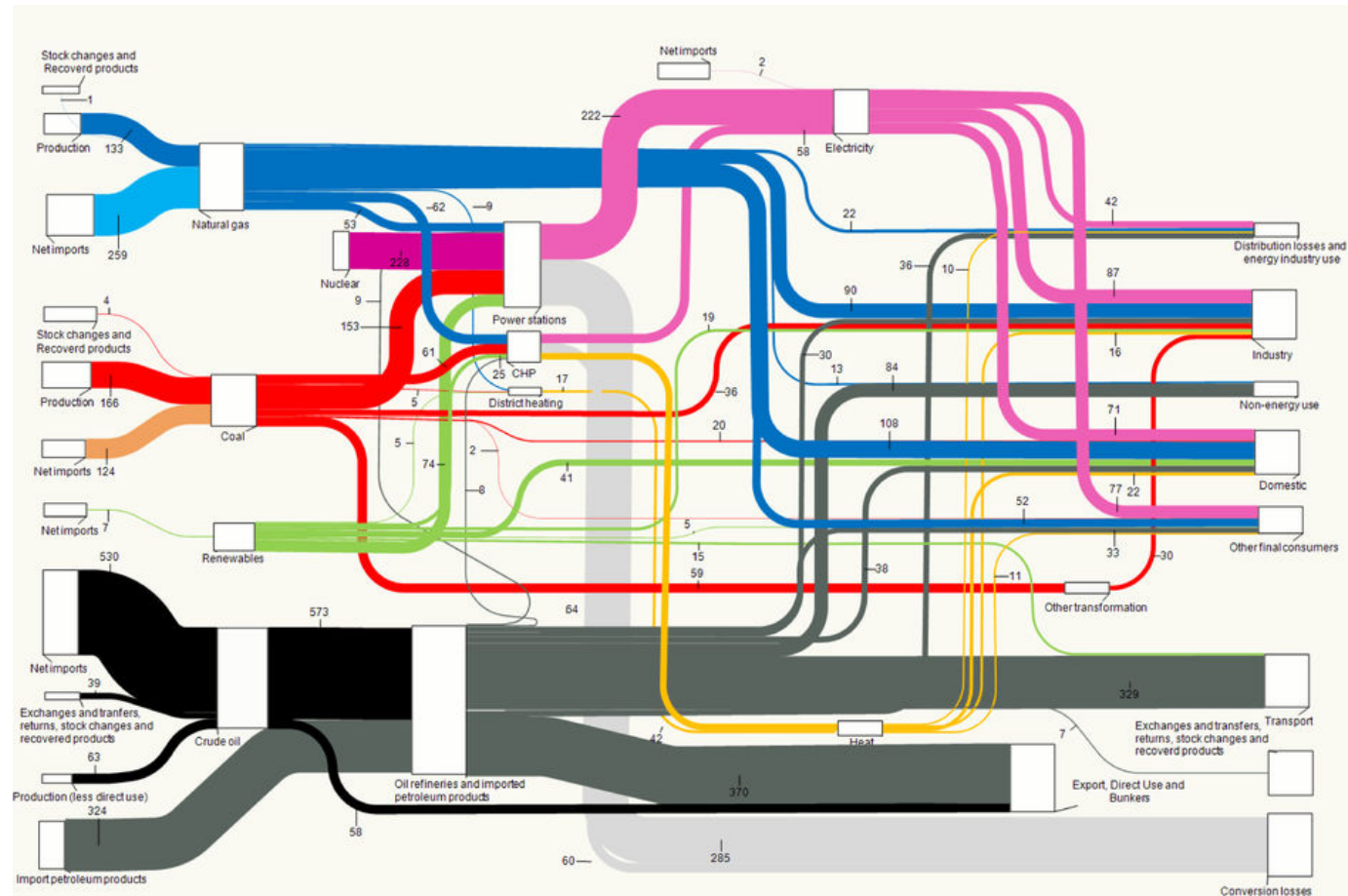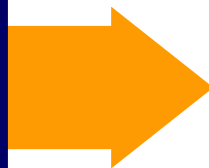
MESSAGE: Model for Energy Supply System Alternatives and their General Environmental Impacts
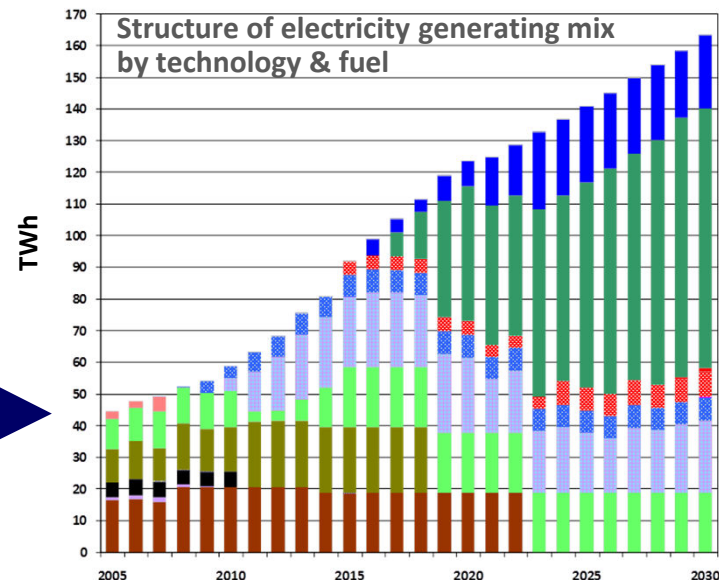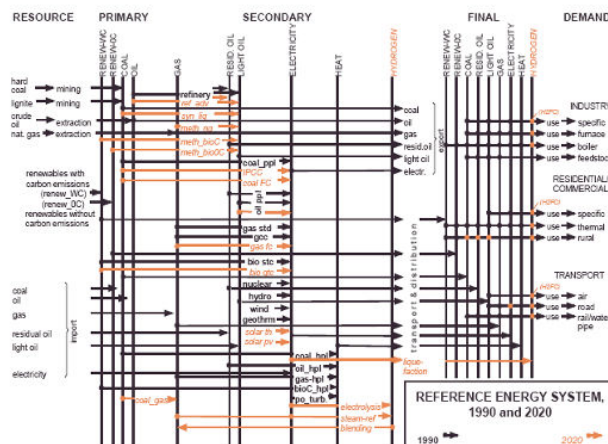
ENERGY

INPUT

- **Energy system structure (including vintage of plant and equipment)**
- **Base year energy flows and prices**
- **Energy demand (e.g., via link to MACRO)**
- **Technology and resource options & their techno-economic performance profiles**
- **Learning and innovation**
- **Technical and policy constraints**

OUTPUT

Structure of electricity generating mix by technology & fuel (TWh, 2005–2030)

REFERENCE ENERGY SYSTEM, 1990 and 2020

- **Primary and final energy mix**
- **Electricity generating mix, capacity expansion/retirement, investments**
- **GHG missions, air pollution, wastes**
- **Health and environmental impacts - via link to GAINS and LCA module**
- **Resource use - energy, water, land (via link to GLOBIOM), materials**
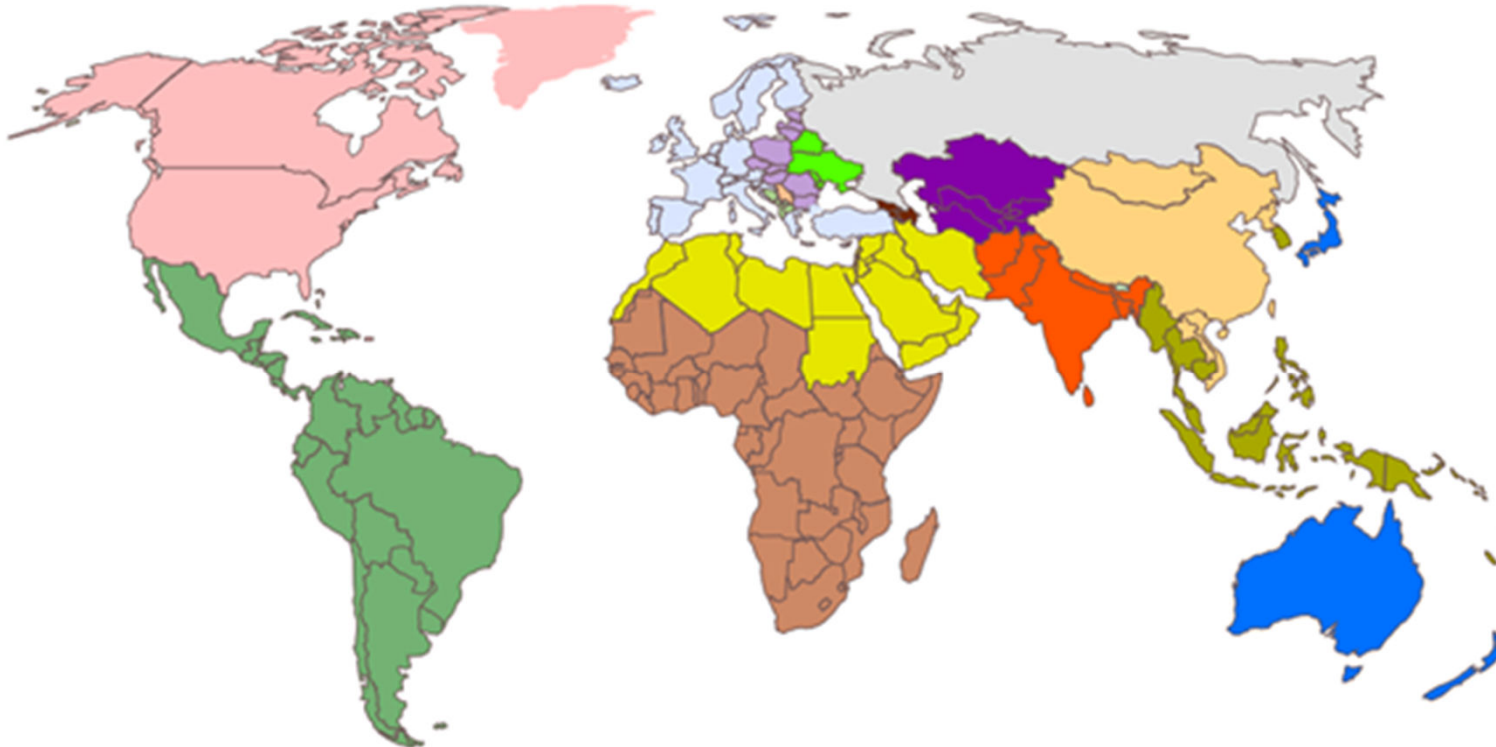- **Trade & import dependence**
- **Prices**

MESSAGE_{ix}

MESSAGE$_{IX}$
Regions Modelled

ENERGY

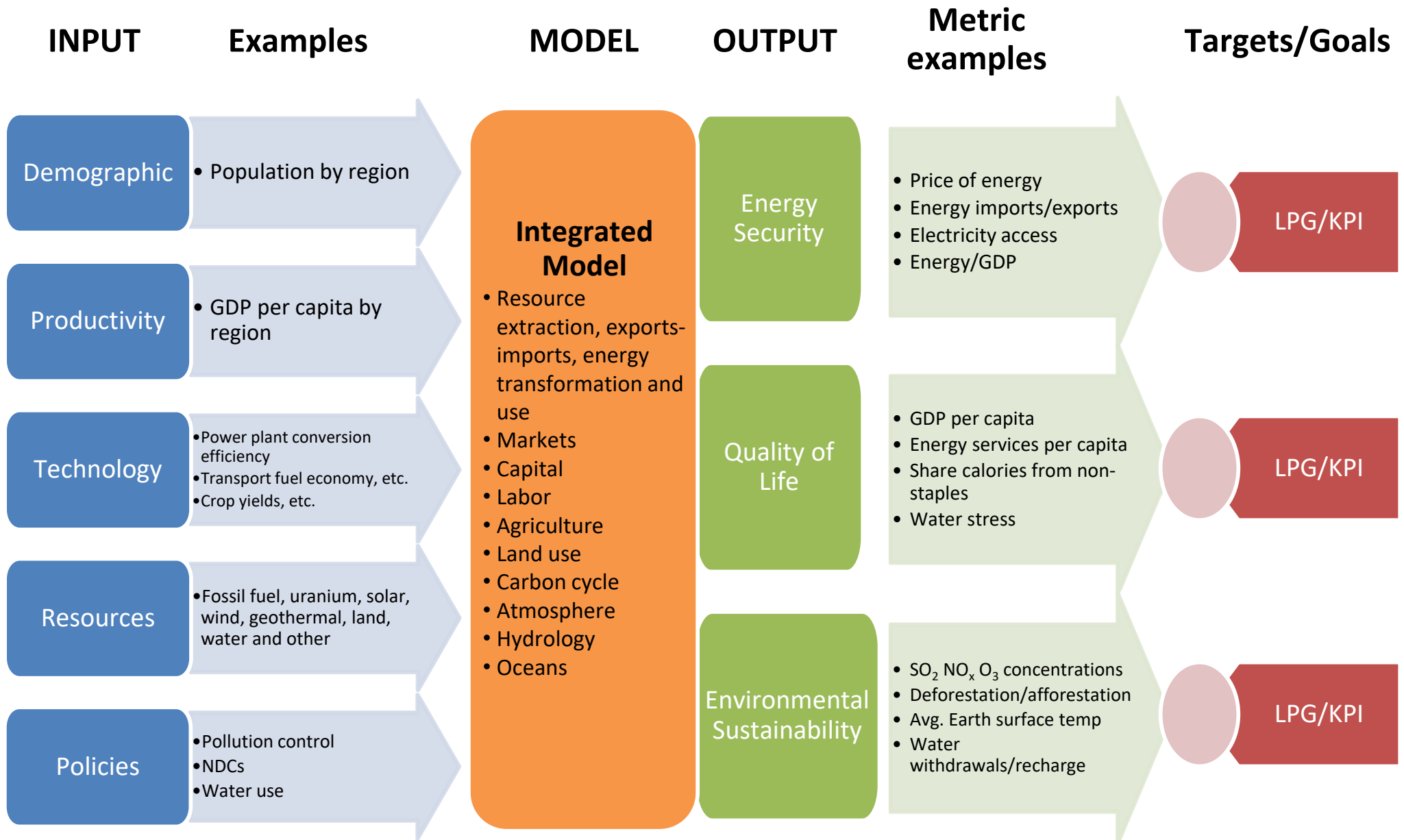|					
AFR	Sub-Saharan Africa	LAC	Latin America and the Caribbean	RUS	Russian Federation
BMU	Belarus, Moldova, Ukraine	MEA	Middle East and North Africa	SAS	South Asia
CAS	Central Asia	NAM	North America	SCS	South Caucasus
CPA	Centrally planned Asia & China	PAO	Pacific OECD	SEE	South Eastern Europe/Western Balkan
CEE	Central and Eastern Europe	PAS	Other Pacific Asia	WEU	Western Europe

15 regions (8 of which are UNEC regions) covering the world

Scenario development
Illustration of scenario design

ENERGY

INPUT	Examples	MODEL	OUTPUT	Metric examples	Targets/Goals
Demographic	• Population by region	**Integrated Model** • Resource extraction, exports-imports, energy transformation and use • Markets • Capital • Labor • Agriculture • Land use • Carbon cycle • Atmosphere • Hydrology • Oceans	**Energy Security**	• Price of energy • Energy imports/exports • Electricity access • Energy/GDP	LPG/KPI
Productivity	• GDP per capita by region		**Quality of Life**	• GDP per capita • Energy services per capita • Share calories from non-staples • Water stress	LPG/KPI
Technology	• Power plant conversion efficiency • Transport fuel economy, etc. • Crop yields, etc.		**Environmental Sustainability**	• SO_2 NO_x O_3 concentrations • Deforestation/afforestation • Avg. Earth surface temp • Water withdrawals/recharge	LPG/KPI
Resources	• Fossil fuel, uranium, solar, wind, geothermal, land, water and other				
Policies	• Pollution control • NDCs • Water use				

Scenarios: Carbon Neutrality

I.   Reference scenario (REF)

Based on SSP 2[*] as point of departure, i.e., without dedicated sustainable energy or climate policies (essentially the REF scenario of the Pathways Project)

II.   Carbon neutrality scenario – UNECE region (CN-UNECE)

Normative scenario mandating carbon neutrality of UNECE's aggregate energy system by 2050 (and beyond)

III.   Carbon neutrality scenario at the regional level (CNN)

Each UNECE region individually realizes carbon neutrality by 2050

III.   Special technology scenarios (so far on the table….)

a)   Hydrogen – production options and markets (H2)

b)   Carbon capture, utilization and storage options; carbon dioxide removal and direct air capture (CCUS)

c)   Nuclear energy – realizing its potential, new application and markets

d)   Low demand (extreme energy efficiency and intensity advances

SSP: Shared Socio-economic pathway to 2100. Pathway 2 is a middle of the road future
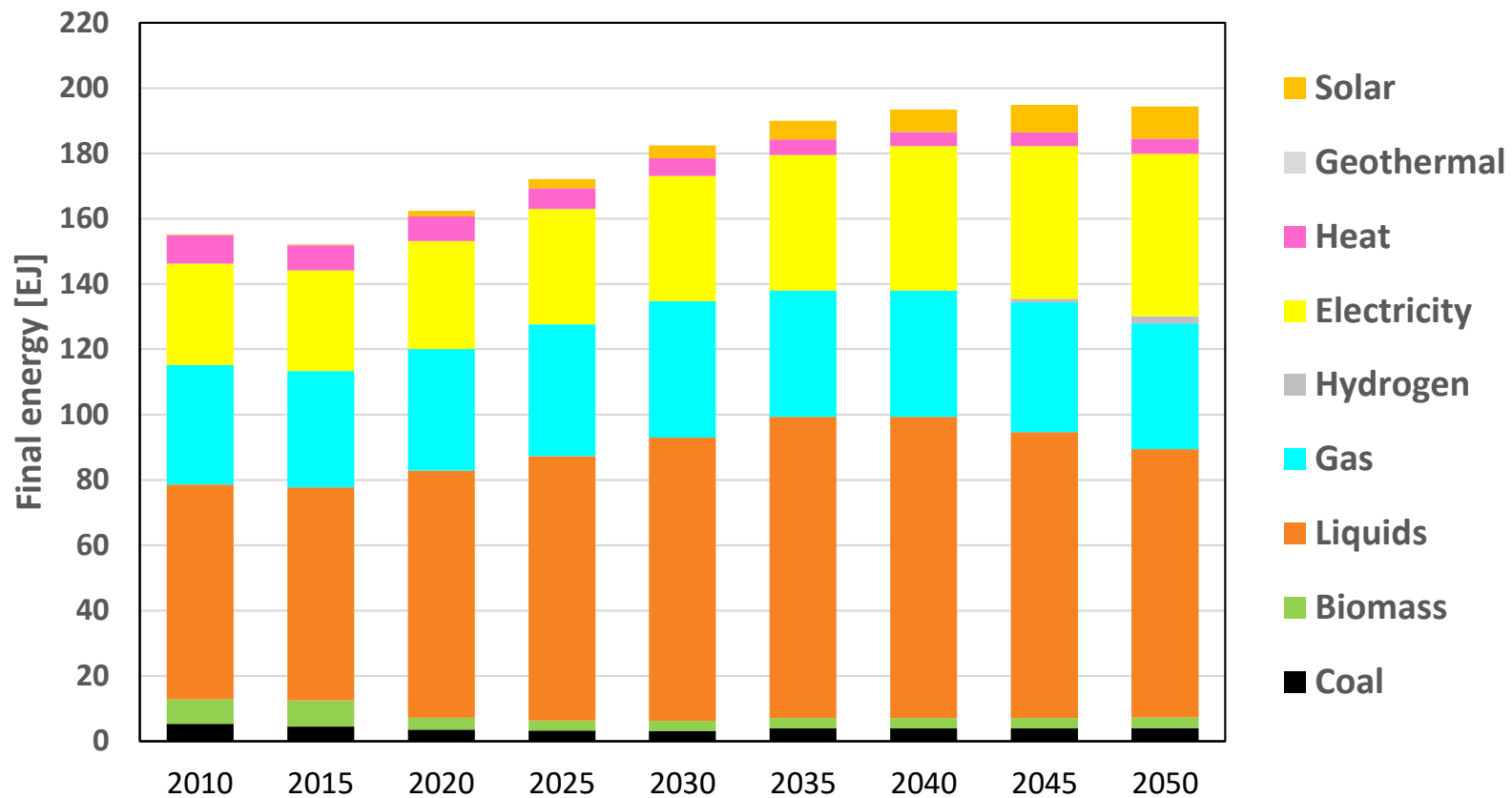
ENERGY

Final energy mix - ECE
REF Scenario

Final energy mix - ECE
CN-UNECE Scenario

Final Energy Mix

Final energy mix - ECE
CN-UNECE versus REF Scenario

Legend:
- Solar
- Geothermal
- Heat
- Electricity
- Hydrogen
- Gas
- Liquids
- Biomass
- Coal

Modeling Results: ECE
Electricity Generation

Electricity generation by technology - ECE REF Scenario

Legend: Wind Offshore, Wind Onshore, CSP, PV, Geothermal, Biomass CCS, Biomass, Hydro, Nuclear, Gas CCS, Gas, Oil CCS, Oil, Coal CCS, Coal
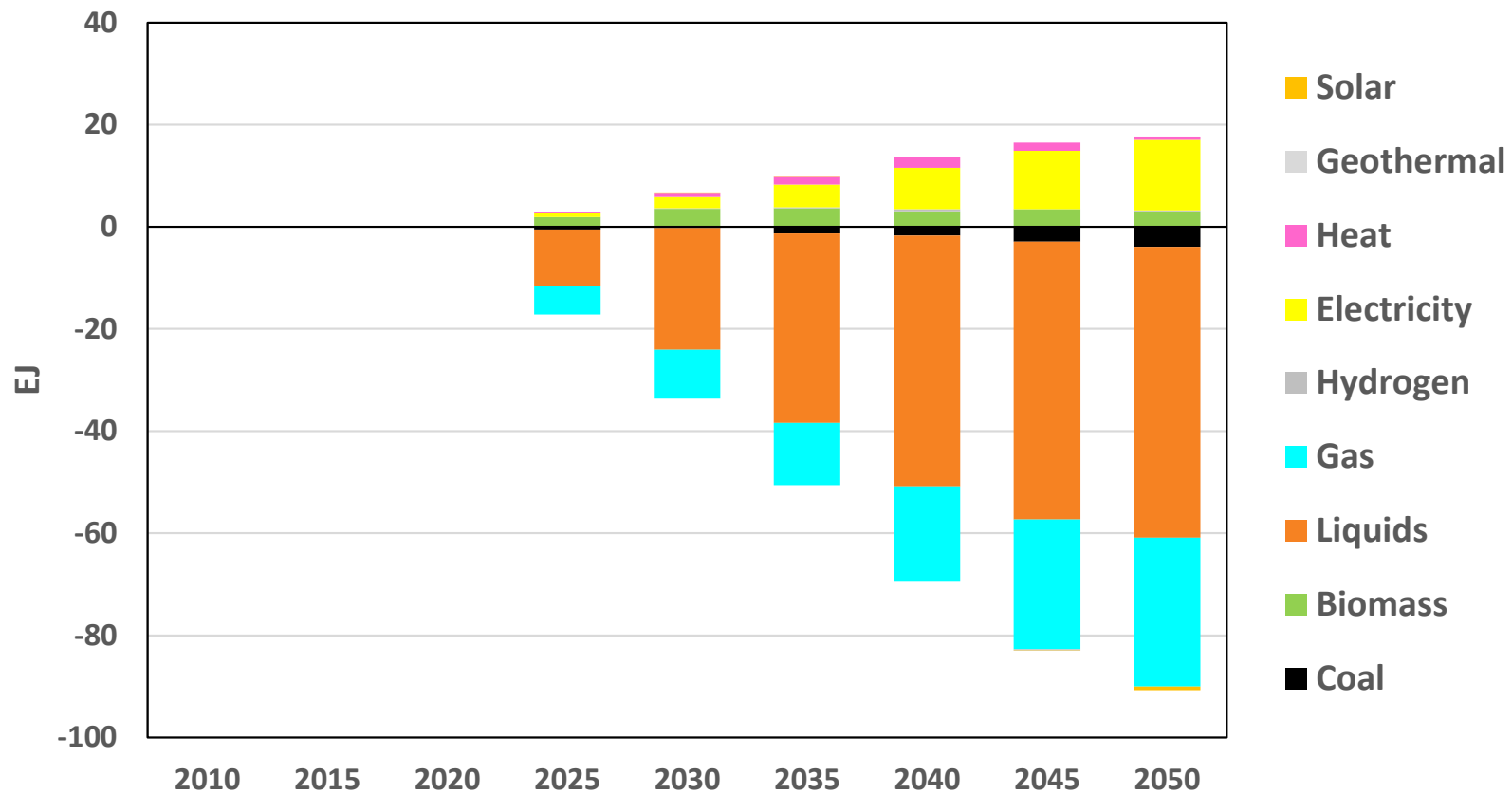
Modeling Results: ECE
Electricity Generation

ENERGY

Electricity generation by technology - ECE CN-UNECE

Legend:
- Wind Offshore
- Wind Onshore
- CSP
- PV
- Geothermal
- Biomass CCS
- Biomass
- Hydro
- Nuclear
- Gas CCS
- Gas
- Oil CCS
- Oil
- Coal CCS
- Coal

Y-axis: TWh (0, 5 000, 10 000, 15 000, 20 000, 25 000)

X-axis: 2010, 2015, 2020, 2025, 2030, 2035, 2040, 2045, 2050

Modeling Results: ECE

ENERGY

Electricity generating capacity by technology - ECE
CN-UNECE versus REF Scenario

Legend:
- Wind Offshore
- Wind Onshore
- CSP
- PV
- Geothermal
- Biomass CCS
- Biomass
- Hydro
- Nuclear
- Gas CCS
- Gas
- Oil CCS
- Oil
- Coal CCS
- Coal

Electricity generating capacity by technology - ECE REF Scenario

Electricity generating capacity by technology - ECE UNECE Scenario

Legend: Wind Offshore, Wind Onshore, CSP, PV, Geothermal, Biomass CCS, Biomass, Hydro, Nuclear, Gas CCS, Gas, Oil CCS, Oil, Coal CCS, Coal

Modeling Results: ECE

Electricity generating capacity

ENERGY

Electricity generating capacity by technology - ECE
CN-UNECE versus REF Scenario
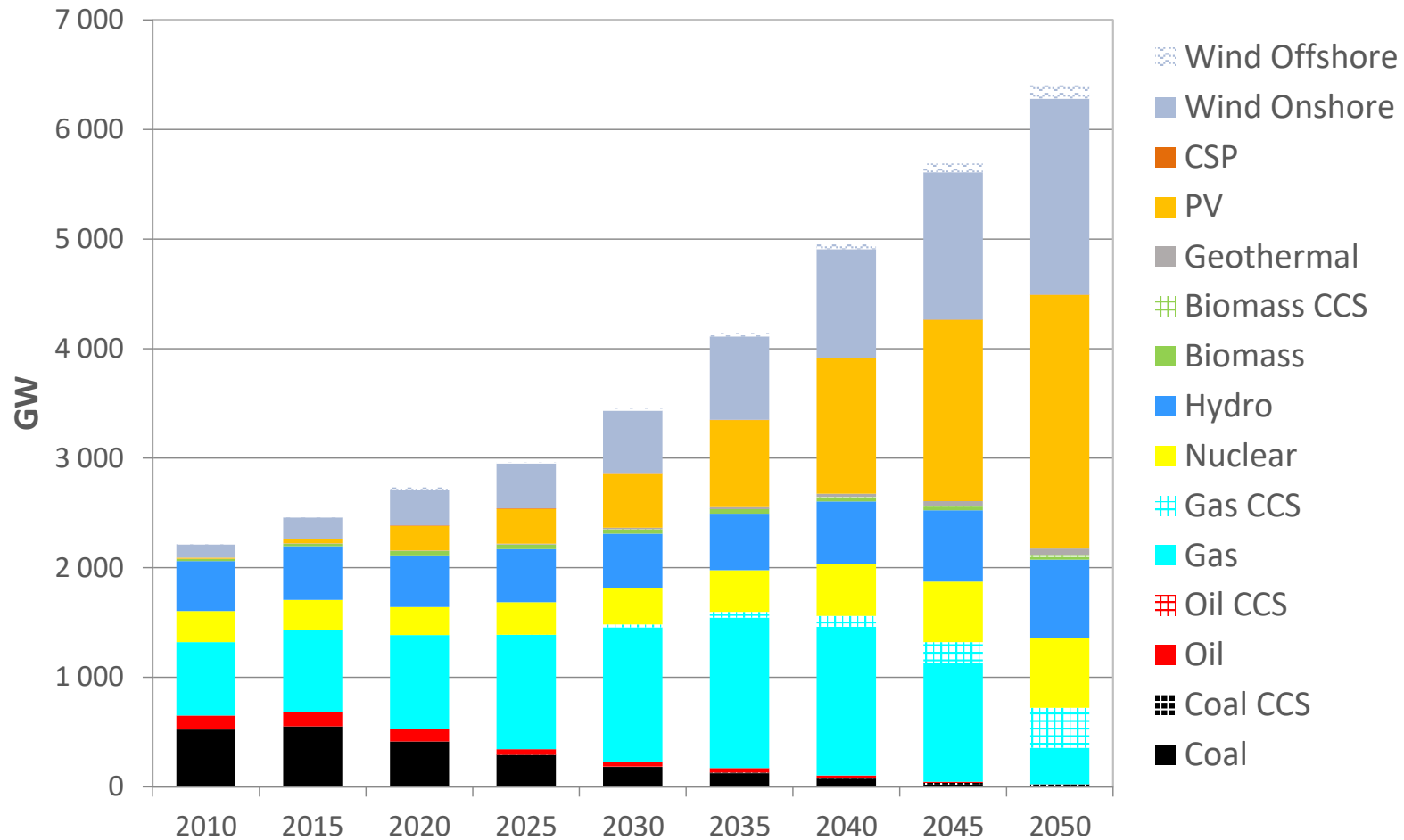
Modeling Results: ECE
Carbon dioxide emissions

ENERGY

CO$_2$ emissions by scenario - ECE

[Million tonnes/year]

Energy system CO$_2$ emissions [Mt/year]

REF

Carbon neutrality

2-degree
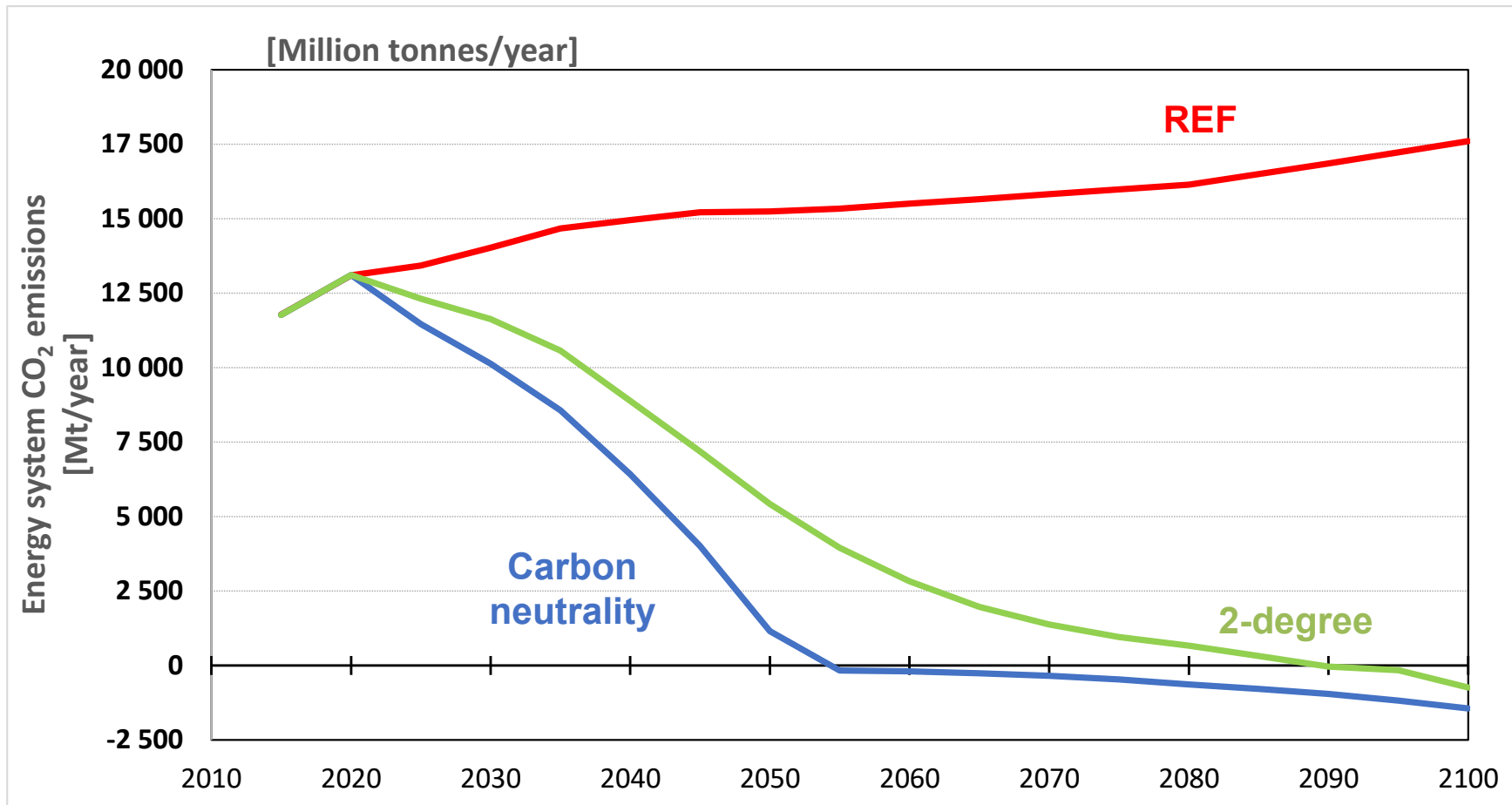
Modeling Results: ECE

Methane emissions

ENERGY

CH$_4$ emissions by scenario - ECE

[Million tonnes/year]

Energy system CO$_4$ emissions [Mt/year]

REF

2-degree

Carbon neutrality
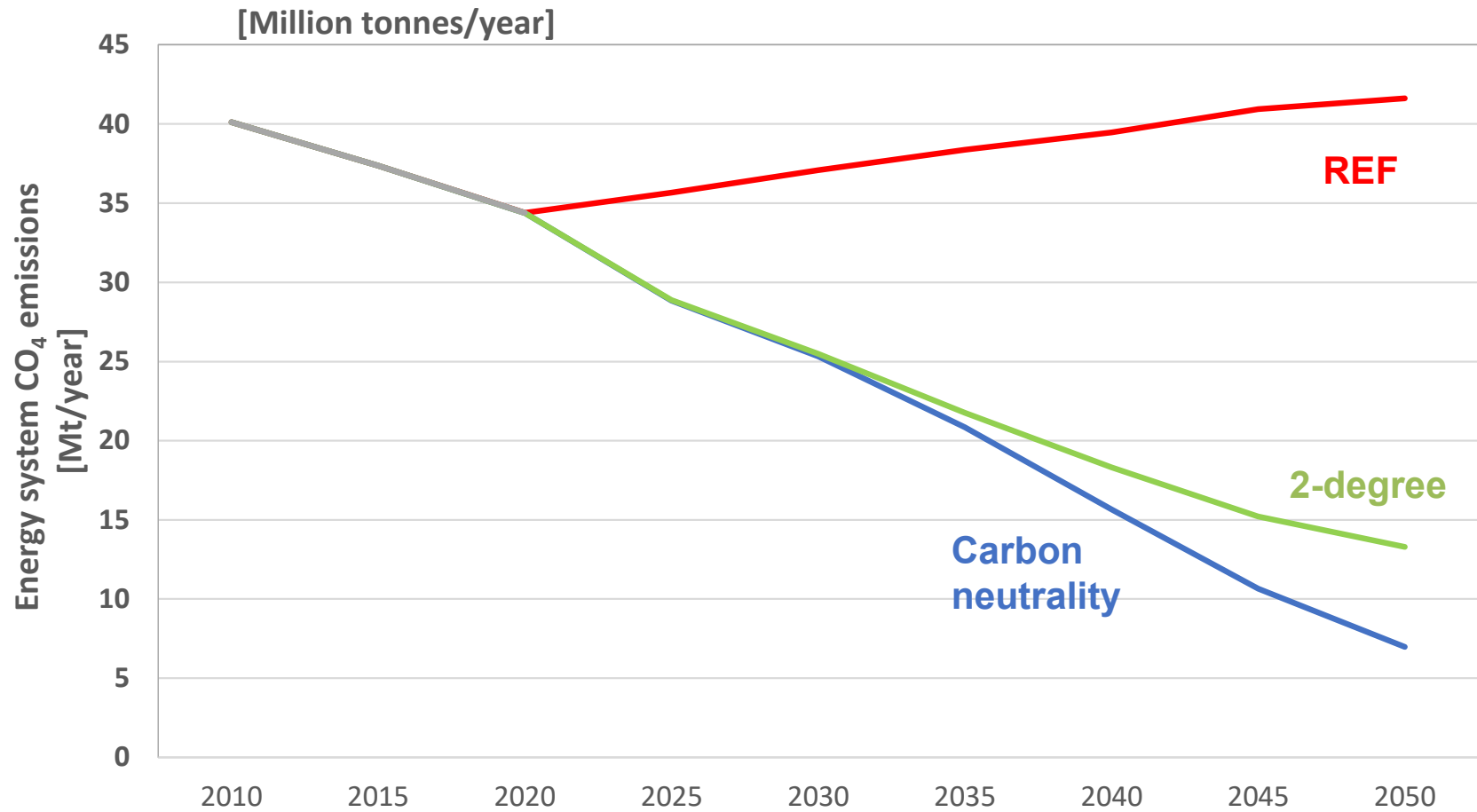
Modeling Results: ECE

Investment needs

ENERGY

Cumulative investments 2020-2050: *26,562 billion US$*
Reference (REF)
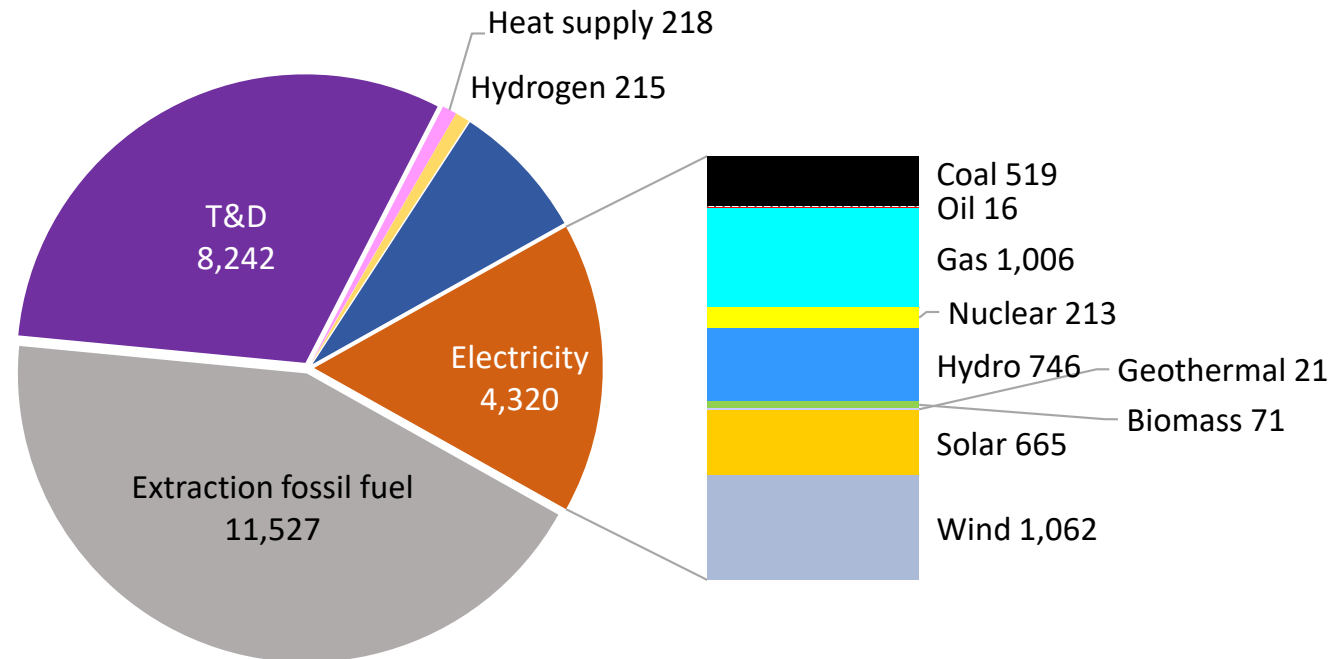
Heat supply 218
Hydrogen 215

T&D 8,242

Electricity 4,320

Extraction fossil fuel 11,527

Coal 519
Oil 16
Gas 1,006
Nuclear 213
Hydro 746 — Geothermal 21
Biomass 71
Solar 665
Wind 1,062

Legend:
- Extraction fossil fuel
- Coal
- Coal CCS
- Oil
- Oil CCS
- Gas
- Gas CCS
- Nuclear
- Hydro
- Biomass
- Biomass CCS
- Geothermal
- Solar
- Wind
- T&D
- Energy efficiency
- Heat supply
- Hydrogen
- Other

- T&D: transmission and distribution of electricity and district heat
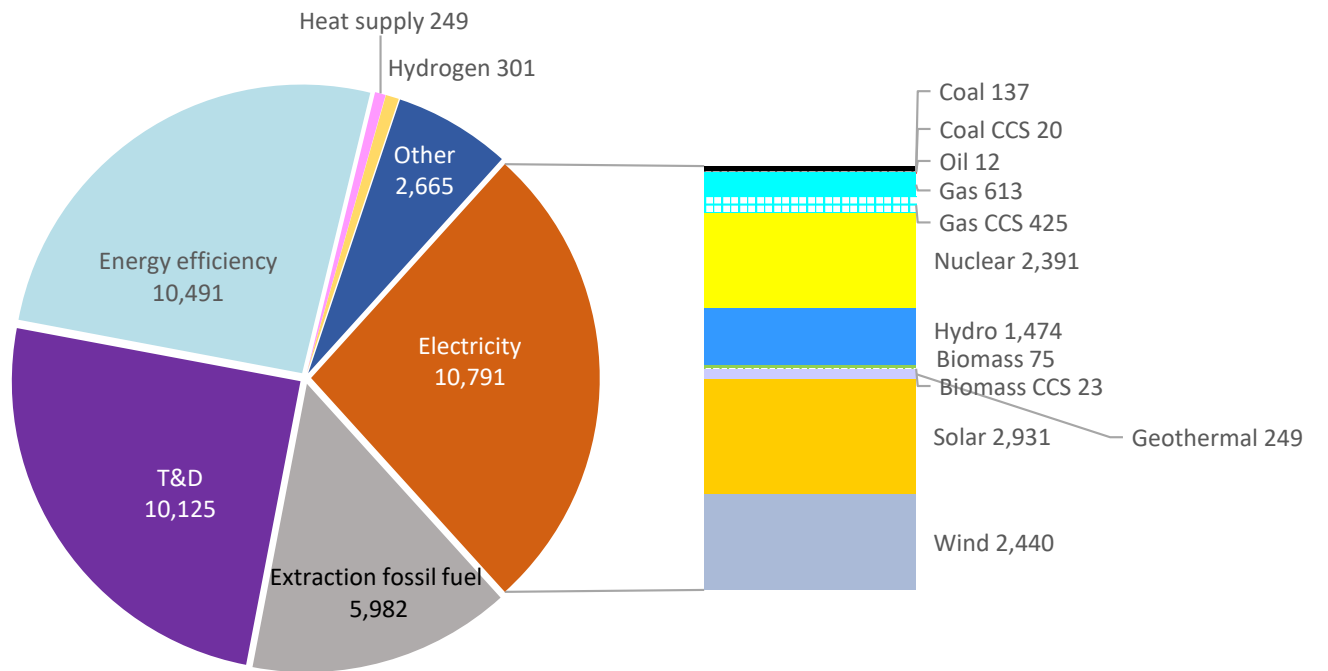- Investments in US$ at 2020 prices and exchange rates

Modeling Results: ECE

Investment needs

Cumulative investments 2020-2050: *40,603 billion US$*
Carbon neutrality (CN)

Heat supply 249
Hydrogen 301
Other 2,665
Energy efficiency 10,491
Electricity 10,791
T&D 10,125
Extraction fossil fuel 5,982

Coal 137
Coal CCS 20
Oil 12
Gas 613
Gas CCS 425
Nuclear 2,391
Hydro 1,474
Biomass 75
Biomass CCS 23
Geothermal 249
Solar 2,931
Wind 2,440

Legend:
- Extraction fossil fuel
- Coal
- Coal CCS
- Oil
- Oil CCS
- Gas
- Gas CCS
- Nuclear
- Hydro
- Biomass
- Biomass CCS
- Geothermal
- Solar
- Wind
- T&D
- Energy efficiency
- Heat supply
- Hydrogen
- Other

- T&D: transmission and distribution of electricity and district heat
- Investments in US$ at 2020 prices and exchange rates

ENERGY

Cumulative investment requirements
REF, CN and 2-degree
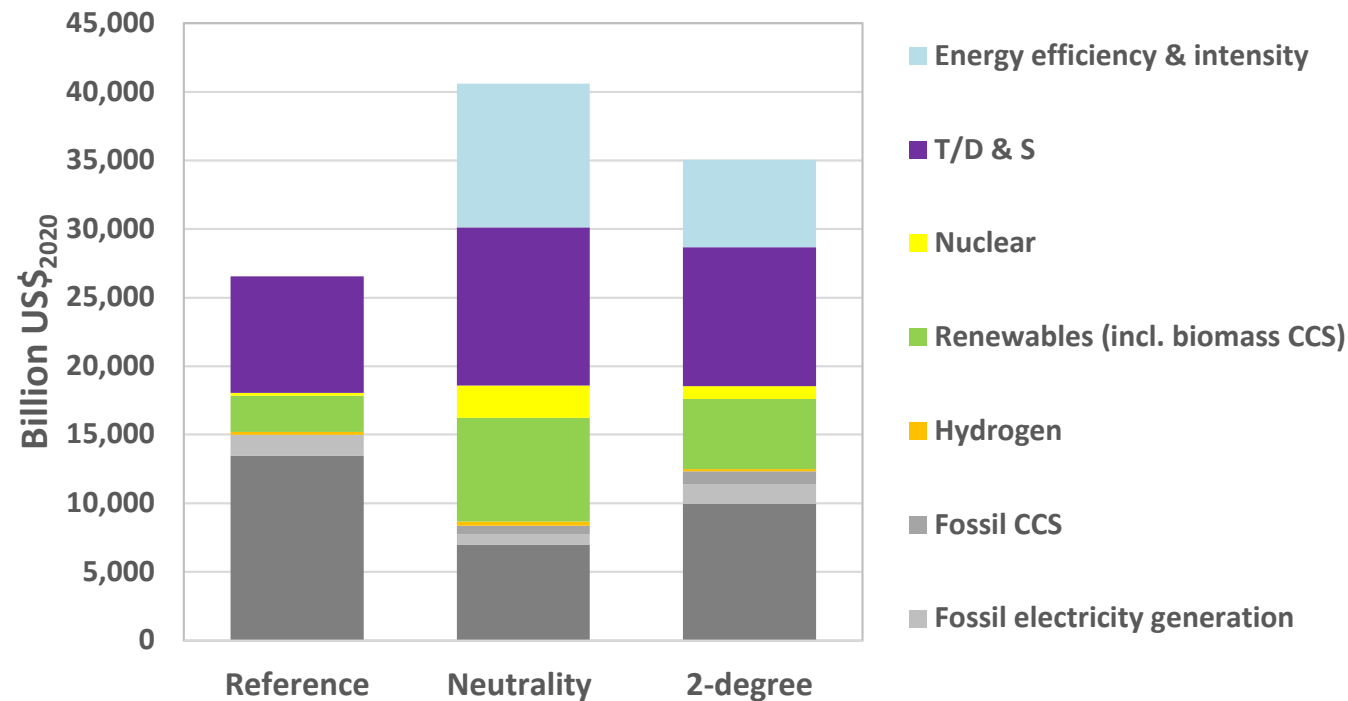
- T/D & S: transmission, distribution and storage of electricity and district heat
- CCS: carbon capture and storage
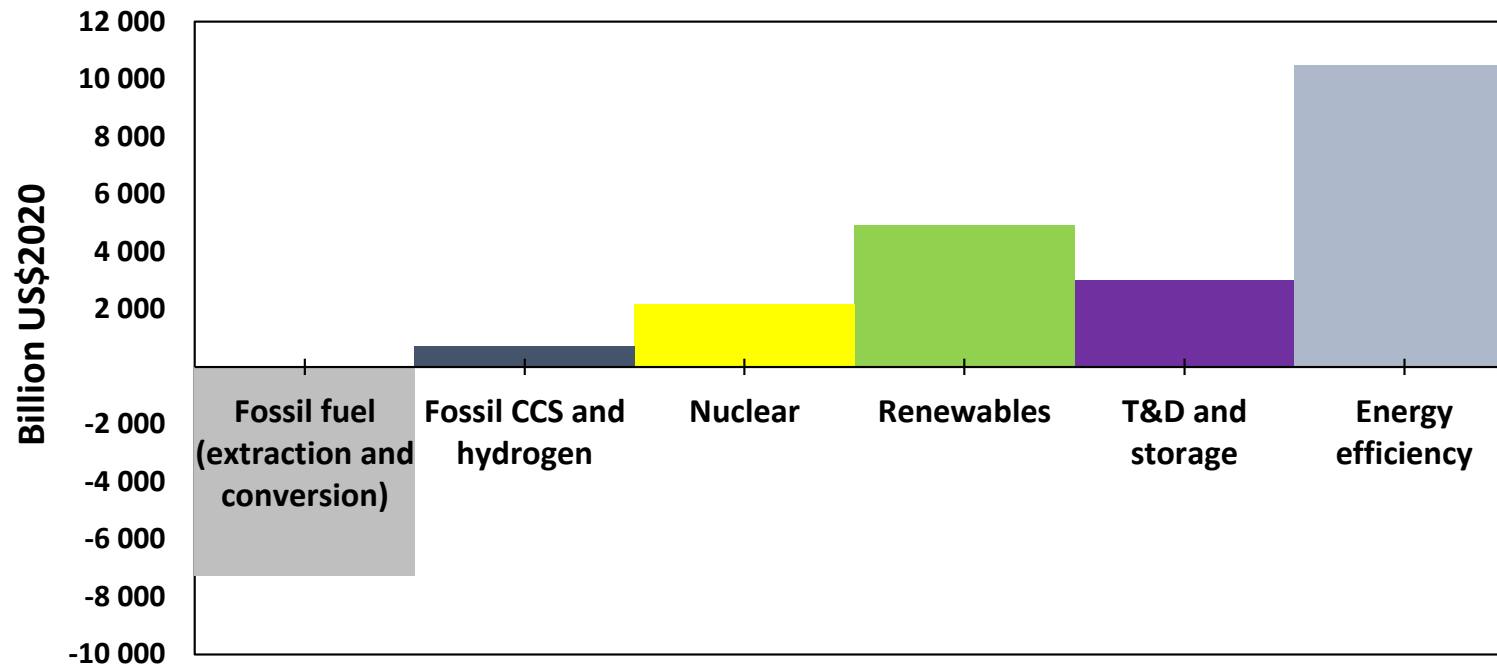- BAT: Best available technology

ENERGY

Investment dynamics 2020-2050, Neutrality vs. Reference

- T/D & S: transmission, distribution and storage of electricity and district heat
- CCS: carbon capture and storage
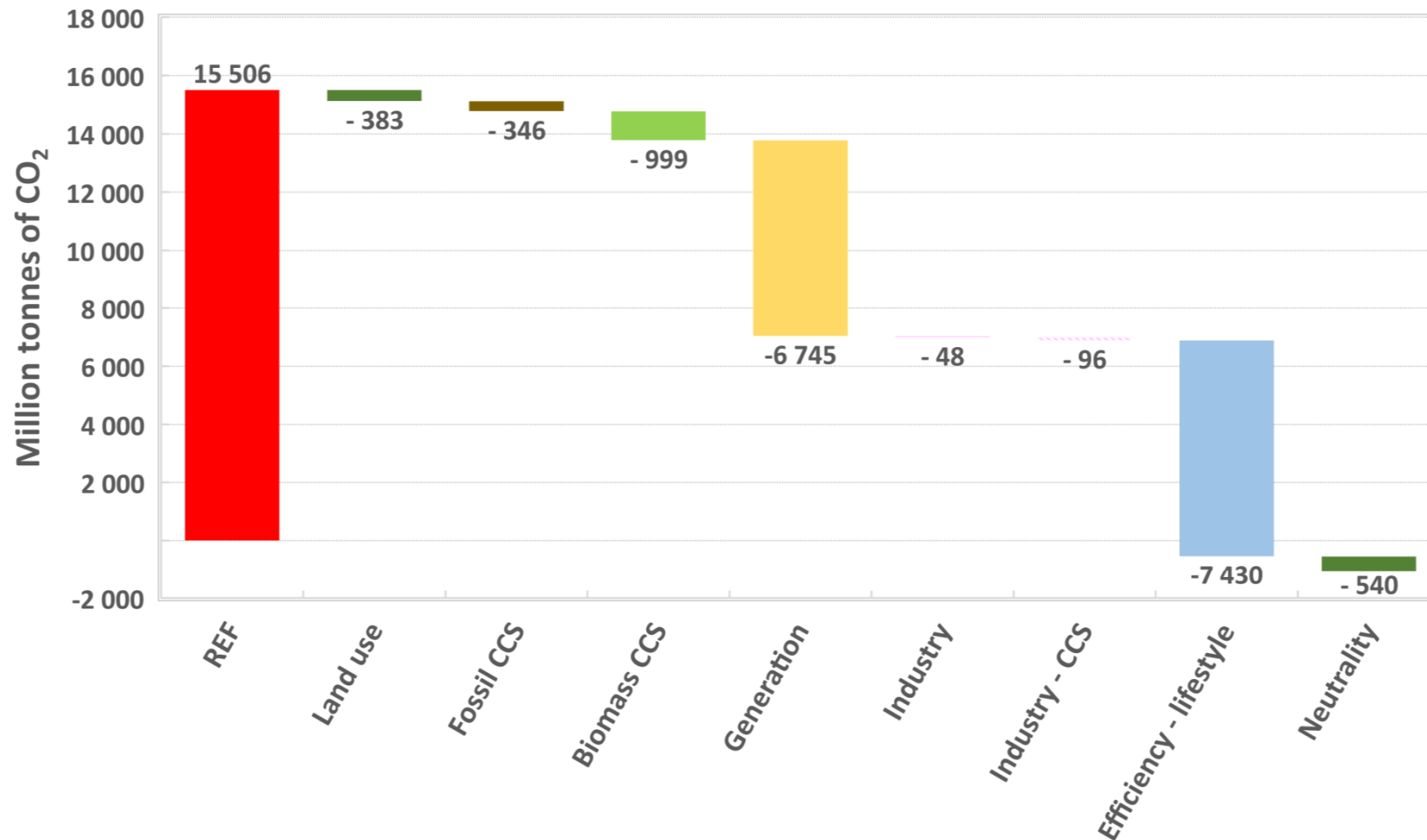- BAT: Best available technology

Modeling Results: ECE
The path to carbon neutrality

Cumulative mitigation steps from REF to CN
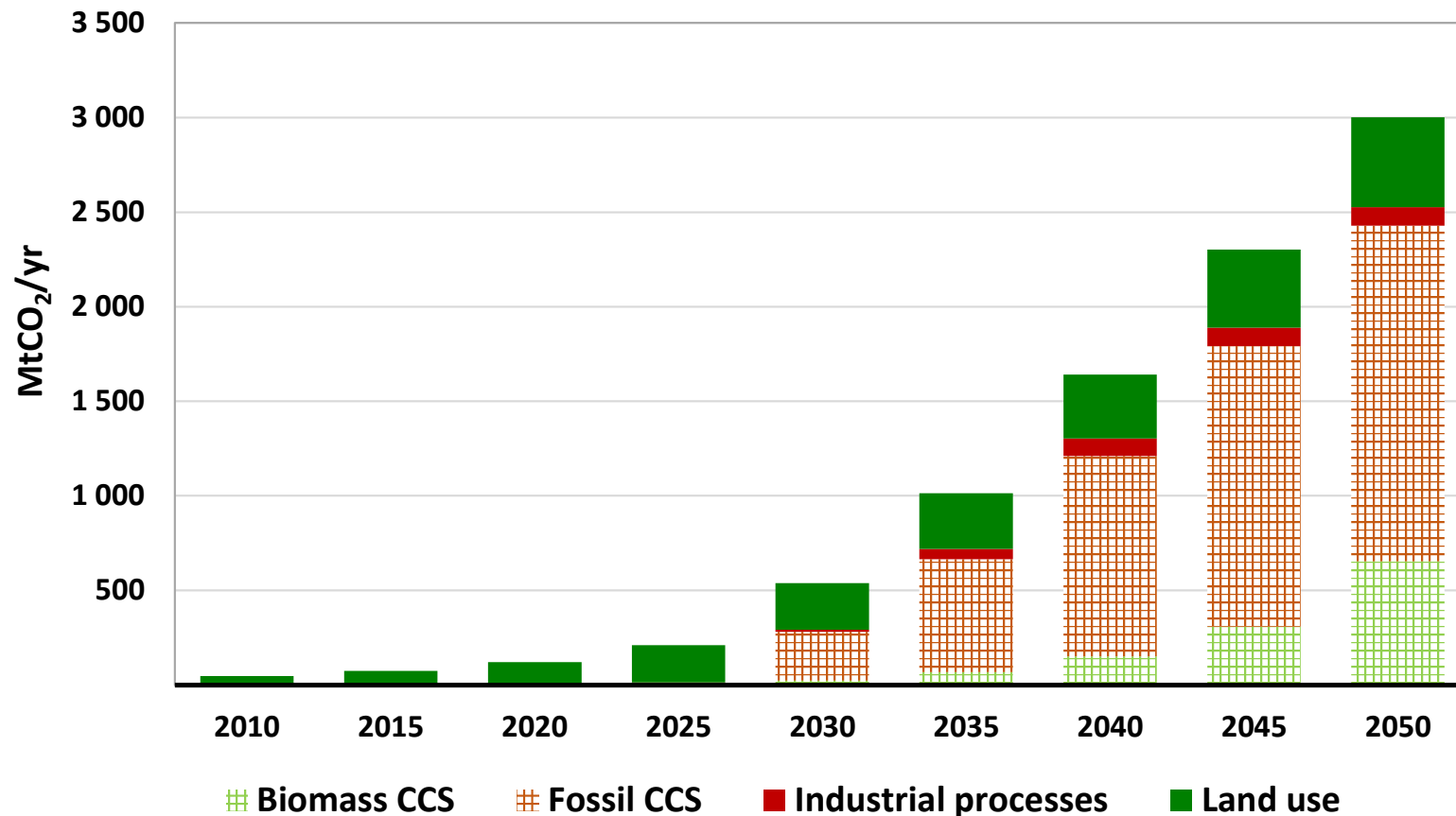(as seen by an observer in 2050)

ENERGY

Modeling Results: ECE
The path to carbon neutrality

ENERGY

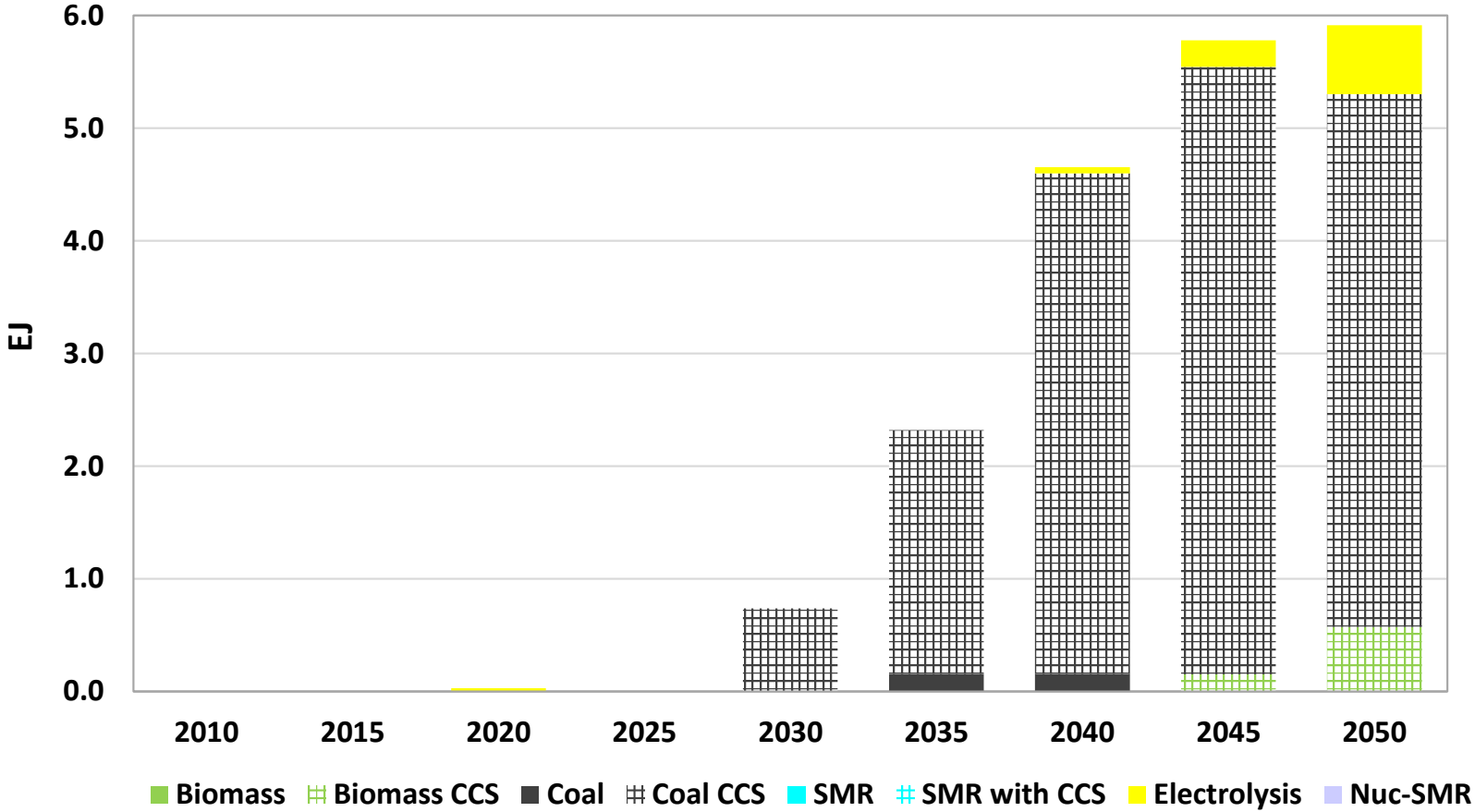## Carbon capture, utilization and storage (sequestration)
A mixed set of measures

Legend: Biomass CCS, Fossil CCS, Industrial processes, Land use

Modeling Results: ECE
The path to carbon neutrality

ENERGY

Hydrogen production in CN

Legend: ■ Biomass ⊞ Biomass CCS ■ Coal ⊞ Coal CCS ■ SMR ⊞ SMR with CCS ■ Electrolysis ■ Nuc-SMR

Reference (REF)

Radar chart legend: 2020, 2030, 2050

Axes: Energy Intensity (FE), Decline in GDP per capita, Energy Expenditure per GDP (FE), Total cost of energy sector per GDP, Carbon emissions per GDP, Share of non-RE in FE, Energy import dependancy, Carbon intensity of electricity

Scale: 0, 0.2, 0.4, 0.6, 0.8, 1

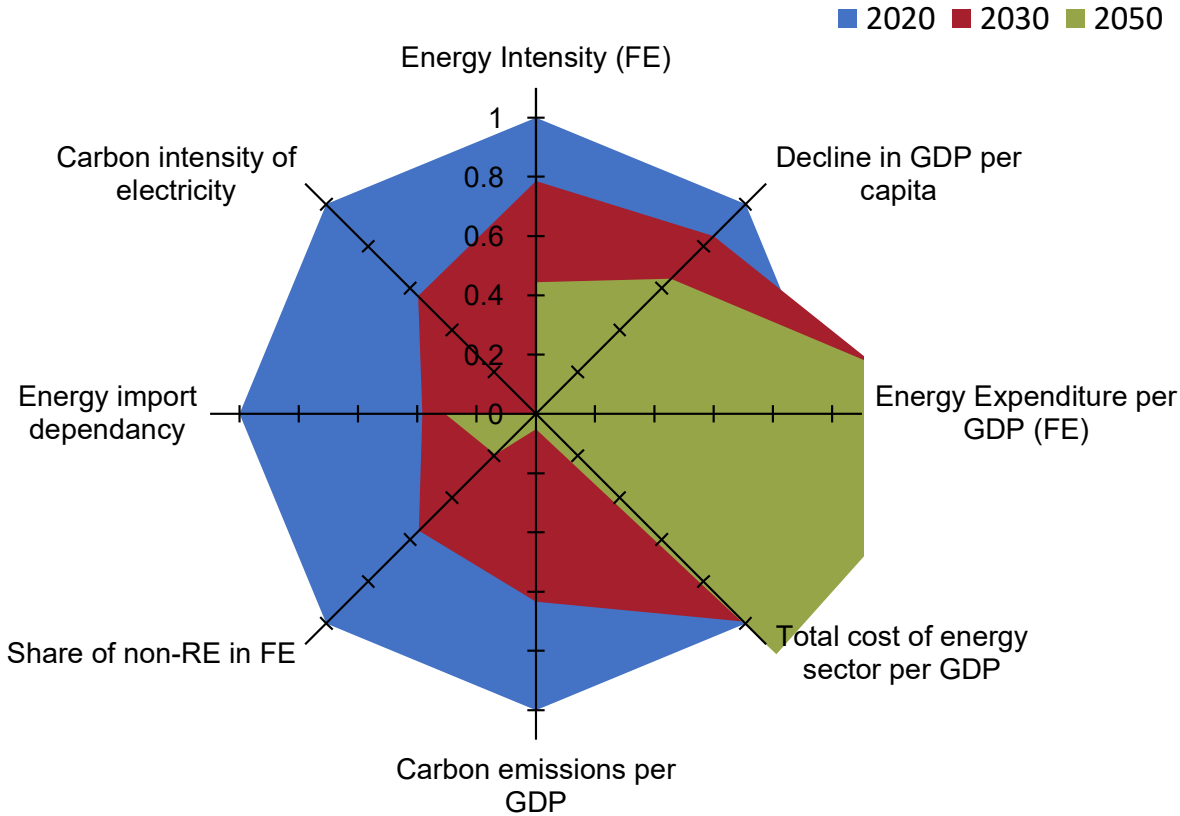## Neutrality (CN)

Modeling Results: ECE
Impact of different futures

ENERGY

Indicators across scenarios (averages between 2020 and 2050)