International Institute for Applied Systems Analysis
IIASA

UNECE

ENERGY

Modeling of Pathways to Sustainable Energy: IIASA results

Exploring and facilitating the transition to sustainable energy systems

MESSAGE$_{IX}$

An Optimization Approach

MESSAGE - Model for Energy Supply System Alternatives and their General Environmental Impacts

- Background: MESSAGE developed and maintained by IIASA (Austria), but also adapted for short-term national analyses and distributed by the IAEA for energy planning capacity building purposes
- Optimization model: Supply must meet predetermined demand at minimum system costs (partial equilibrium)
- System representation: Detailed energy resource and energy infrastructure representation (energy source-to-service chains)
- Purpose: Policy analysis and scenario development (medium- to long-term; global; multi-sector; energy-emissions-economy) within an internally consistent integrated assessment modeling framework
- Sectors: All energy sectors (supply & demand); link to rest of the economy via MACRO model; simple climate mode (w/o feedback mechanism)
- Regional aggregation: World divided up into 14 regions
- Methodology/solution structure: Combination of linear programming (LP) energy-engineering model + aggregated macro-economic model (non-linear) + logit-based discrete choice model for mode choice in transport (optional) + household fuel choice model for cooking (optional)
- Level of foresight in decisions: Perfect foresight (to 2100); myopic mode possible
  - Time steps: Statistical data for 2015 and 2015 (IEA, IRENA, Platts, USGS, BGR, etc.)
  - First calculated year 2020, then 5 years intervals until 2060, thereafter 10 year intervals

Model Overview

IIASA Integrated Assessment Framework

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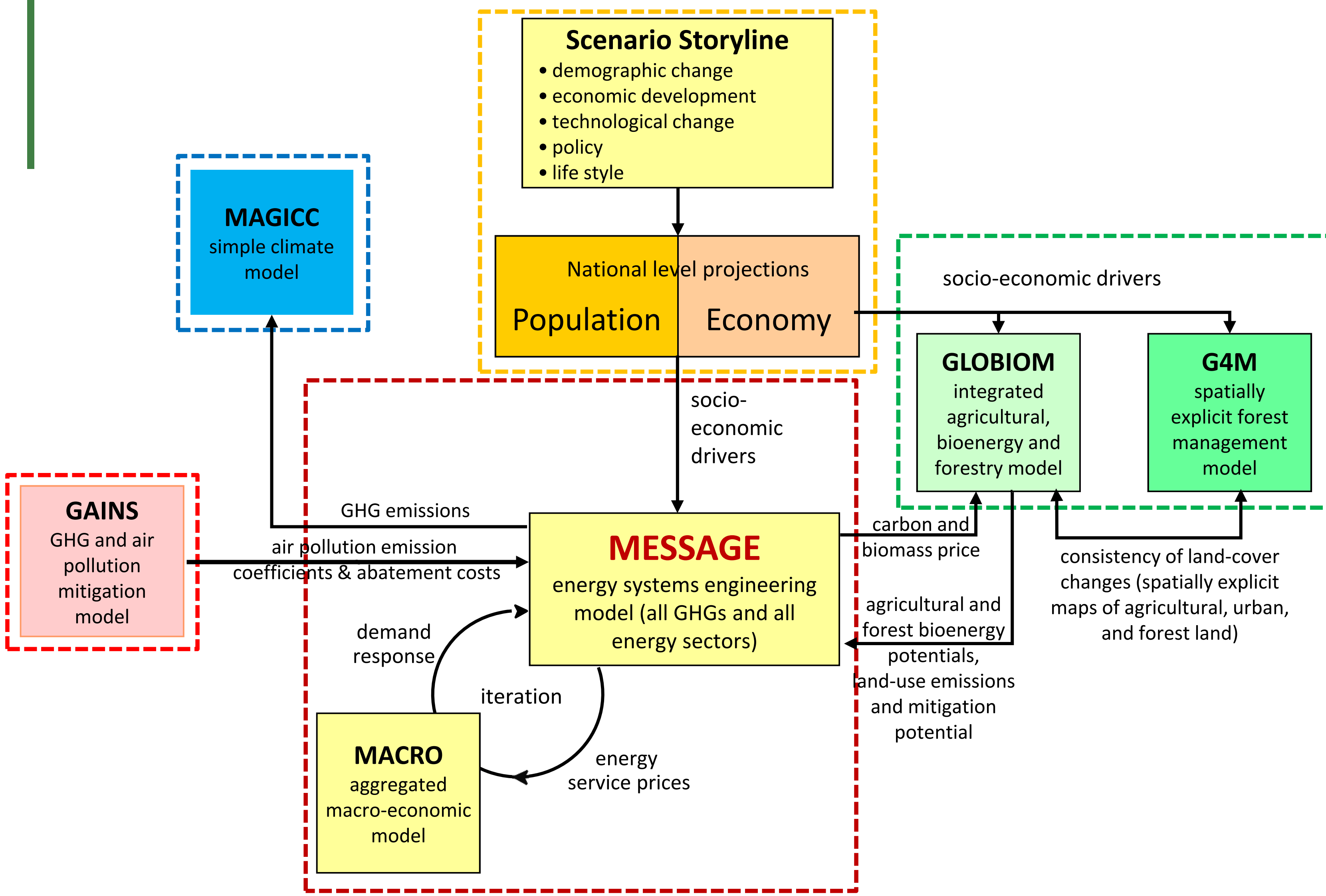

Graphic courtesy of Volker Krey (IIASA)

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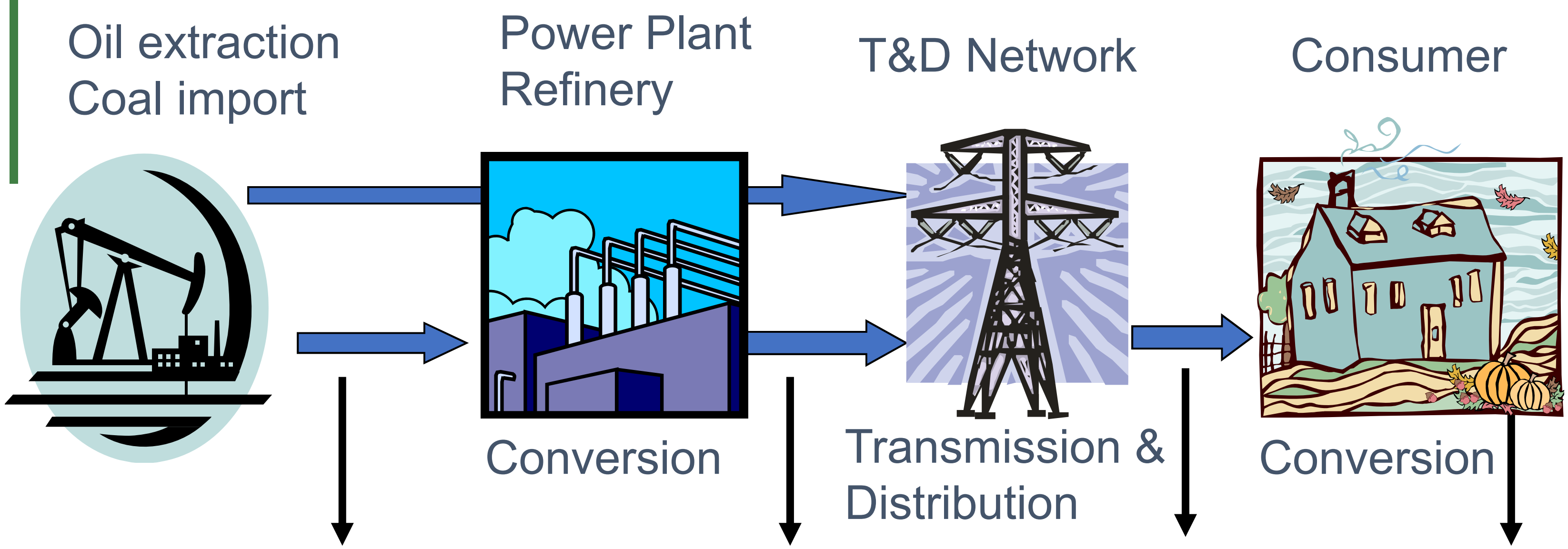
Energy System

ENERGY



PRIMARY energy	SECONDARY energy	FINAL energy	USEFUL energy
- coal	- diesel	- diesel	- heat
- oil	- kerosene	- kerosene	- light
- gas	- gas	- gas	- mechanical energy
- water	- electricity	- electricity	- ……
- sun	- coal	- coal	
- uranium	-…….		

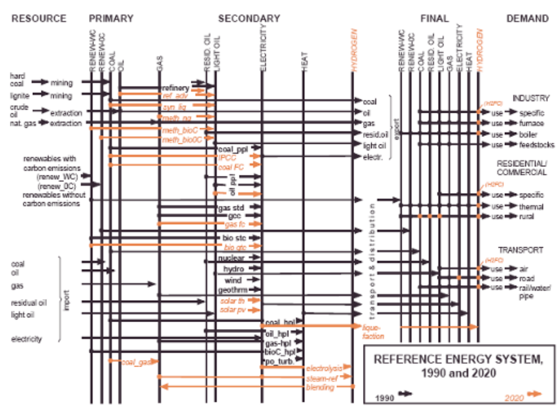
Overview

MESSAGE$_{ix}$ Energy System

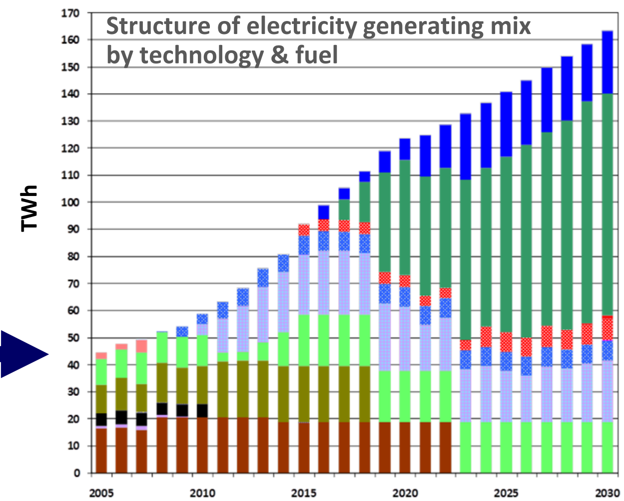
ENERGY

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
- Technical and policy constraints



OUTPUT



- 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

Models? Not crystal balls!

Processing data and assumptions

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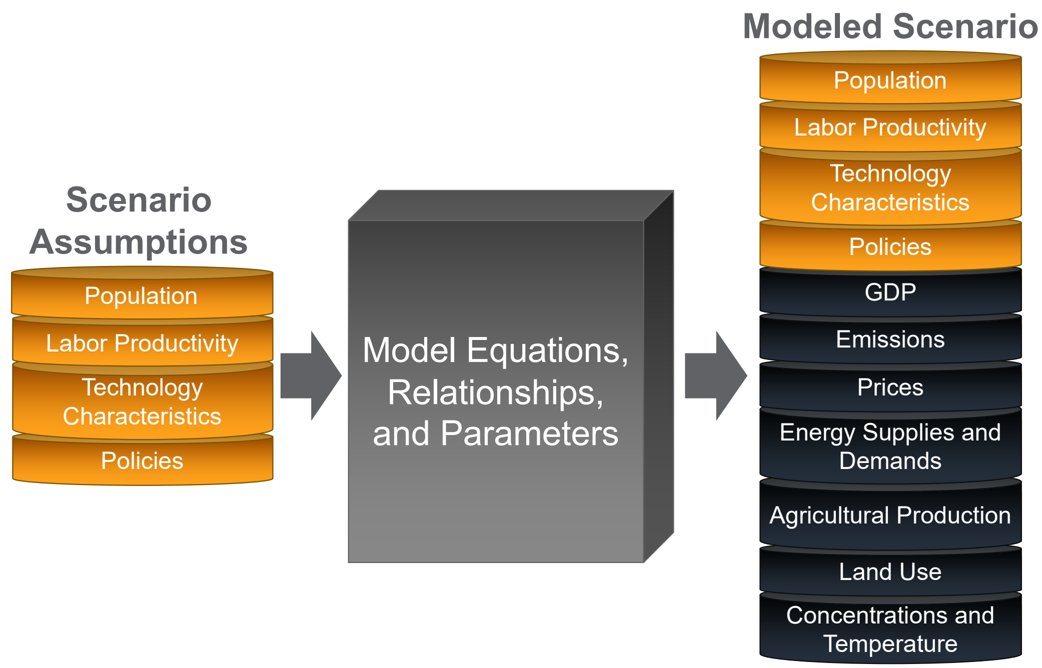
- Models are mathematical representations of real world relationships, calibrated with historical data
- Assumptions required to parameterize models
  - Future rates of technological development
  - Socioeconomics
  - Policy changes
- The model solves the mathematical relationships, given the input assumptions
- Scenarios explore different assumptions about inputs
- Policies can be defined through changes to model assumptions or specific policy goals



<u>Using models</u>

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

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

Scenario development

Illustration of scenario design

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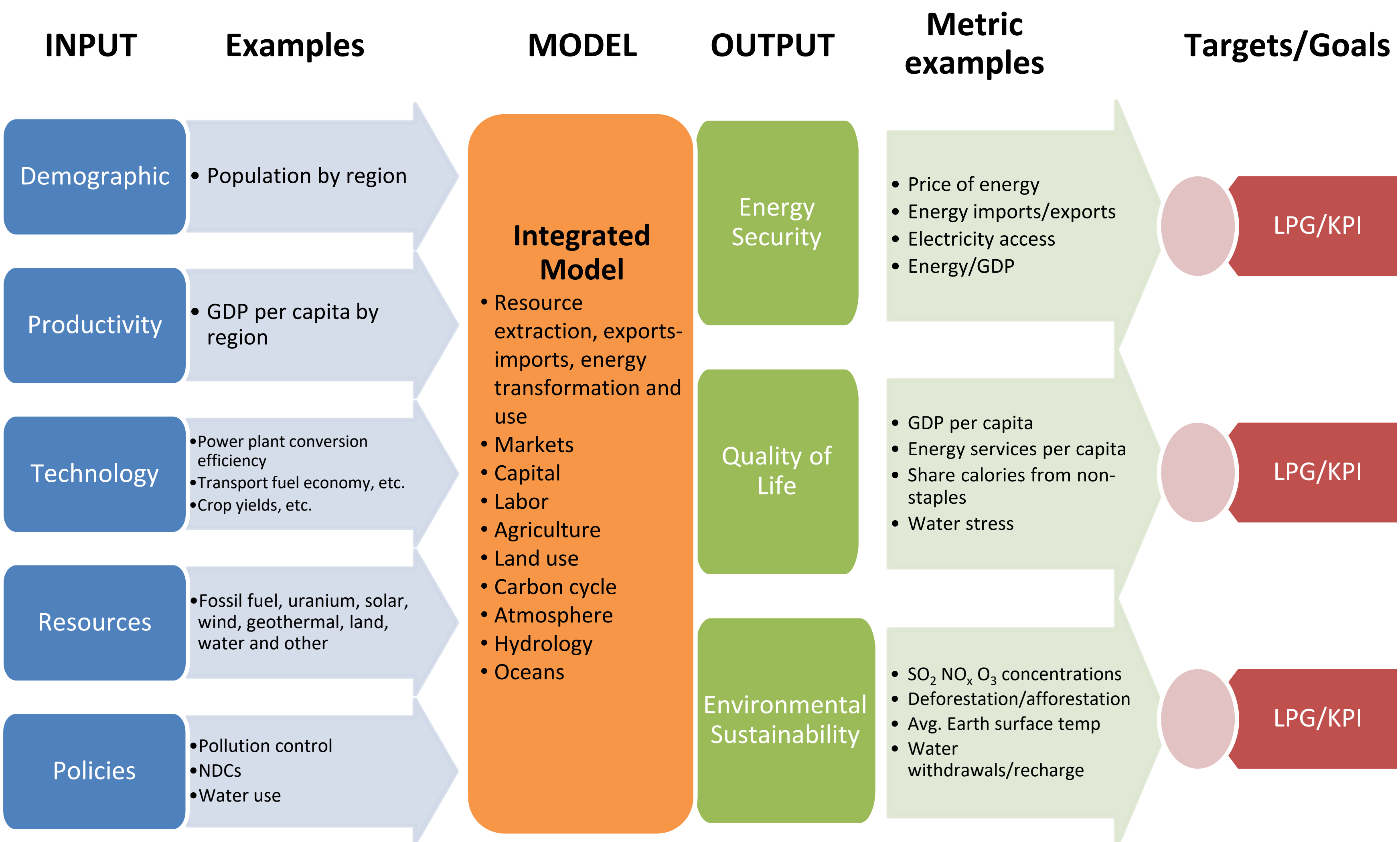

Scenarios

Scenarios and Sensitivities of the Pathways Project

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- Policy scenarios - reflect various levels of emissions constraints based on explicit sustainability policies
  - **REF** - no climate policy, SSP2 Middle of the Road Development
  - **NDC** - regional CO_2 constraints consistent with country-level NDCs and current sustainability policies through 2030 with "continued ambition" through 2100
  - **P2C** - global CO_2 budget to achieve a 2ºC target by 2100
- Policy scenarios are further explored by technology sensitivities
  - Technology sensitivities are intended to represent different potential technological development pathways in which specific technologies develop more quickly or slowly than in the REF assumptions
  - Technology sensitivities exclude technology learning costs or economic incentives for accelerated technology uptake
  - A technology's sensitivity case should be compared to its own reference scenario to inform decision makers about the impacts of alternative technology priorities on reaching sustainability development objectives
- Technology sensitivities
  - REF (reference energy technology assumptions)
  - RES (reduced capital costs for geothermal, solar, and wind
  - NUC (reduced capital costs for nuclear)

SSP2: “Middle of the road”

Reference Scenario

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Why the SSPs?

- **SSPs[1] are widely used** in the Sustainable Development (SD) and Climate Change (CC) communities. They represent well described and ‘agreed’ development pathways.
- **Peer reviewed and vetted** - No knowledge gain by adding yet a new set of scenarios

Why SSP2 out of five SSPs?

- “**Middle of the road**” scenario deemed most suitable analyzing the four scenario spaces developed by UNECE expert network between 2015 and 2016
- Social, economic, and technological trends proceed along historical patterns
  - Moderate population development
  - Economic development and income growth proceed unevenly
  - Technological development follows an evolutionary path (no revolutionary breakthroughs)
  - No reluctance to use unconventional fossil resources
  - Fossil fuel dependency decreases slowly
  - No explicit climate change policies
  - Environmental systems experience degradation
  - **In Summary:** Slow progress on reaching the SDGs

[1]Adapted from B. van Ruijven (2015); K. Riahi (2017); and O’Neil (2017)

Pathways Project and Sustainable Energy

Reminder: Three Pillars

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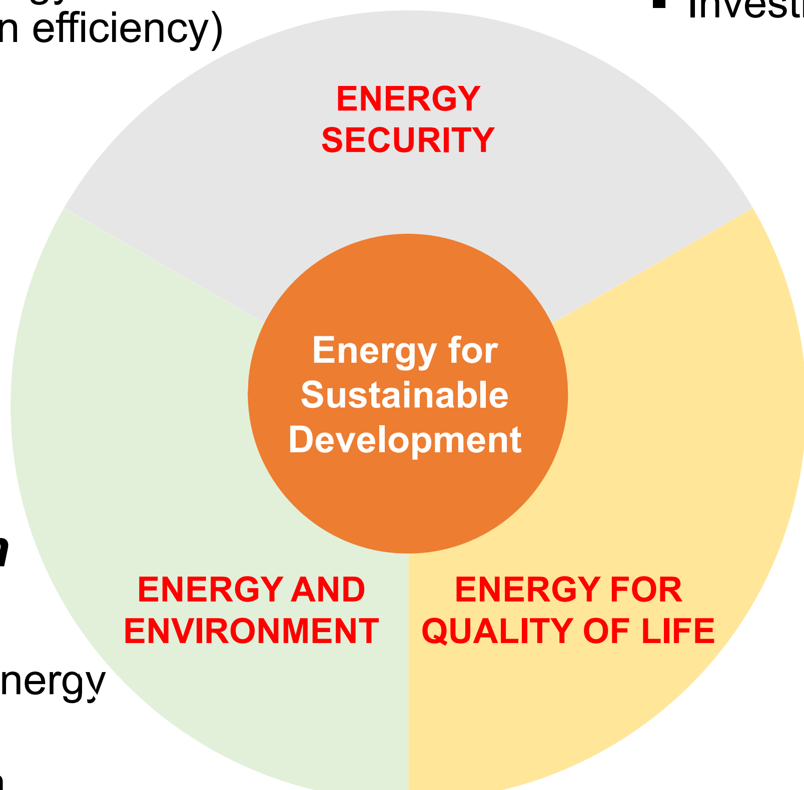
"Secure the energy needed for economic development"

- Energy Efficiency (energy intensity of economy, rate of improvement of energy intensity, conversion efficiency)
- Fuel mix
- Net energy trade
- Investment requirements



"Minimize adverse energy system impacts on climate, ecosystems & human health"

- GHG emissions from the energy system
- Energy-related air pollution, water use & water stress

"Provide affordable energy that is available for all at all times"

- Access to energy services
- Energy affordability
- Food security (biomass use)

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Regional Resolution

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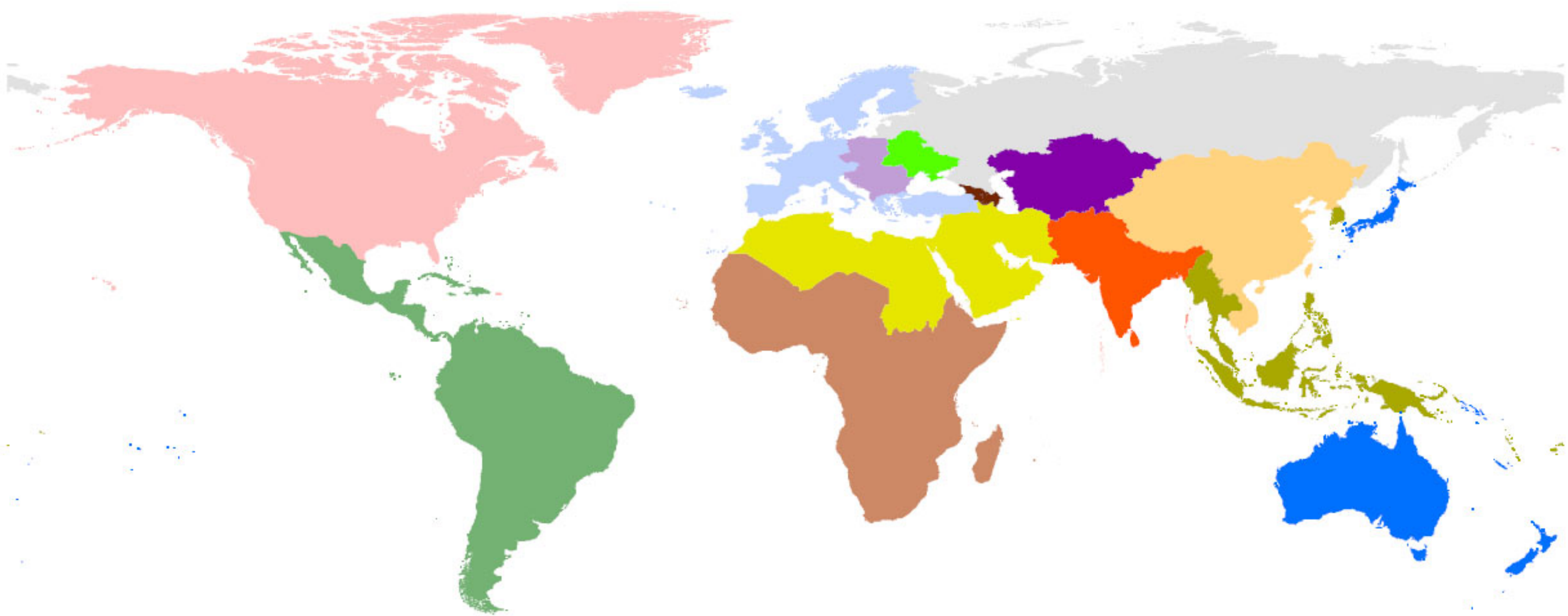
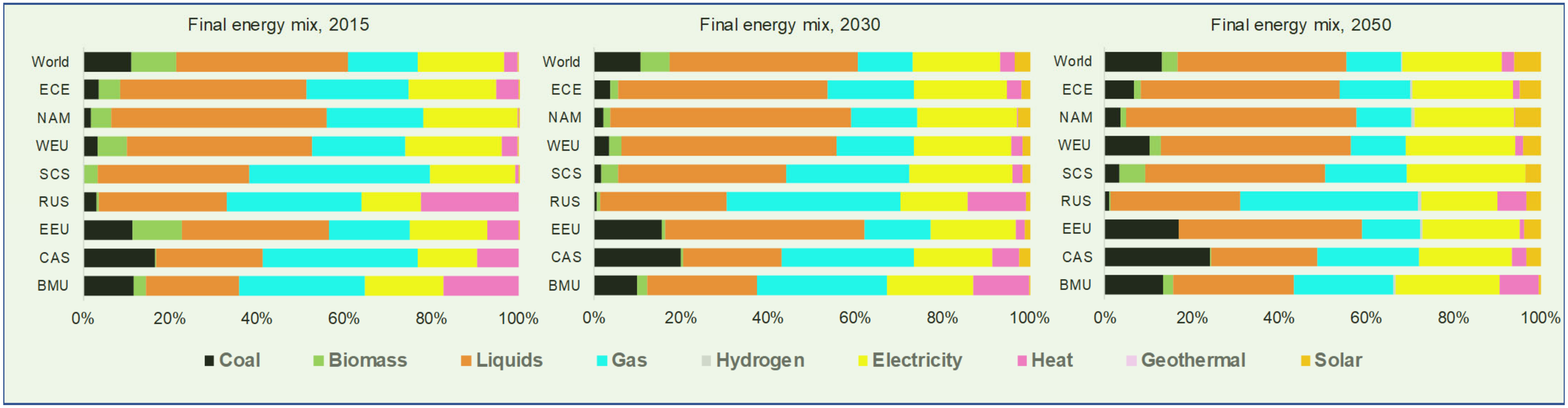
AFR	Sub-Saharan Africa	LAC	Latin America and the Caribbean	RUS	Russian Federation
BMU	Belarus, Moldova, Ukraine	MEA	Middle East and North Africa	SAS	South Asia
CAS	Central Asia	NAM	North America	SCS	South Caucasus
CPA	Centrally planned Asia & China	PAO	Pacific OECD	WEU	Western Europe
EEU	Central and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



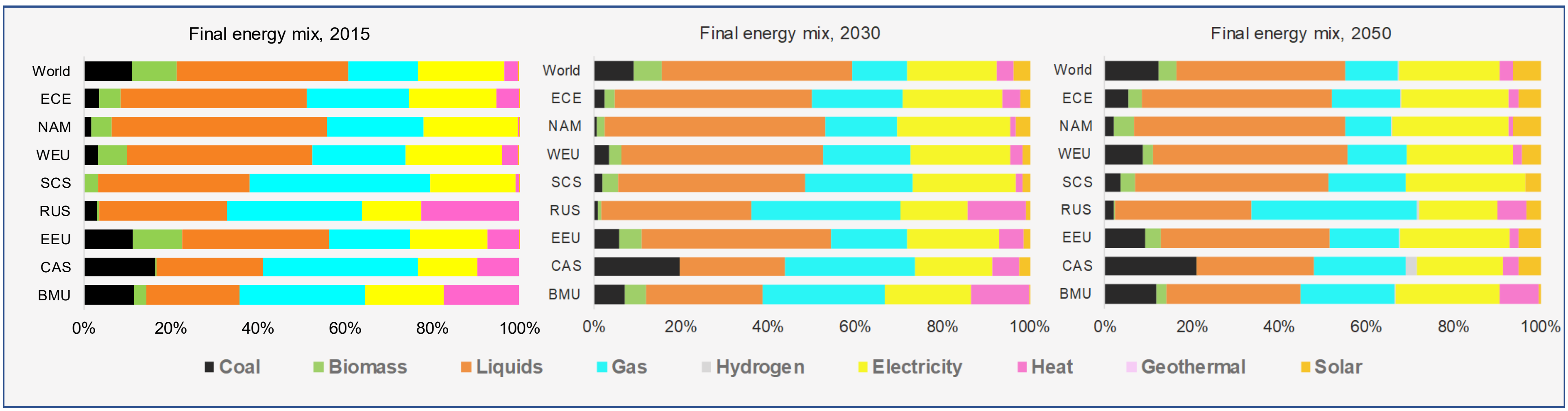
Modeling Results: Final energy transformation

ENERGY

REF scenario



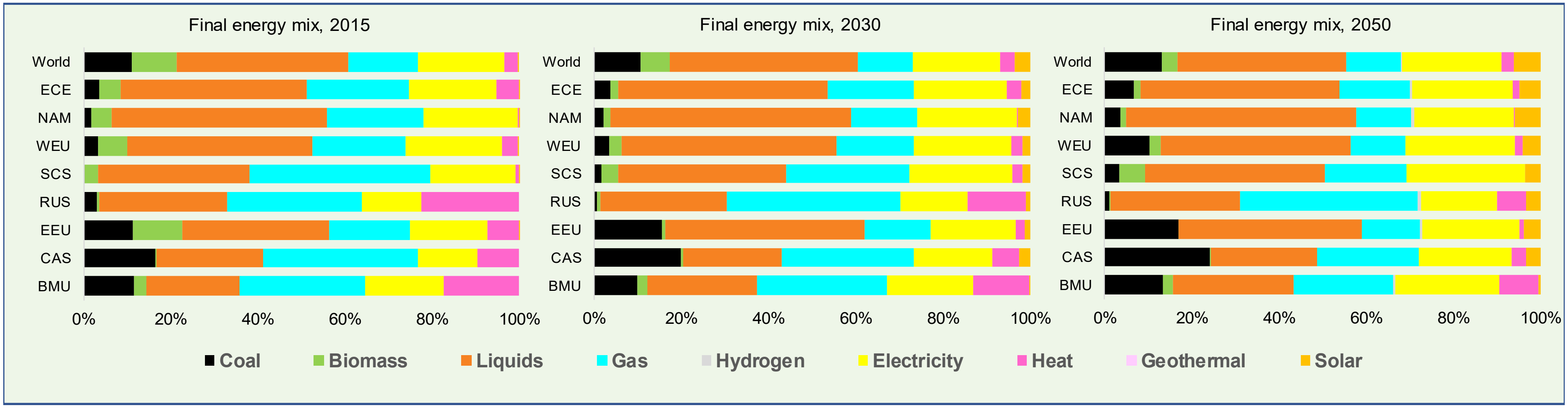
NDC scenario



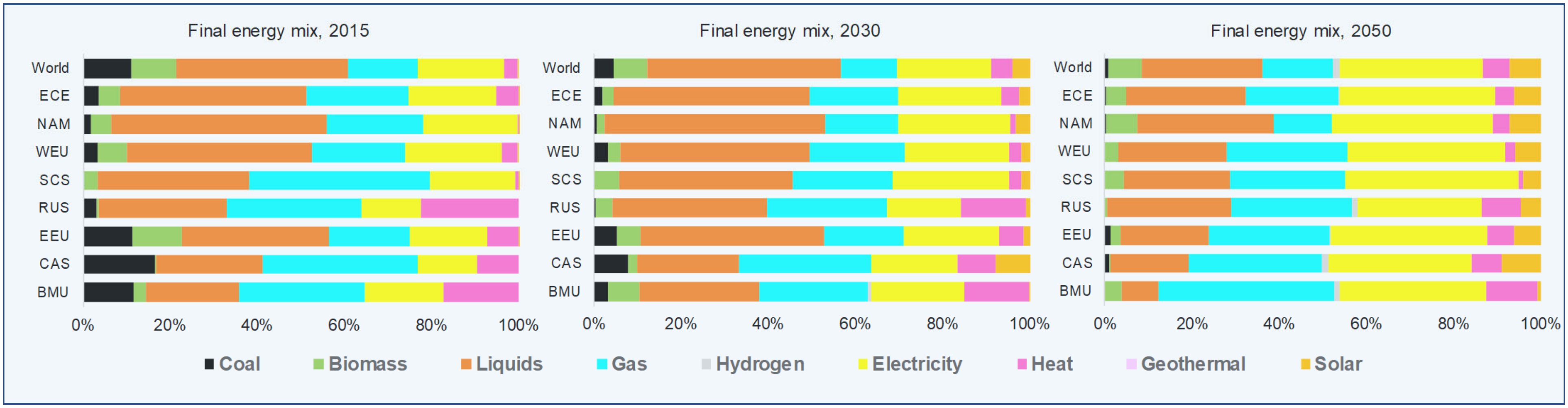
Modeling Results: Final energy transformation

ENERGY

REF scenario



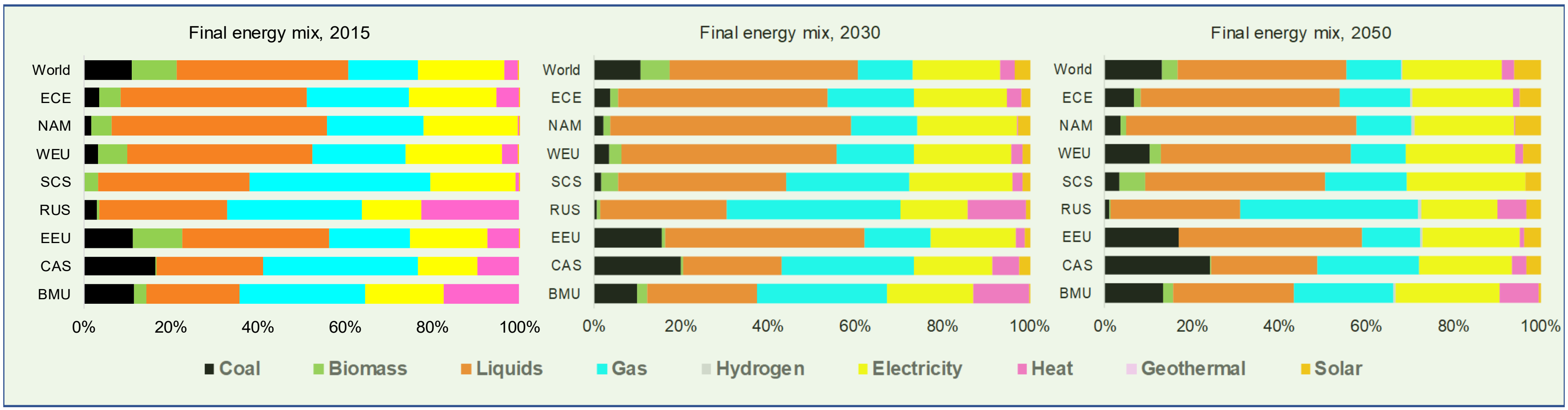
P2C scenario



Modeling Results: Final energy transformation

ENERGY

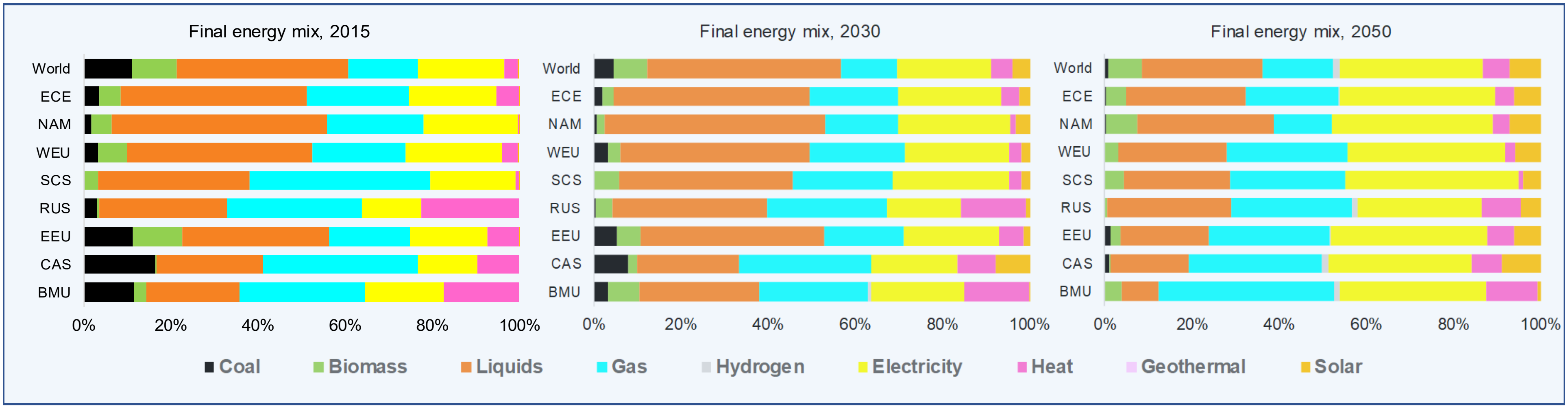
REF scenario



Modeling Results: Final energy transformation

ENERGY

P2C scenario



Modeling Results: ECE

Final Energy Mix

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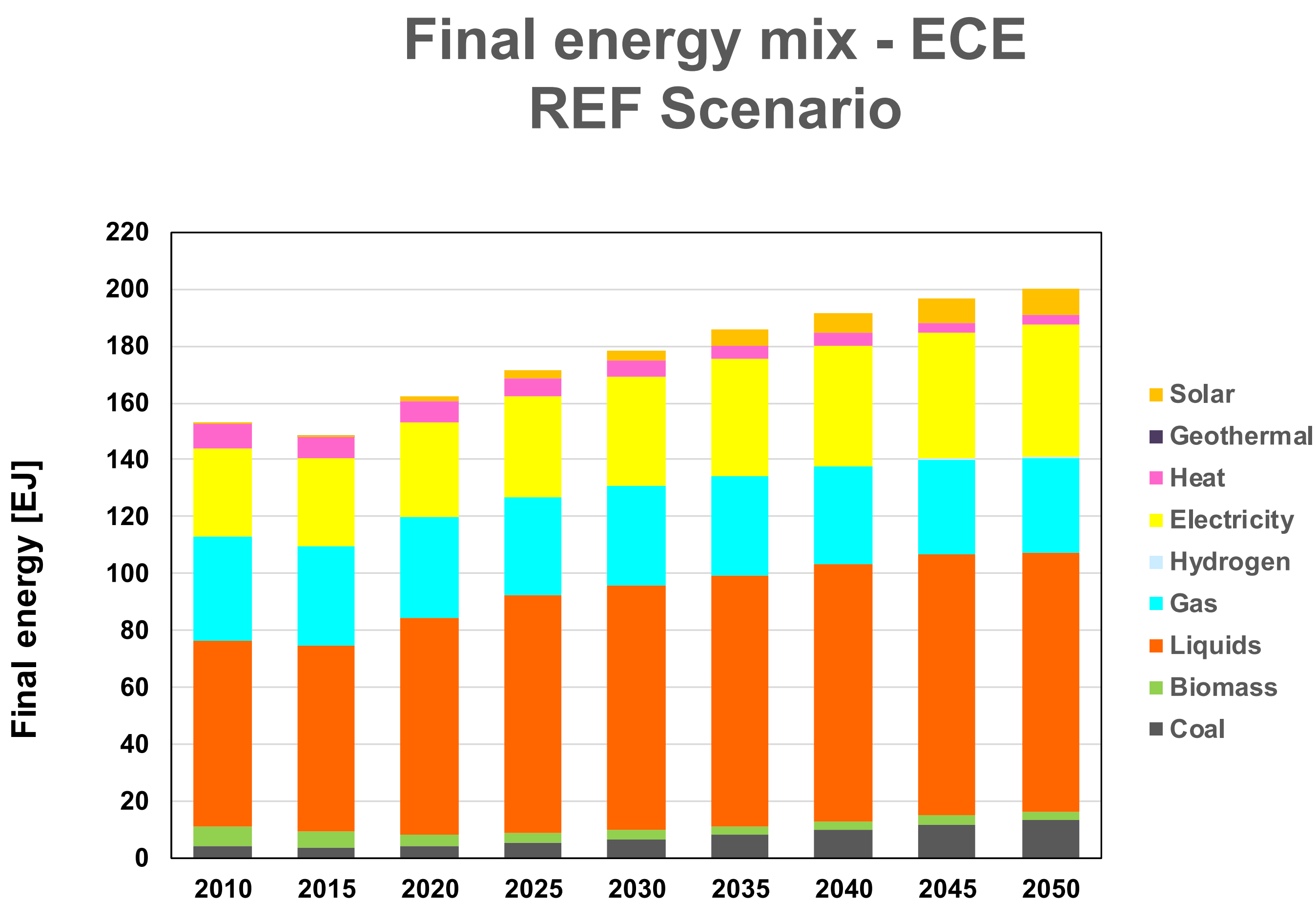
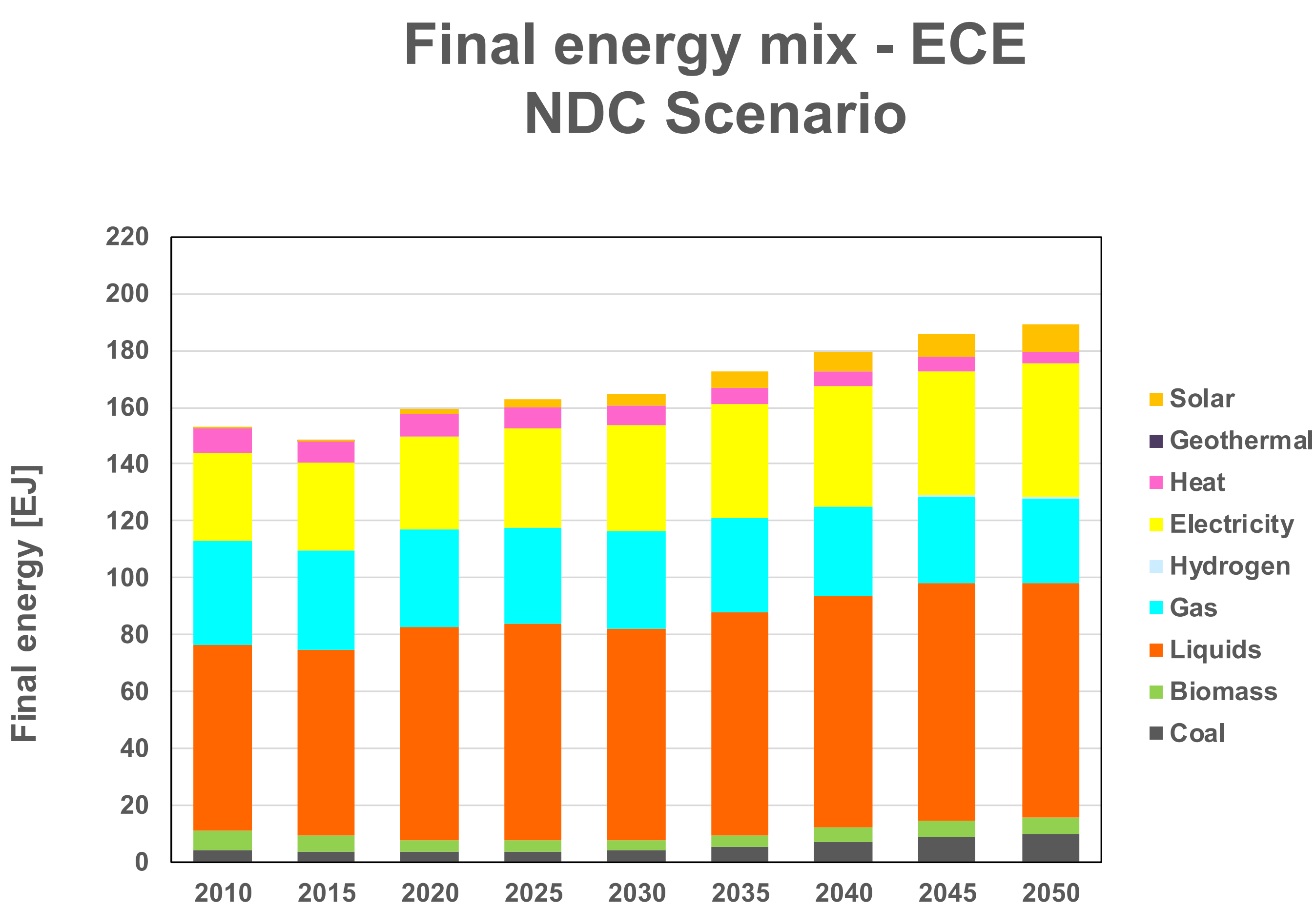


- *Total final energy demand after 2020 grows by a modest 0.7% per year reflecting demographic change*
- *Strong development of liquid fuels (transportation and non-energy uses)*
- *Gas underperforms*
- *District heat is displaced by solar heating and electricity*
- *Solids inch up, especially coal in industry, throughout the study horizon*

Modeling Results: ECE

Final Energy Mix

ENERGY

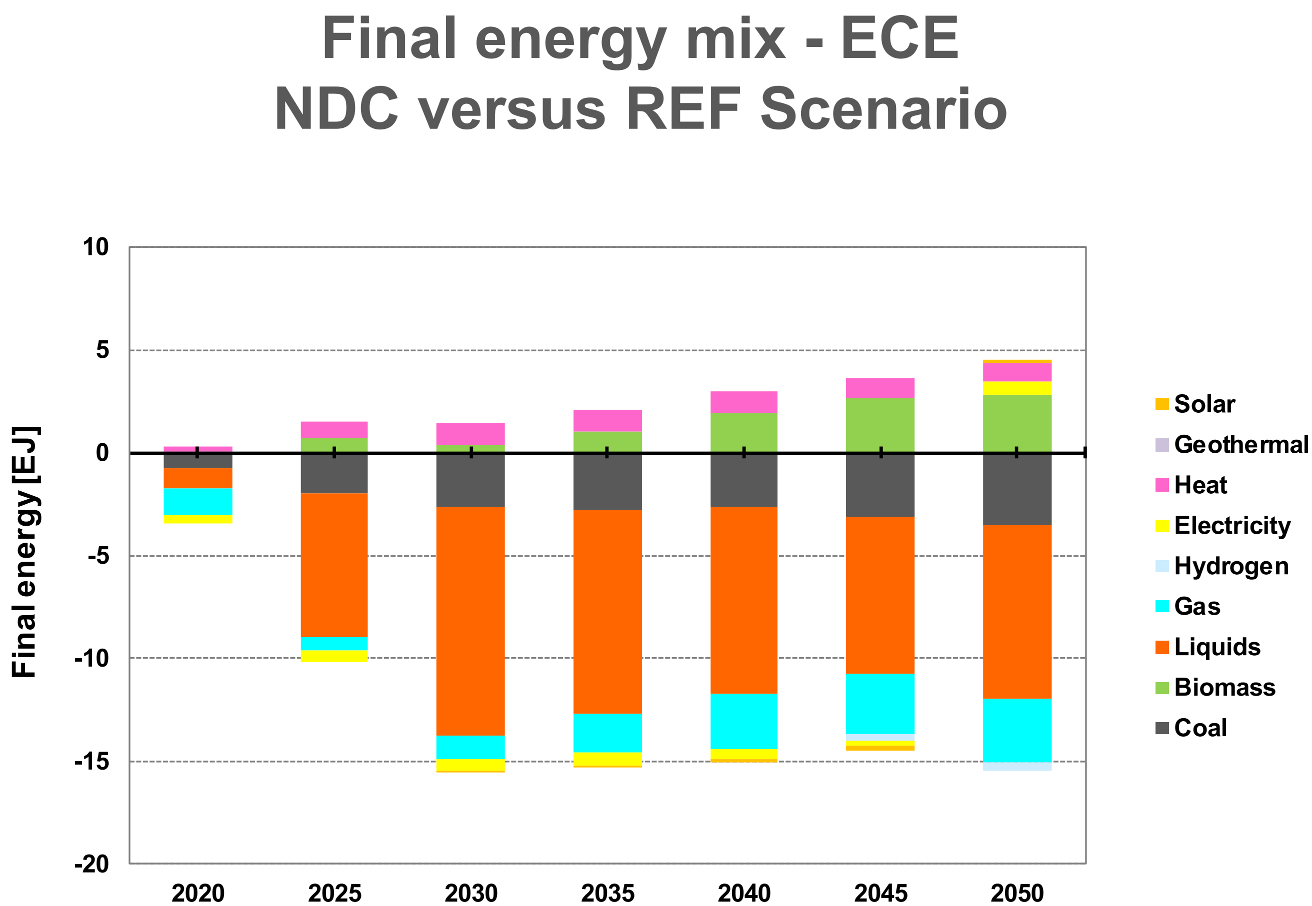


- *NDCs reduce final energy demand:*
  - *efficiency*
  - *fuel shifting*
  - *infrastructure adaptation*
- *Between 2020 and 2050 final demand grows for all fuels (albeit at a lower pace than in REF) except:*
  - *District heat and*
  - *Gas*
- *Liquids and electricity substitute gas*

Modeling Results:

Final Energy Mix: Scenario differences

ENERGY

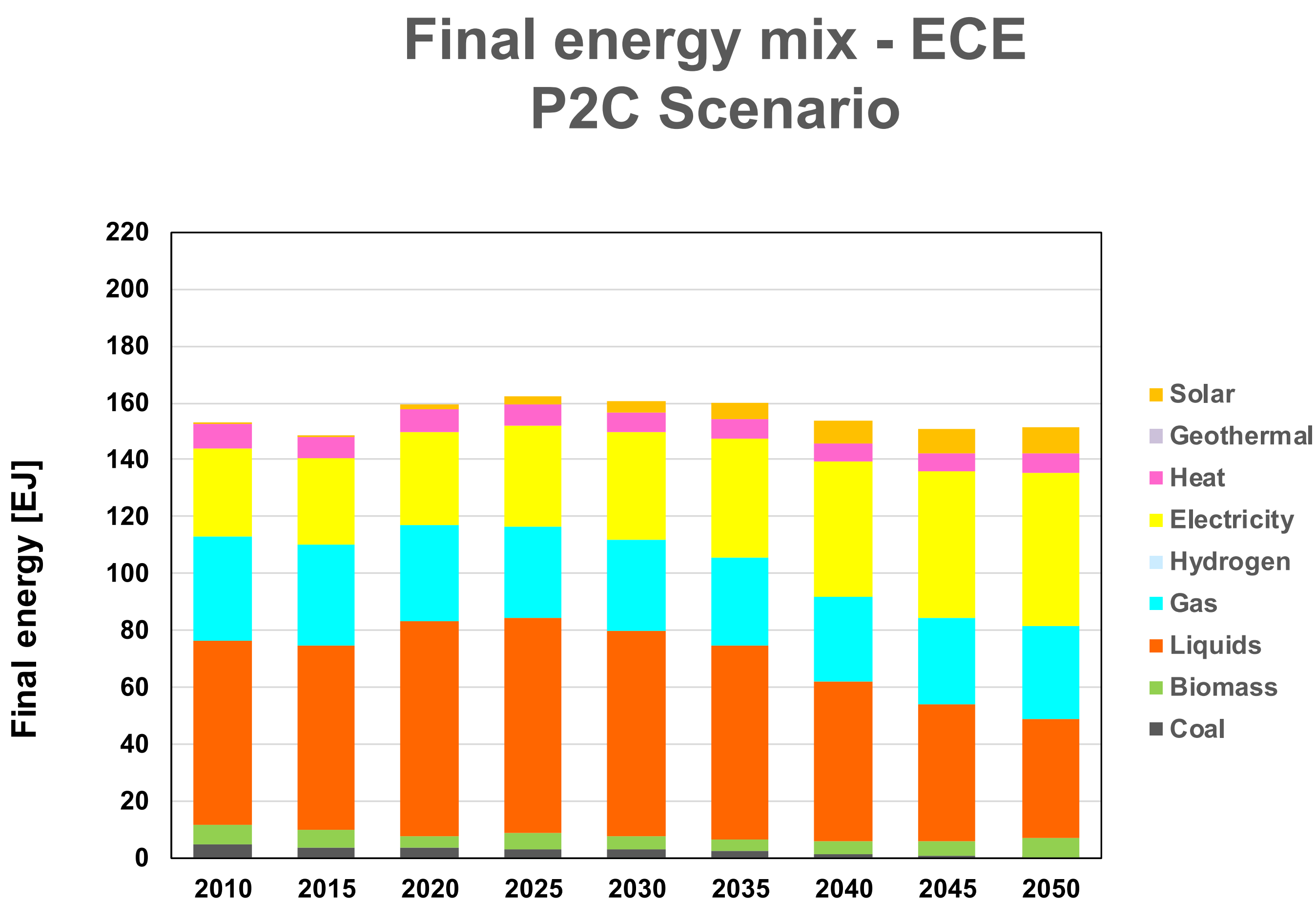


- *NDC invoked energy intensity & efficiency improvements take*
  - *a direct toll on fossil fuels and*
  - *in the short run indirectly on electricity*
- *Biomass has most to gain*
- *The decline of district heat is lower than in REF*

Modeling Results: ECE

Final Energy Mix

ENERGY

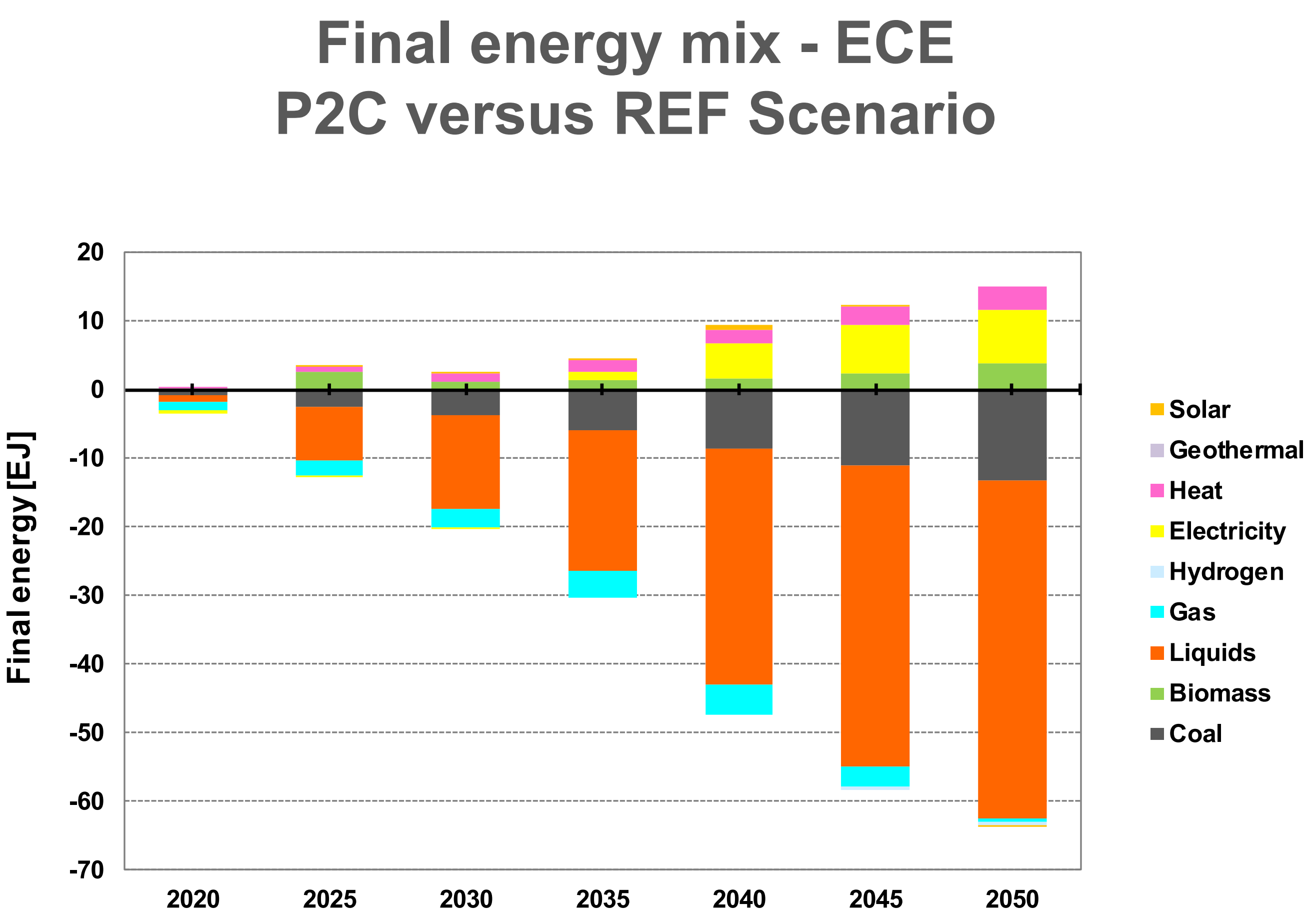


- *After initial modest growth, final energy faces decades of steady contraction reflecting climate mitigation induced energy system transformation*
- *Total demand 25% lower by 2050 vs REF*
  - *Efficiency & intensity improvements*
  - *Technology and structural change*
  - *Life style changes*
- *The future end-use system is based on*
  - *grid-dependent energy service provisions*
  - *decentralized or home & smart systems*

Modeling Results: ECE

Final Energy Mix: Scenario differences

ENERGY



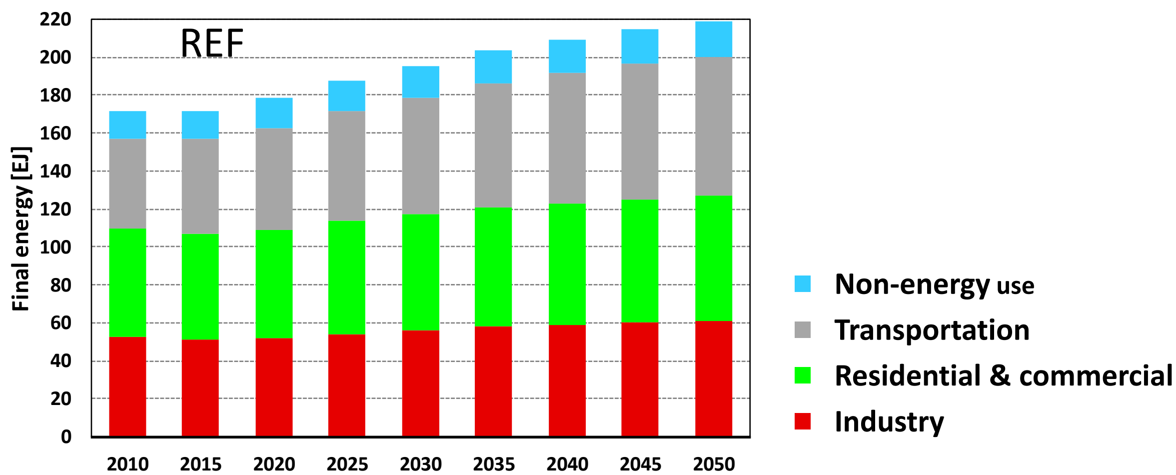
- *Final energy demand reductions through technology change and intensity improvements in*
  - *Transportation*
  - *Industries, and*
  - *To a lesser extent households*
- *Shift to higher reliance on electricity after 2030*
- *Higher shares of electricity displace lower efficient fossil and GHG emitting fuels*

Modeling Results: ECE

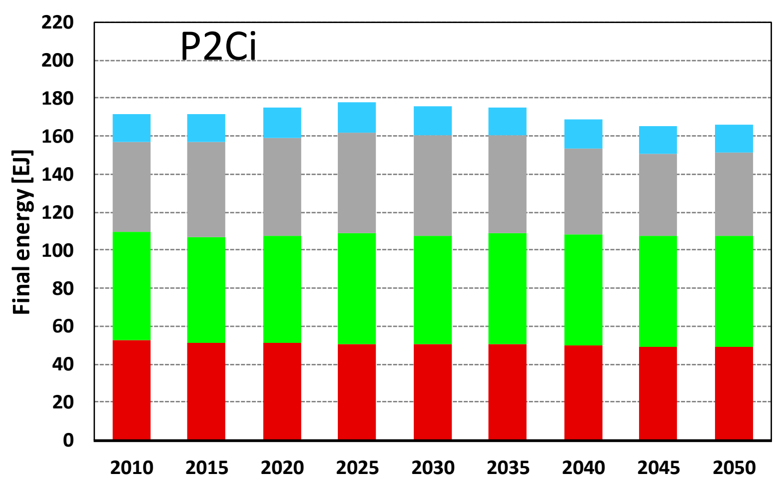
Sector implications

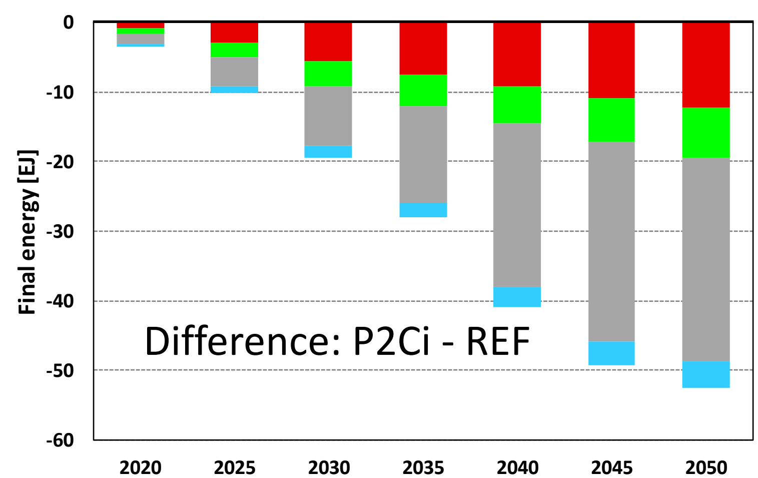
ENERGY

Final energy by sector - ECE



- *Main impact: Demand side management & energy intensity improvements as the capital stock is progressively renewed*
- *Transportation and industry are the prime target sectors*



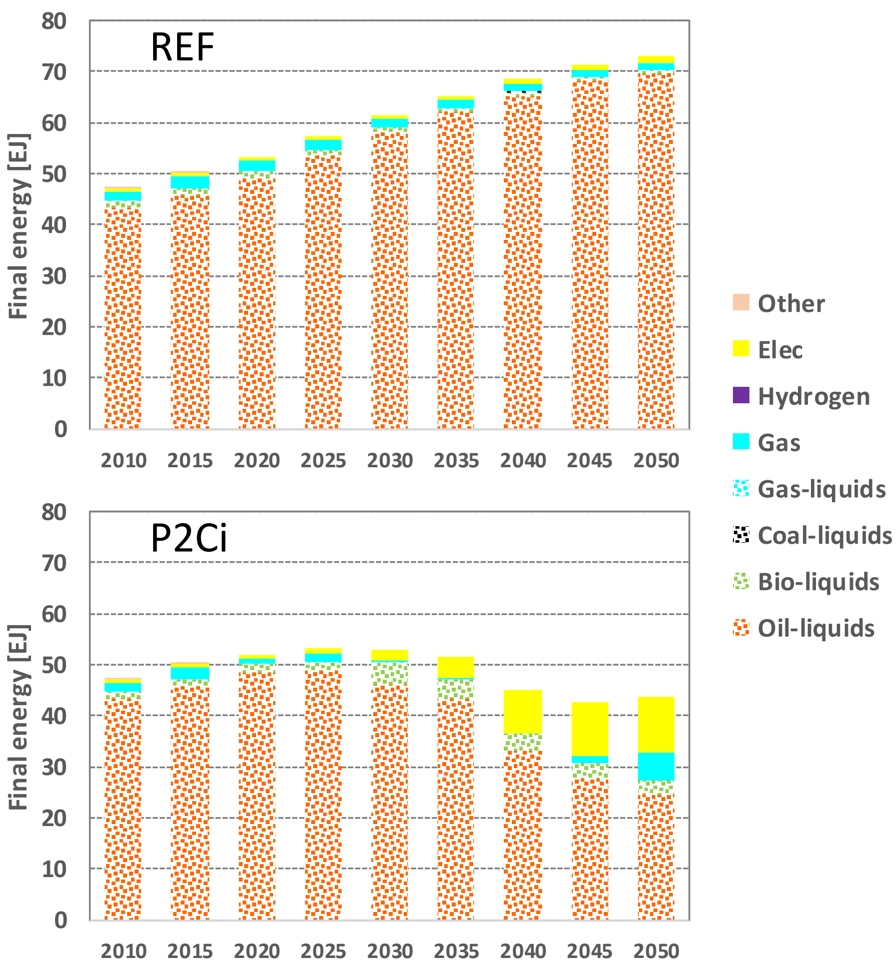


Modeling Results: ECE

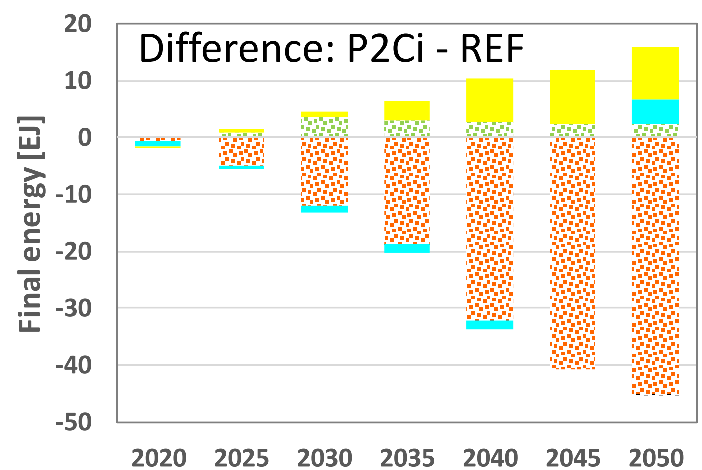
Sector implications: Transportation

ENERGY

Final transportation sector - ECE



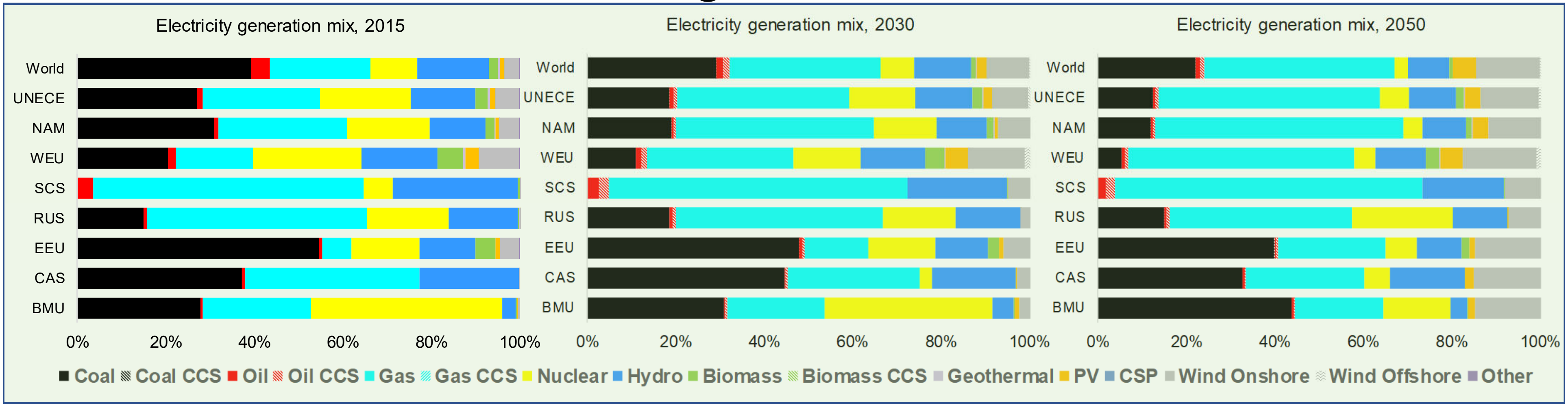
- ***REF:*** *40% increase in transport related FE demand by 2050*
- *Liquids with steadily expanding market share*
- ***P2C:*** *Strong market penetration of electric mobility*
- *Natural gas takes on the role of a swing fuel*
- *Bio-liquids with a strong market growth by 2030 – thereafter they give way to electricity and gas*



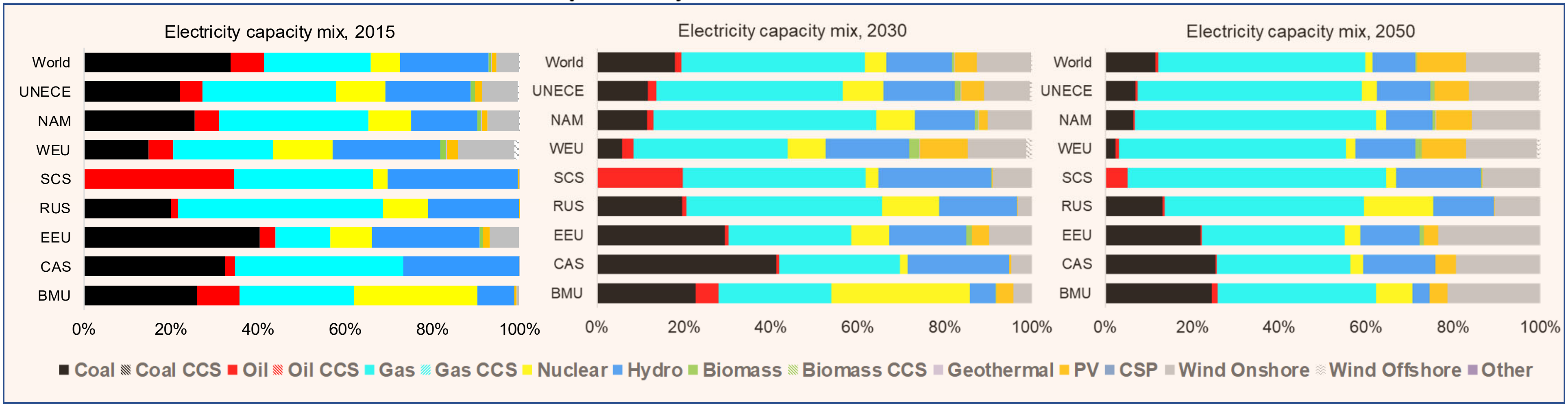
Modeling Results: Electricity sector transformation

ENERGY

Generating mix – REF scenario



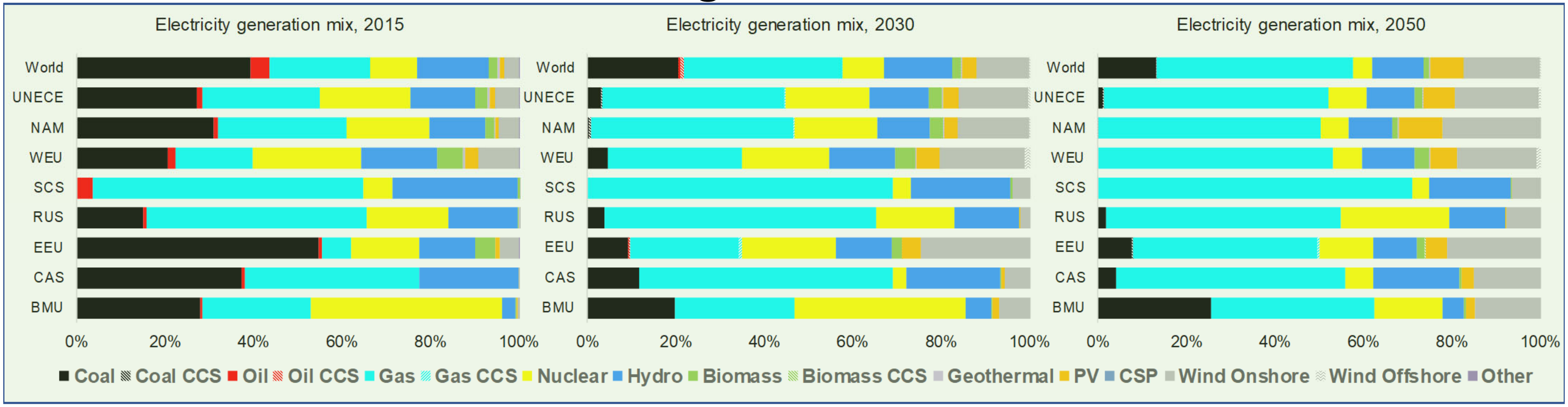
Capacity mix – REF scenario



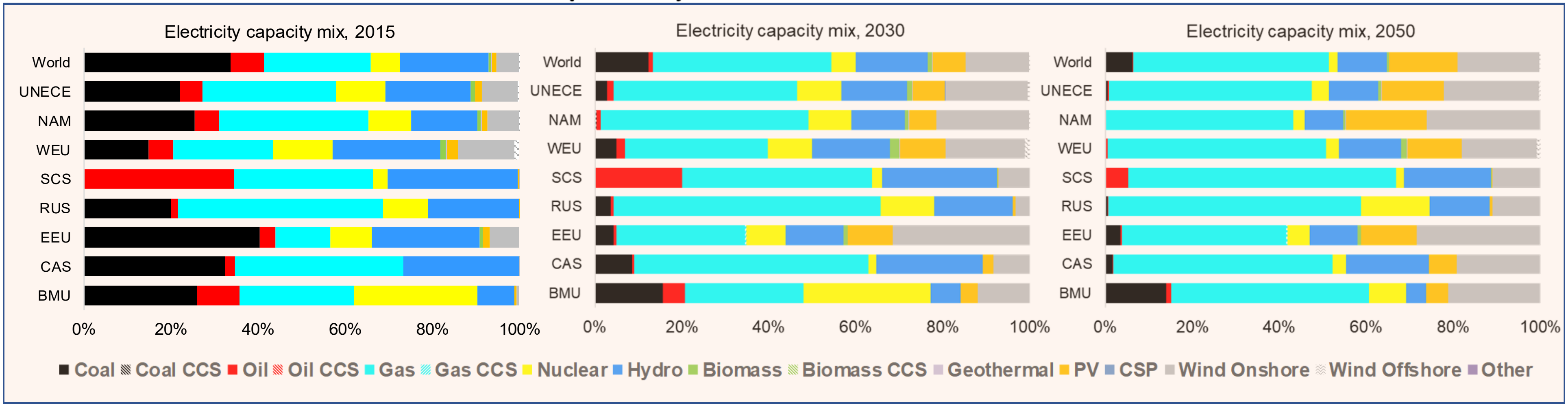
Modeling Results: Electricity sector transformation

ENERGY

Generating mix – NDC scenario



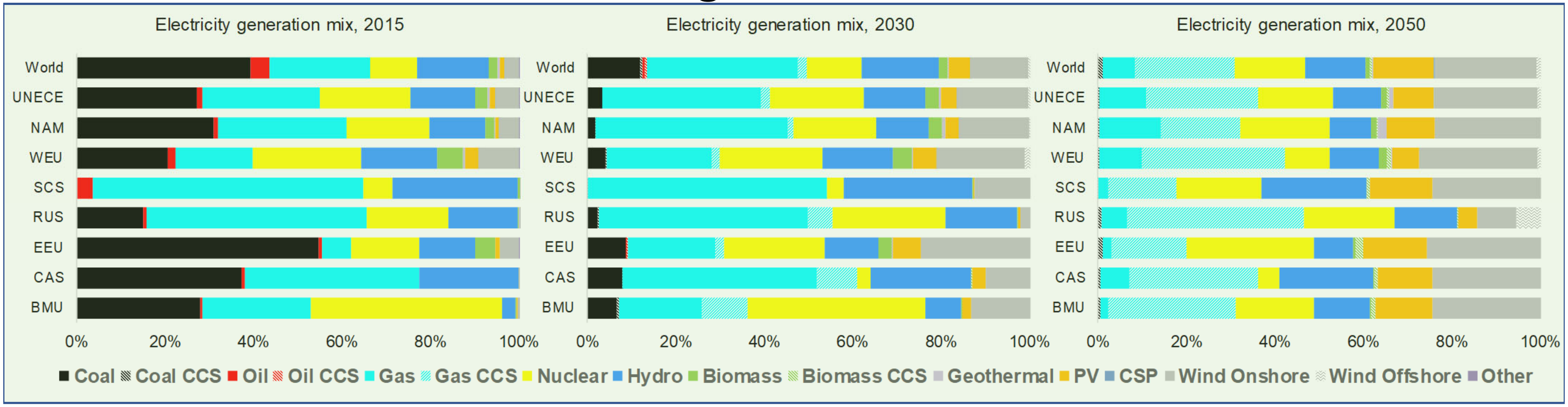
Capacity mix – NDC scenario



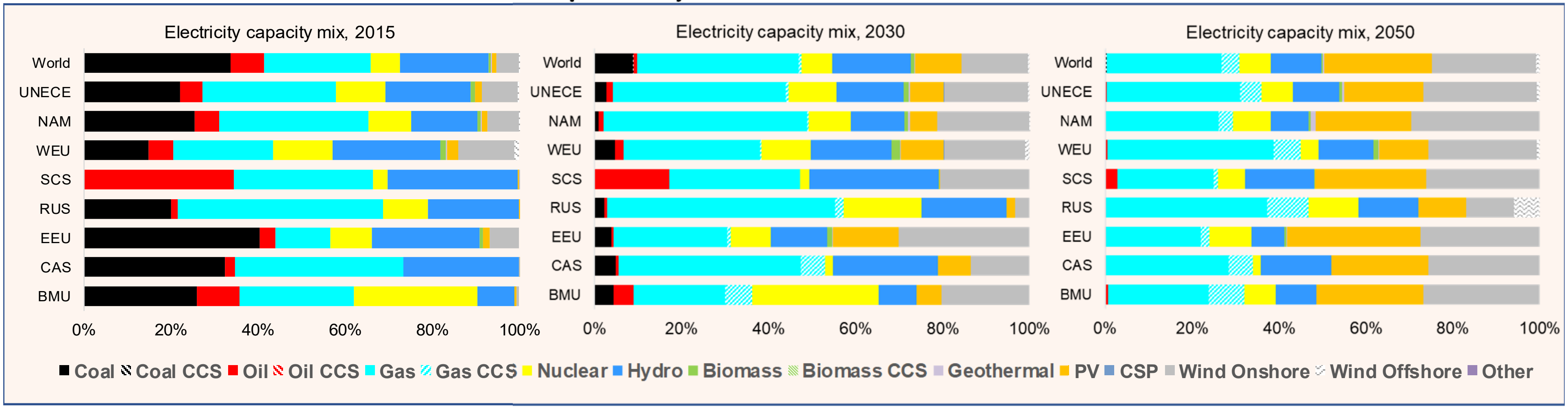
Modeling Results: Electricity sector transformation

ENERGY

Generating mix – P2C scenario



Capacity mix – P2C scenario



Modeling Results: ECE

Electricity Generation

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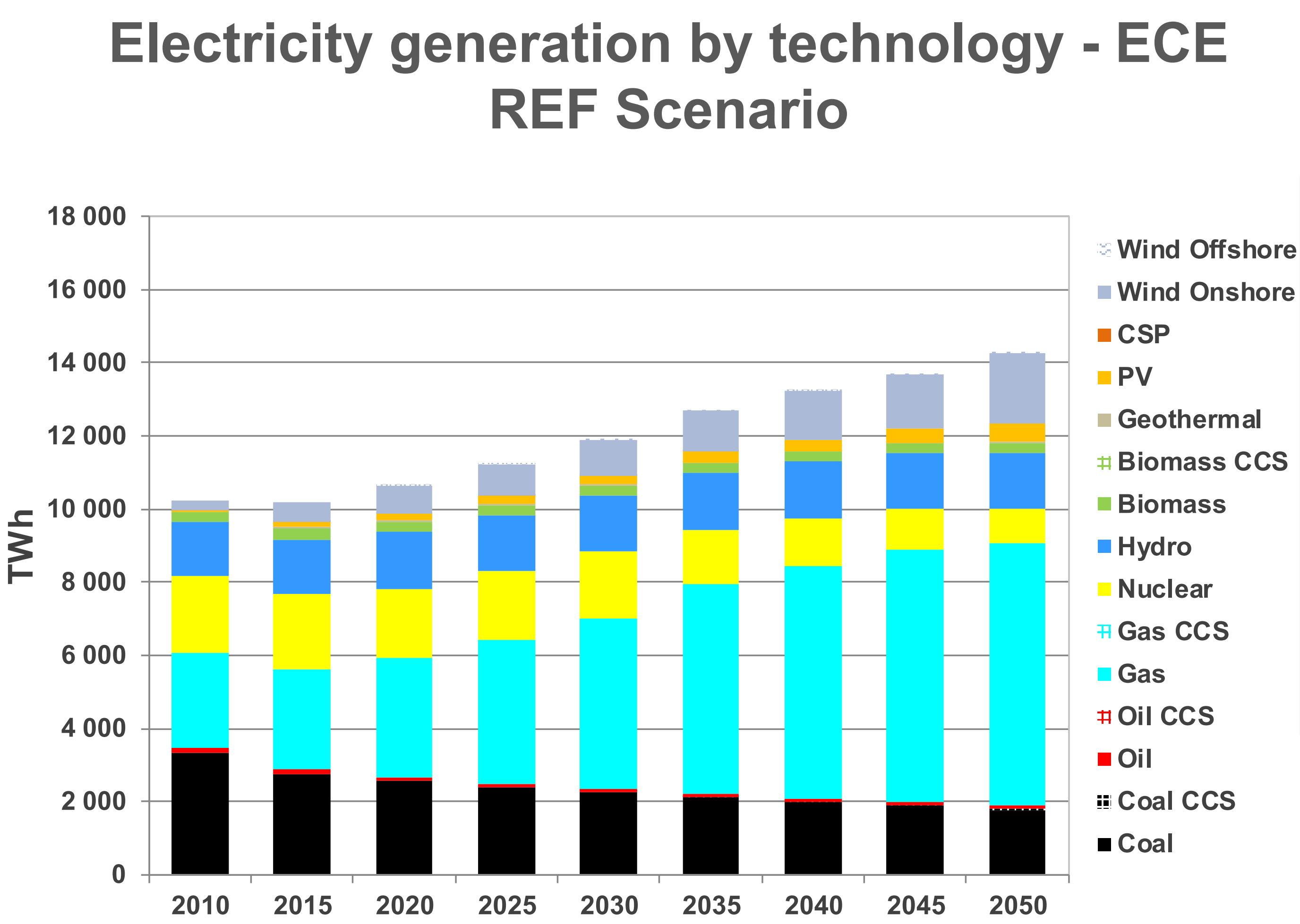


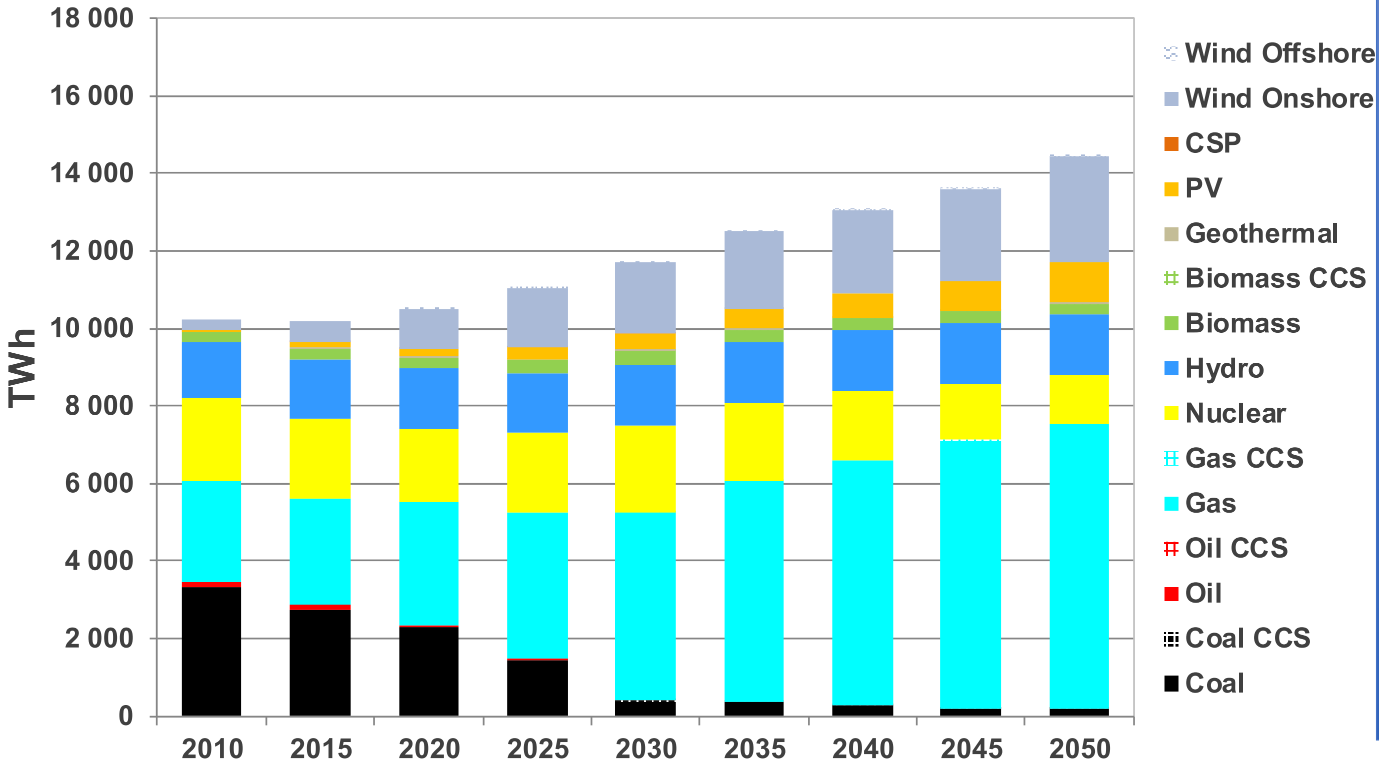
- *Typical business-as-usual development (SSP2) in electricity generation*
- *By 2050 hydro, variable renewables cap the kind of irresistible expansion of natural gas*
- *Coal and nuclear appear to follow a long-term phase out trajectory*

Modeling Results: ECE

Electricity Generation

ENERGY

Electricity generation by technology - ECE NDC

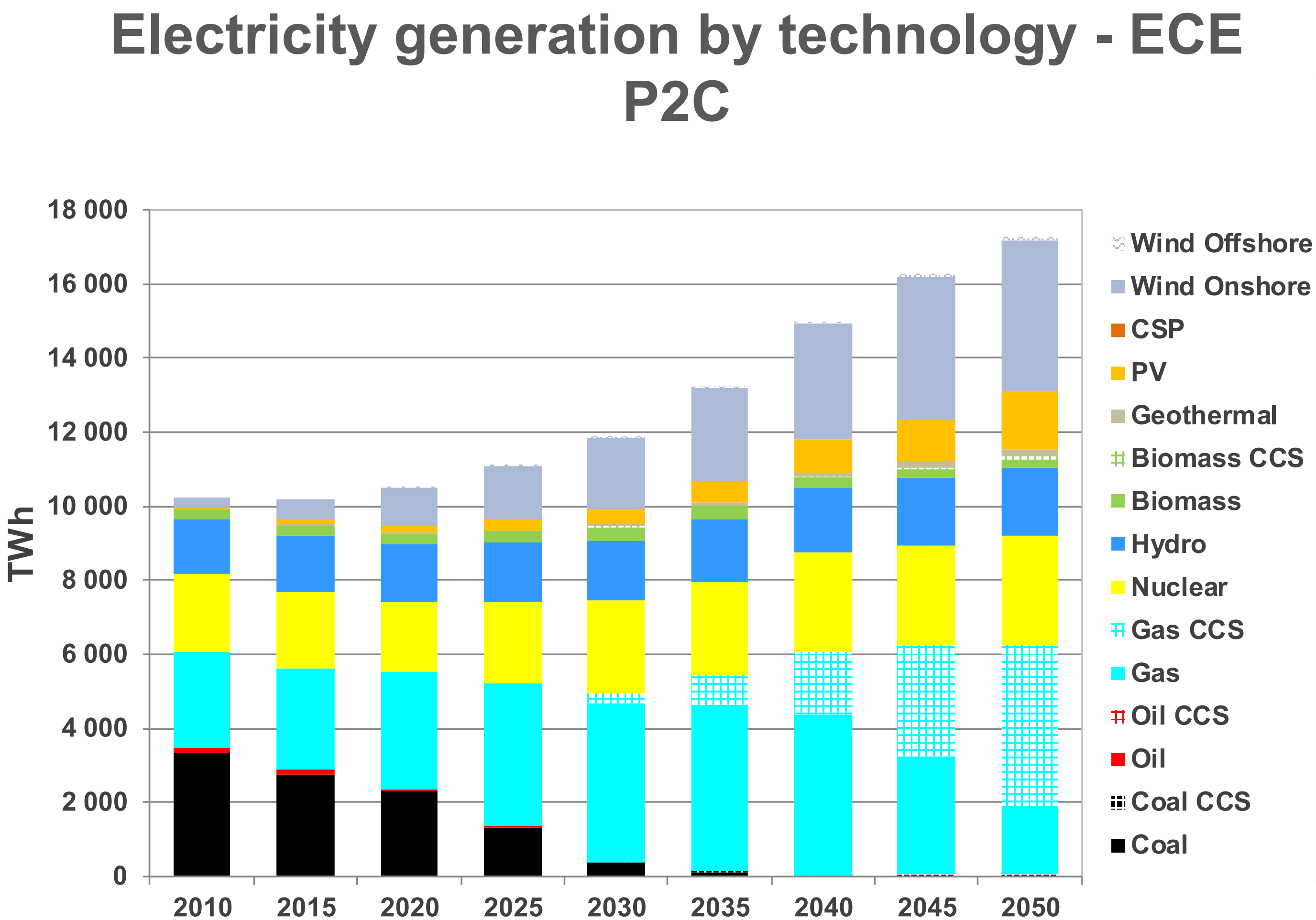


- *Somewhat higher total electricity output due to stepped up electric mobility (outpaces efficiency improvements in other sectors)*
- *Quick replacement of coal-fired electrify by natural gas*
- *After 2015 expansion of all renewables*
- *Hardly visible: Timid beginnings of coal and gas generation with retrofitted CCS*

Modeling Results: ECE

Electricity Generation

ENERGY



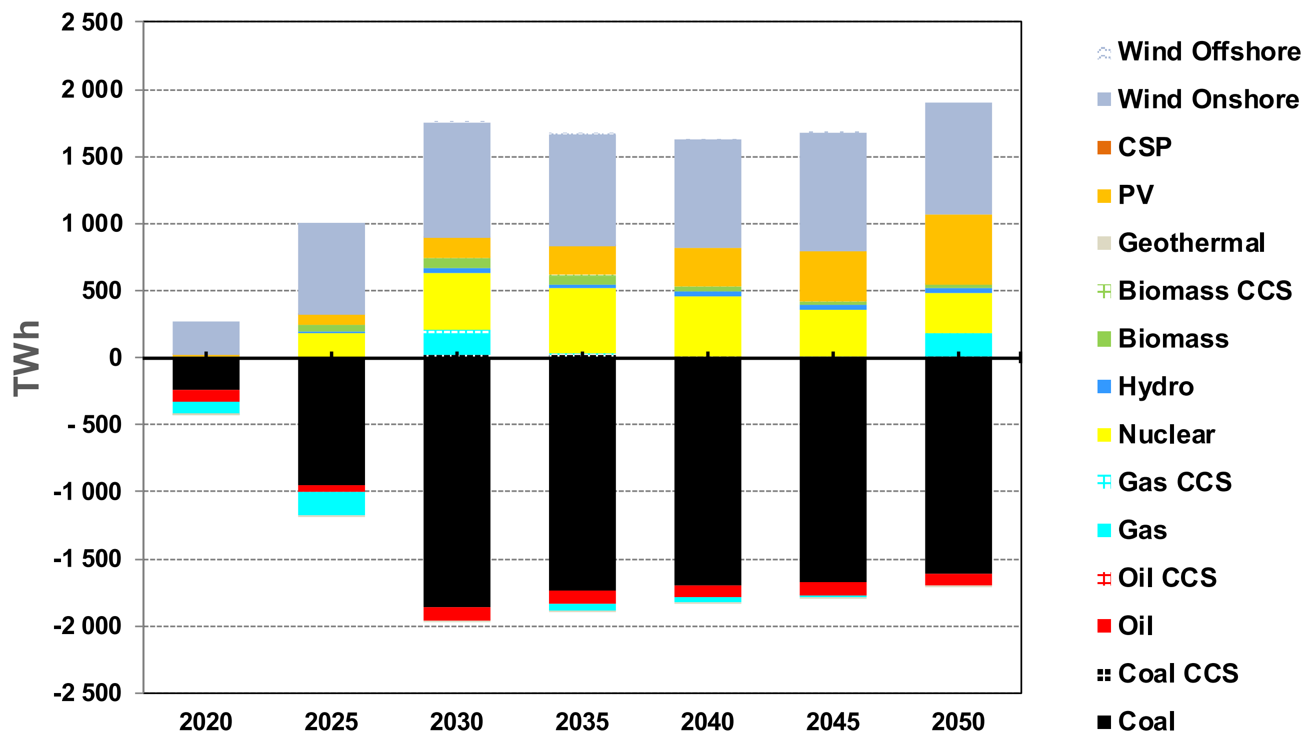
- *20% higher electricity demand by 2050*
- *Fundamental realignment of generation structure*
- *Gas with CCS allows the fuel to maintain its lead in generation*
- *Coal gets completely phased out (some minor coal with CCS survives until 2050)*
- *Fast expansion of off-shore wind and solar PV*
- *Steady expansion of nuclear power*

Modeling Results: ECE

Electricity Generation

ENERGY

Electricity generation by technology & fuel - ECE
Difference: NDC - REF



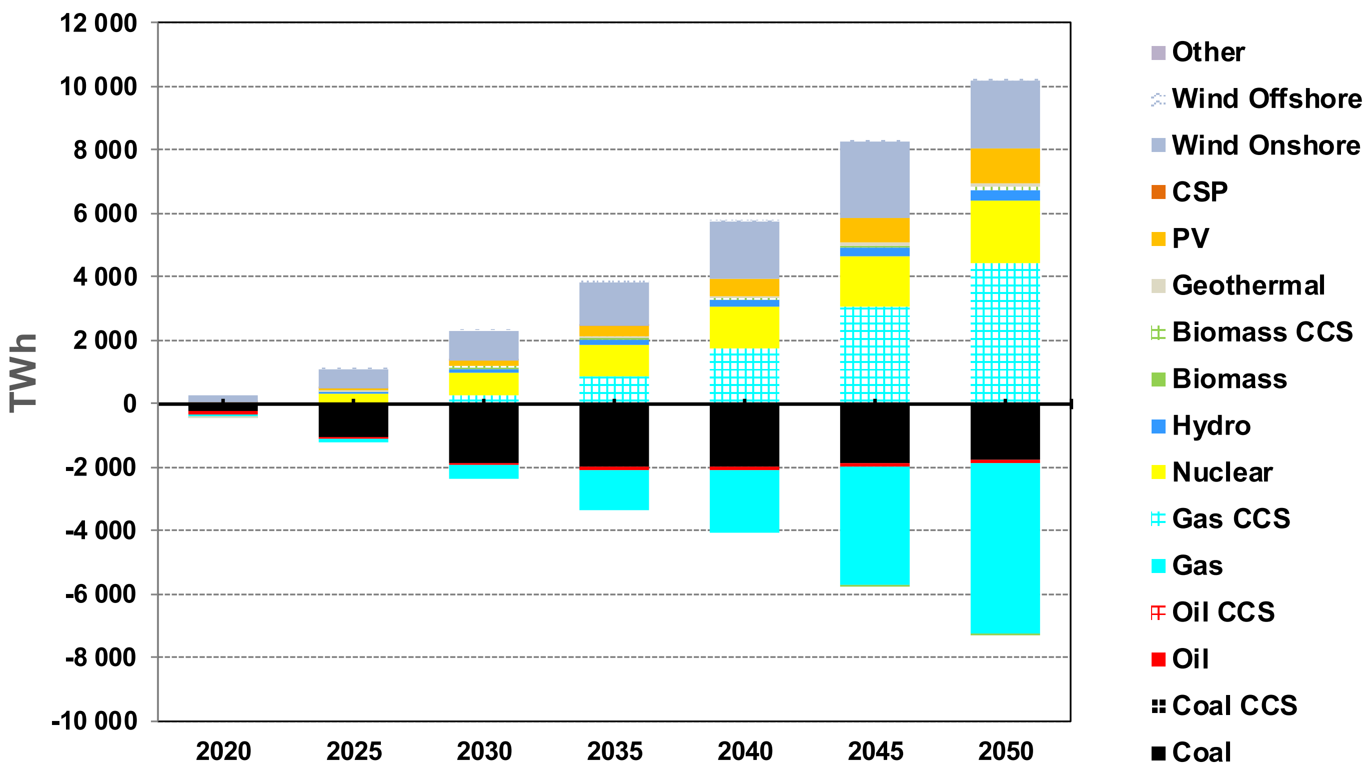
- *Response of electricity generation to NDCs:*
- *Restructuring of about 15% of ECE generation*
- *Wind and later on PV establish their market compatibility*
- *Nuclear power absorbs parts of the base-load generation previously serviced by coal*

Modeling Results: ECE

Electricity Generation

ENERGY

Electricity generation by technology & fuel - ECE
Difference: P2C - REF



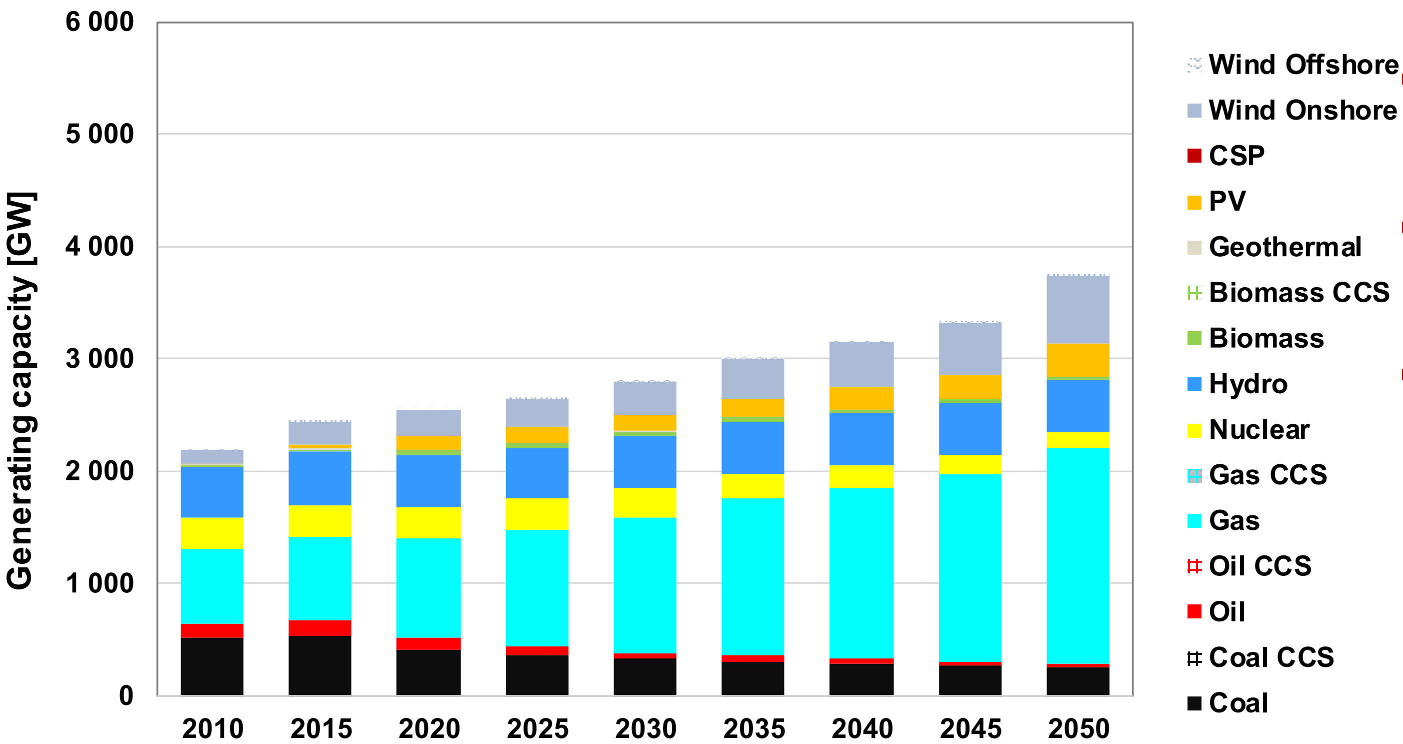
- *Gas with CCS allows gas to maintain its lead in generation*
- *Coal is completely phased out (some minor coal with CCS survives until 2050)*
- *Fast expansion of off-shore wind and solar PV*
- *Steady expansion of nuclear power*

Modeling Results: ECE

Electricity generating capacity

ENERGY

Electricity generating capacity by technology - ECE REF Scenario



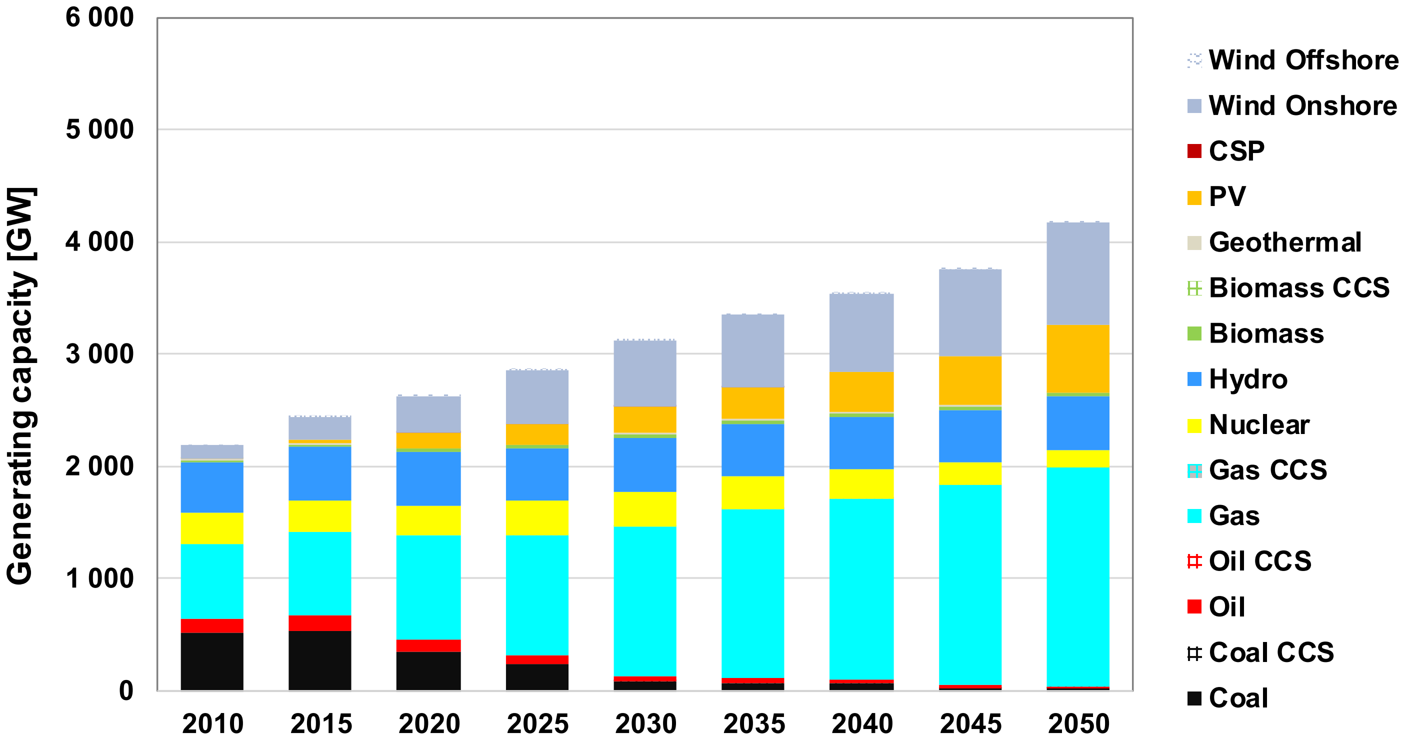
- *Capacity structure reflects REF generation mix*
- *Natural gas tightens its grip on the market throughout 2050*
- *Coal capacities decline in the long run as gas is providing balancing service to variable renewables*

Modeling Results: ECE

Electricity generating capacity

ENERGY

Electricity generating capacity by technology - ECE NDC



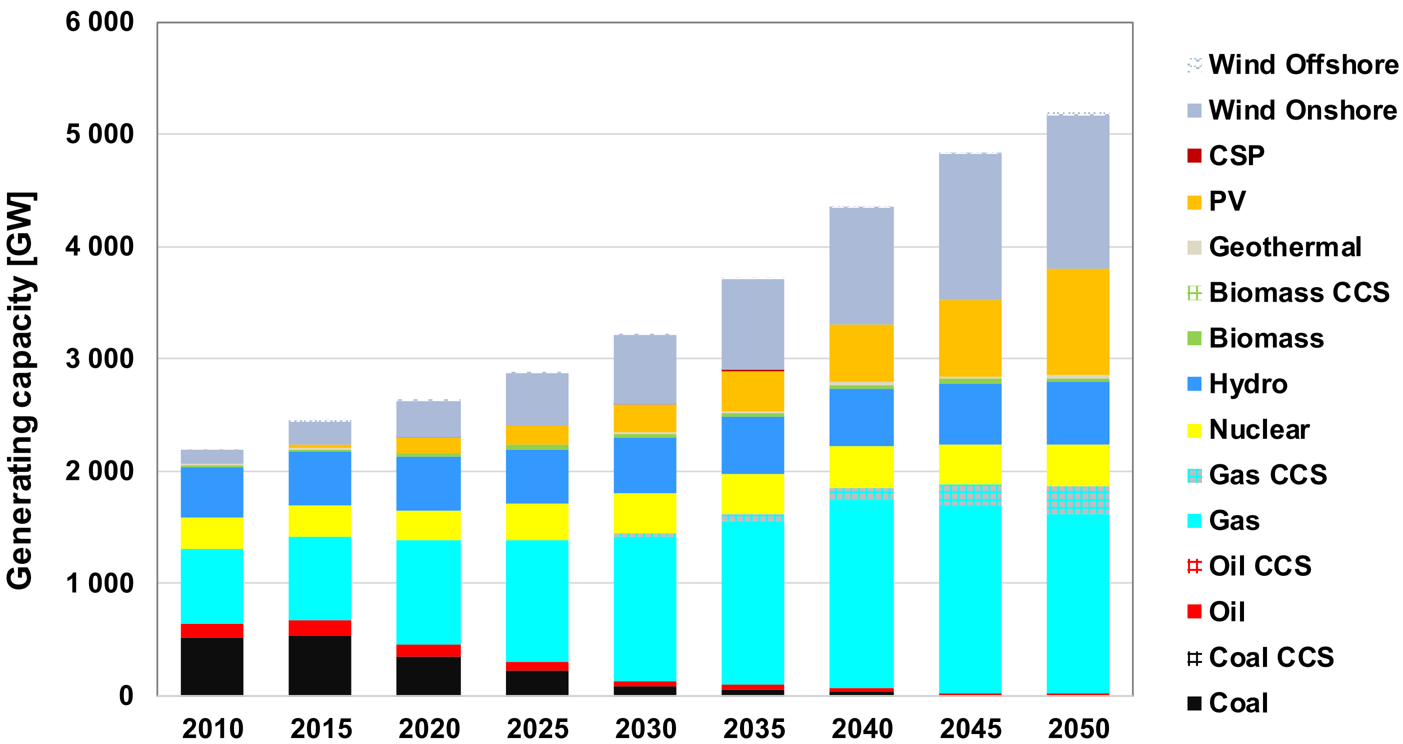
- *Higher total capacity requirements due to larger variable renewable generation*
- *Natural gas capacities continue as the lead technology and almost totally replaces coal*
- *Renewables account for almost 50% of total generating capacity*

Modeling Results: ECE

Electricity generating capacity

ENERGY

Electricity generating capacity by technology - ECE P2C



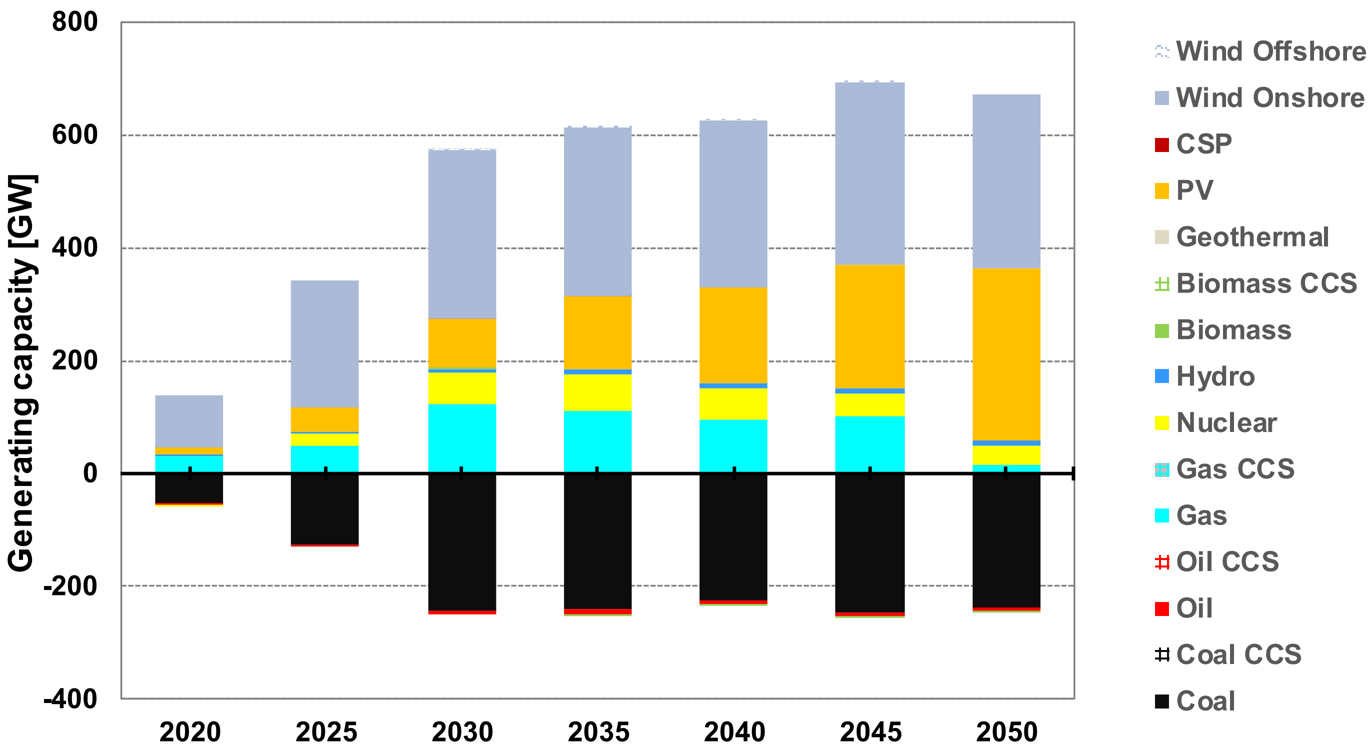
- *Even higher total capacity requirements due to larger variable renewable generation*
- *Renewables account for 58% of total generating capacity (80% of which is VRE)*
- *Nuclear power provides a substantial share of base load capacity*
- *Natural gas capacities now increasingly relying on CCS*
- *Coal and oil capacities practically phased-out by 2050*

Modeling Results: ECE

Electricity generating capacity

ENERGY

Electricity generating capacity by technology & fuel - ECE
Difference: NDC - REF



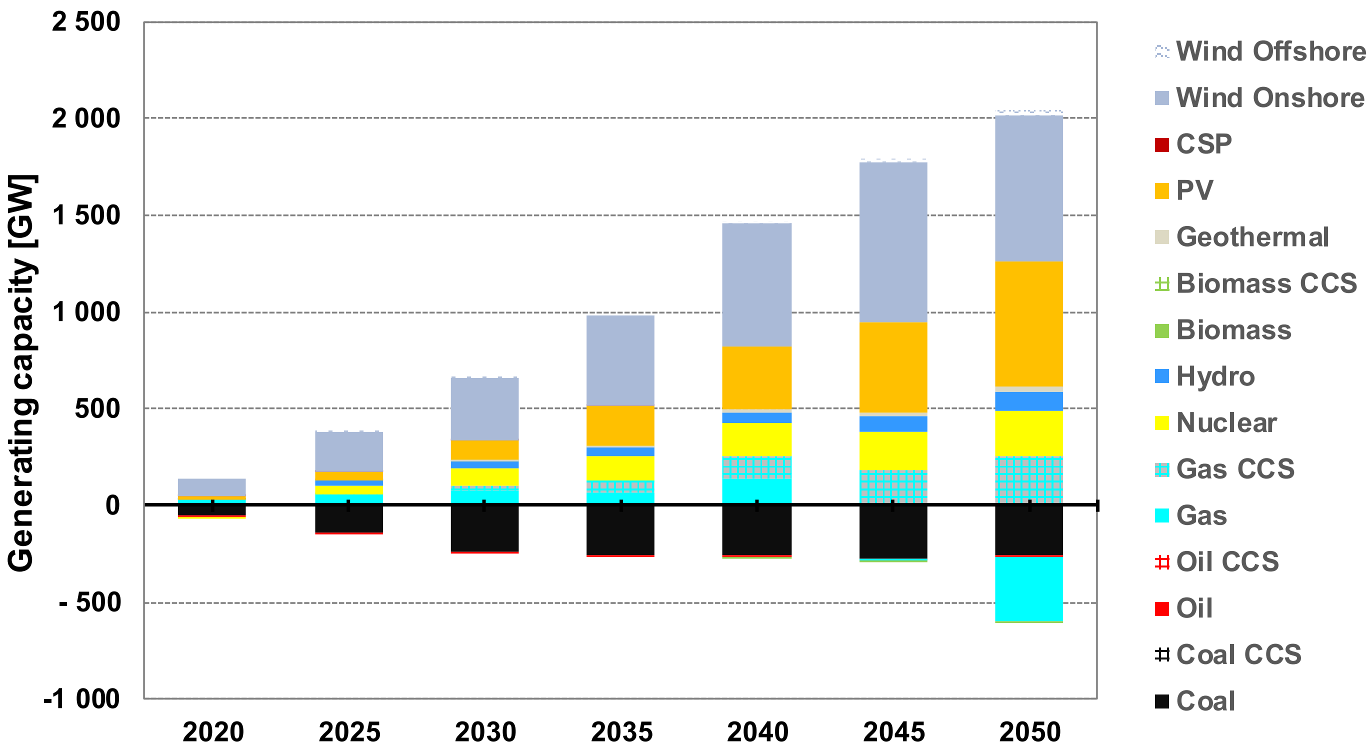
- *Comments on earlier capacity slides apply*
- *Major role of wind and solar*
- *Other low carbon options including nuclear power increasingly displace baseload coal*

Modeling Results: ECE

Electricity generating capacity

ENERGY

Electricity generating capacity by technology & fuel - ECE
Difference: P2C - REF



- *A striking substitution of 2 GW of low carbon capacity (70% of which are VRE) for some 600 MW of unabated coal and gas capacity.*
- *Major role of wind and solar*
- *Other low carbon options including nuclear power increasingly displace baseload coal*

Modeling Results: Primary energy transformation

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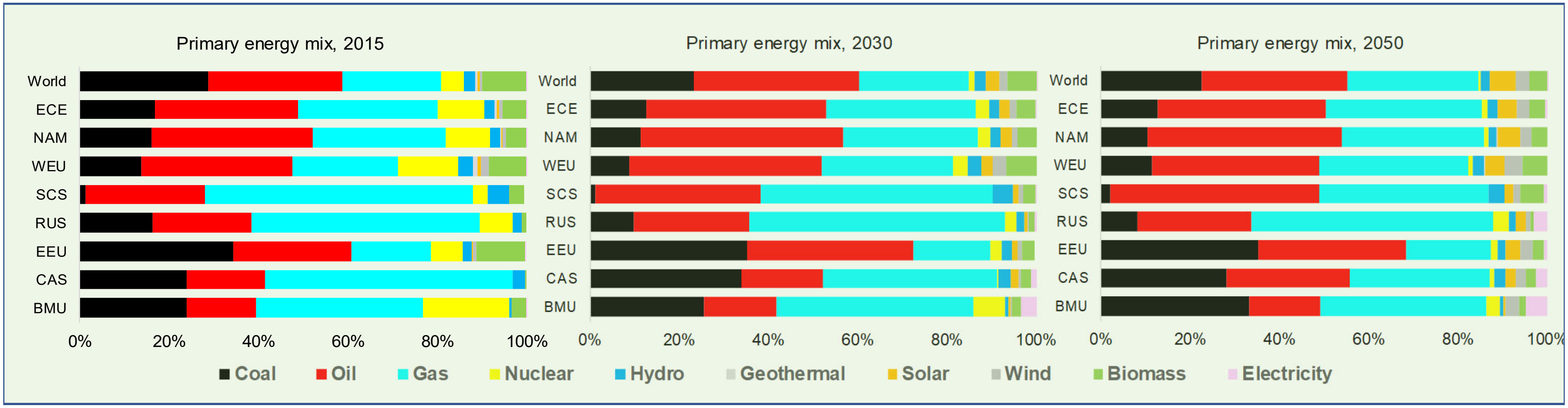
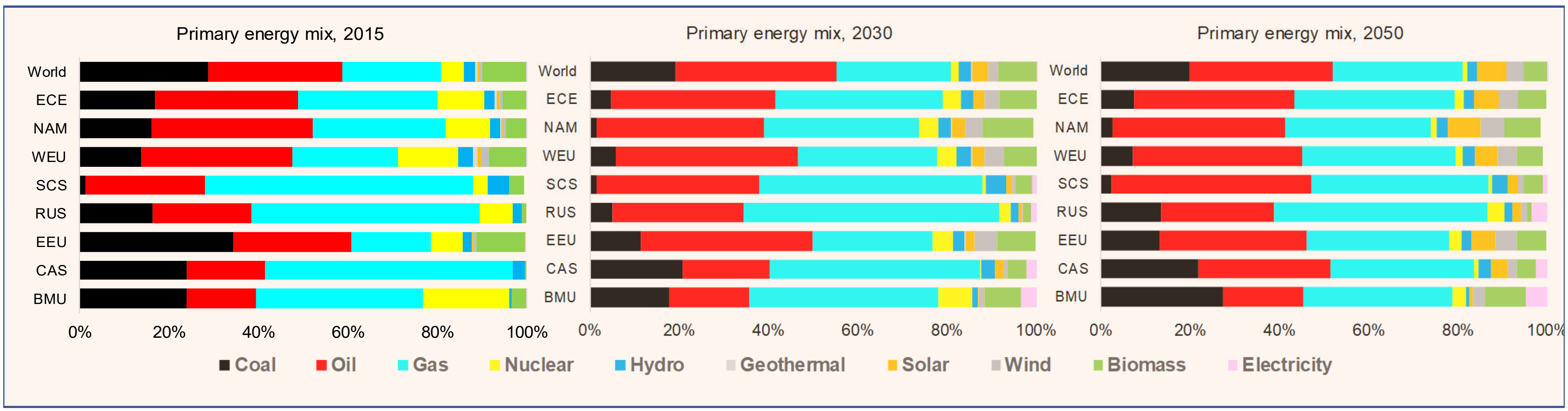
REF scenario



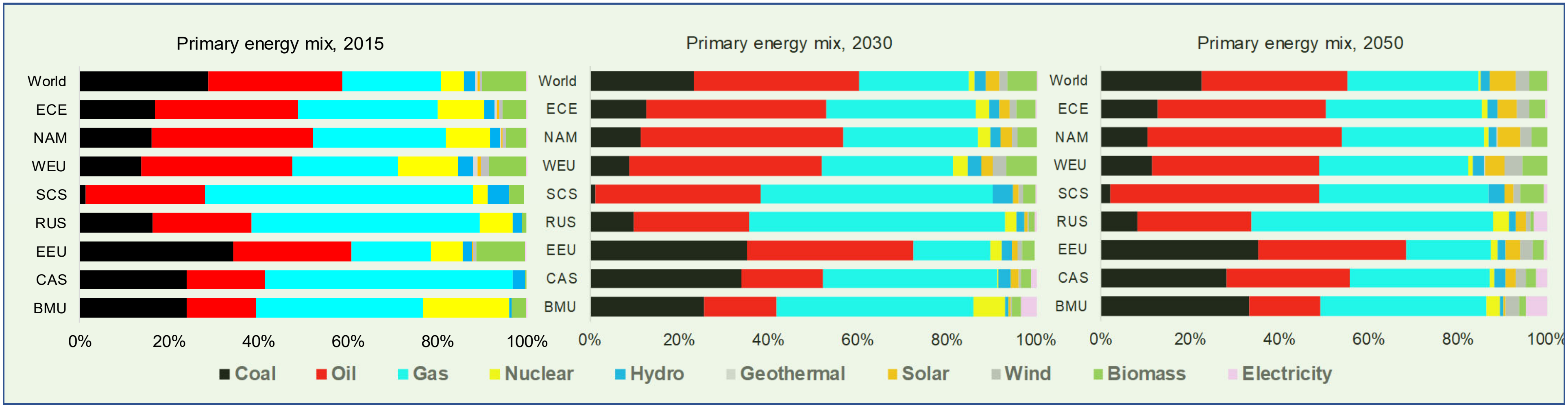
NDC scenario



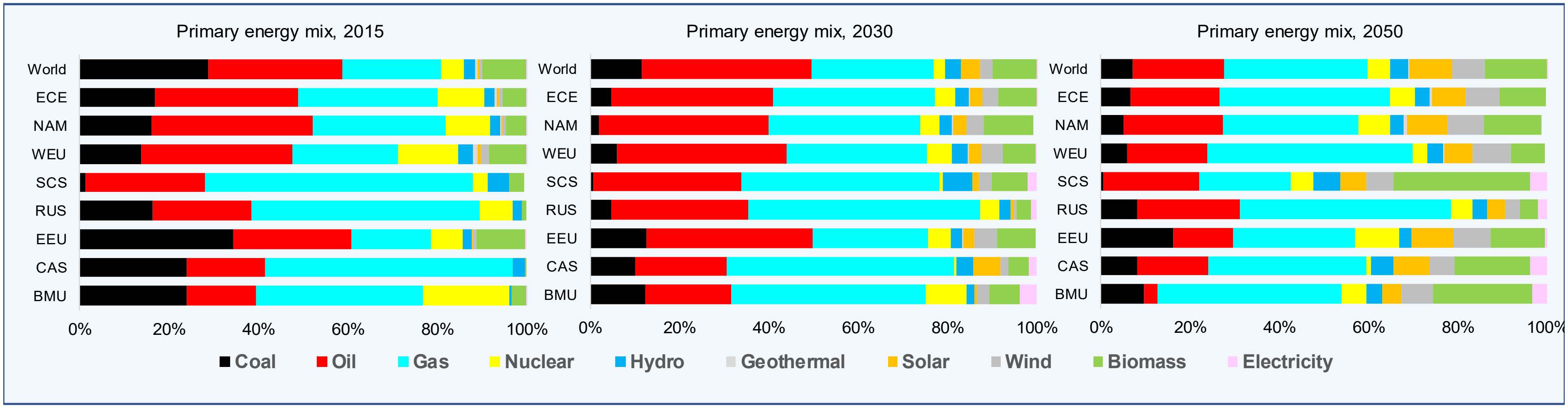
Modeling Results: Primary energy transformation

ENERGY

REF scenario



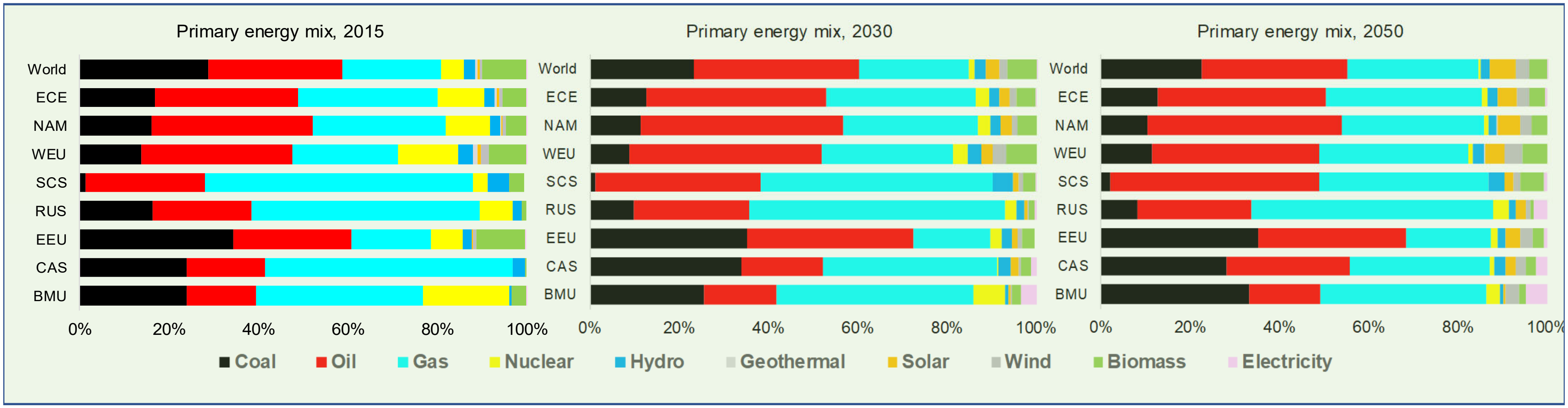
P2C scenario



Modeling Results: Primary energy transformation

ENERGY

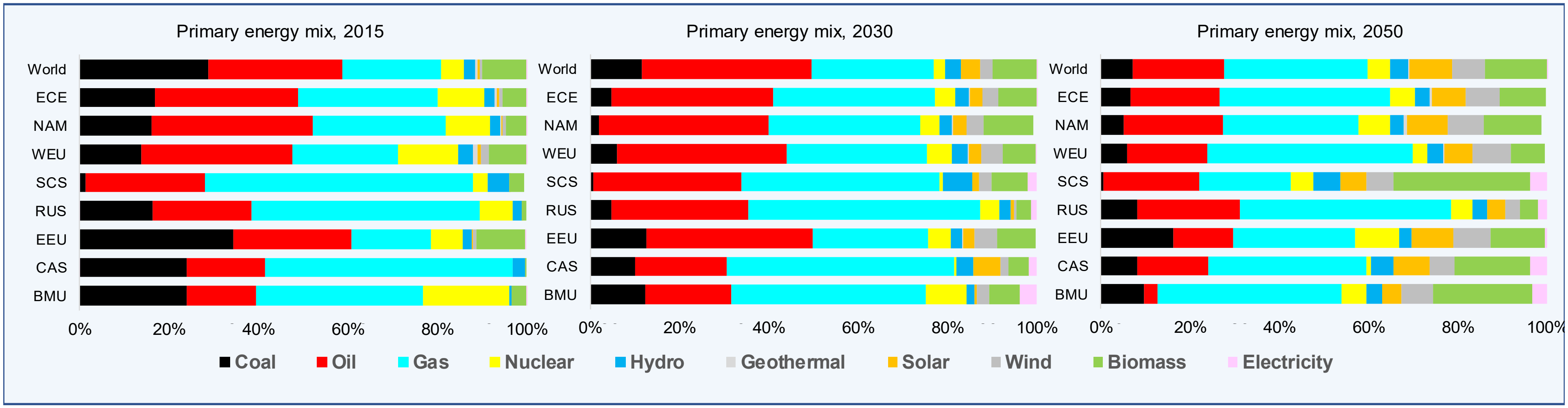
REF scenario



Modeling Results: Primary energy transformation

ENERGY

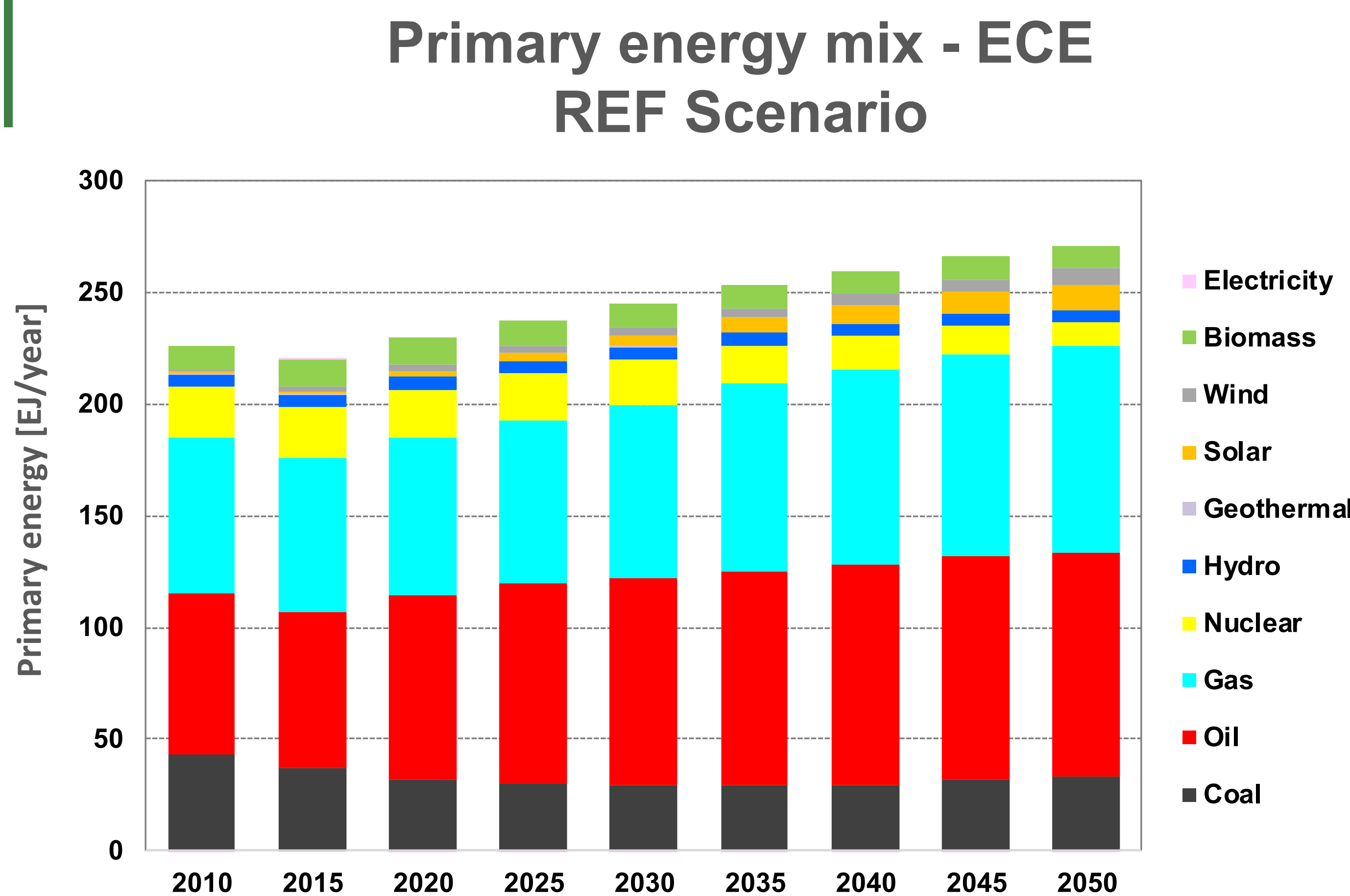
P2C scenario



Modeling Results: ECE

Primary Energy

ENERGY

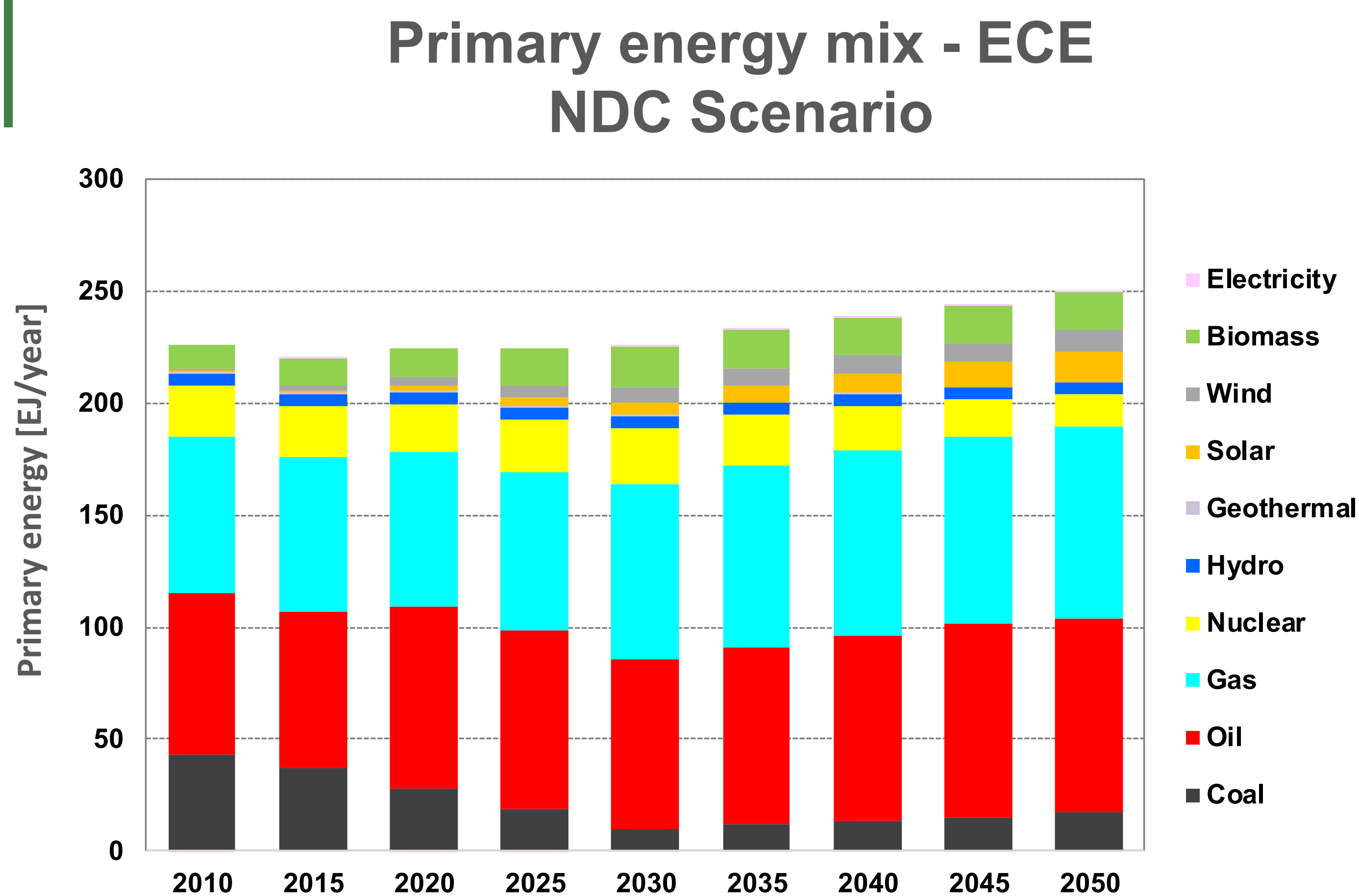


- *Business-as-usual trends in primary energy supply*
- *Oil remains the largest PE source but is seriously challenged by natural gas*
- *Coal share declines from 19.5% (2010) to less than 13% (2050)*
- *Fossil fuels still account for 86% of PE supply by 2050*
- *Renewables gain 4 percentage points between 2010 and 2050 (13%)*
- *Nuclear faces a steadily shrinking market share*

Modeling Results: ECE

Primary Energy

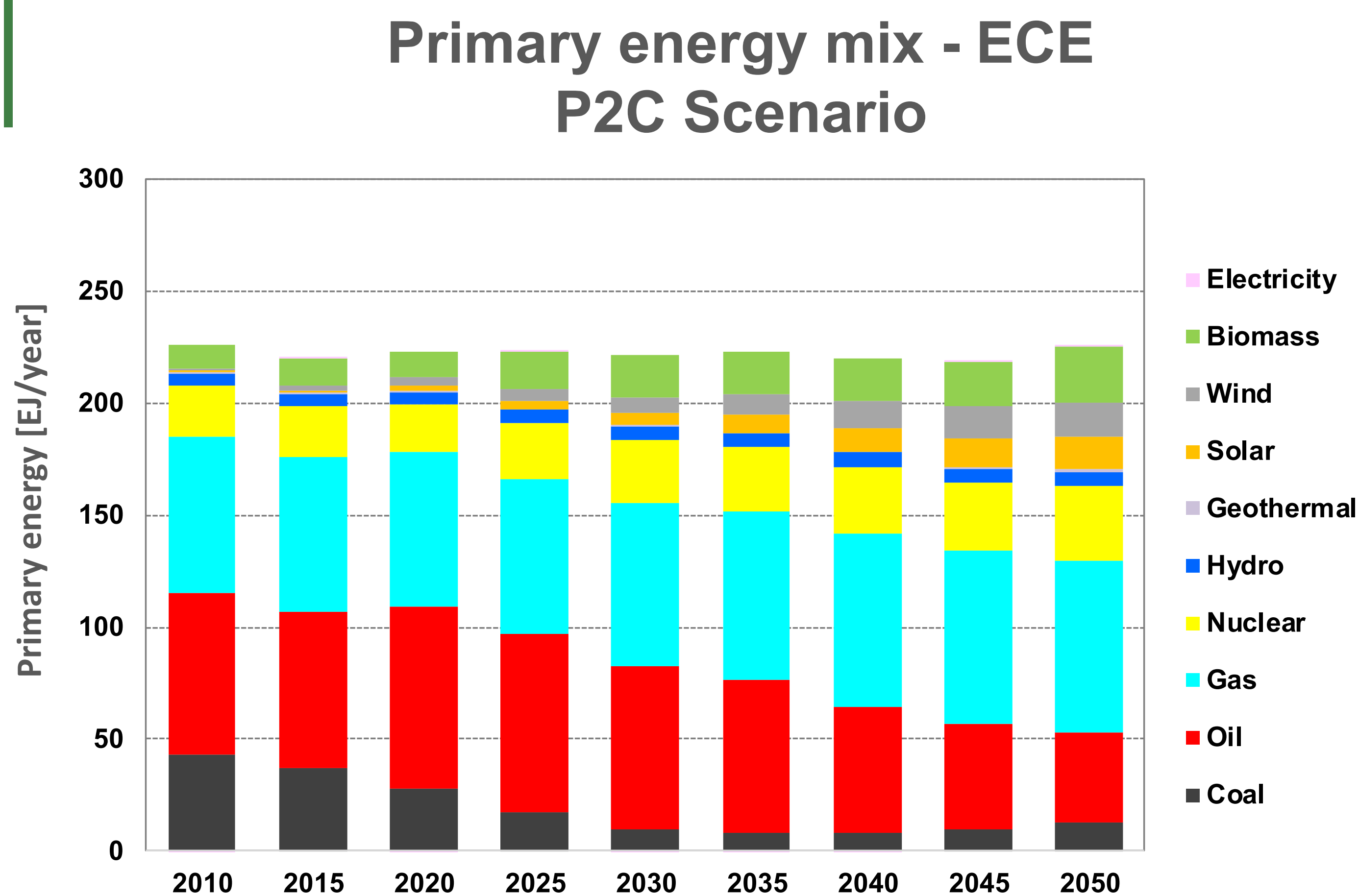
ENERGY



- *PE demand 8% lower by 2050 due to efficiency & intensity improvement measures*
- *Oil splits the PE lead position with gas (2050)*
- *Coal share declines to less than 5% (2030) but rebounds to 7.3% (2050) due to modest post-2030 NDC ambitions*
- *Fossil fuels still account for 79% of PE supply by 2050 – RE up to 18.9%*
- *After a short come back (2030), nuclear returns to slip-sliding PE market share*

Modeling Results: ECE

Primary Energy

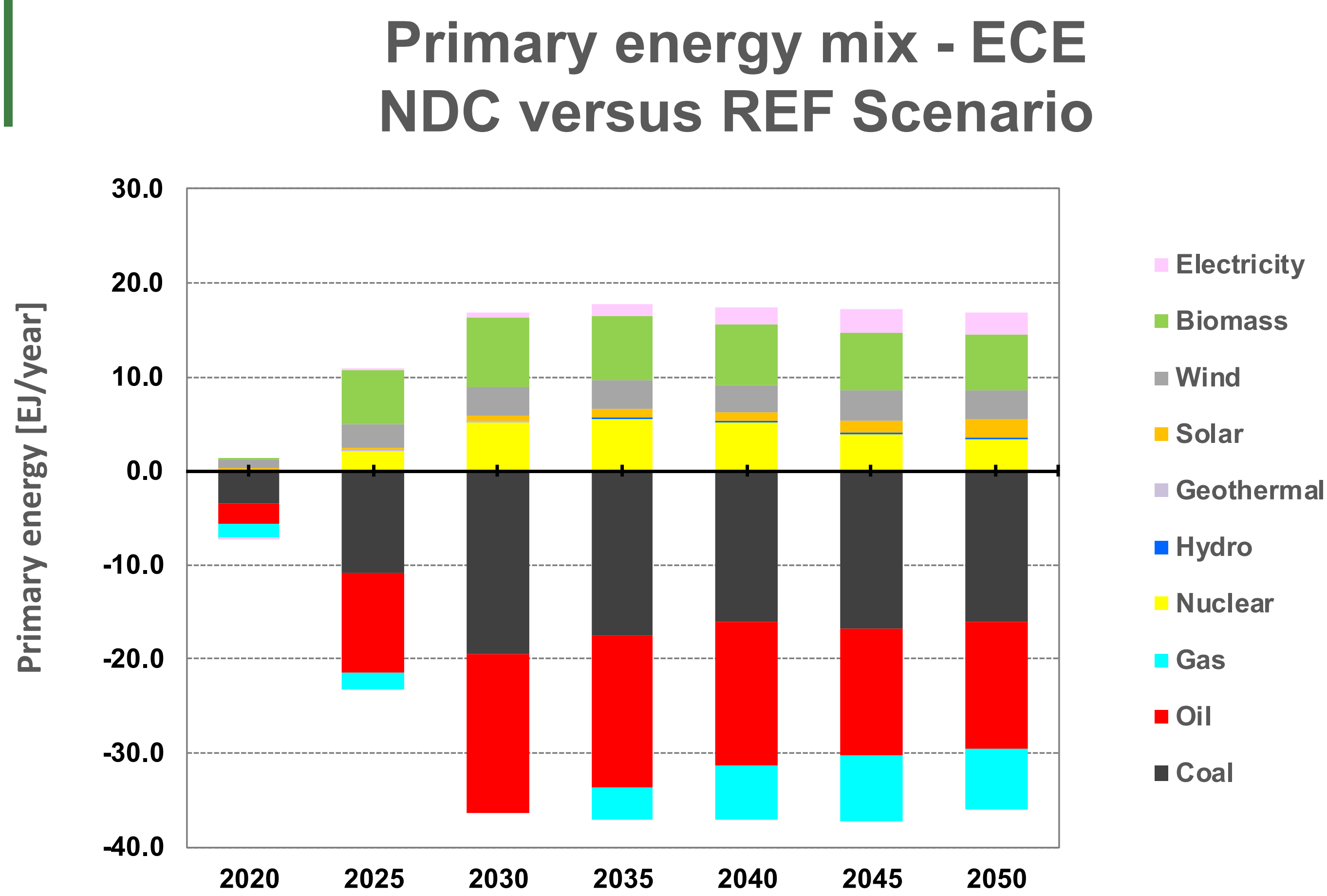


- *PE demand 23% lower by 2050 – in EJ about the level of 2010*
- *Gas takes the lead and dominates the PE mix*
- *Fossil fuels still account for 64% of PE supply by 2050*
- *RE up to 31% with biomass as the front running renewable*
- *Nuclear power returns as a solid PE source with a 5.4% market share*

Modeling Results: ECE

Primary Energy: Scenario differences

ENERGY

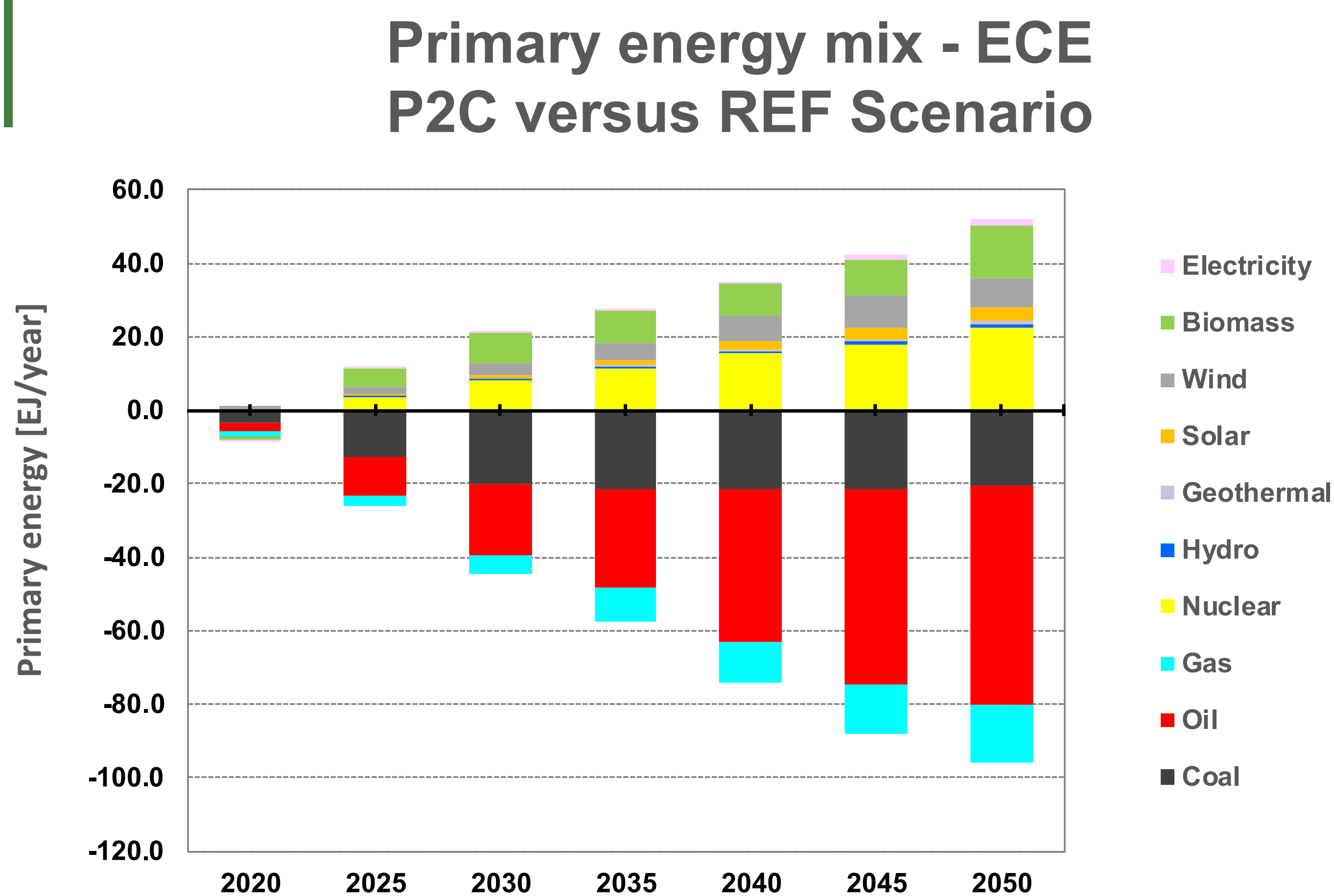


- *Clear signs of the beginnings of energy system transformation*
- *Efficiency*
- *Persistent substitution of fossil fuels with low carbon alternatives*

Modeling Results: ECE

Primary Energy: Scenario differences

ENERGY



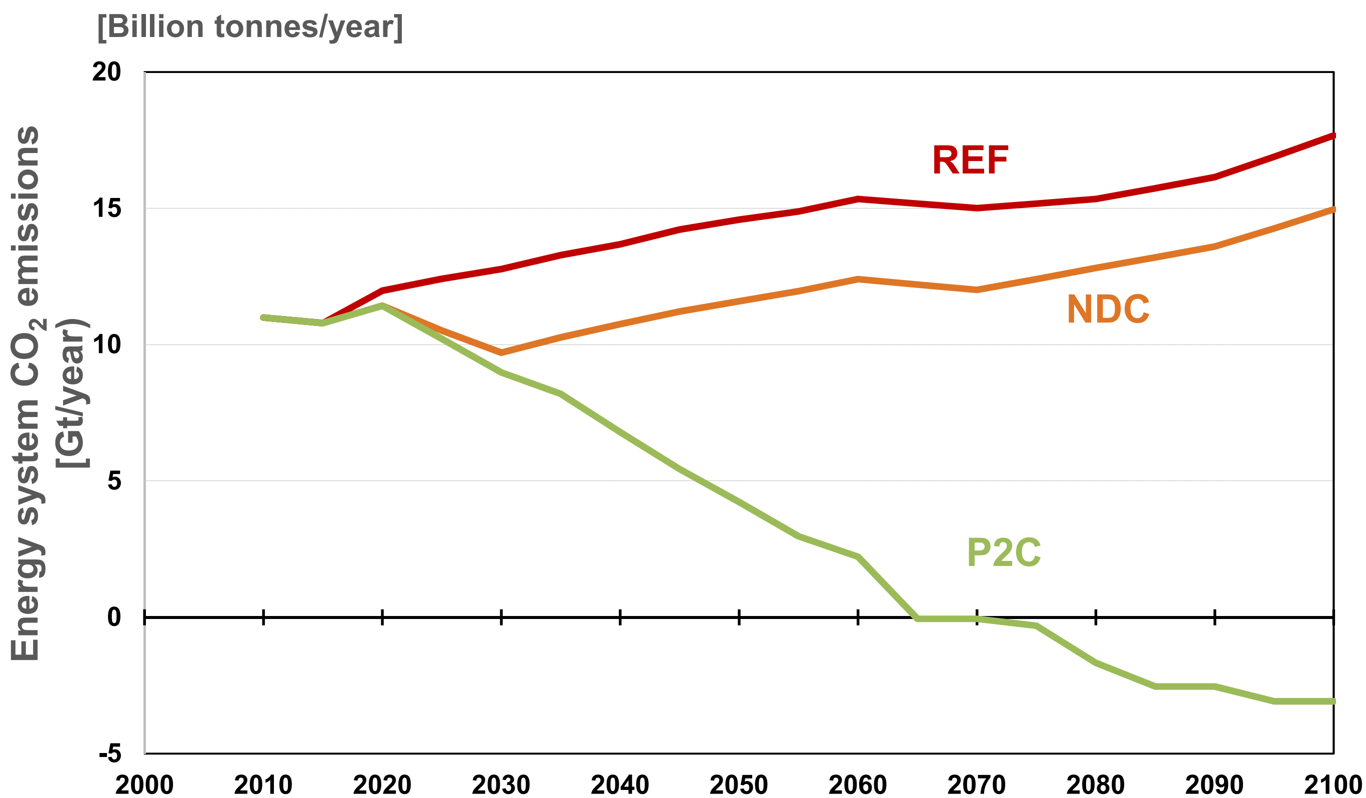
- *Fundamental energy system transformation well on its way*
- *Demand side responses*
- *Assertive substitution of fossil fuels with a mix of low carbon PE alternatives*

Modeling Results: ECE

Carbon dioxide emissions

ENERGY

Energy related CO_2 emissions by scenario - ECE



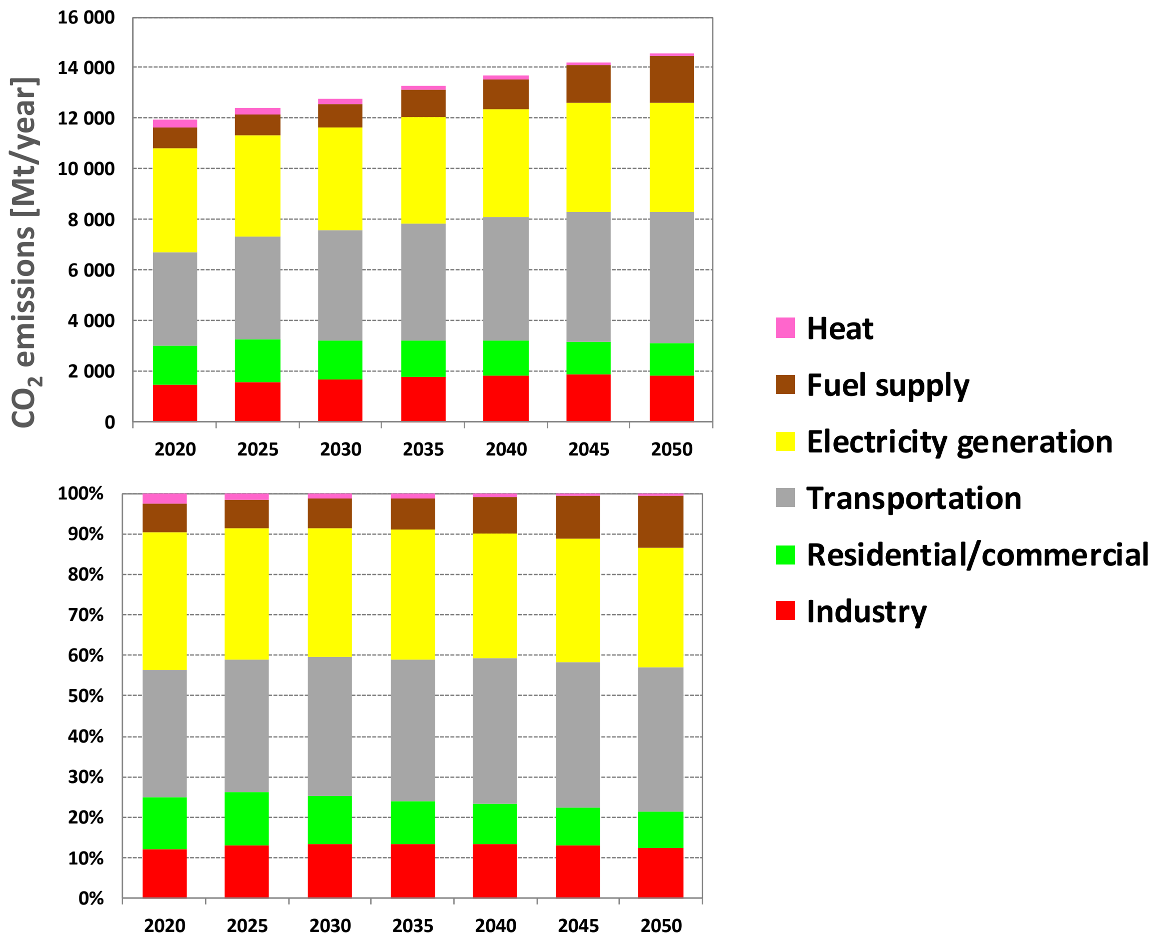
- *REF: Cumulative ECE CO_2 emissions amount to 1,250 Gt over the period 2020 to 2100 (considerably more than the global carbon budget to remain with in the P2C budget)*
- *NDC: Cumulative (2020-2100) NDC emissions are 18% or 225 Gt CO_2 lower than in REF*
- *P2C: Negative emissions mandatory after 2070*
- *Emissions peak by 2020*

Modeling Results: ECE

Carbon dioxide emissions

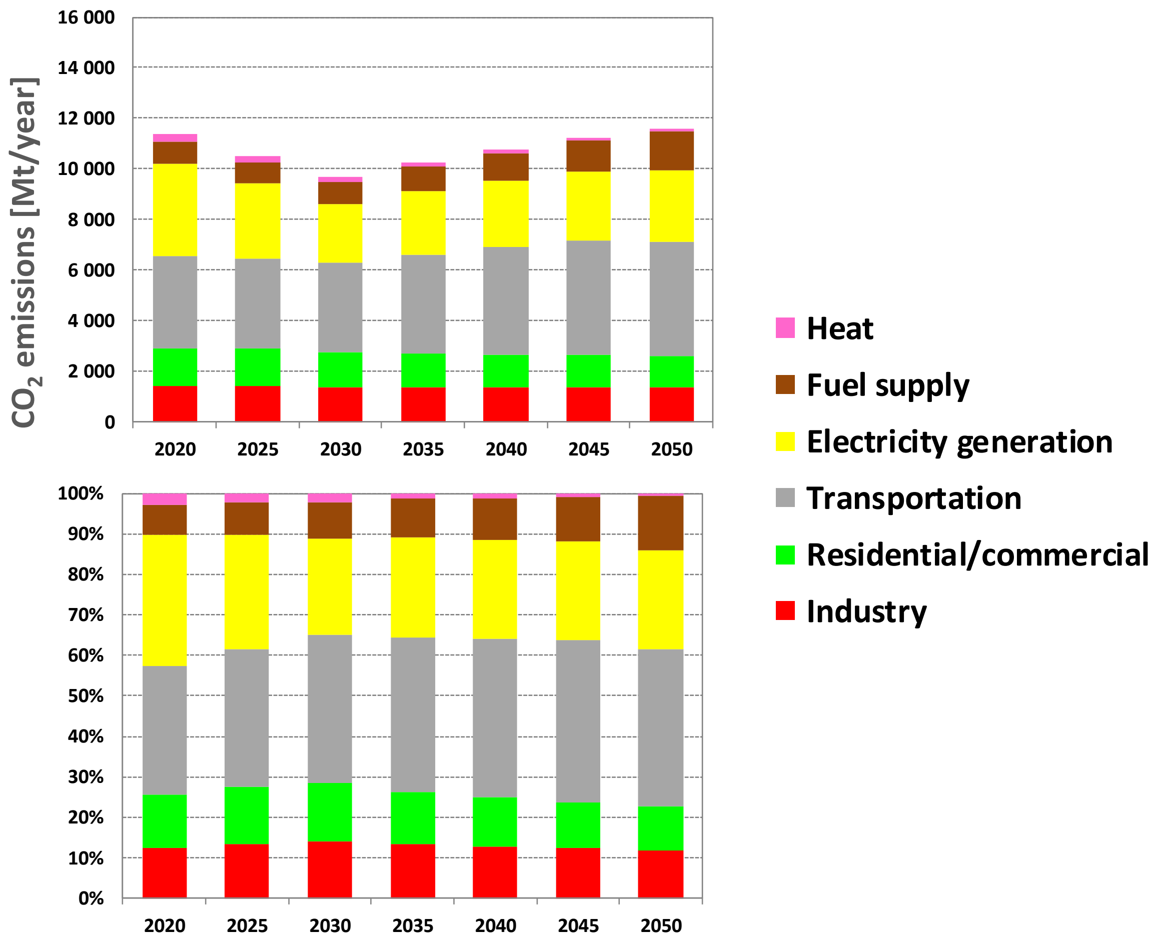
ENERGY

CO_2 emissions by sector – ECE REF Scenario



- *CO_2 emissions from fossil upstream operations and, to a lesser extent, transportation and industry are on the rise*
- *Residential/commercial sector emissions are stable after a short-term expansion*
- *Similar dynamics for electricity*
- *Heat supply emissions are steadily declining*

CO_2 emissions by sector – ECE NDC Scenario

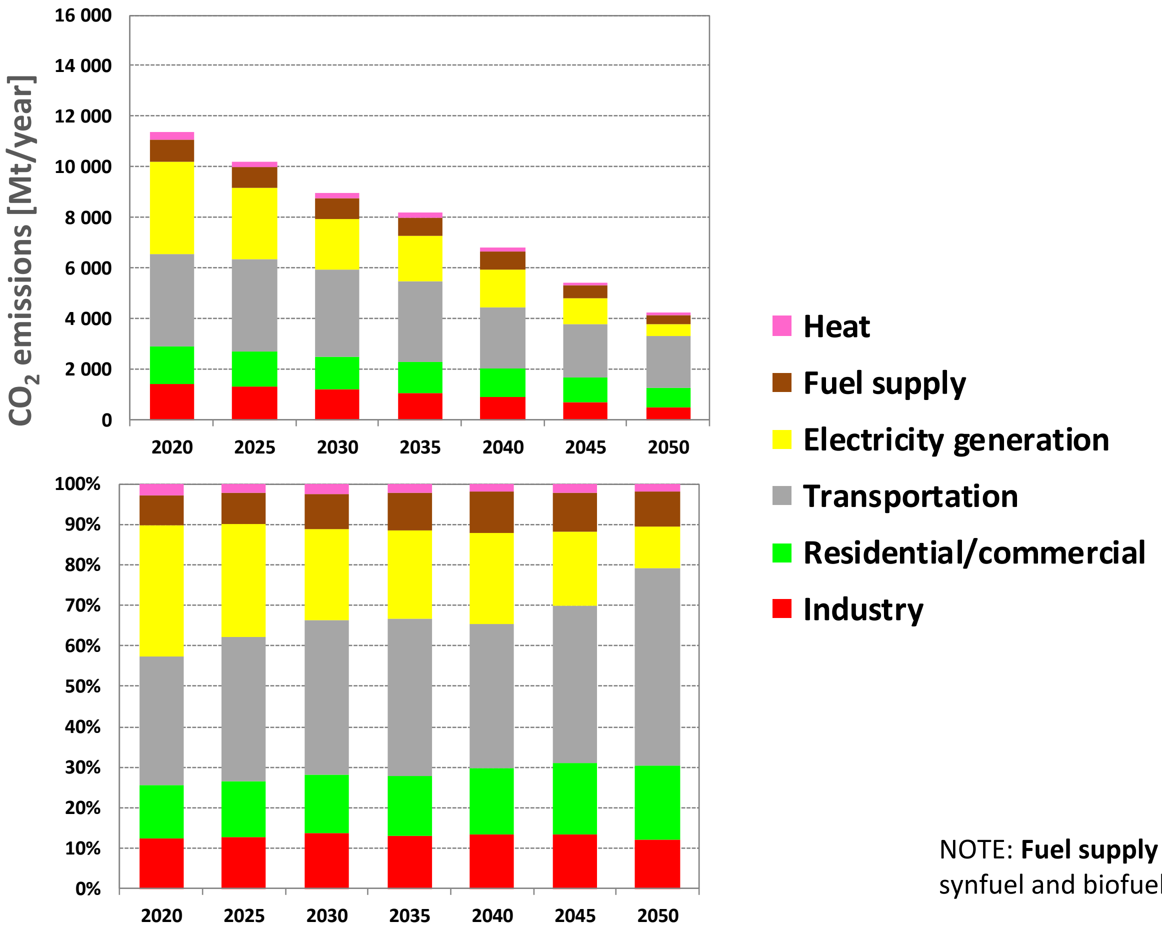


- *Electricity generation related CO_2 reductions more pronounced in the short run than in REF*
- *The gains are largely absorbed by fossil upstream operations, followed by transportation and industry*
- *NDC impact on emission reductions fades after 2030*

Modeling Results: ECE

Carbon dioxide emissions

CO_2 emissions by sector – ECE P2C Scenario



- *Electricity generation related CO_2 reductions almost entirely eliminated by 2050*
- *Transportation becomes largest CO_2 emitting sector*
- *Shares of R/C and industry increase despite declining emissions in absolute terms*

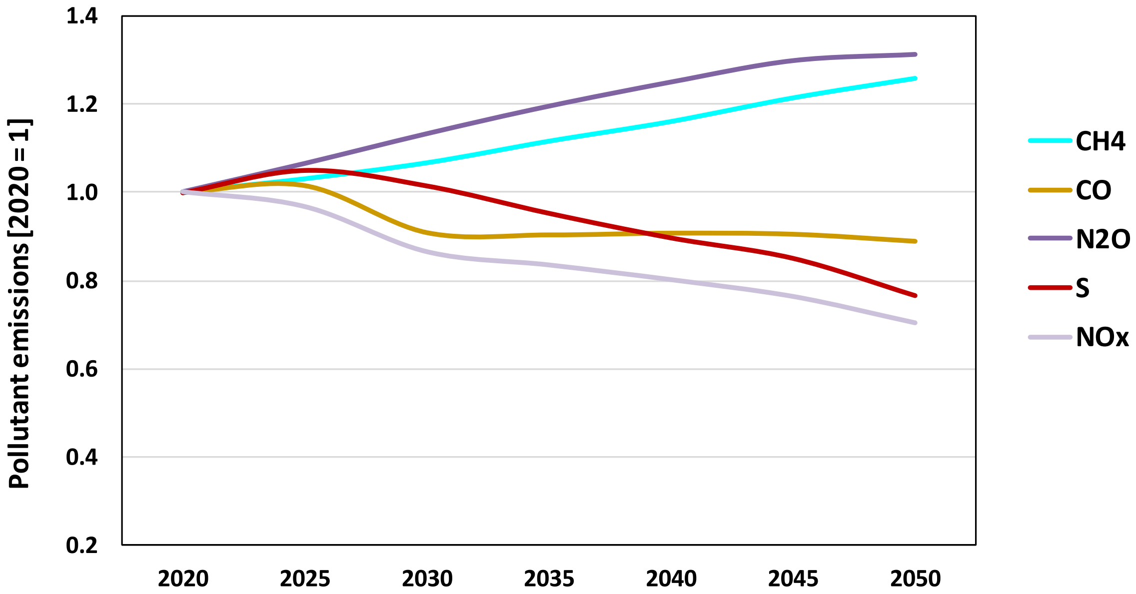
NOTE: **Fuel supply** includes emissions from extraction, refining, synfuel and biofuel manufacture

Modeling Results: ECE

Air quality

ENERGY

Non-CO_2 pollutant emissions – ECE REF



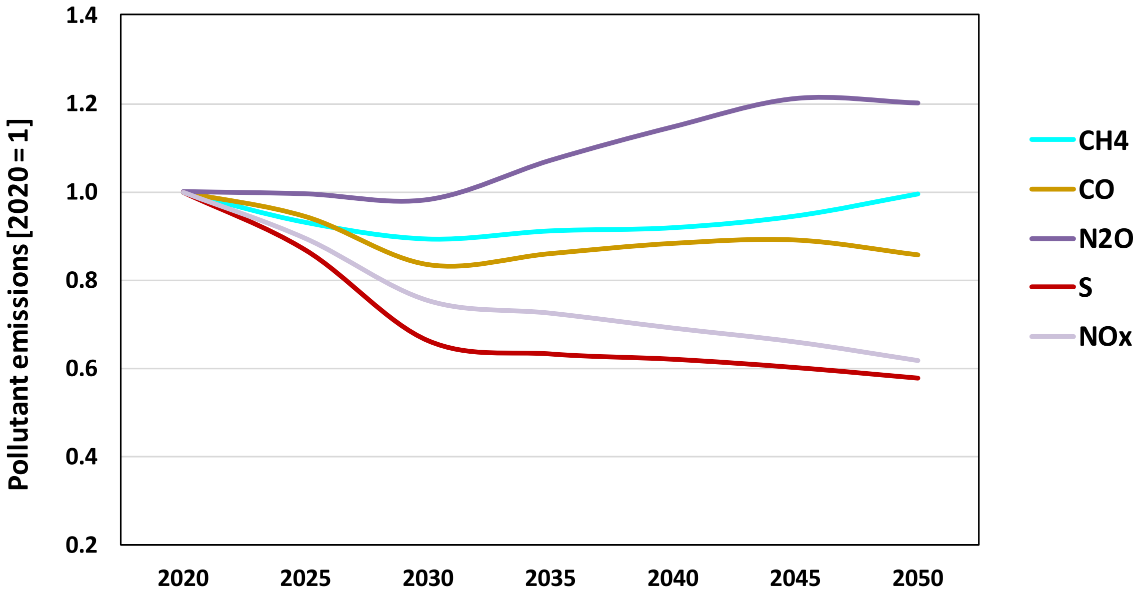
- *Sulfur emissions decrease after a temporary rise as*
  - *coal becomes less popular as end-use fuel*
  - *coal combustion technology for electricity generation increasingly equipped with desulfurization, denitrification and PM abatement equipment*
- *Methane emissions grow with overall natural gas use in the energy system*
- *N2O mirror the growth of oil based transportation fuels and fossil fuel combustion*

Modeling Results: ECE

Air quality

ENERGY

Non-CO_2 pollutant emissions – ECE NDC



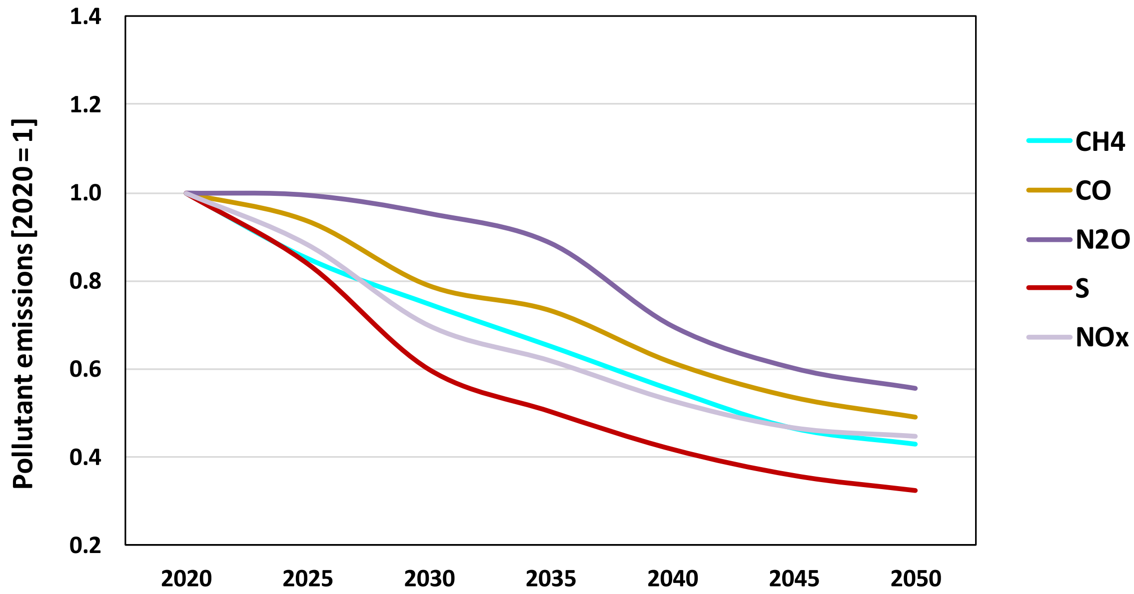
- *NDC driven changes in the energy sector further reduce sulfur releases as*
  - *gas and renewables substitute for coal and oil in electricity generation and several end-use sectors*
  - *electricity providing transportation services contain N2O emissions*

Modeling Results: ECE

Air quality

ENERGY

Non-CO_2 pollutant emissions – ECE P2C



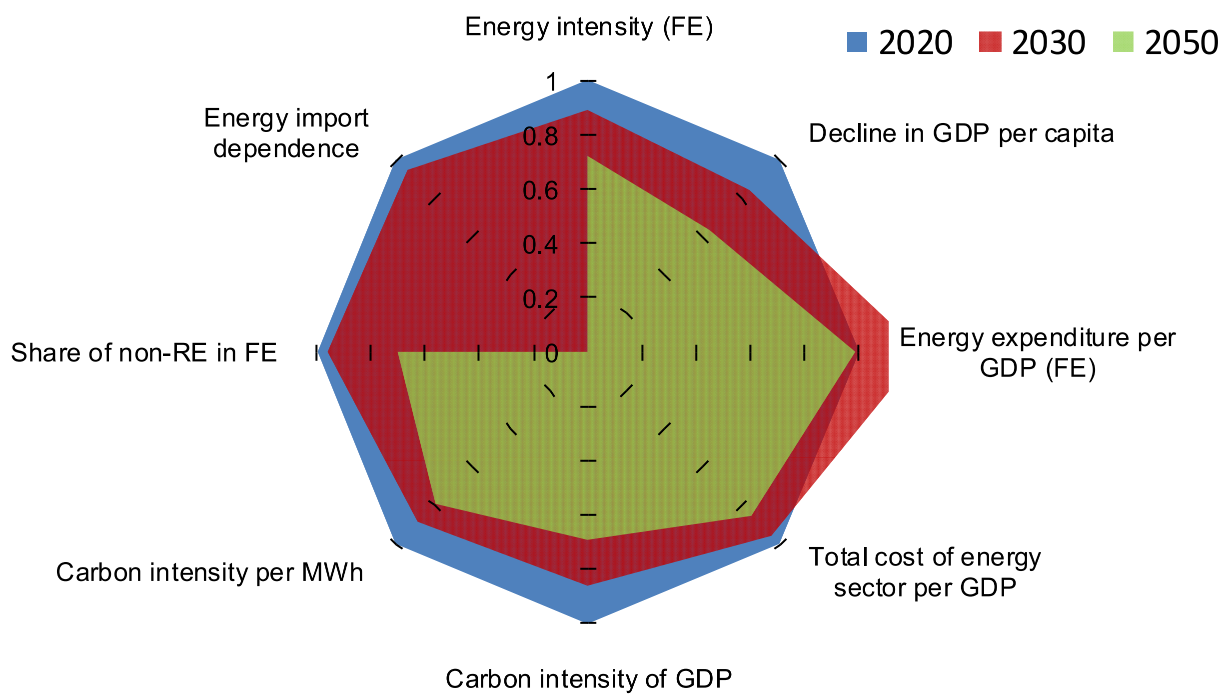
- ***P2C leads to substantial reductions in air born pollutant emissions – quasi a co-benefit of the energy system transformation to protect the global climate system***

Modeling Results: Indicators

Tradeoffs and synergies: ECE

ENERGY

Energy and environment indicators - ECE REF Scenario -



- Indicators are scaled relative to 2020 (2020=1), and any *improvement in an indicator will result in values lower than 1*
- If the shape of polygon becomes smaller compared to 2020, it shows improvement in the indicators

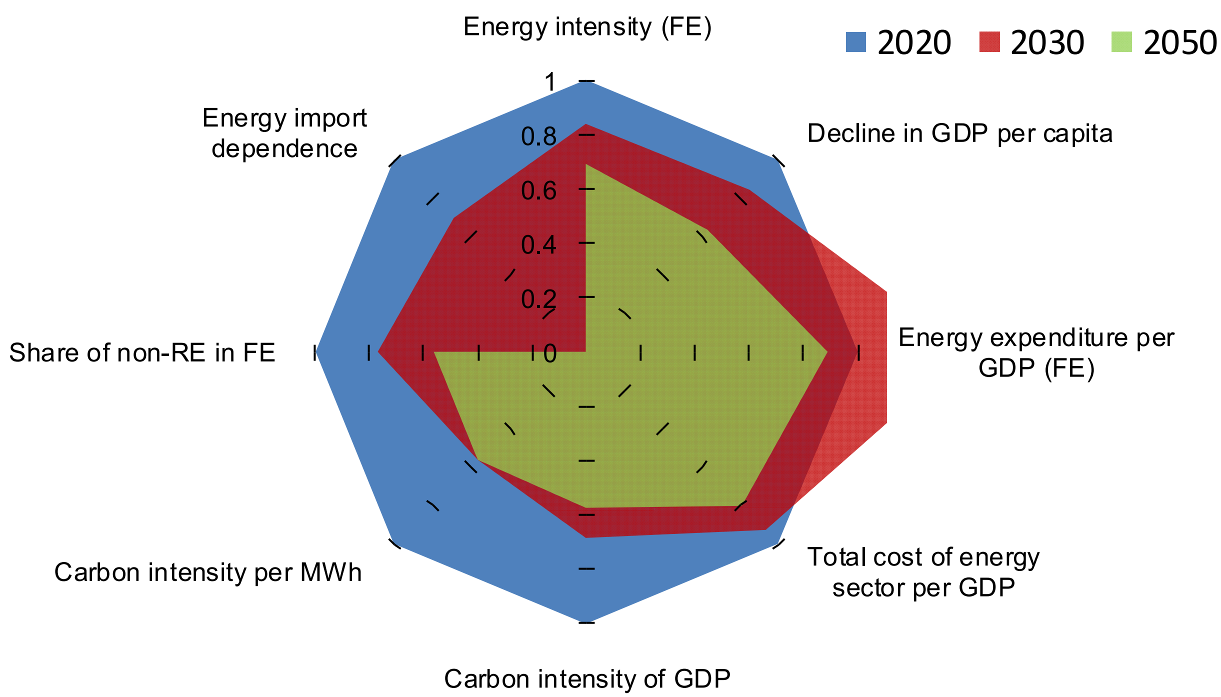
- *All indicators improve in REF except "energy expenditures per GDP"*
- *Energy expenditures per GDP increase to 9% in 2030 (up from 7.3% in 2020) – then return to 7.2% by 2050*
- *Energy import dependence: ECE as a region switches to a net energy exporter by 2050*
- *Improvement in the share of RE and reduction of CO_2 emissions per GDP due to lower energy intensity of the economy*
- *Carbon intensity of GDP declines faster than CO_2/MWh*
- *Total energy sector costs reduced due to becoming a net energy exporting region*

Modeling Results: Indicators

Tradeoffs and synergies: ECE

ENERGY

Energy and environment indicators - ECE
NDC Scenario



- Indicators are scaled relative to 2020 (2020=1), and any *improvement in an indicator will result in values lower than 1*
- If the shape of polygon becomes smaller compared to 2020, it shows improvement in the indicators

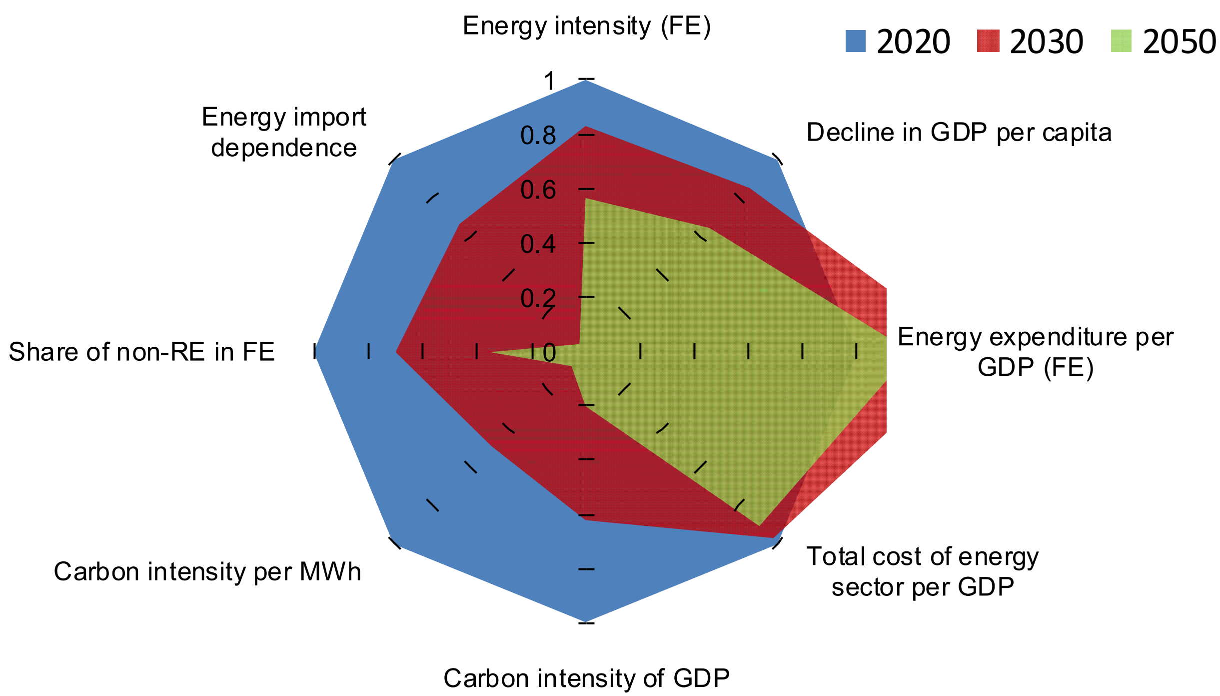
- *NDCs lead to a notable improvement in the share of RE by 2030*
- *A moderate continuation of NDC improves most of indicators after 2030*
- *Marked improvement of CO_2/MWh (more pronounced than carbon intensity of GDP)*
- *Meeting NDC increases 2030 Energy expenditures per GDP (versus REF)*
- *No notable change in GDP per capita or energy import dependence*
- *Total energy sector costs reduced due to higher non-fossil domestic energy use and switching to a net energy exporting region*

Modeling Results: Indicators

Tradeoffs and synergies: ECE

ENERGY

Energy and environment indicators - ECE P2C Scenario



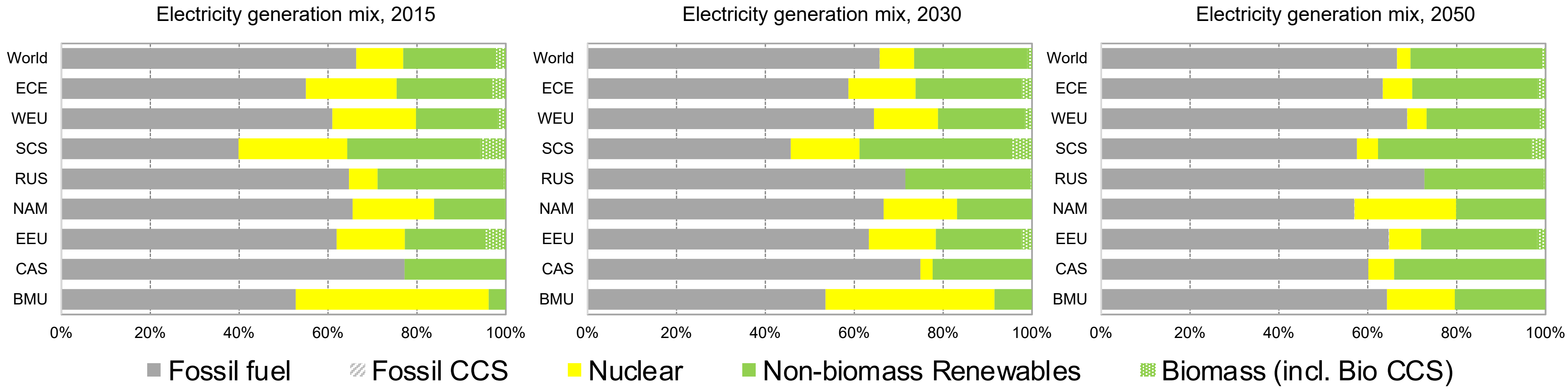
- *Energy system transformation clearly discernible by 2050*
- *Significant change in energy expenditures by 2030 (11.4% vs 9% in Ref) before returning to 9.6% in 2050 (Ref 7,2%)*
- *Drastic improvement of the CO_2/MWh indicator (>95% compared to 2020) outpacing carbon intensity of GDP*
- *Energy intensities decline along with the unprecedented investments in efficiency measures*
- *Share of renewables reaches xx% by 2050T*
- *The polygon for 2050 (green) visually tilts toward the cost pillars, i.e., away from the other indicators*

- Indicators are scaled relative to 2020 (2020=1), and any *improvement in an indicator will result in values lower than 1*
- If the shape of polygon becomes smaller compared to 2020, it shows improvement in the indicators

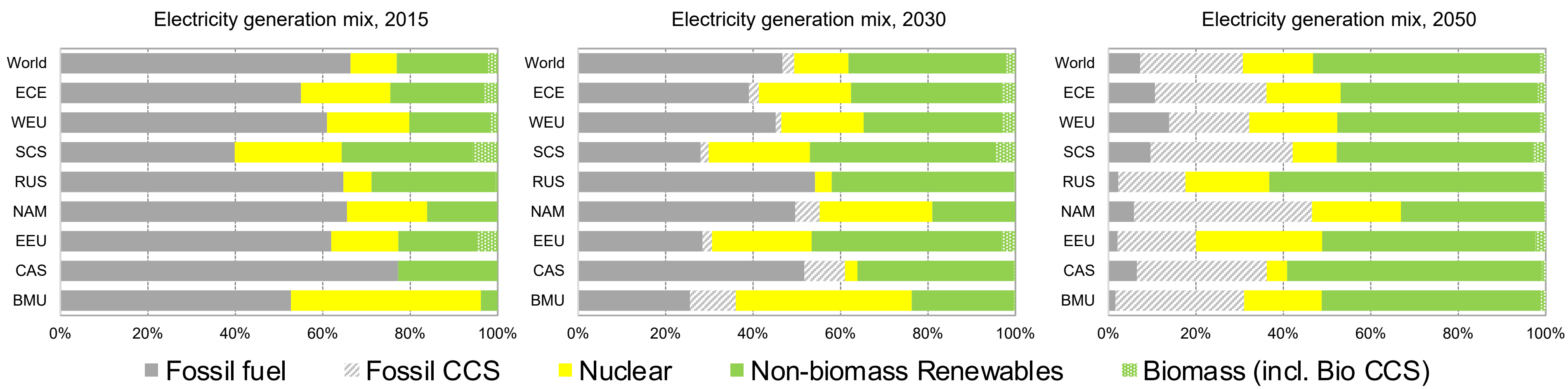
Modeling Results: Shares of low carbon technologies

ENERGY

Shares of low carbon technologies – REF Scenario



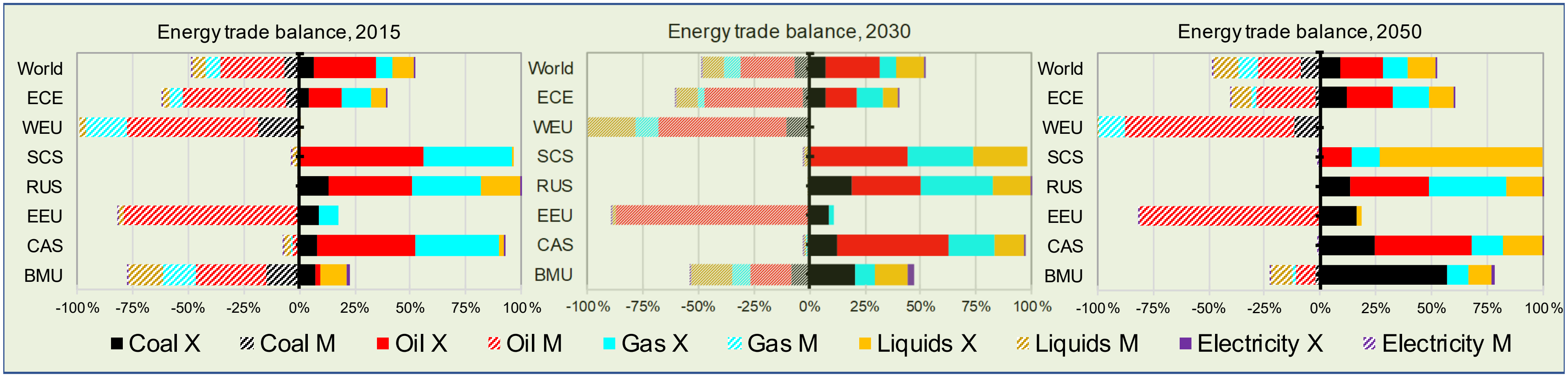
Shares of low carbon technologies versus unabated fossil fuel use – P2C Scenario



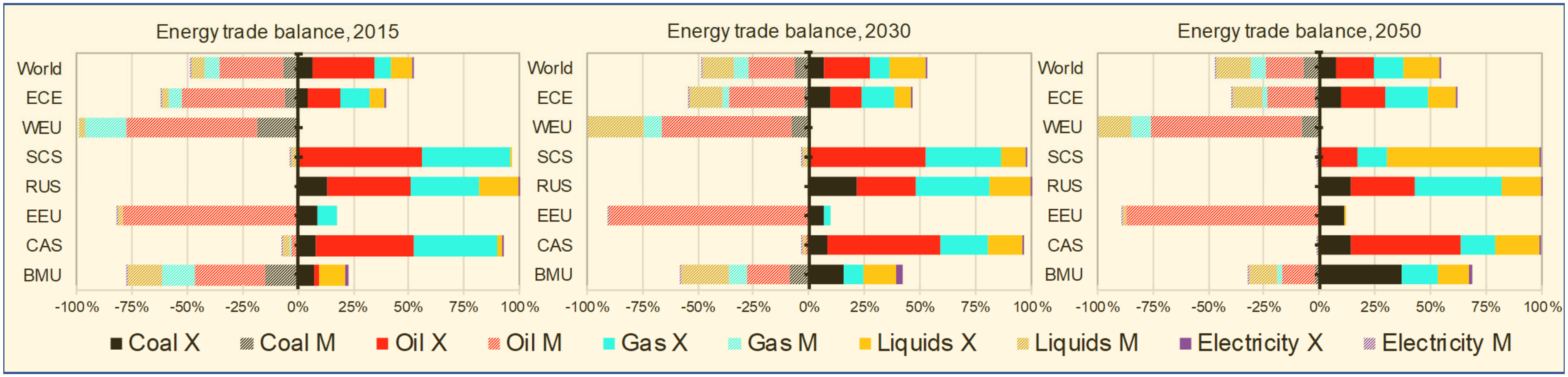
Modeling Results: Energy trade* by region

ENERGY

REF Scenario



NDC Scenario

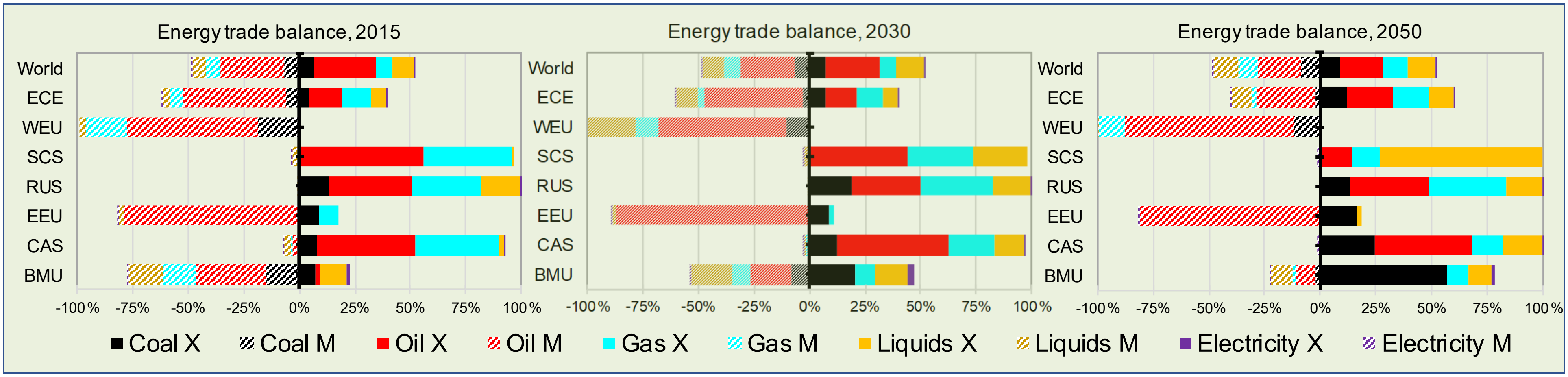


* Panels show the percentage of a region's energy imports and exports (by fuel) in relation to the region's total energy trade volume in physical units

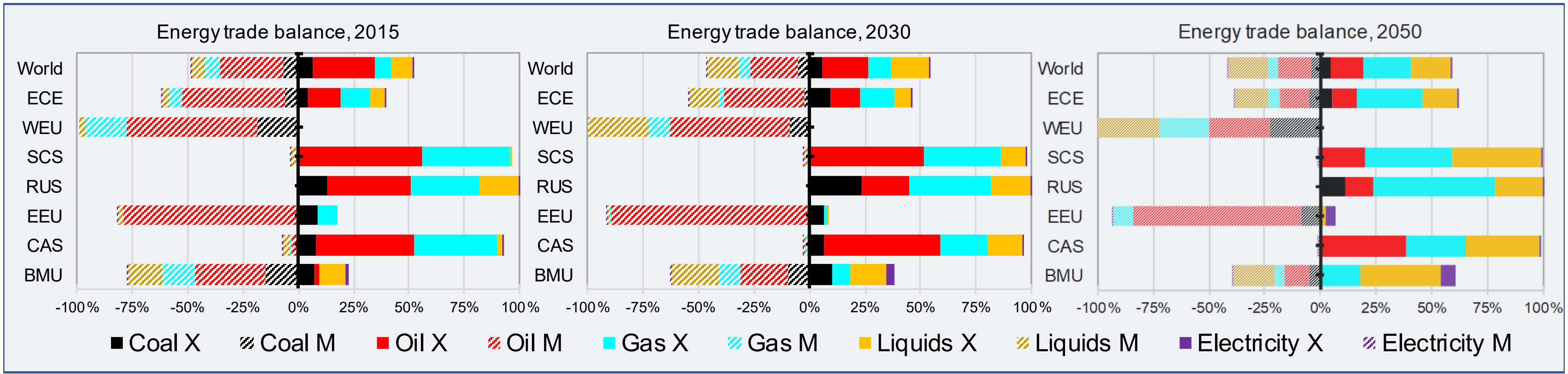
Modeling Results: Energy trade* by region

ENERGY

REF Scenario



P2C Scenario

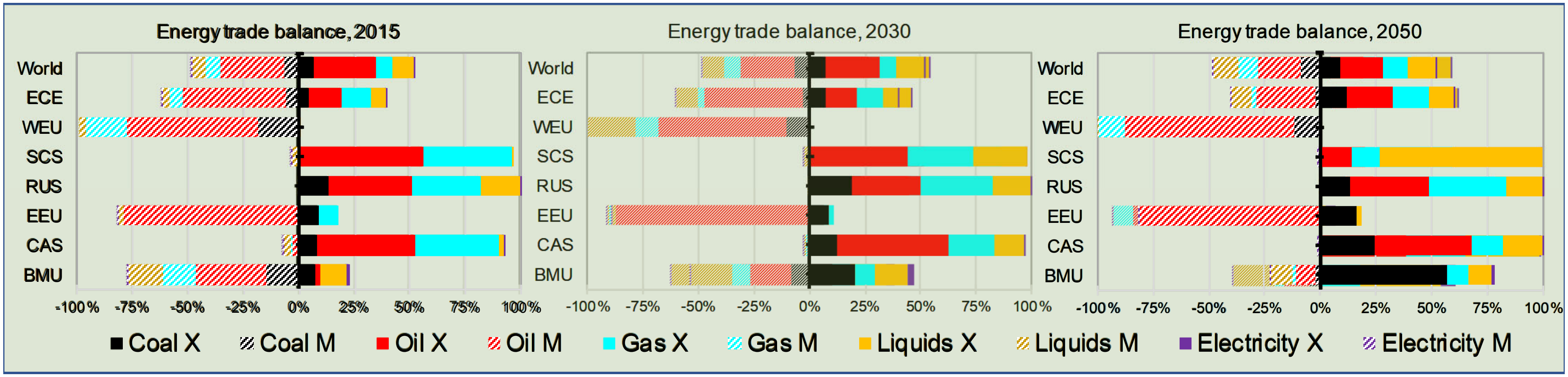


* Panels show the percentage of a region's energy imports and exports (by fuel) in relation to the region's total energy trade volume in physical units

Modeling Results: Energy trade* by region

ENERGY

REF Scenario



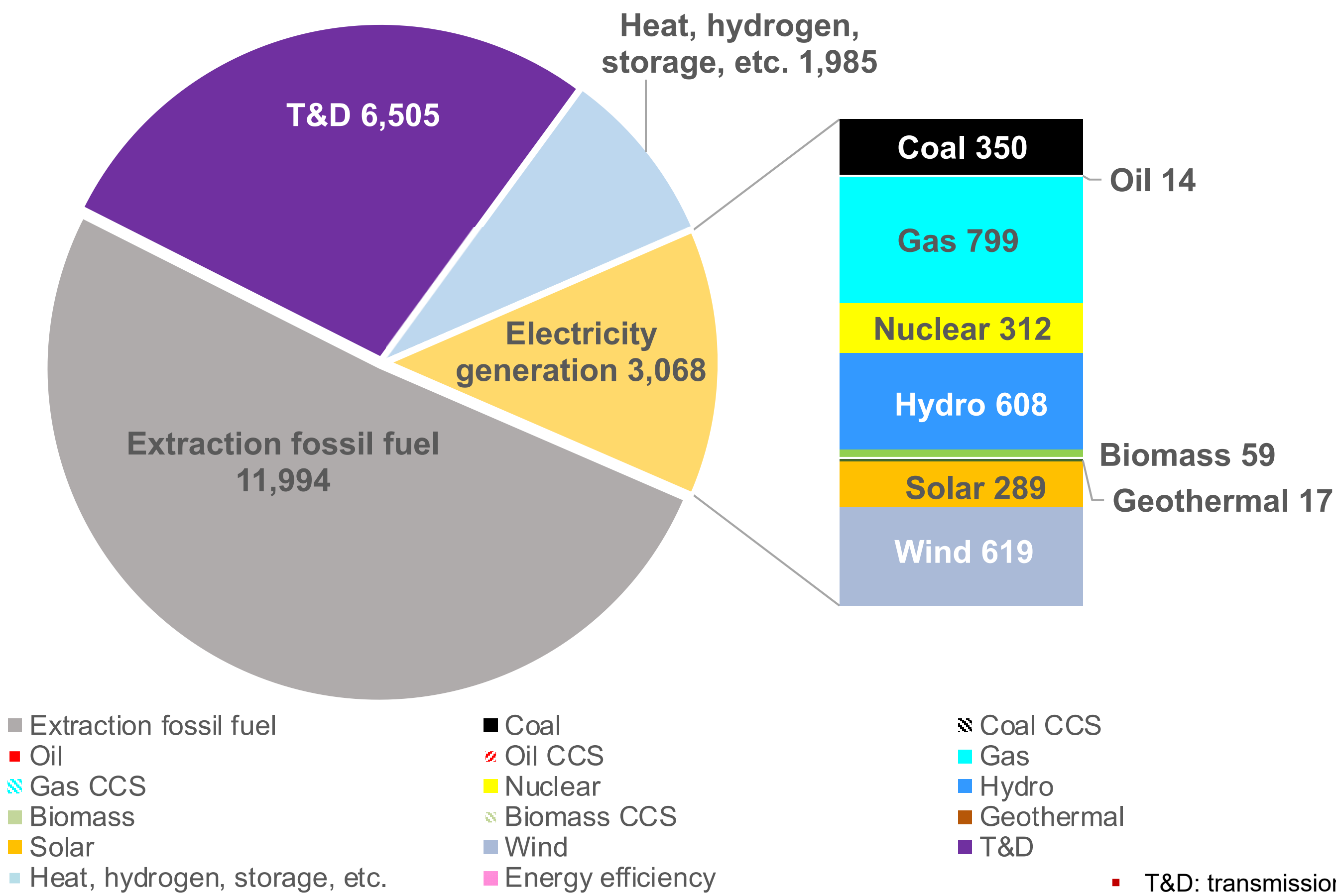
* Panels show the percentage of a region's energy imports and exports (by fuel) in relation to the region's total energy trade volume in physical units

Modeling Results: Indicators

Investment needs: ECE

ENERGY

Cumulative investments 2020-2050: *23,552 billion US$*
REF - ECE



- *Fossil fuel extraction absorbs 50% of total energy sector investments*
- *T&D commands twice as much capital than investments in electricity generating equipment*
- *Generation investments are dominated by lowest carbon emitting hydro power and wind plants followed by nuclear power and solar*
- *Heat, hydrogen, refining, bioliquids, storage, etc. account for almost two trillion US$*

- T&D: transmission and distribution of electricity and district heat
- Investments in US$ at 2010 prices and exchange rates

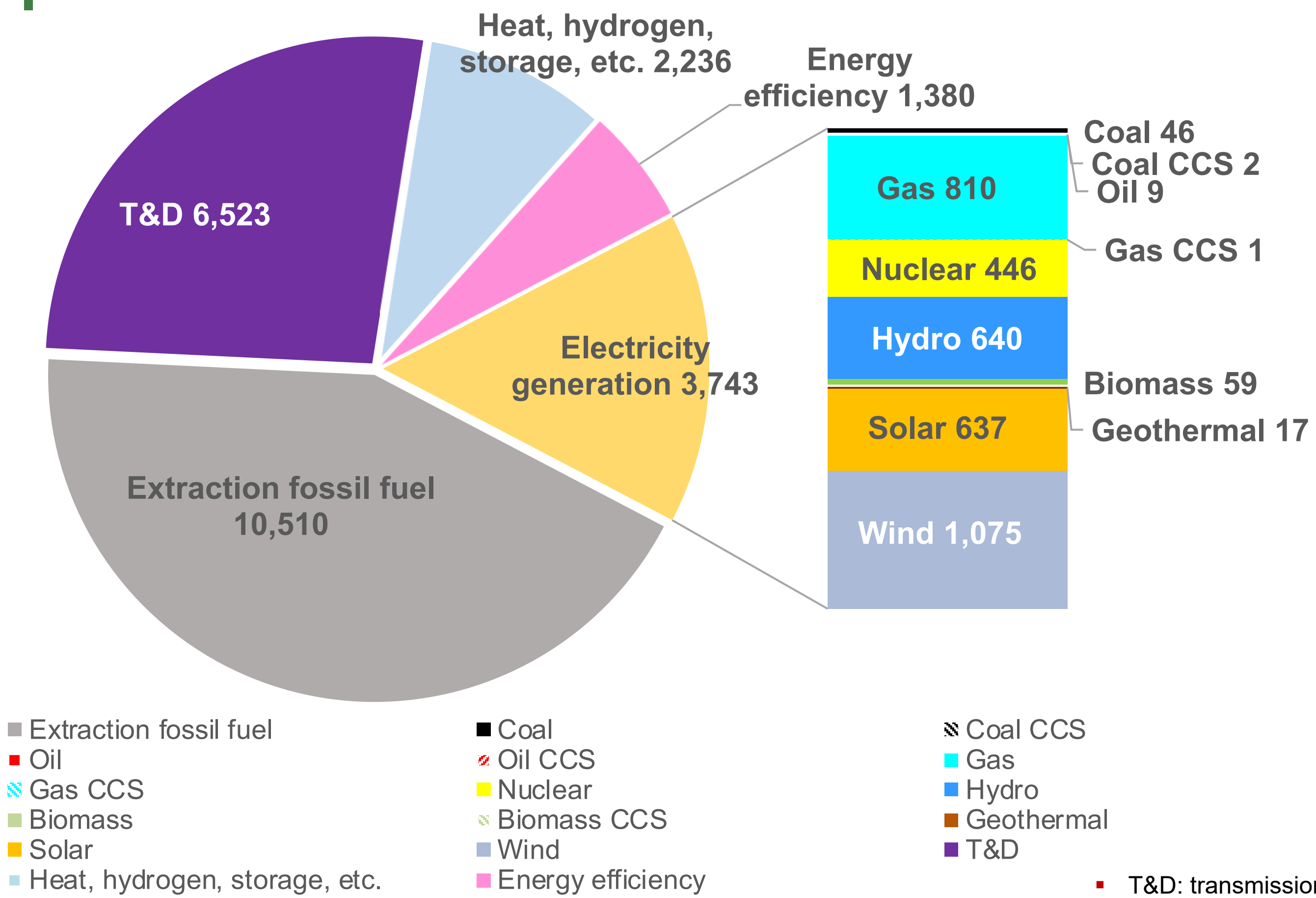
Modeling Results: Indicators

Investment needs: ECE

ENERGY

Cumulative investments 2020-2050: *24,391 billion US$*

NDC - ECE



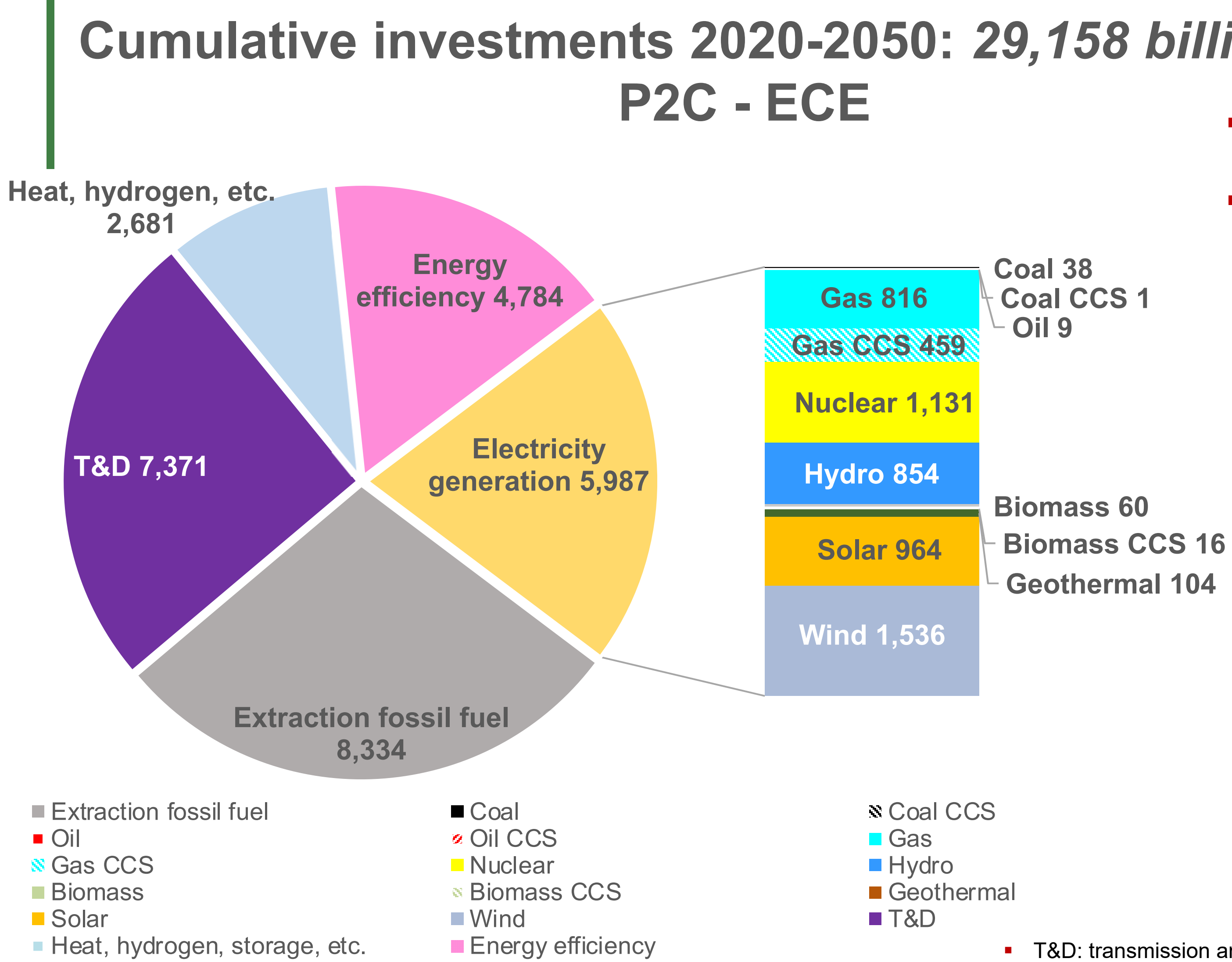
- *Total investments slightly higher (by ~800 billion US$) than in REF*
- *Different investment portfolio:*
  - *Lower upstream fossil fuel investments (than REF)*
  - *Energy efficiency and intensity reduction measures are steadily introduced*
  - *Investments in wind and solar dominate generation*
  - *Investment in coal greatly reduced (some CCS retrofits)*

- T&D: transmission and distribution of electricity and district heat
- Investments in US$ at 2010 prices and exchange rates

Modeling Results: Indicators

Investment needs: ECE

ENERGY



- *P2C raises the investment bar by 5.6 trillion US$ (24%)*
- *Significant change in investment structure*
  - *Lower upstream investments*
  - *Energy efficiency absorbs 25% of capital outlays*
  - *Generation commands almost twice as much capital investment than in REF*
  - *Renewables account for 60% of generation investment*
  - *No significant investments in fossil electricity generation other than gas*
  - *Gas generation with CCS accounts for 55% of total gas generation investment*
  - *Nuclear power becomes the third largest generating investment category*

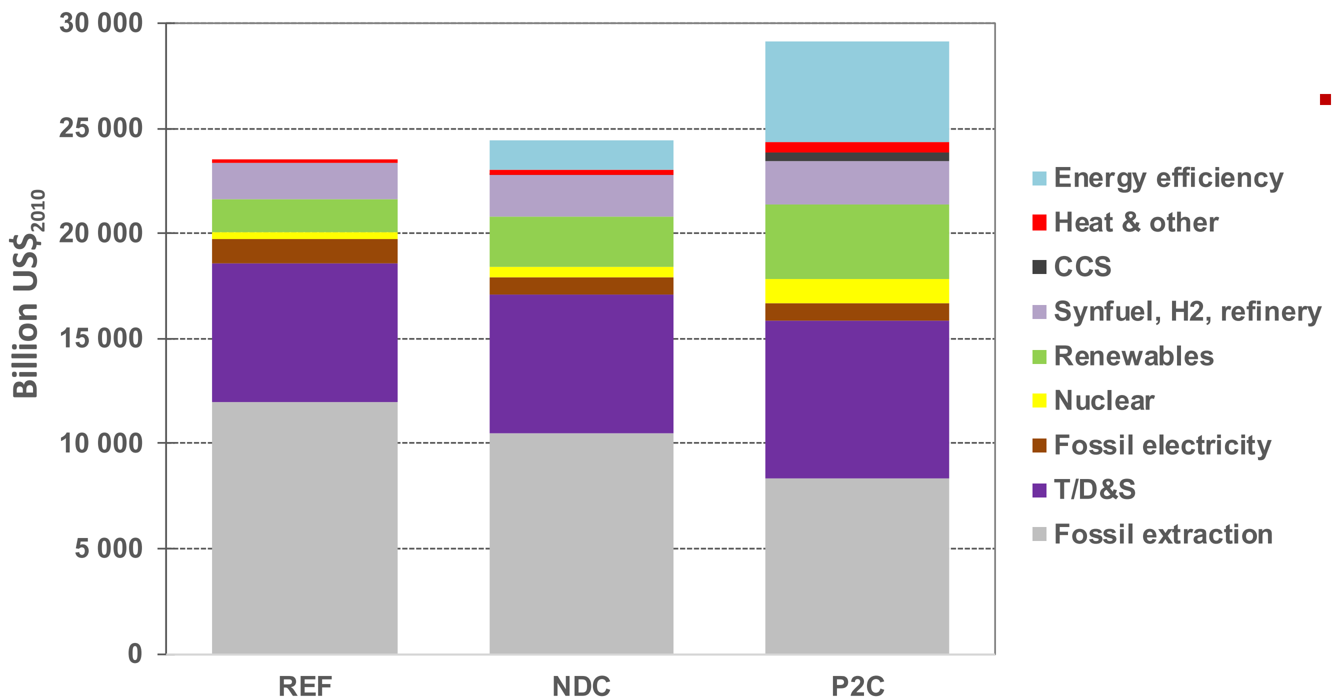
- T&D: transmission and distribution of electricity and district heat
- Investments in US$ at 2010 prices and exchange rates

Modeling Results: Indicators

Investment needs: ECE

ENERGY

Comparing investment requirements - ECE REF, NDC and P2C scenarios



- *Graph shows the steadily changing investment patterns by scenario:*
  - *Upstream fossil investments decline*
  - *Gas generation with CCS*
  - *Efficiency and renewables*
  - *T/D&S remain strong investment*
  - *Nuclear power*

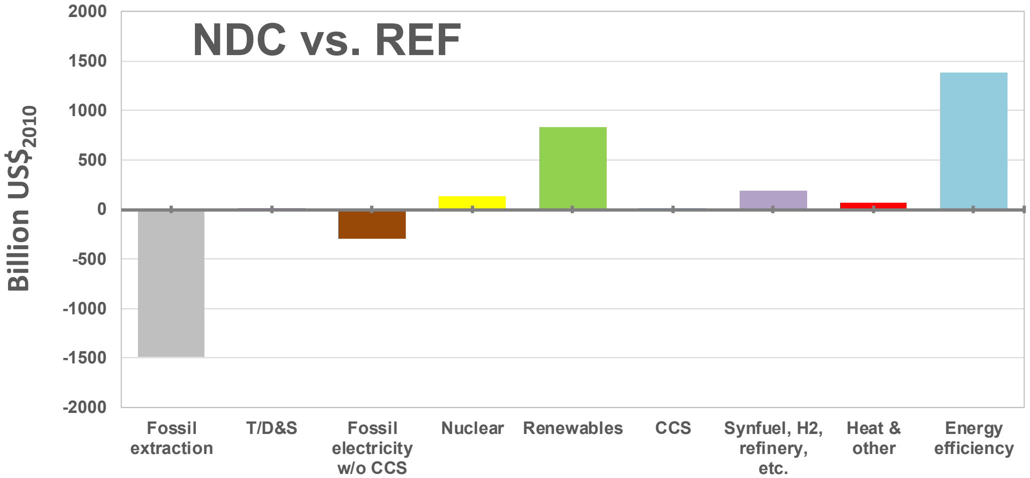
- T/D&S: transmission, distribution and storage of electricity and district heat
- CCS: carbon capture and storage
- H2: hydrogen
- BAT: Best available technology

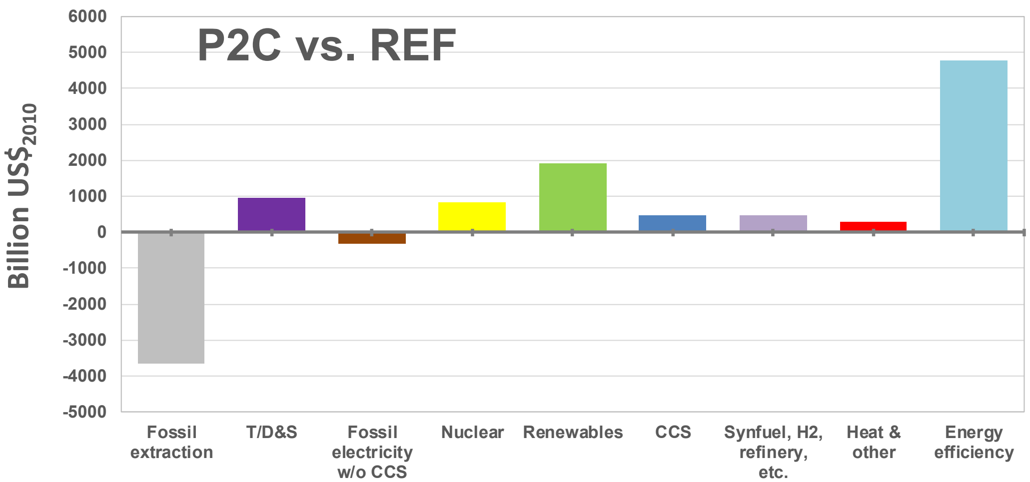
Modeling Results: Indicators

Investment needs: ECE

ENERGY

Distributional effects of investment requirements between scenarios - ECE





NDC vs. REF

- *See earlier comments:*
- *Clearly visible shift from upstream investments and fossil electricity generation to expenditures in energy efficiency and renewables*

P2C vs. REF

- *Even stronger investment shift from upstream to efficiency and renewables (Note: Scale change)*
- *Gas CCS and renewables are the winners in electricity generating*

Summary Remarks

Lessons learned and the way forward

ENERGY

I. Current NDC mitigation commitments are insufficient to achieve a 2ºC target

- MESSAGE could not reach a P2C target based on the NDC driven system changes introduced by 2030
- More determined action is needed before 2030

II. Extension of assessments beyond the Environmental Pillar

- The model analyses to date are environment centric – the Pathways Project needs quantitative stakeholder input on regionally specific sustainability criteria in the context of sustainable energy

III. Technology exclusion limits mitigation flexibility and increases costs

- Excluding CCS, a potential hydrogen age, nuclear energy and fusion or extensive LNG trade can be impede the implementation of regional climate targets

IV. Technological change is essential

- There is considerable technological change and innovation in the pipeline which deserves further scrutiny within the Pathways project. Example: Economic bulk electricity storage

V. Regional approaches

- An alignment of policies on global issues to increase the impact of measures

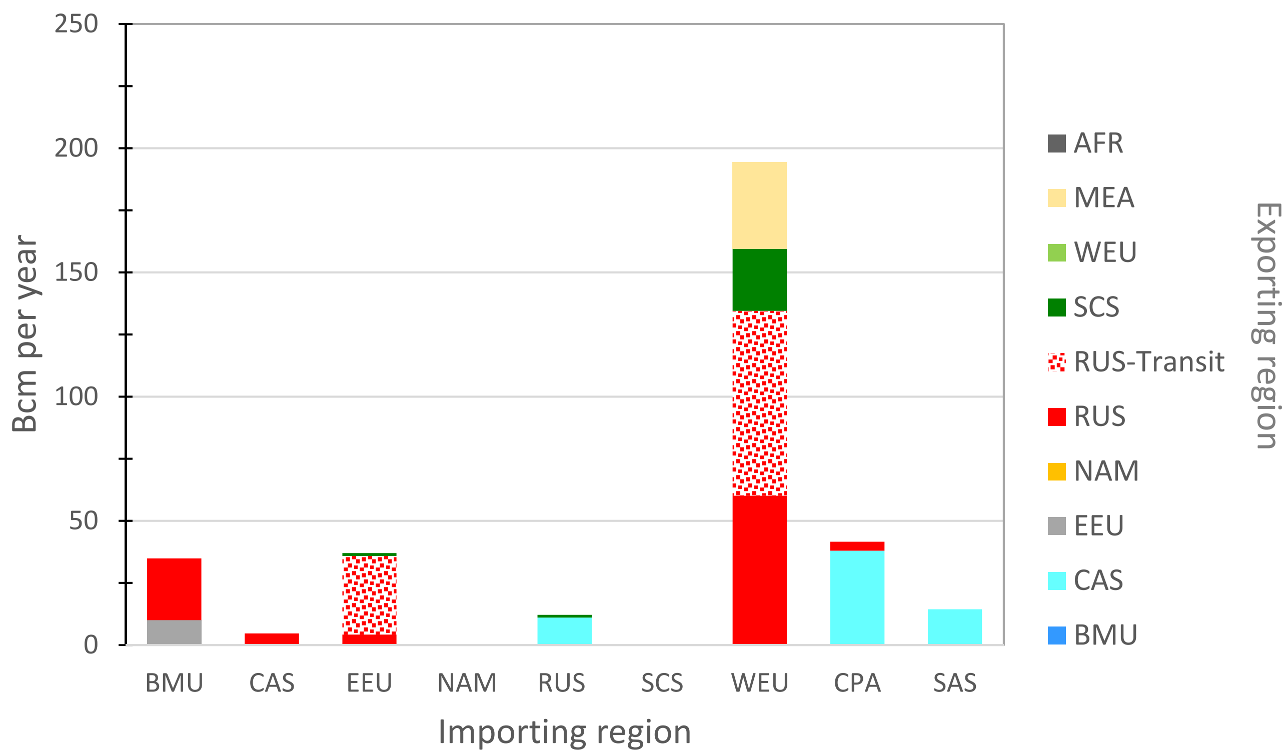
Modeling Results: UNECE

Gas Trade

ENERGY

Natural gas trade in 2015 – Importing regions

Origins of gas trade involving ECE regions [bcm]



Graph shows gas trade from the vantage point of importing region or the origins of gas imports

Only pipeline gas is modeled point-to-point and shown here (LNG is modelled using uses a pool approach and flows cannot be allocated between specific regions)

Note: A fair share of BMU gas imports from RUS is transit gas to EEU and WEU – see gas imports of EEU and WEU from BMU

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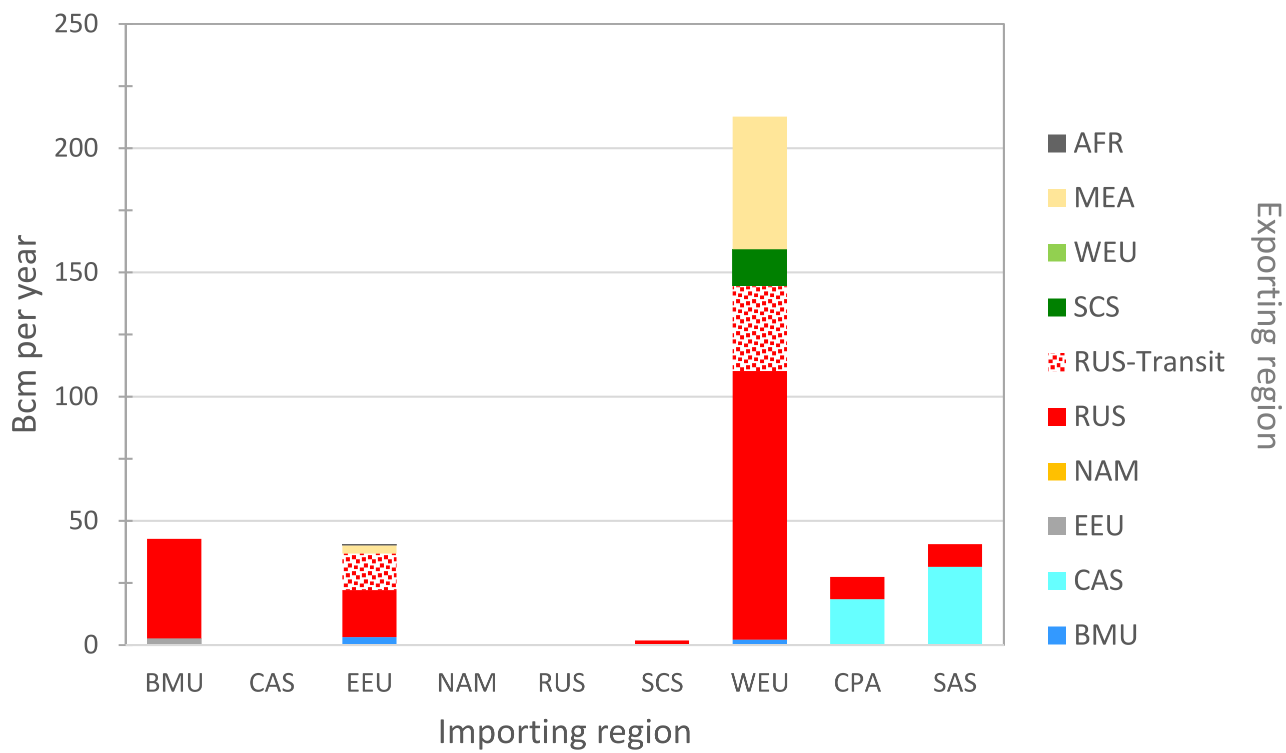
Modeling Results: UNECE

Gas Trade

ENERGY

Natural gas trade – REF Scenario: 2030

Origins of gas trade involving ECE regions [bcm]



BMU imports decline with the operation of Nord Stream II and new pipelines in the southern European (e.g., Blue Stream, TAP) corridor.

WEU imports up by 15% essentially from RUS (32 bcm) and MEA (21 bcm)

MEA pipeline exports to Europe see beginnings of deliveries from the Middle East in addition to North Africa

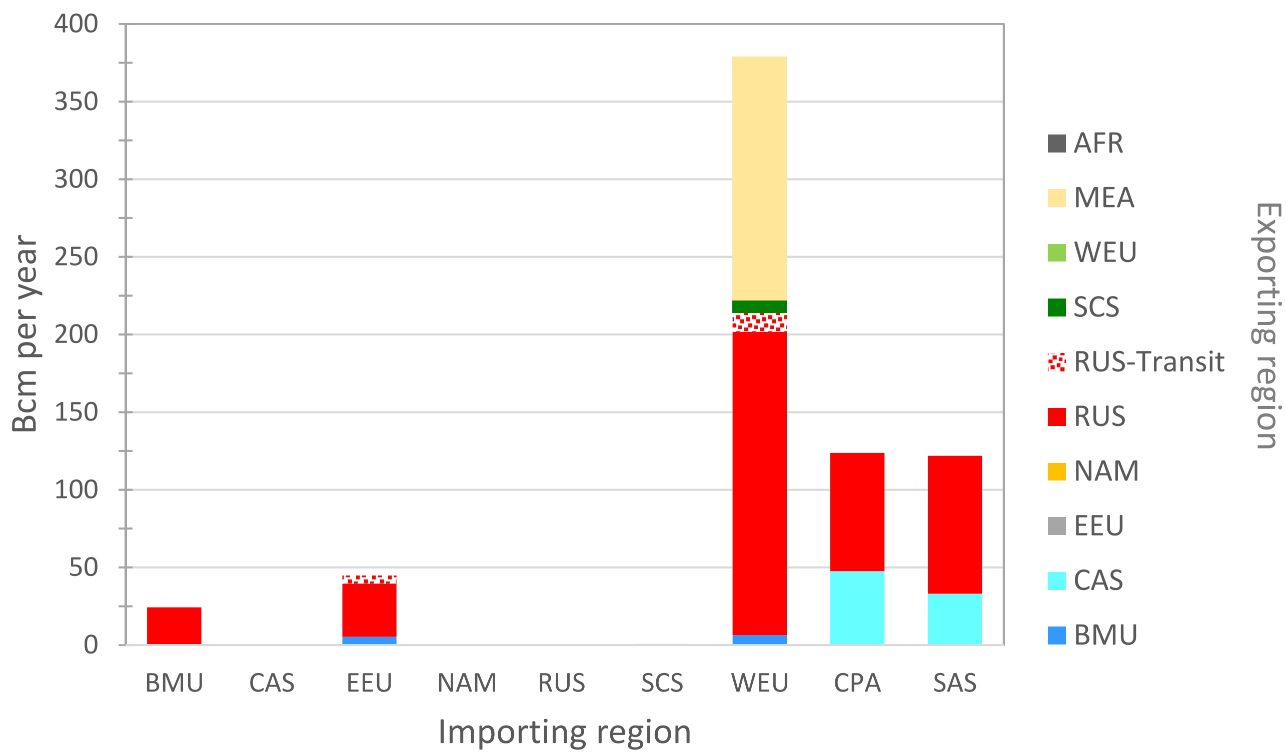
Modeling Results: UNECE

Gas Trade

ENERGY

Natural gas trade – REF Scenario: 2050

Origins of gas trade involving ECE regions [bcm]



Note change in scale of y-axis

Gas trade expands significantly (doubling versus 2015 after netting out transfers)

Pipeline trade dominated by RUS but with market diversification into CPA (China) and SAS (India)

CAS eyes these markets located to its East as well

MEA steps exports up to balance the void created by the RUS orientation to CPA and SAS

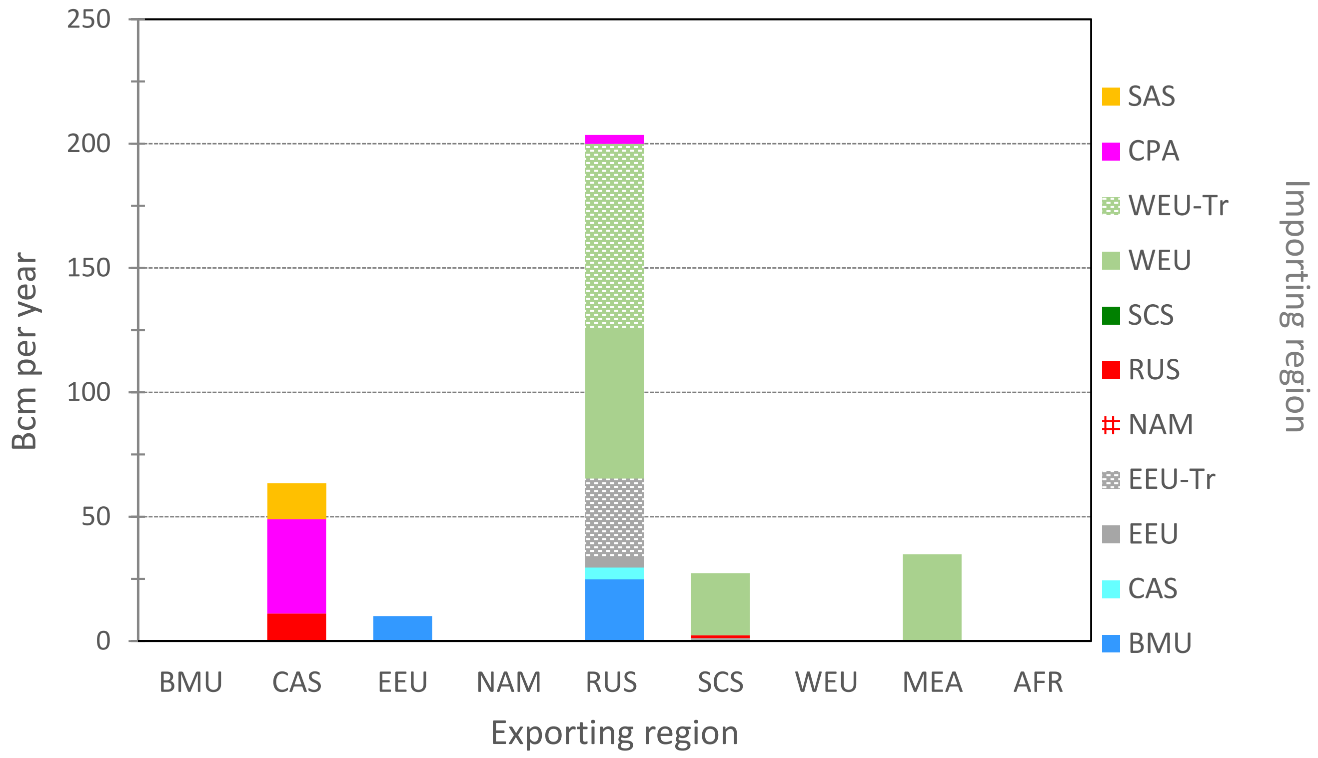
Modeling Results: UNECE

Gas Trade

ENERGY

Natural gas trade in 2015 – Exporters

Destinations of gas trade involving ECE regions [bcm]



Gas exports in the ECE region historically dominated by RUS.

WEU is the main destination of gas exports (all sources)

Transit gas accounts for a large share of gas exports

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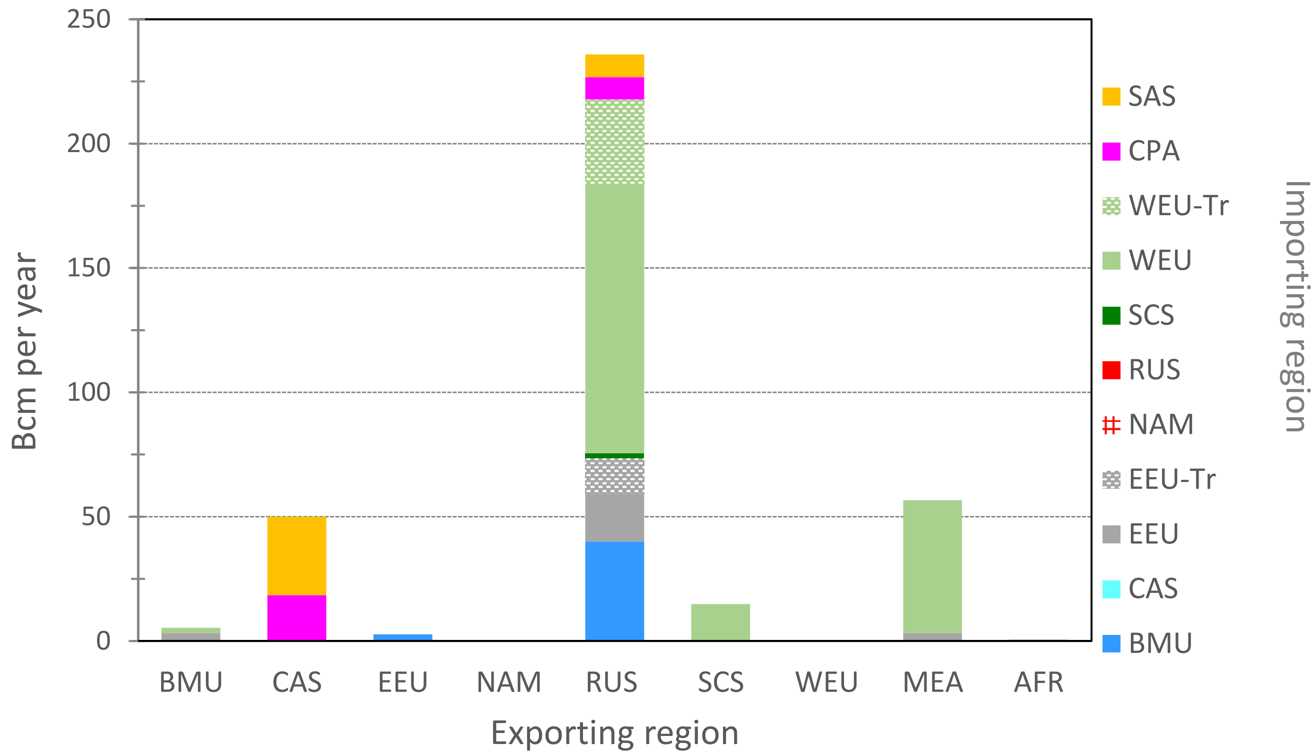
Modeling Results: UNECE

Gas Trade

ENERGY

Natural gas trade – REF Scenario: 2030

Destinations of gas trade involving ECE regions [bcm]



Exporters seek diversification (demand security) – China and South Asia gain importance as long-term gas markets

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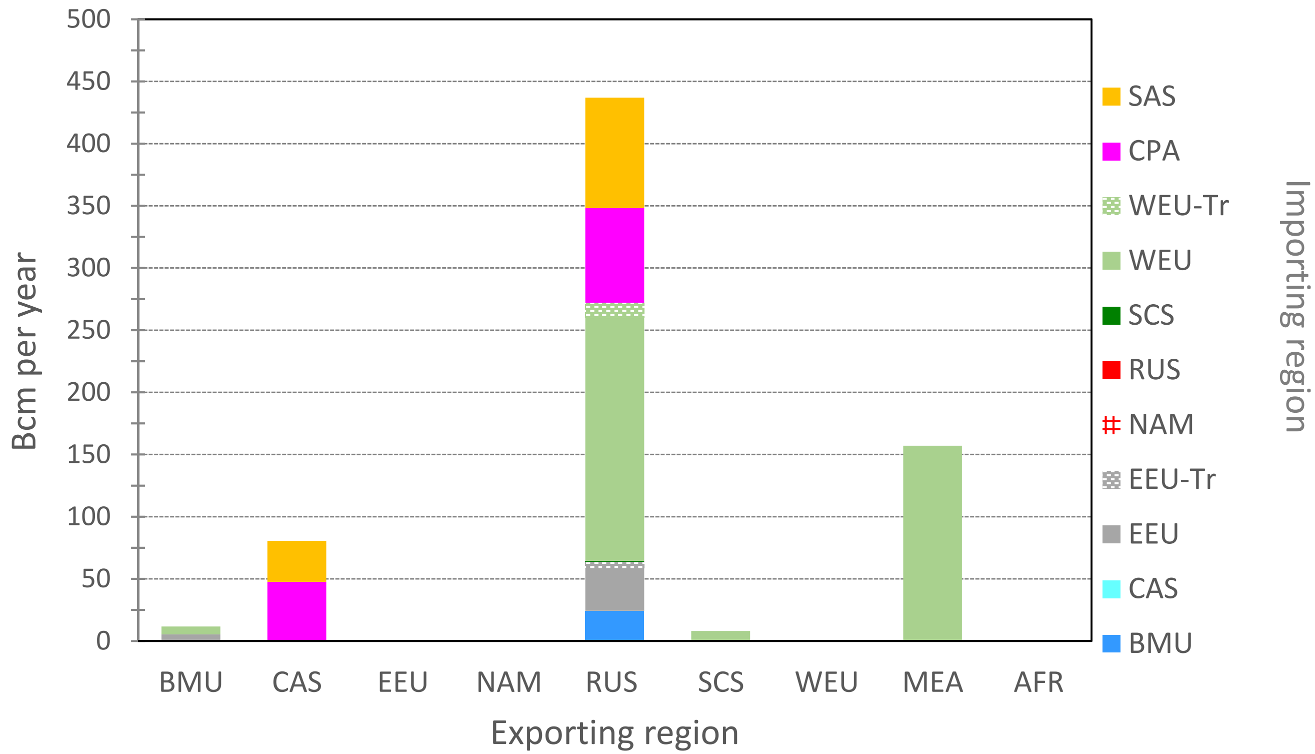
Modeling Results: UNECE

Gas Trade

ENERGY

Natural gas trade – REF Scenario: 2050

Destinations of gas trade involving ECE regions [bcm]



Russia's leading export role not only unchallenged but expanding.

Exports to ECE regions steadily supplement by gas sales to CPA (China) and SAS (India)

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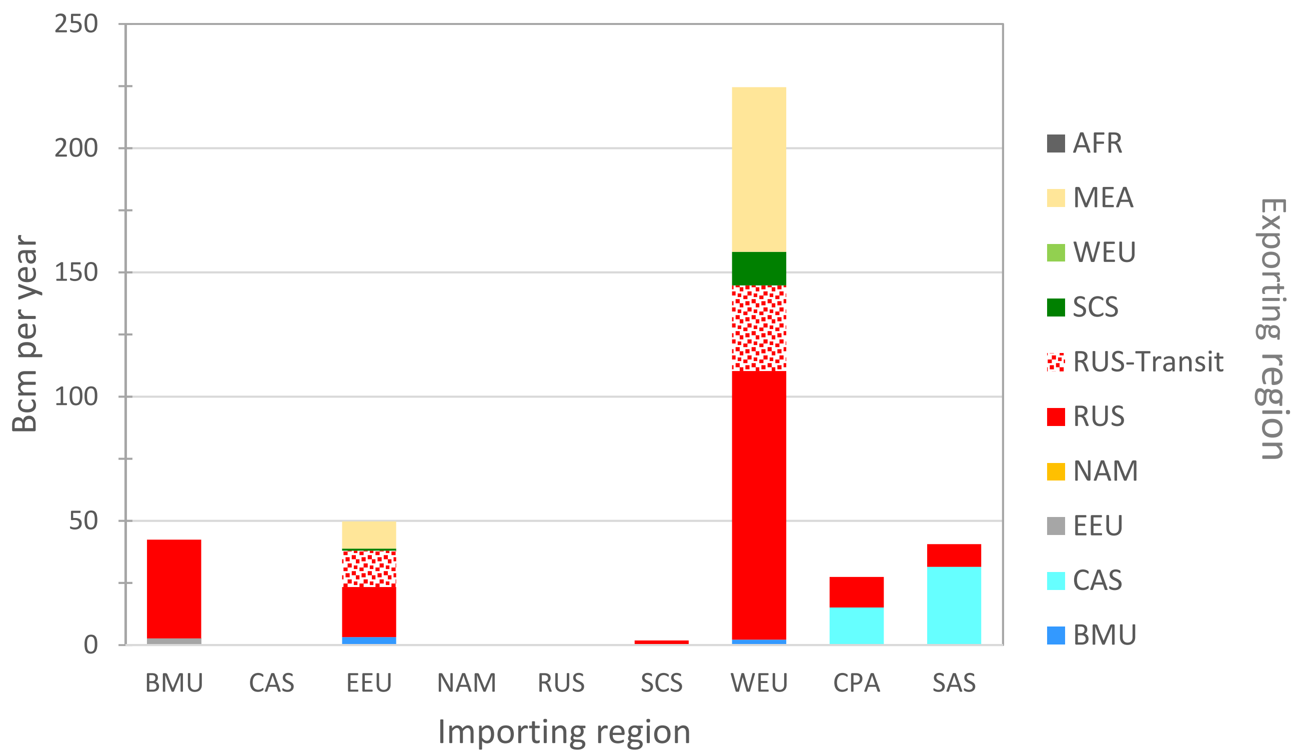
Modeling Results: UNECE

Gas Trade

ENERGY

Natural gas trade – NDC Scenario: 2030

Origins of gas trade involving ECE regions [bcm]



NDCs only marginally impact ECE's gas trade pattern

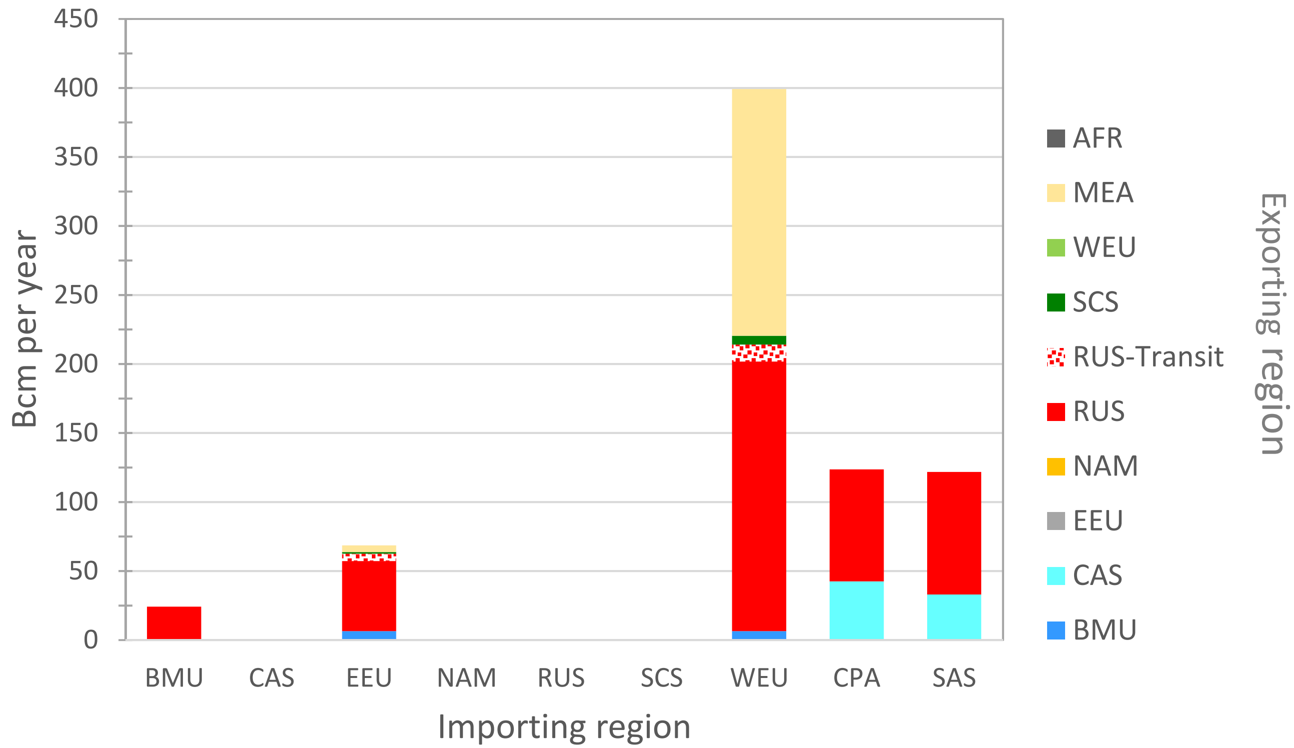
Modeling Results: UNECE

Gas Trade

ENERGY

Natural gas trade – NDC Scenario: 2050

Origins of gas trade involving ECE regions [bcm]



NDCs as modeled here lack ambition and thus dos not notably change gas trade pattern and volume (compared with REF)

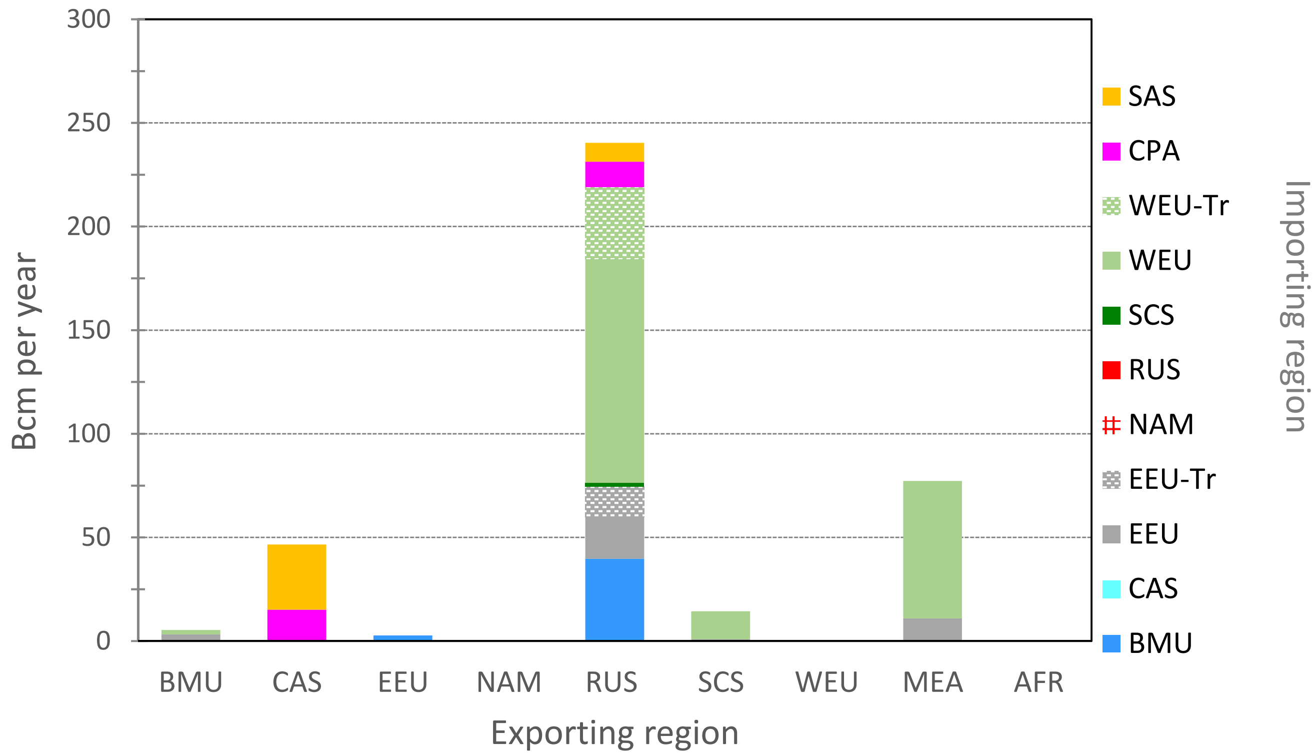
Modeling Results: UNECE

Gas Trade

ENERGY

Natural gas trade – NDC Scenario: 2030

Destinations of gas trade involving ECE regions [bcm]



Mirror image of the import situation – no

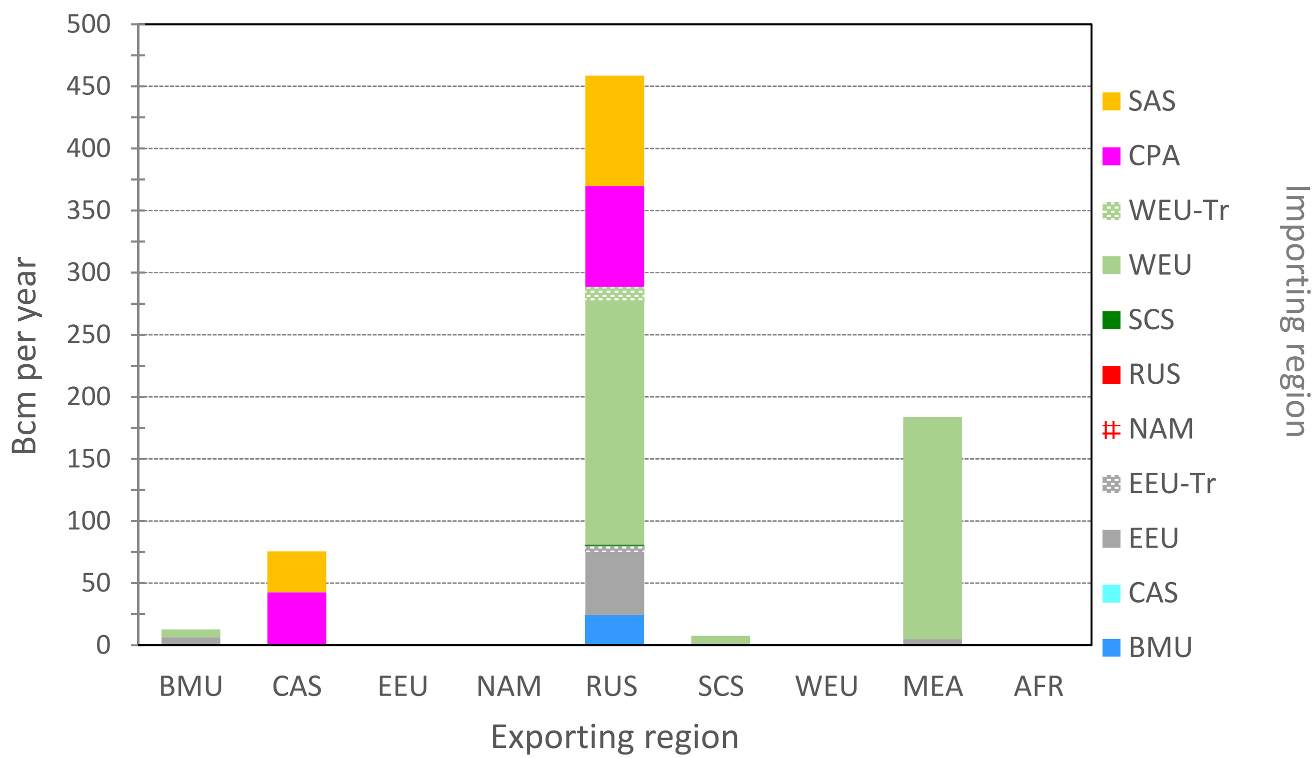
Modeling Results: UNECE

Gas Trade

ENERGY

Natural gas trade – NDC Scenario: 2050

Destinations of gas trade involving ECE regions [bcm]



Russia's leading export role not only unchallenged but expanding – higher dependence on European markets than in REF

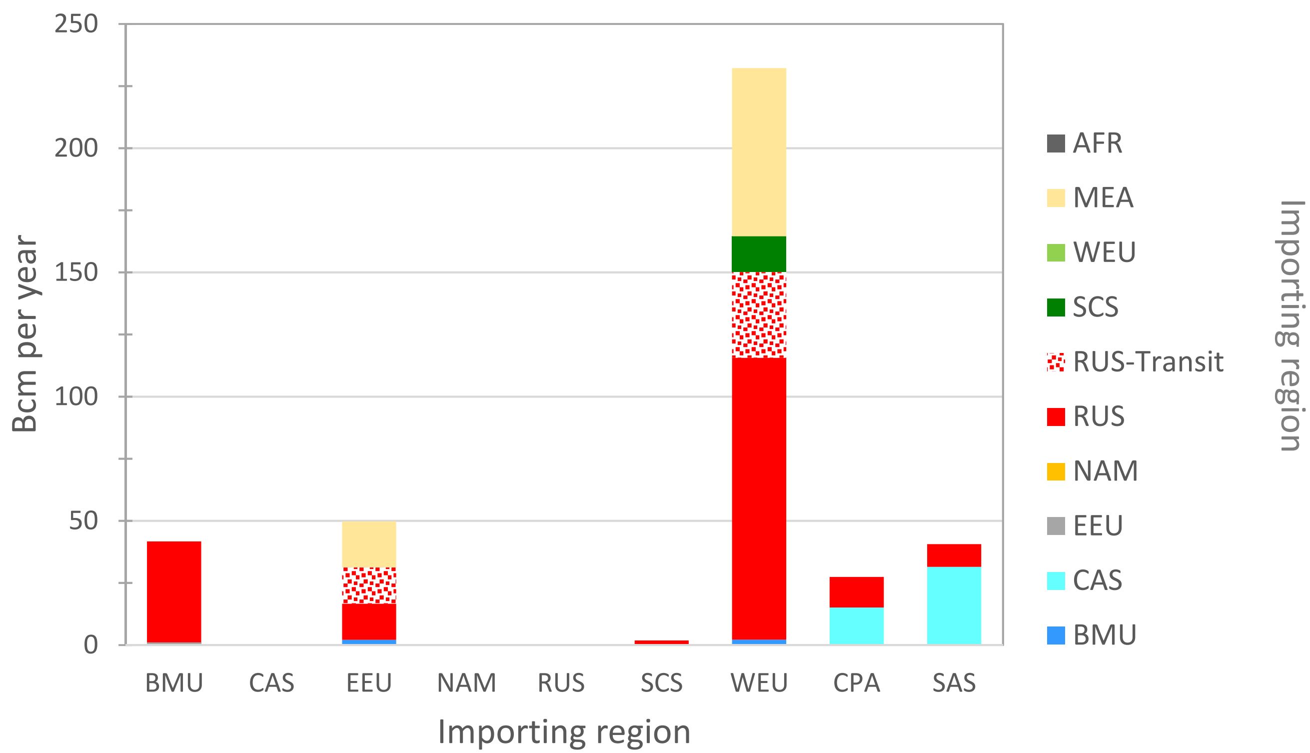
Modeling Results: UNECE

Gas Trade

ENERGY

Natural gas trade – NDC Scenario: 2050

Destinations of gas trade involving ECE regions [bcm]



Russia's leading export role not only unchallenged but expanding – higher dependence on European markets than in REF

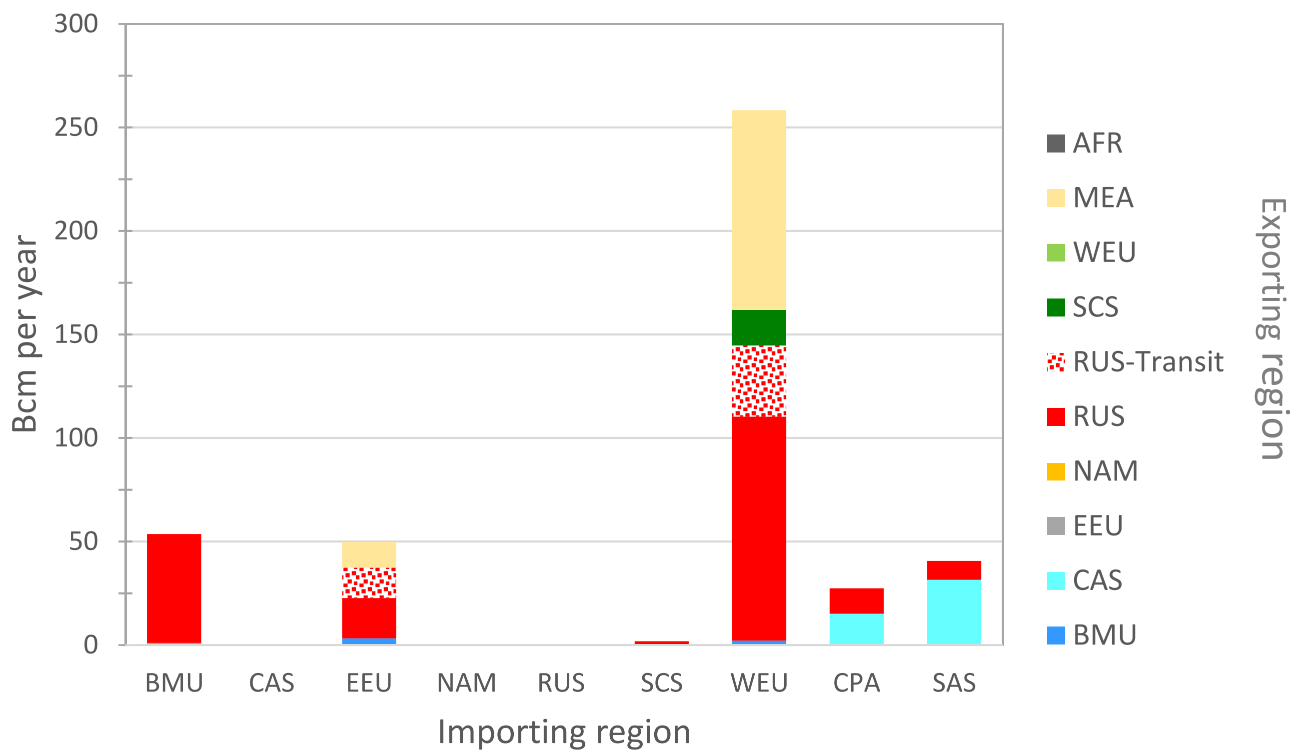
Modeling Results: UNECE

Gas Trade

ENERGY

Natural gas trade – P2C Scenario: 2030

Origins of gas trade involving ECE regions [bcm]



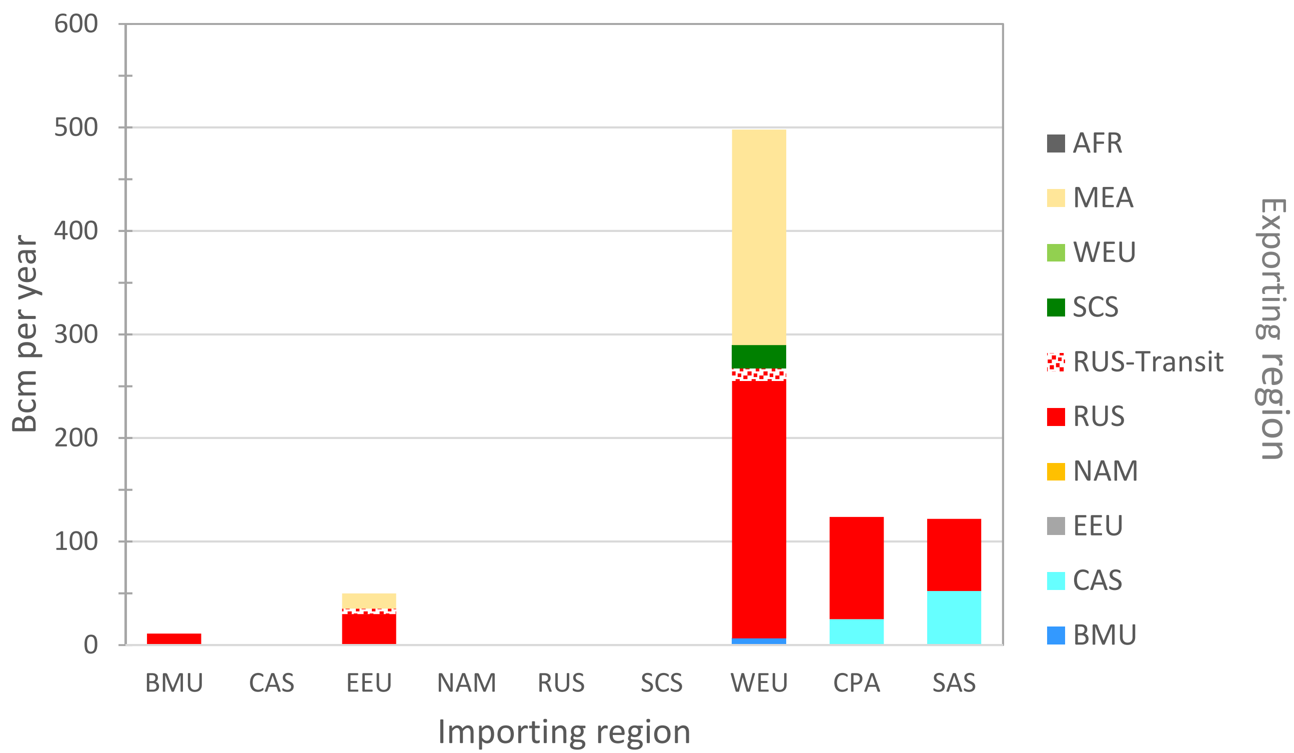
Total ECE gas imports up by 18% or 66 bcm versus REF

Largest export gains by MEA (74 bcm) and RUS (49 bcm)

Modeling Results: UNECE
Gas Trade

ENERGY

Naturals gas trade – P2C Scenario: 2050
Origins of gas trade involving ECE regions [bcm]



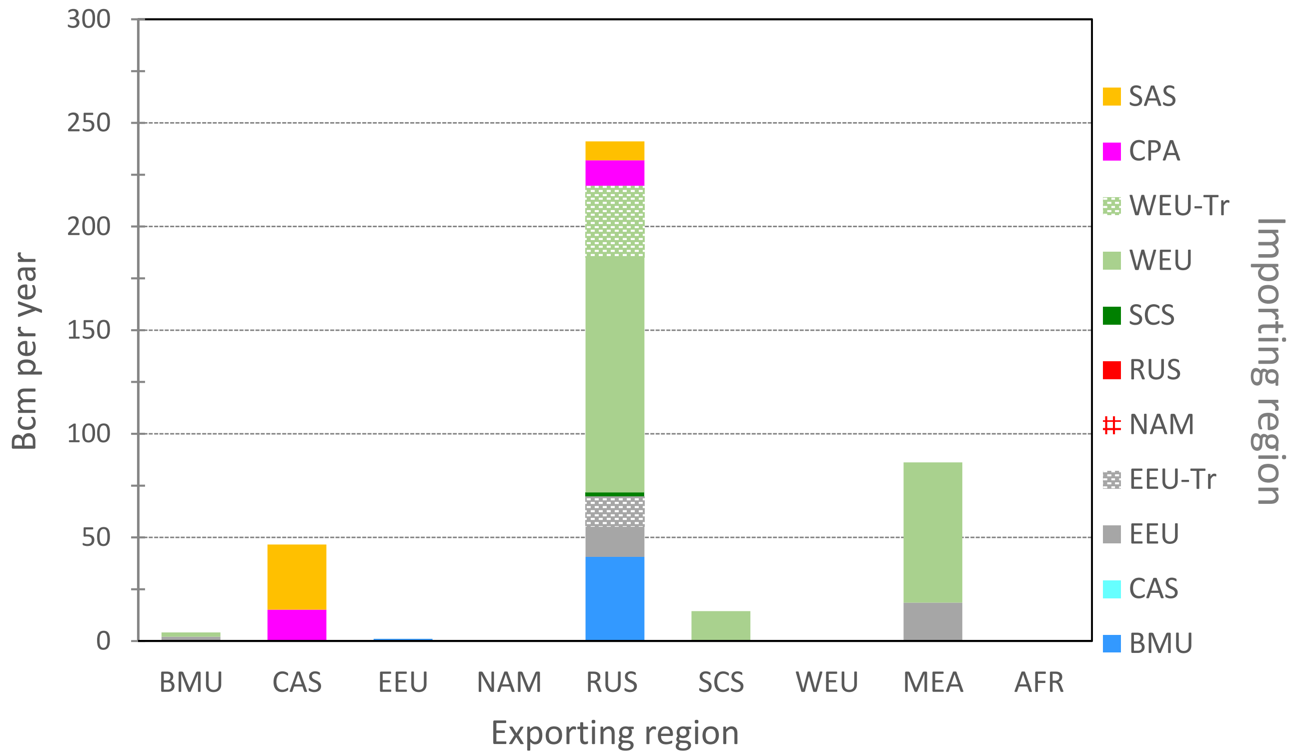
Total pipeline gas trade reaches 882 bcm of which 637 bcm are imports by the ECE

Based on the way gas resources of MEA are currently modeled and accessible by WEU and EEU, MEA takes on a lion’s share of the European import demand, while RUS ventures into CPA and CAS

Modeling Results: UNECE
Gas Trade

ENERGY

Natural gas trade – P2C Scenario: 2030
Destinations of gas trade involving ECE regions [bcm]



Exports mirror import pattern and volumes

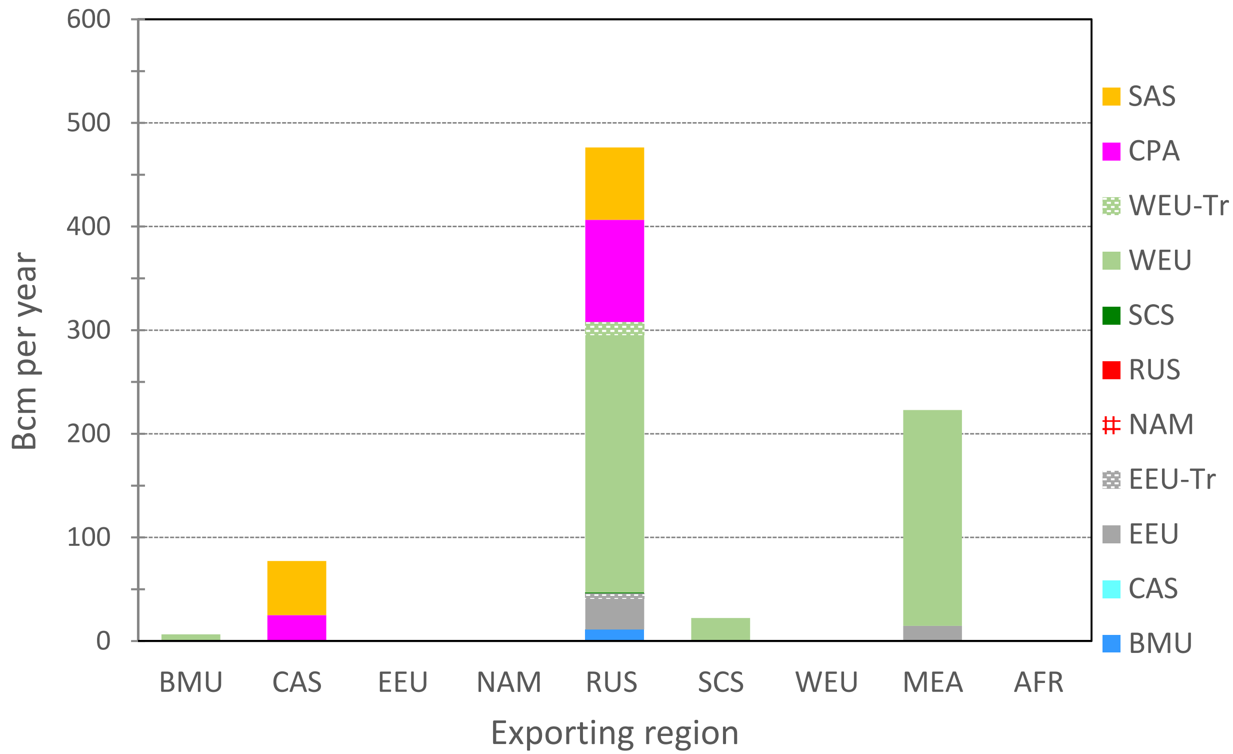
Modeling Results: UNECE

Gas Trade

ENERGY

Natural gas trade – P2C Scenario: 2050

Destinations of gas trade involving ECE regions [bcm]



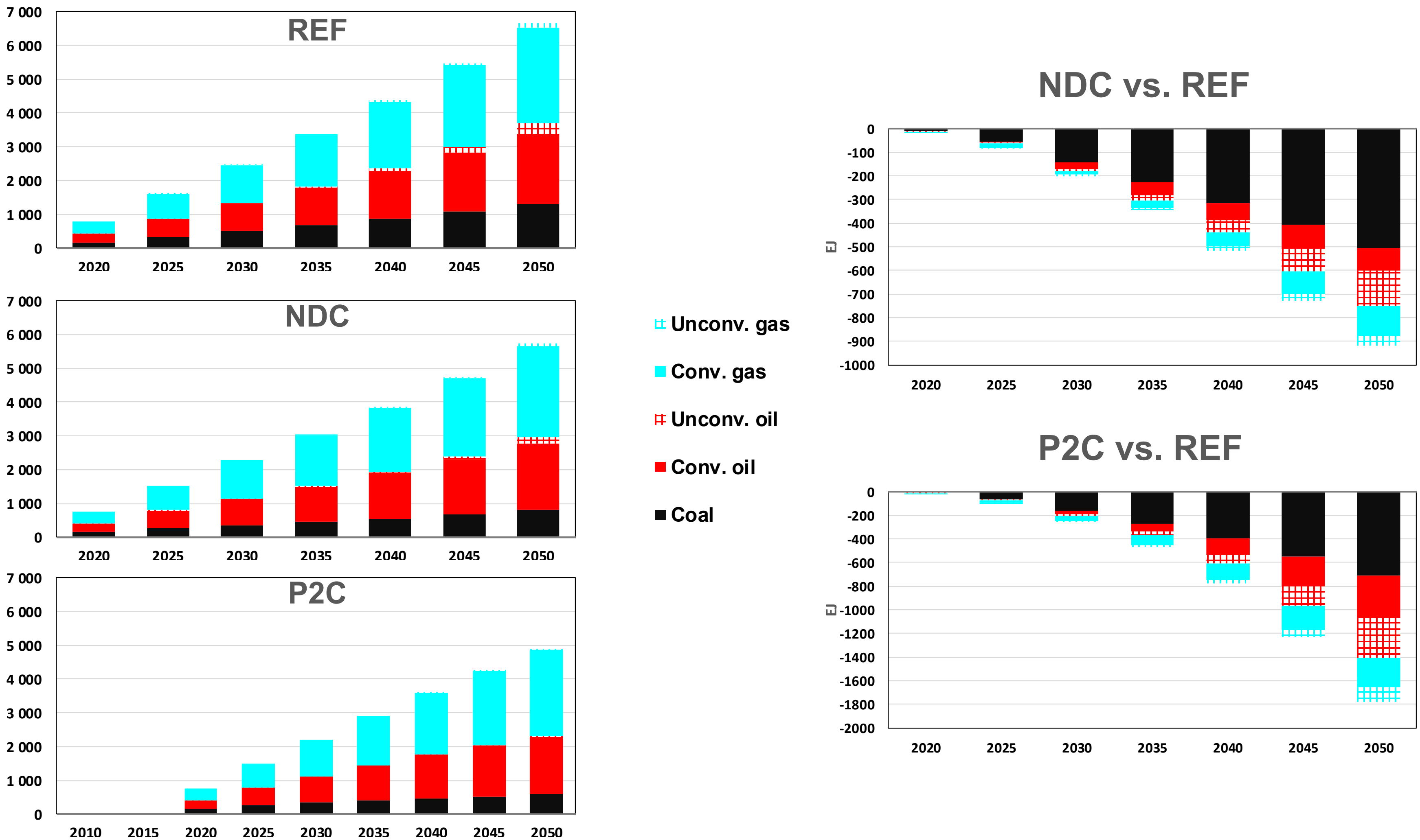
Modeling Results: Indicators

Resource extraction: ECE

ENERGY

Cumulative fossil fossil resource extraction

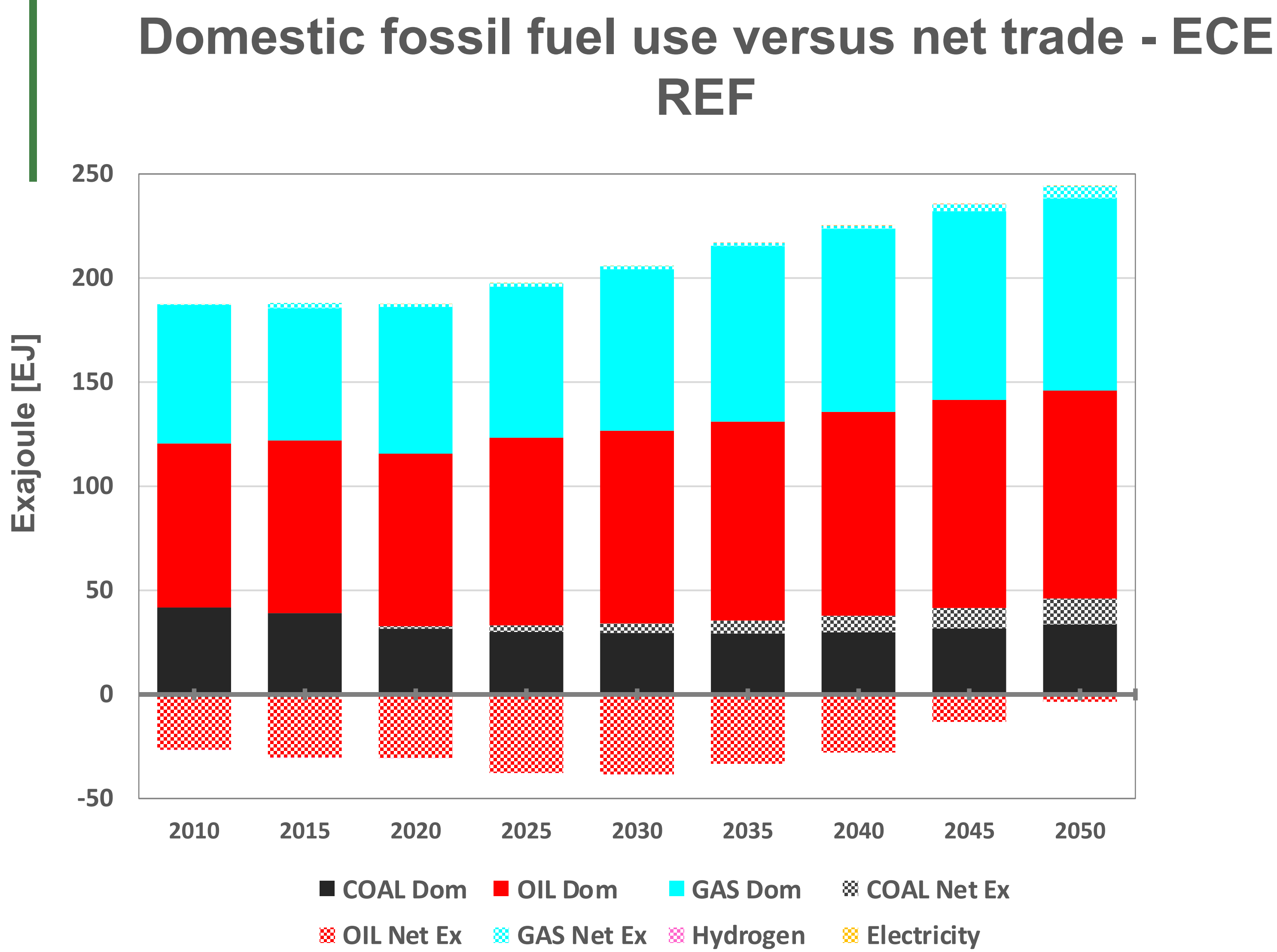
Difference in cumulative fossil resource extraction 2020 to 2050



Modeling Results: Indicators

Domestic use versus trade: ECE

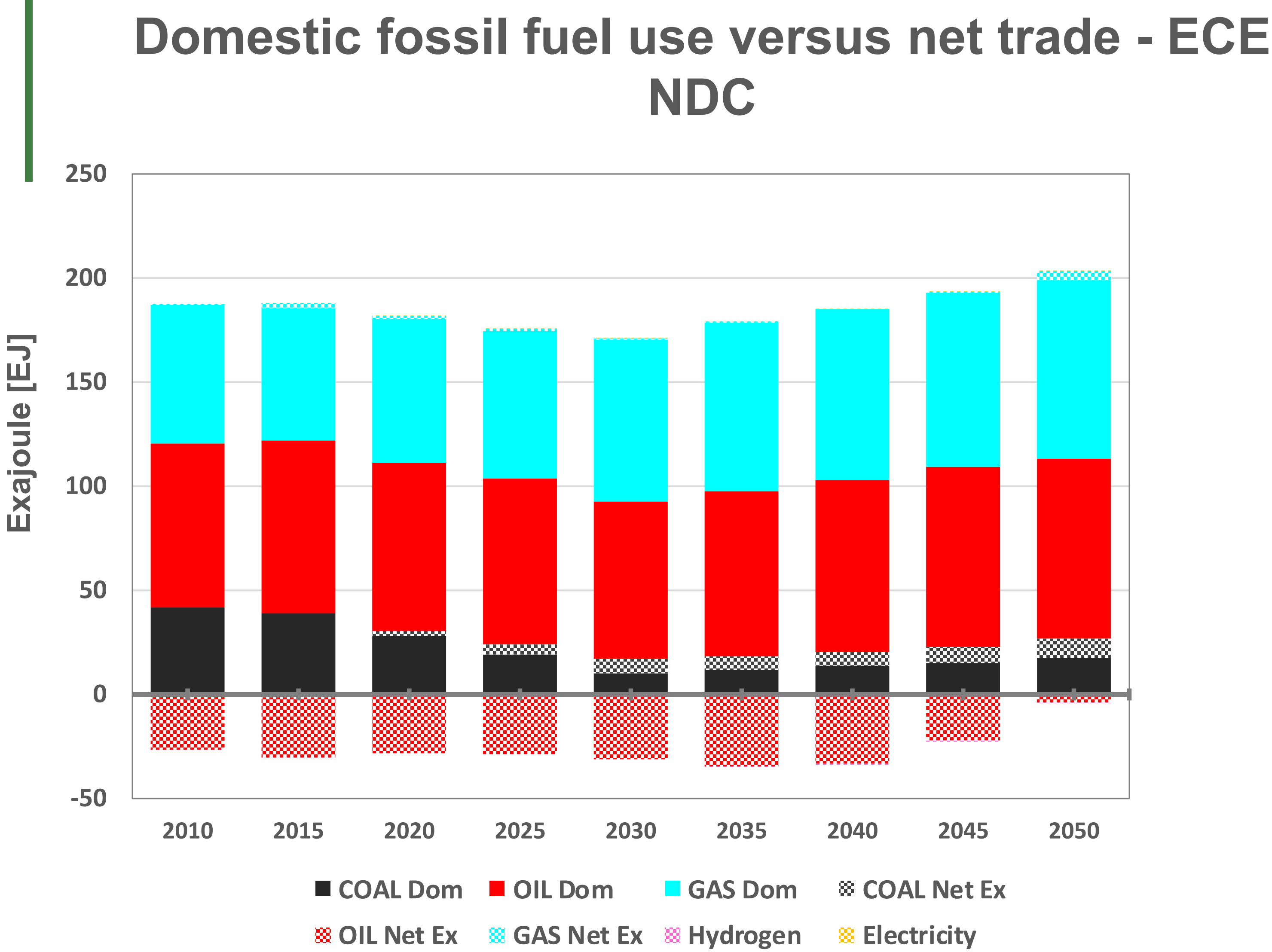
ENERGY



Modeling Results: Indicators

Domestic use versus trade: ECE

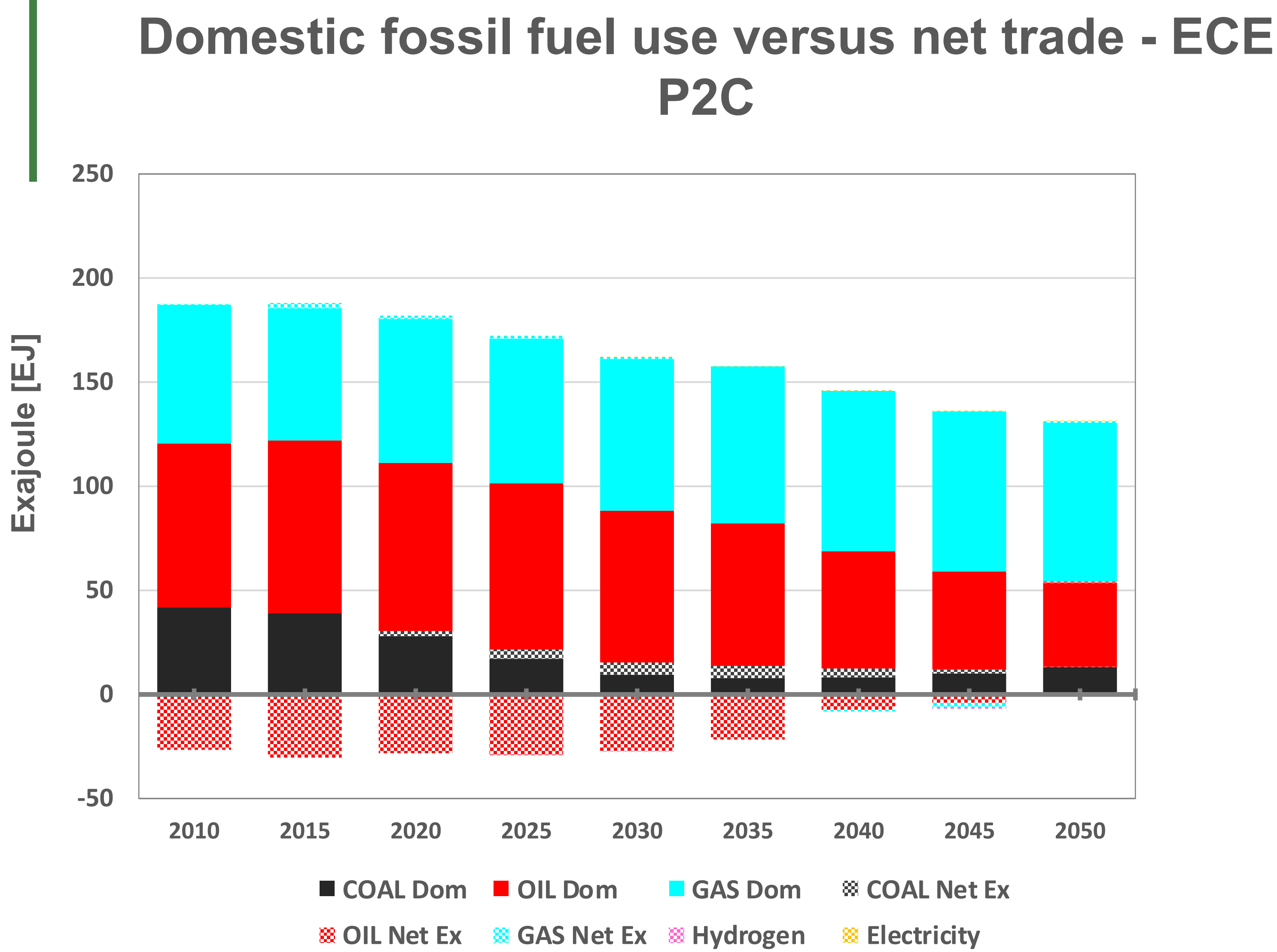
ENERGY



Modeling Results: Indicators

Domestic use versus trade: ECE

ENERGY



Models

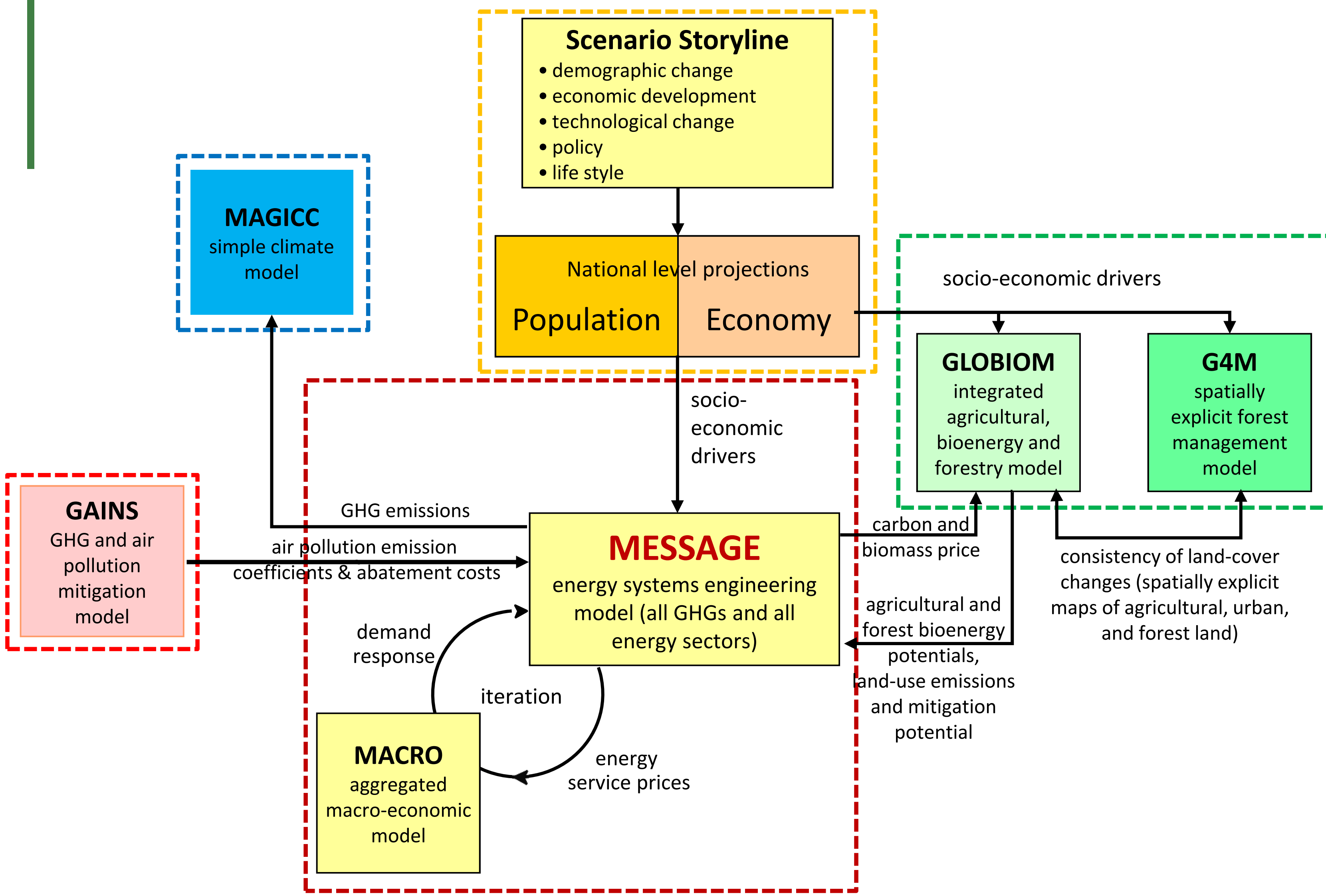
Why and what for?

- Models are simplified mathematical representations of real world relationships, calibrated with historical data
- Simplifications include but are nor limited to geographical detail, boundaries (what is included and what is not), economic sector representations, technology and resource resolution (levels of aggregation), temporal scope,…….
- Equations set operational rules reflecting real energy system interactions and flows
- Assumptions required to parameterize models
  - Future rates of technological development
  - Socioeconomics
  - Policy changes
- The model solves the mathematical relationships (equations, dependencies, policies, etc.), given the input assumptions
- Scenarios are internally consistent images of the future
- Policies can be defined through changes to model assumptions ***or*** specific policy goals (normative objectives)
- Models do not make decisions - they are tools to inform decision makers on different implications of different policy options or 'what – if' questions

Model Overview

IIASA Integrated Assessment Framework

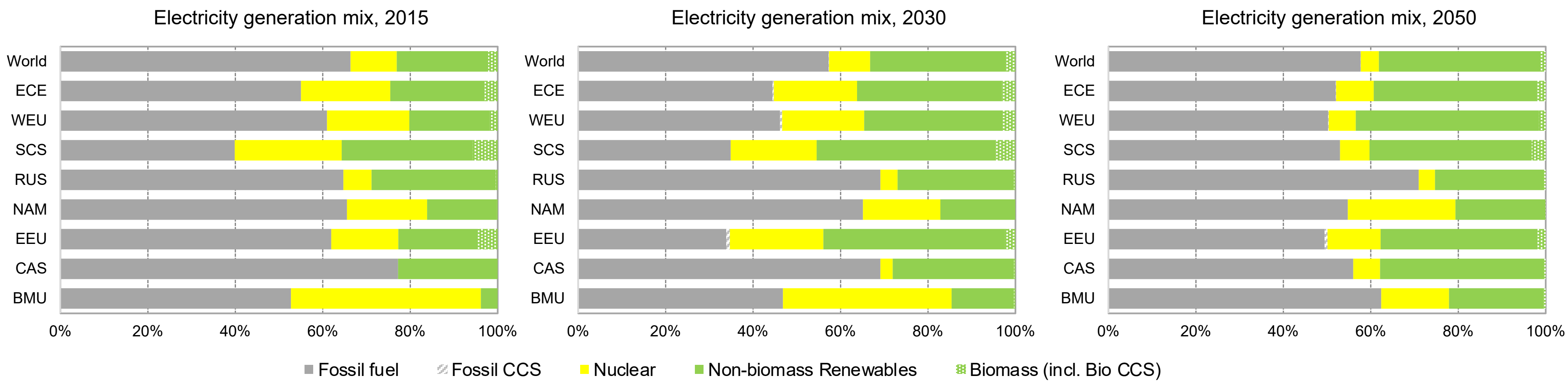
ENERGY



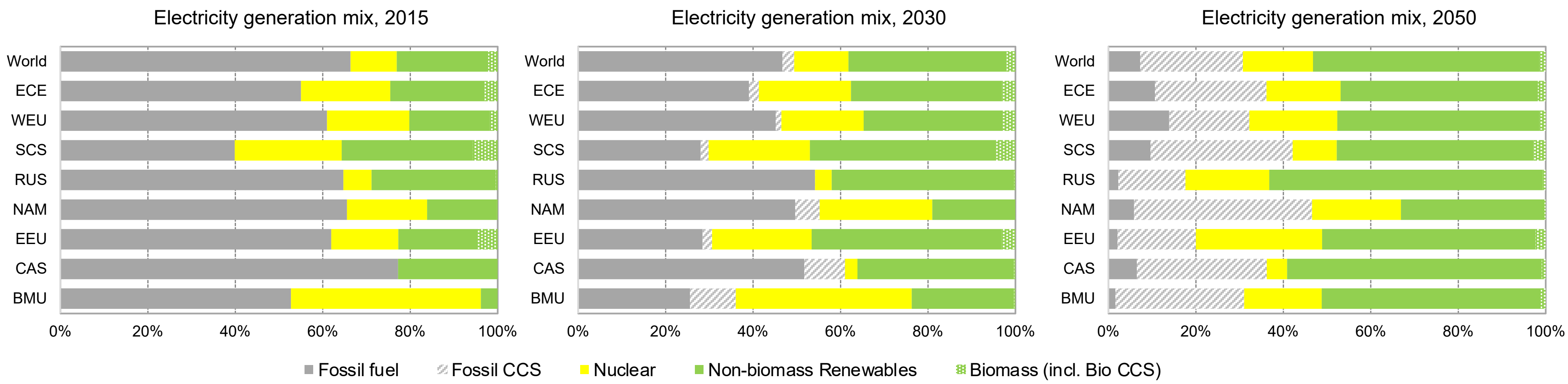
Graphic courtesy of Volker Krey (IIASA)

Modeling Results:

Shares of low carbon technologies – NDC Scenario



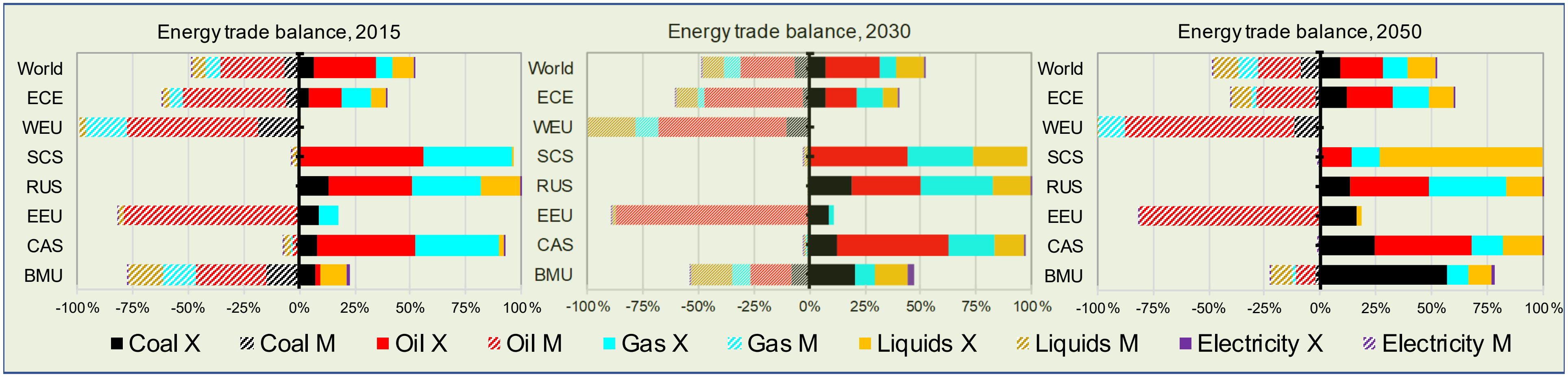
Modeling Results:
Shares of low carbon technologies versus unabated fossil fuel use – P2C Scenario



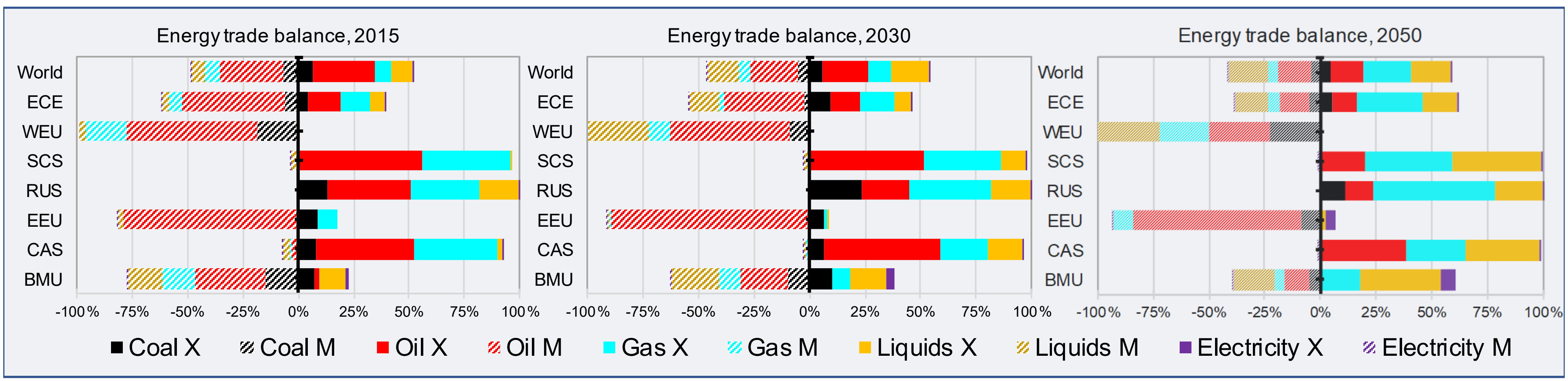
Modeling Results: Energy trade* by region

ENERGY

P2C Scenario



P2C Scenario

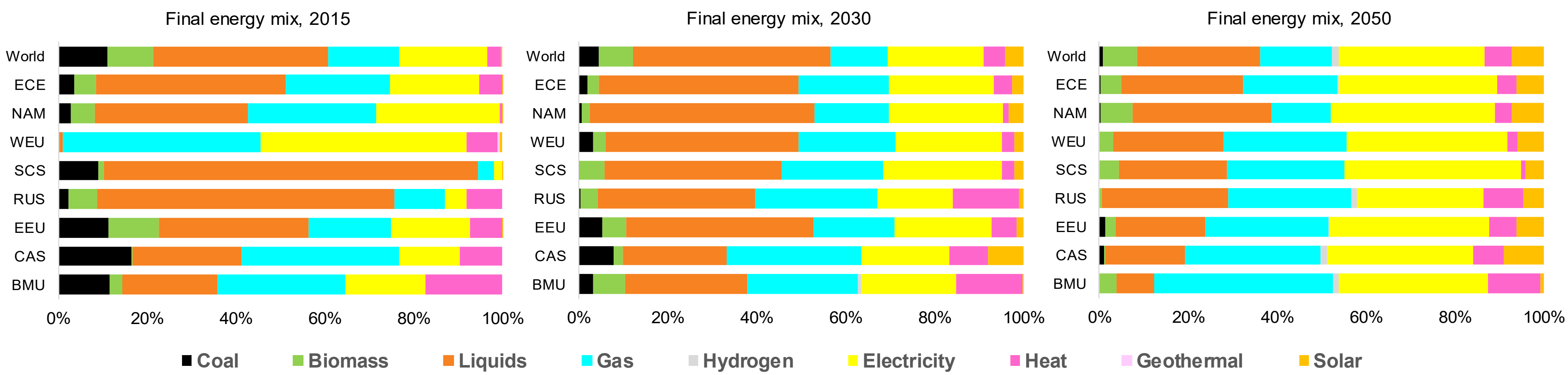


* Panels show the percentage of a region’s energy imports and exports (by fuel) in relation to the region’s total energy trade volume in physical units

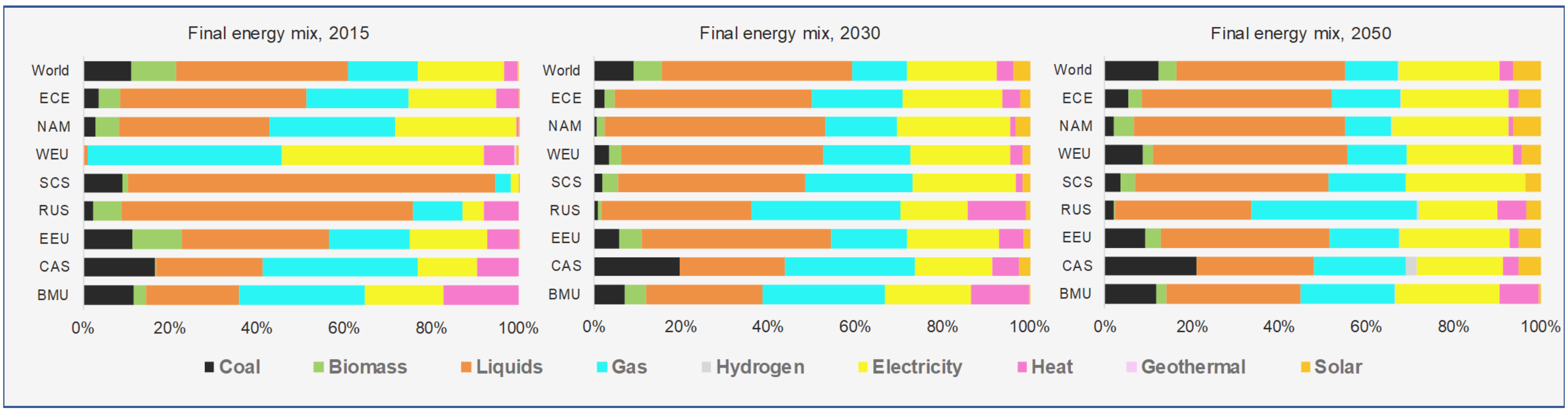
Modeling Results: Final energy transformation

ENERGY

P2C scenario



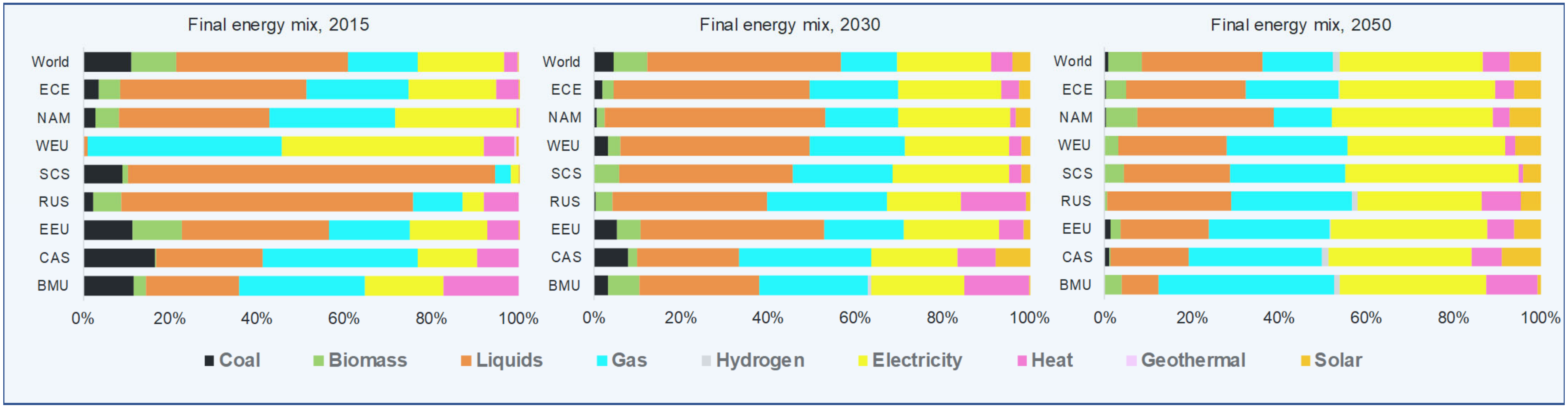
NDC scenario



Modeling Results: Final energy transformation

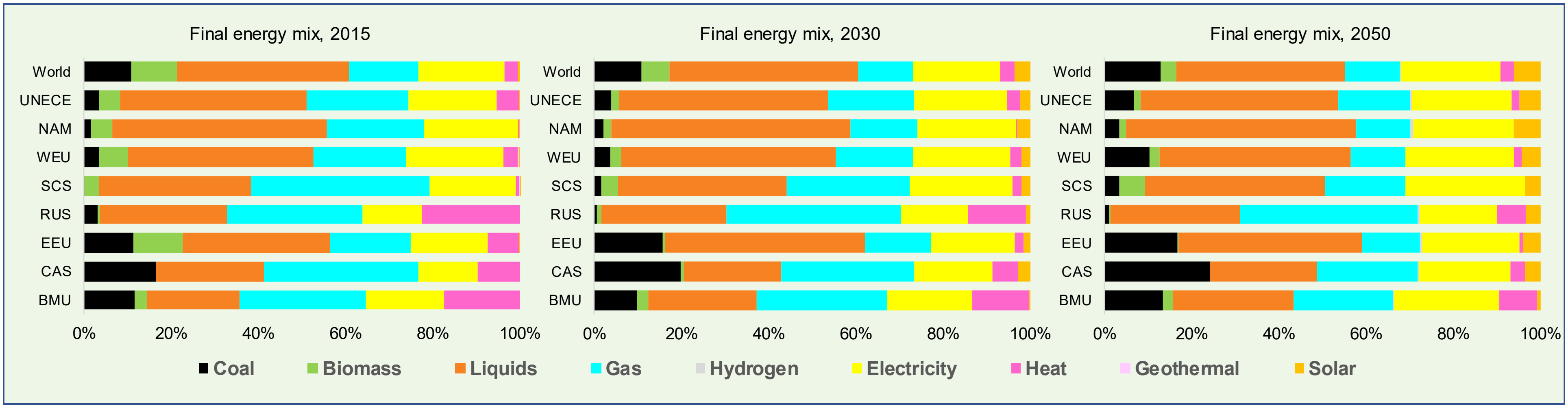
ENERGY

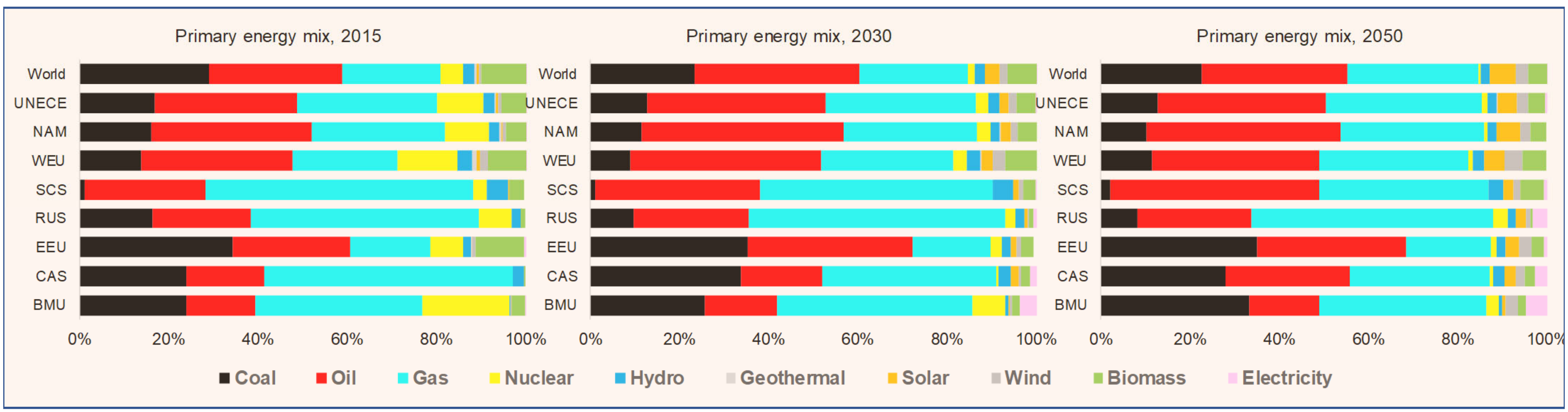
P2C scenario



Modeling Results:

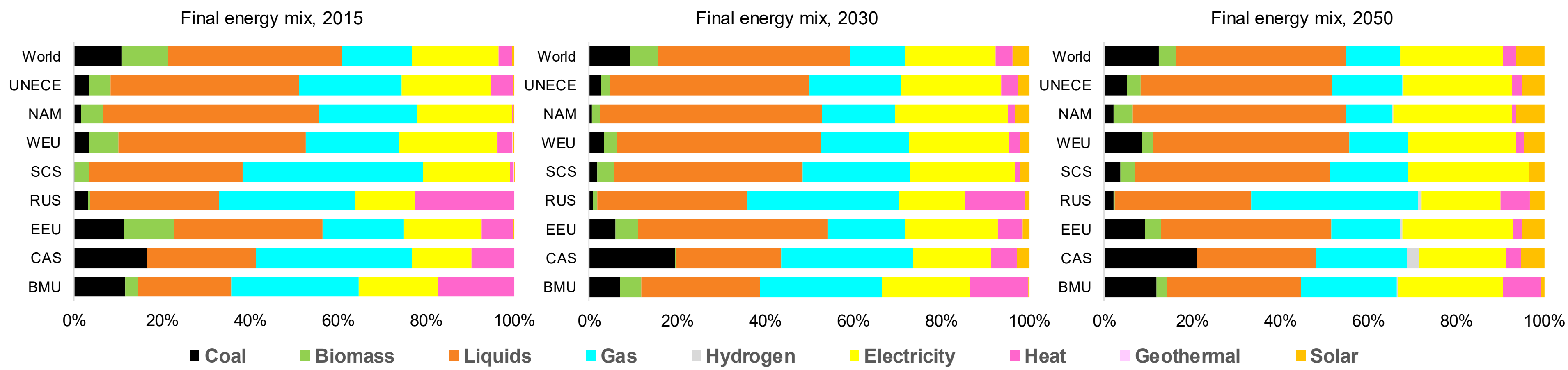
Final and primary energy: Transformation – REF Scenario

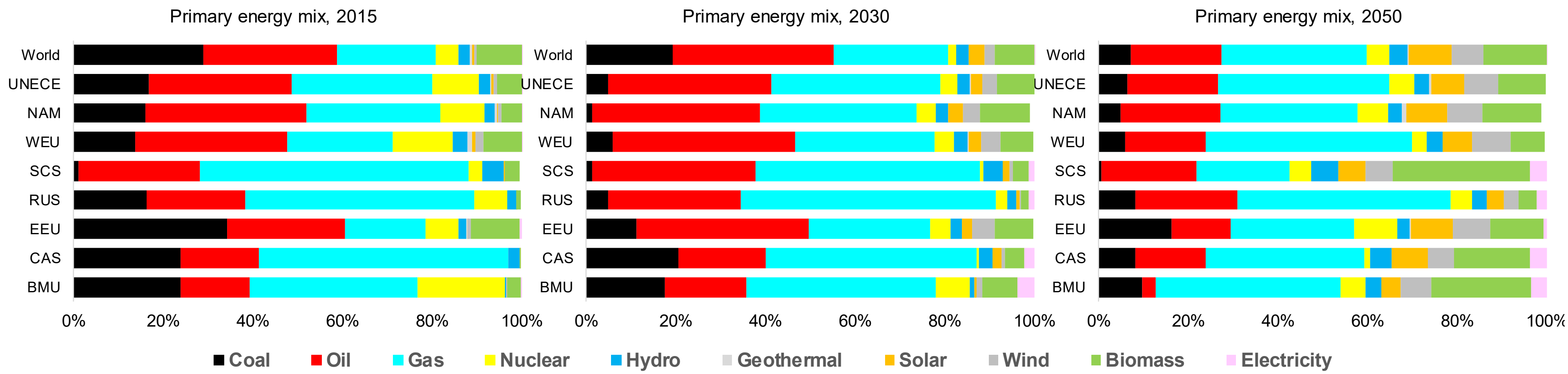




Modeling Results:

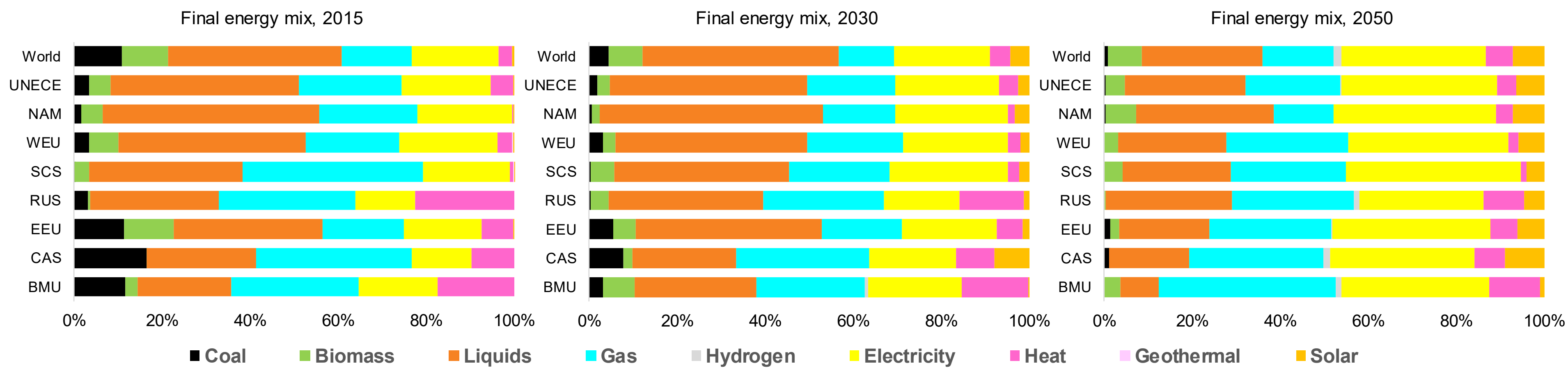
Final and primary energy: Transformation – NDC Scenario

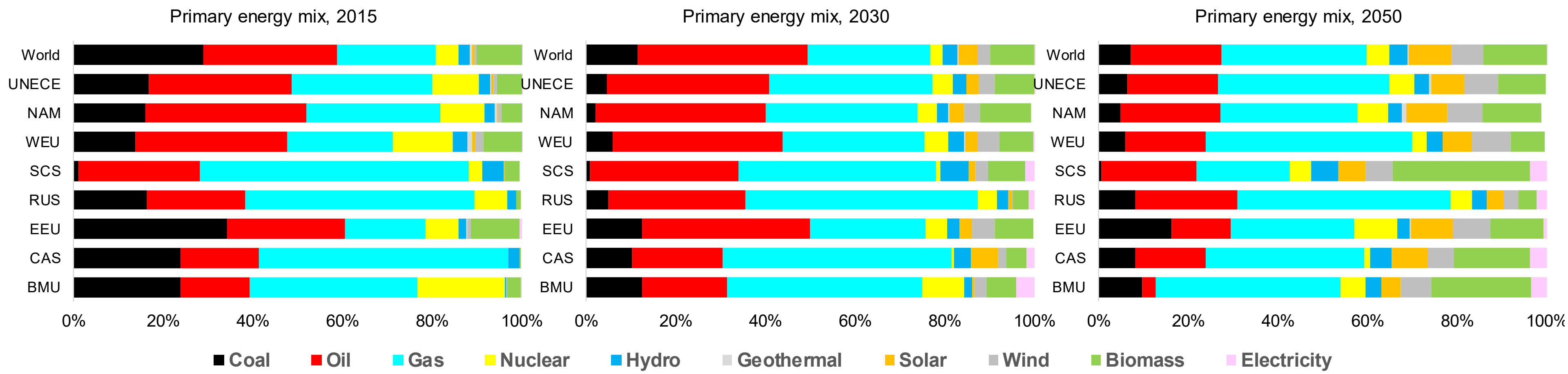




Modeling Results:

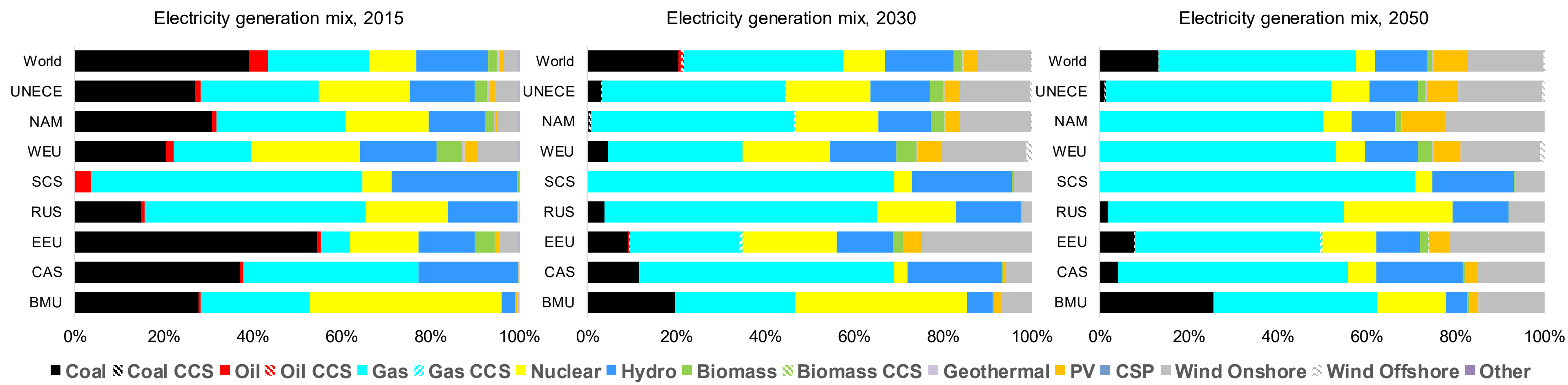
Final and primary energy: Transformation – P2C Scenario

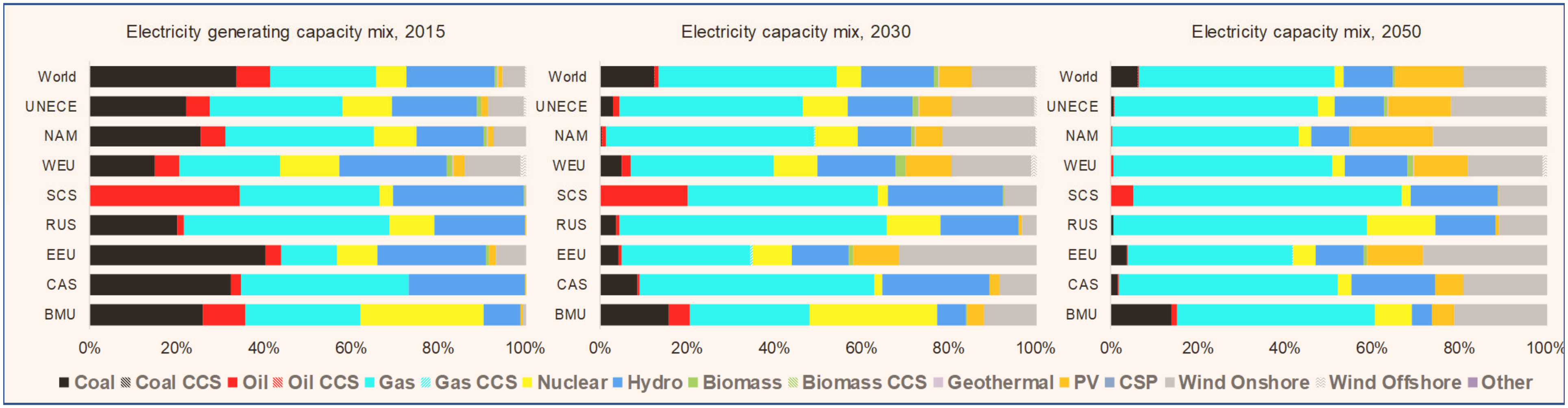




Modeling Results:

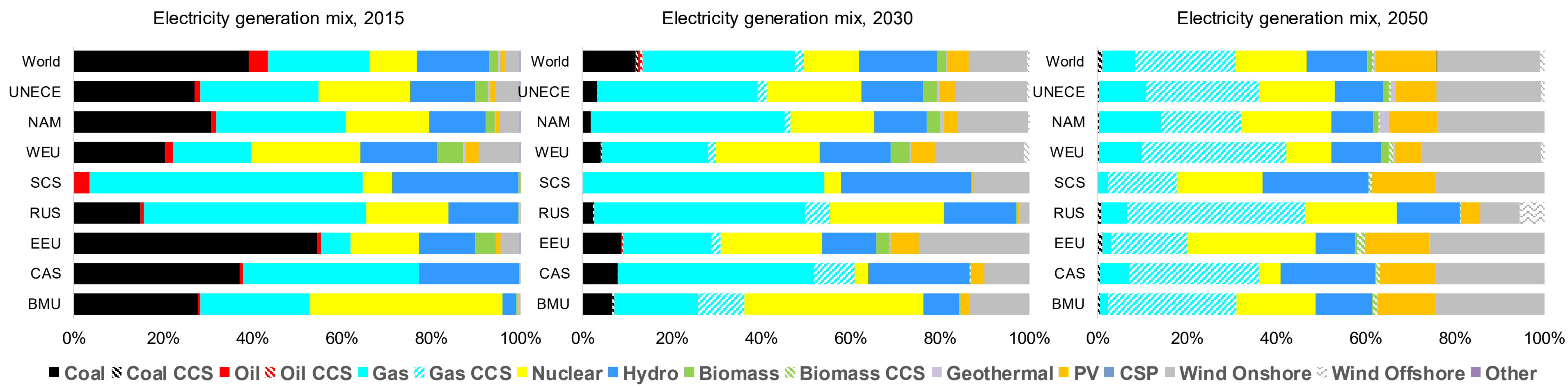
Electricity: Transformation – NDC Scenario

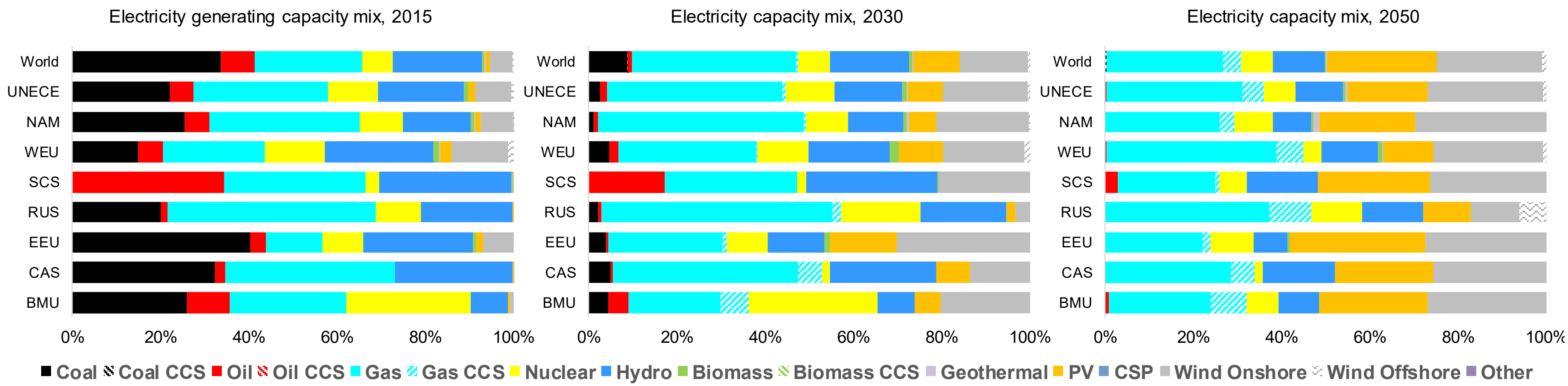




Modeling Results:

Electricity: Transformation – P2C Scenario





Coal Oil Gas Nuclear Hydro Geothermal Solar Wind Biomass Electricity

Coal Biomass Liquids Gas Hydrogen Electricity Heat Geothermal Solar

Coal Coal CCS Oil Oil CCS Gas Gas CCS Nuclear Hydro
Biomass Biomass CCS Geothermal PV CSP Wind Onshore Wind Offshore Other

Coal Coal CCS Oil Oil CCS Gas Gas CCS Nuclear Hydro
Biomass Biomass CCS Geothermal PV CSP Wind Onshore Wind Offshore Other

Coal Coal CCS Oil Oil CCS Gas Gas CCS Nuclear Hydro Biomass Biomass CCS Geothermal PV CSP Wind Onshore Wind Offshore Other

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

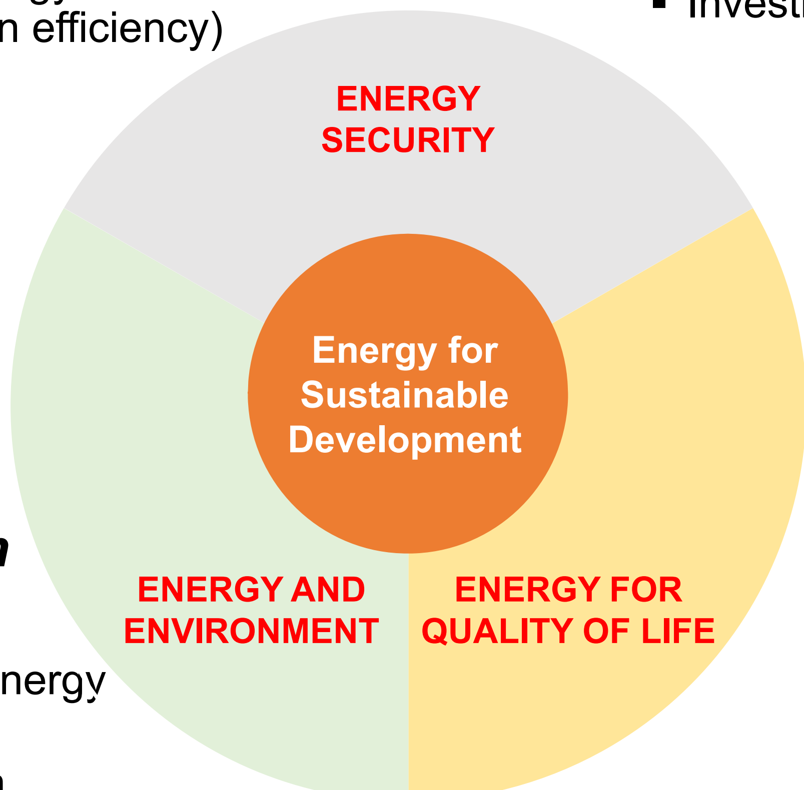
Pathways Project and Sustainable Energy

Reminder: Three Pillars

ENERGY

“Secure the energy needed for economic development”

- Energy Efficiency (energy intensity of economy, rate of improvement of energy intensity, conversion efficiency)
- Fuel mix
- Net energy trade
- Investment requirements



“Minimize adverse energy system impacts on climate, ecosystems & human health”

- GHG emissions from the energy system
- Energy-related air pollution, water use & water stress

“Provide affordable energy that is available for all at all times”

- Access to energy services
- Energy affordability
- Food security (biomass use)