IAM in National Decarbonization Pathways

PLCY-798K

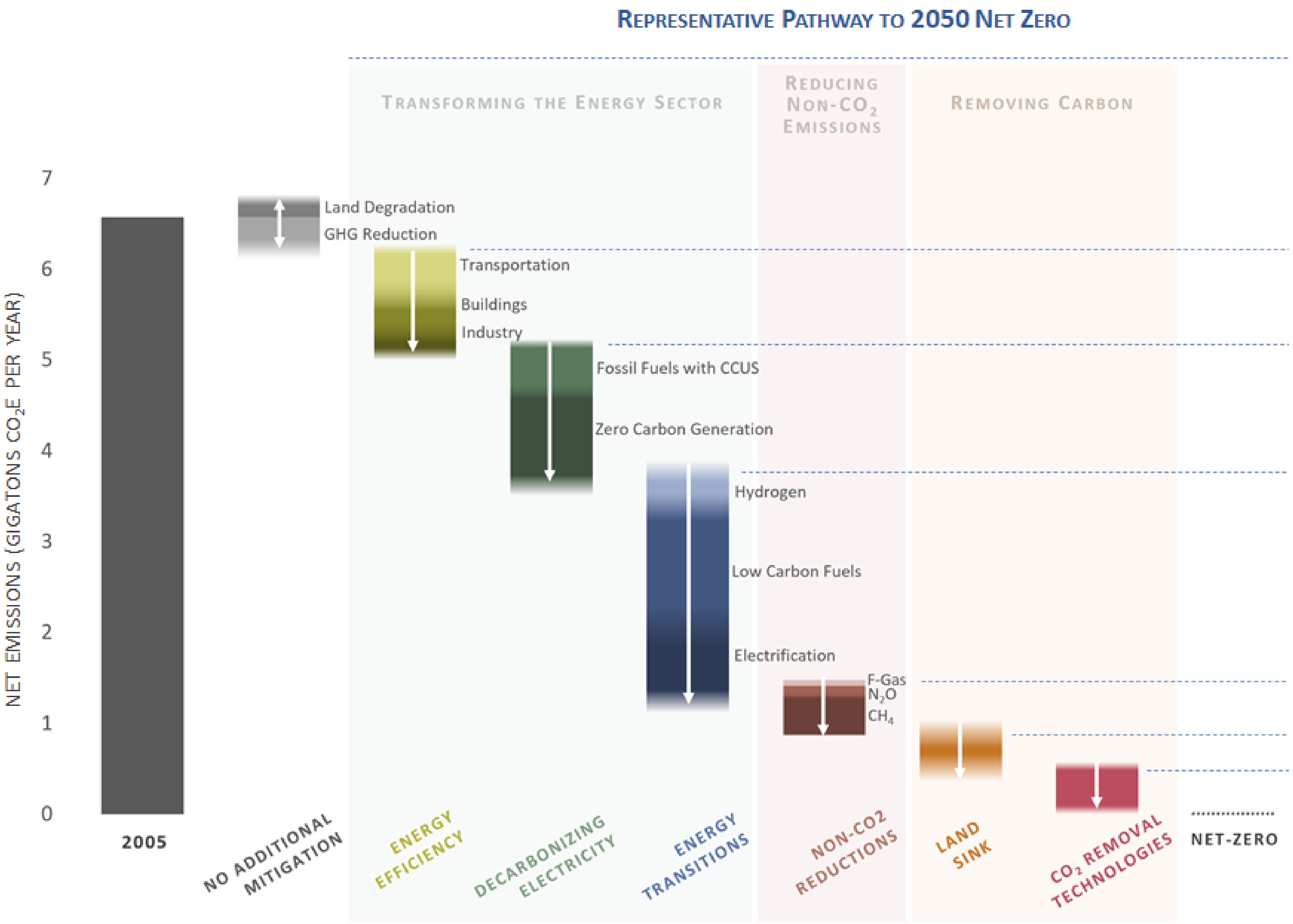
Integrated Human-Earth System Modeling and Policy Assessment

April 1, 2023

Key questions being asked in national contexts

- Research/policy questions
    - Deep decarbonization pathways
    - Sectoral specific transitions to a low-carbon energy system
    - Impacts of specific policies
    - Societal implications
        - Air quality/health
        - Employment, just transition
        - Economic growth, etc.
    - Climate change impacts
- Stakeholders
    - Governments: policy and science offices
    - Business
    - NGOs
    - How to inform decision making
- Tools: different tools / combinations of tools can be applied depending on research question

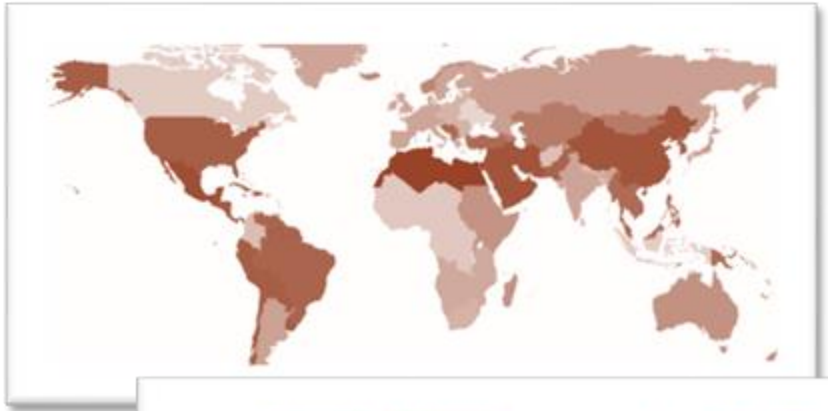
The U.S. Long-Term Strategy



Global Change Analysis Model

Model Coverage

32 Energy & Economy Regions



384 Land Regions

235 Water Basins

- GCAM is a **global hierarchical equilibrium integrated assessment model**
- GCAM links **Economic**, **Energy**, **Land-use**, **Water**, and **Climate** systems in a technology-rich model
- Runs to **2100** in **5-year time-steps**
- Emissions of 16 greenhouse gases (GHG) and air pollutants are tracked
- GCAM is natively coupled to a simple climate model HECTOR, but can also be coupled to Energy Exascale Earth System Model (E3SM)
- GCAM is a community model, download link and documentation available at:
  http://jgcri.github.io/gcam-doc/toc.html
- GCAM is primarily developed with support from Office of Science, but has wide reaching applications in policy, science, and philanthropies

Global Change Analysis Model

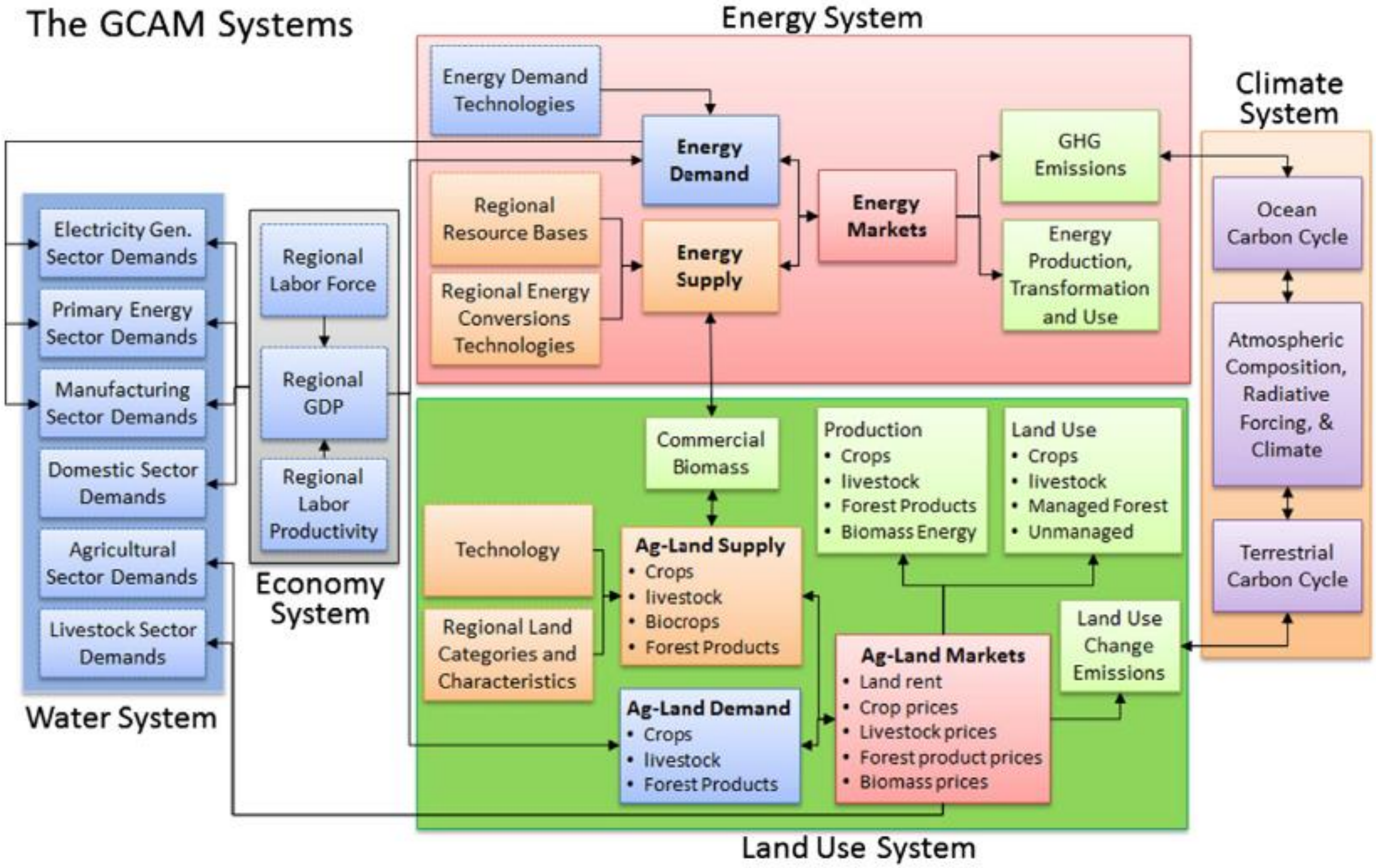


Image source: Hejazi, M. et al. Long-term global water projections using six socioeconomic scenarios in an integrated assessment modeling framework. Technol. Forecast. Soc. Change 81, 205–226 (2014).

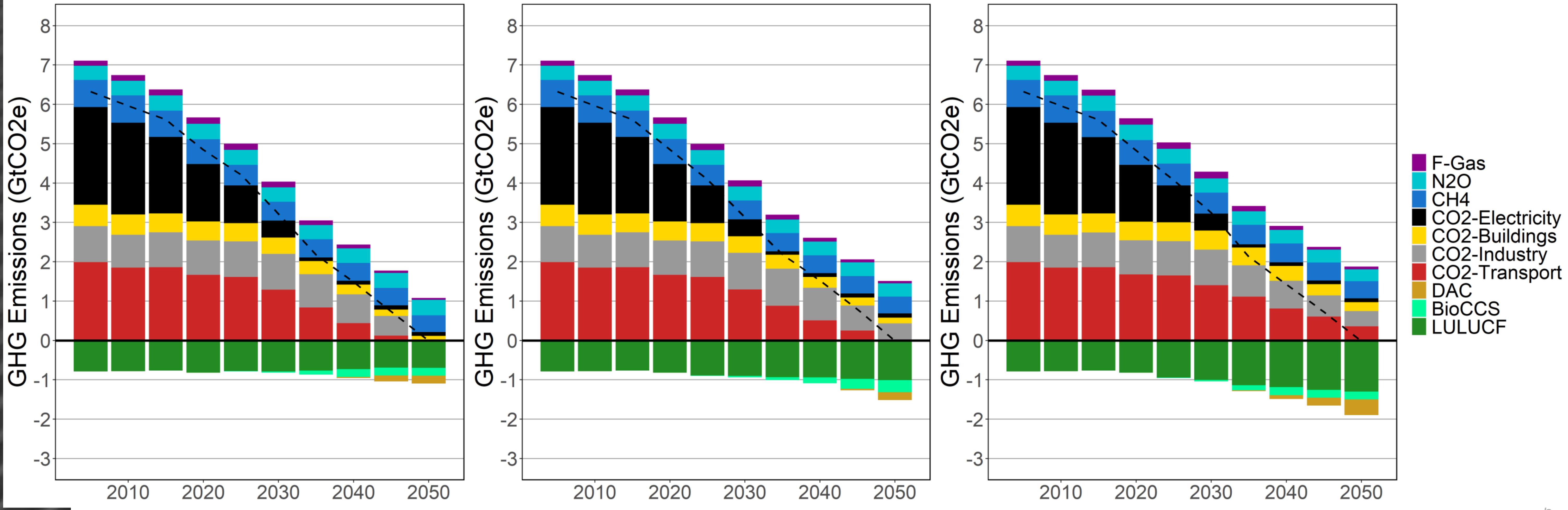
GHG Emissions

Low CDR

Med CDR

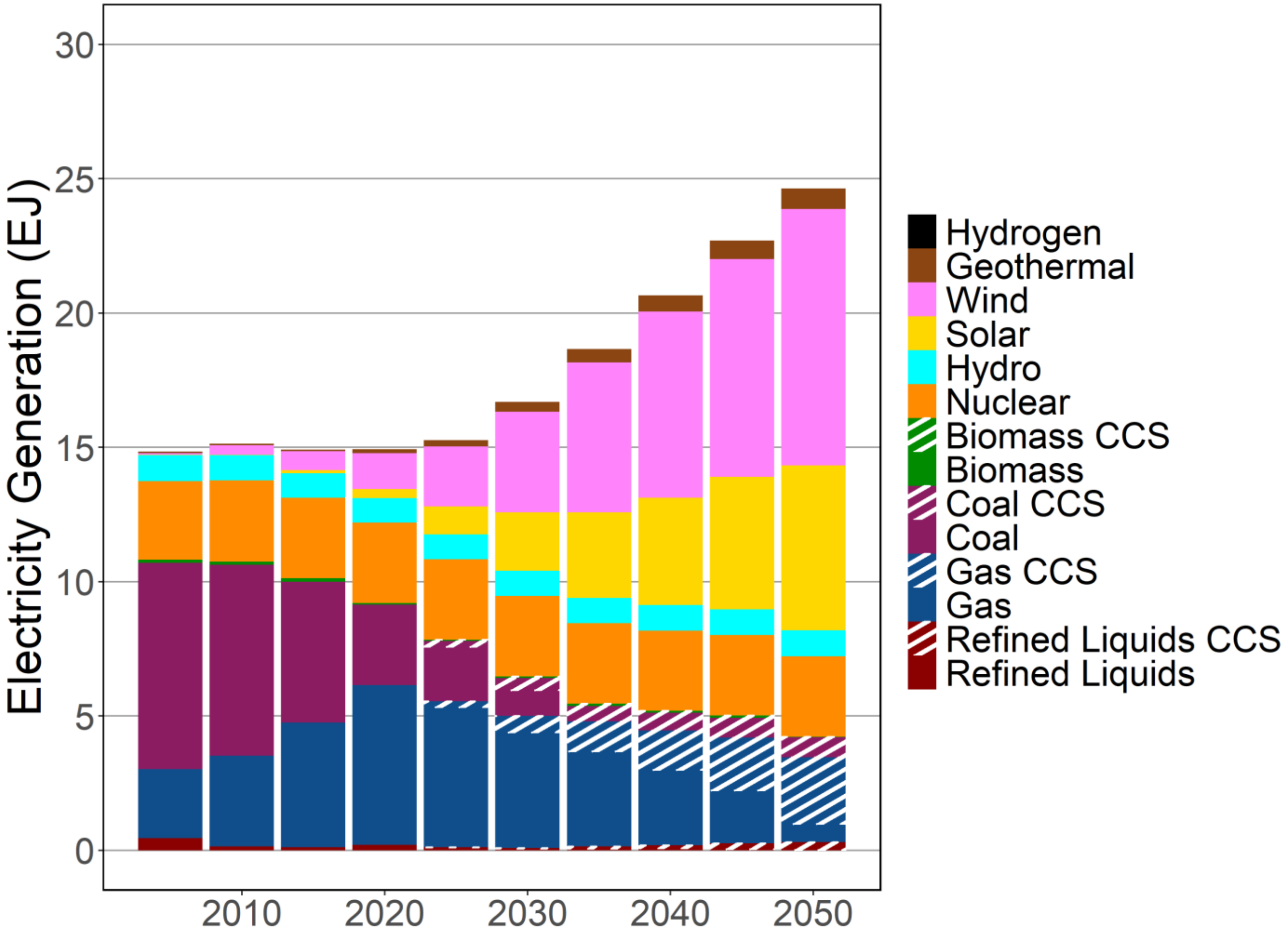
High CDR

+ High Energy Demand

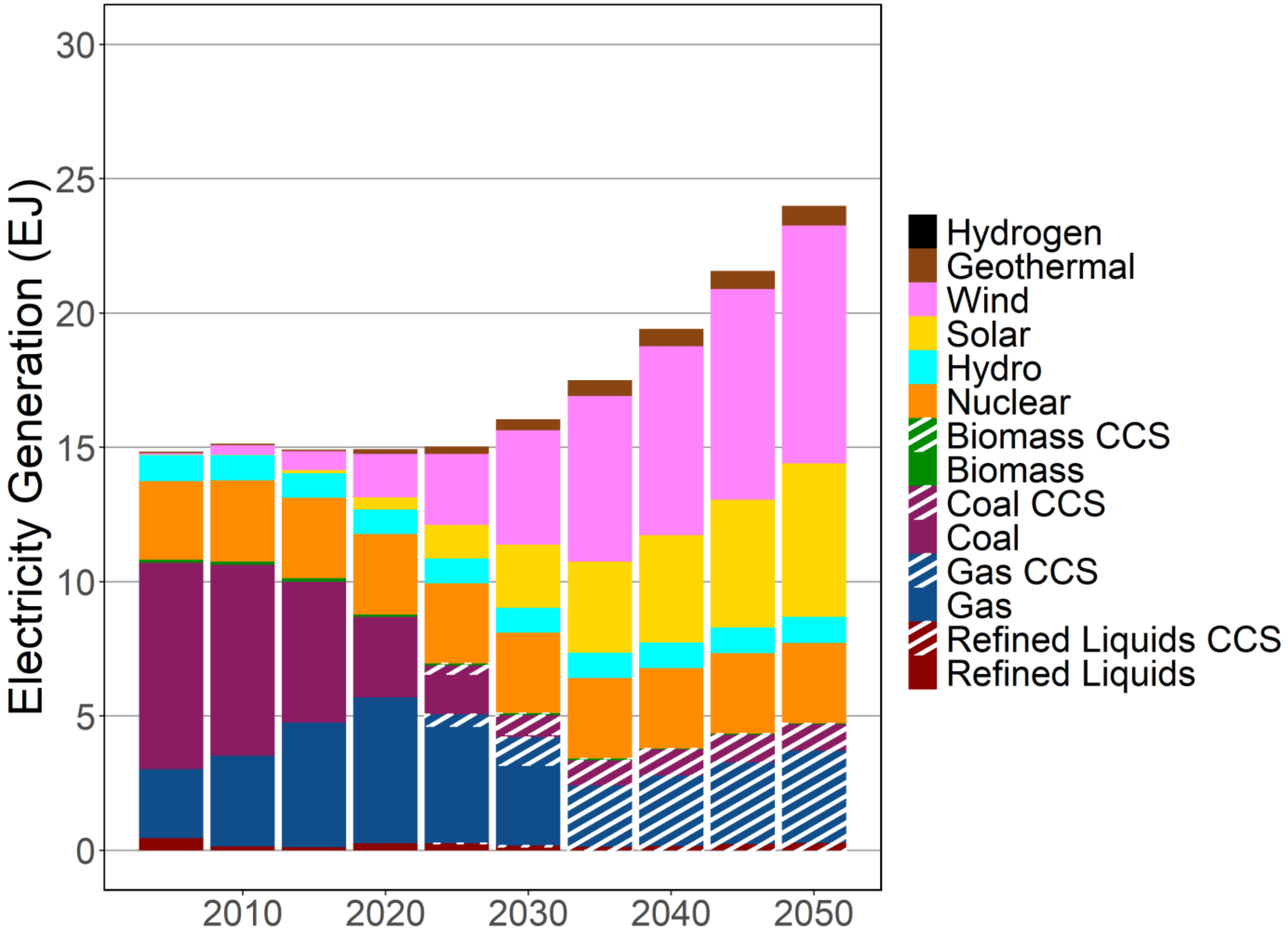


Electricity Generation

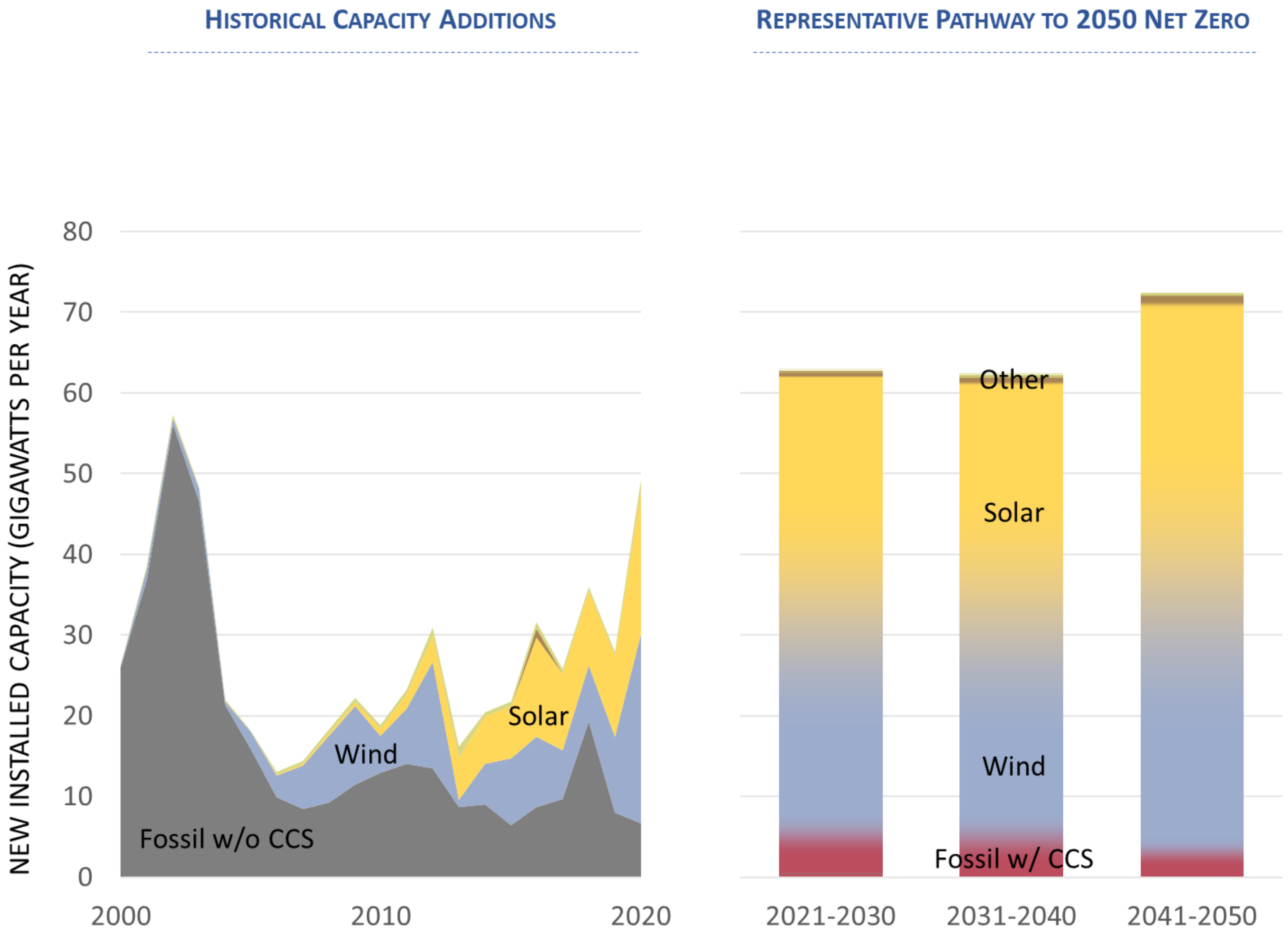
Standard Elec



Advanced Elec



Power Sector Transition



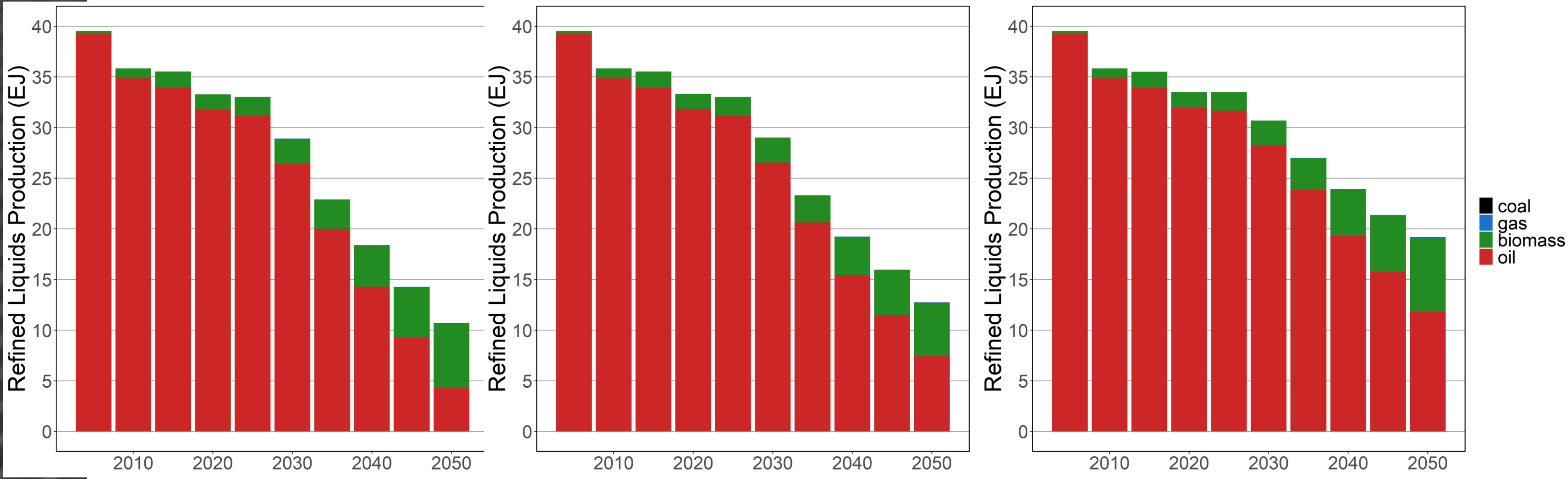
Refined Liquids Production

Low CDR

Med CDR

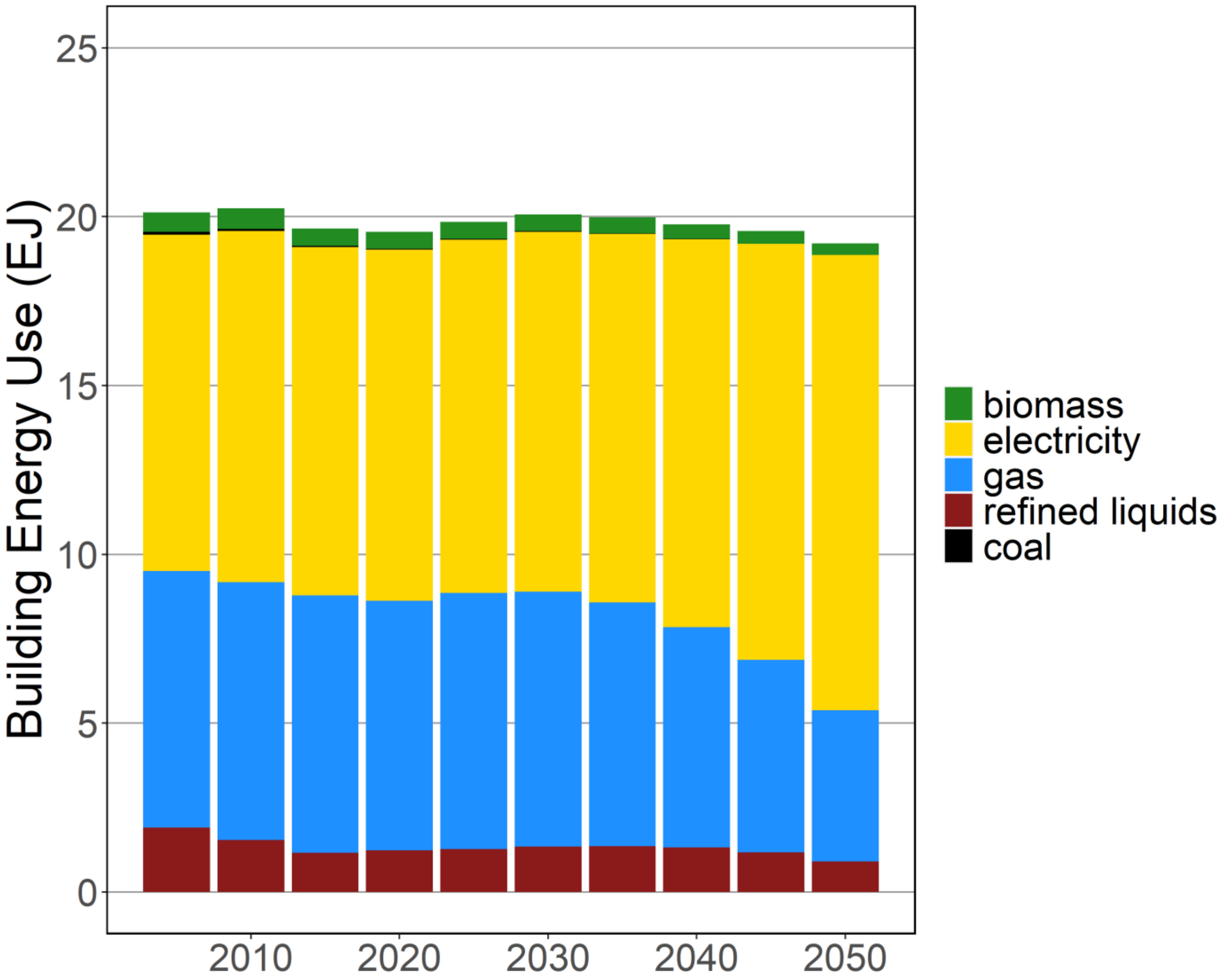
High CDR

+ High Energy Demand

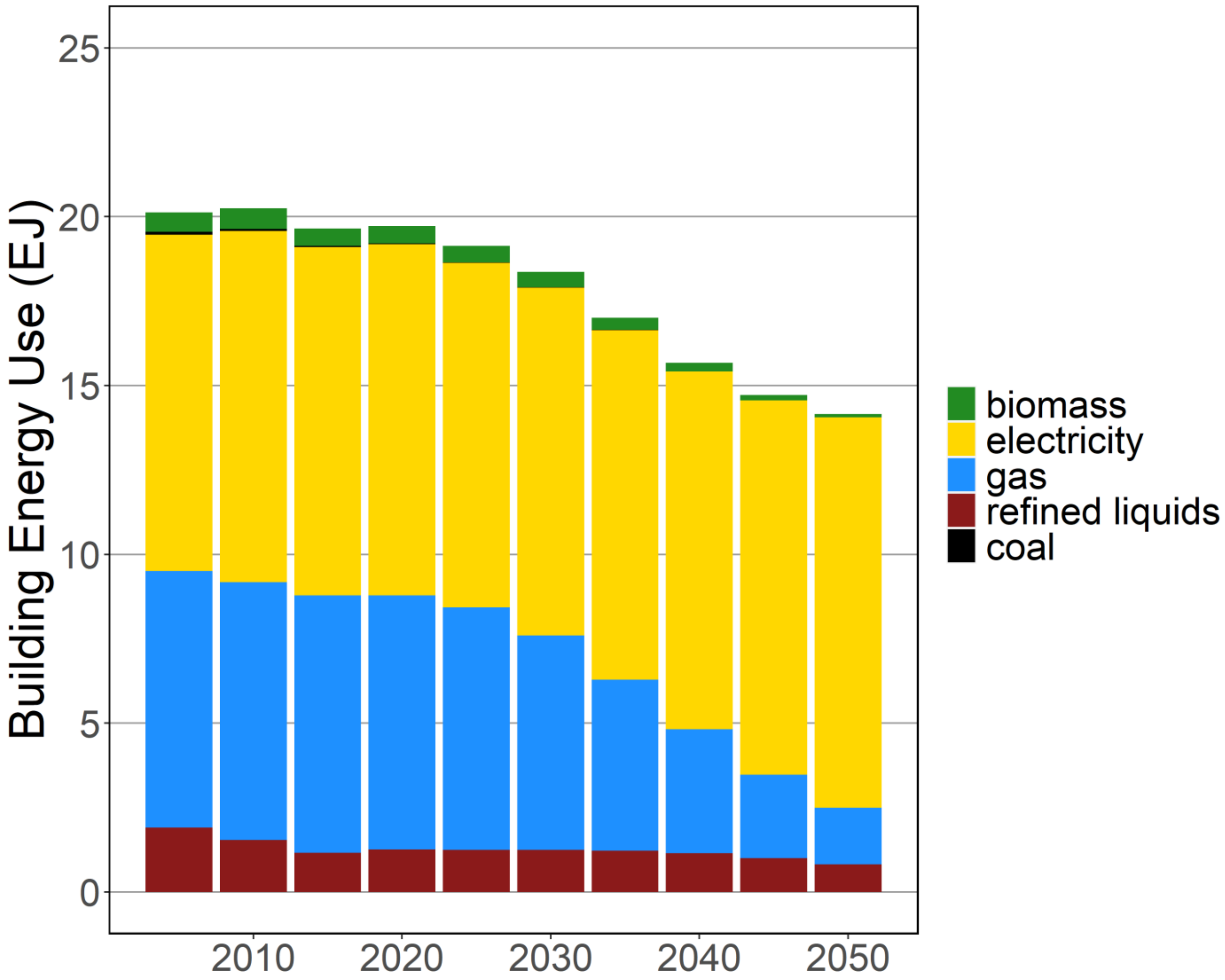


Building Final Energy

Reference Buildings

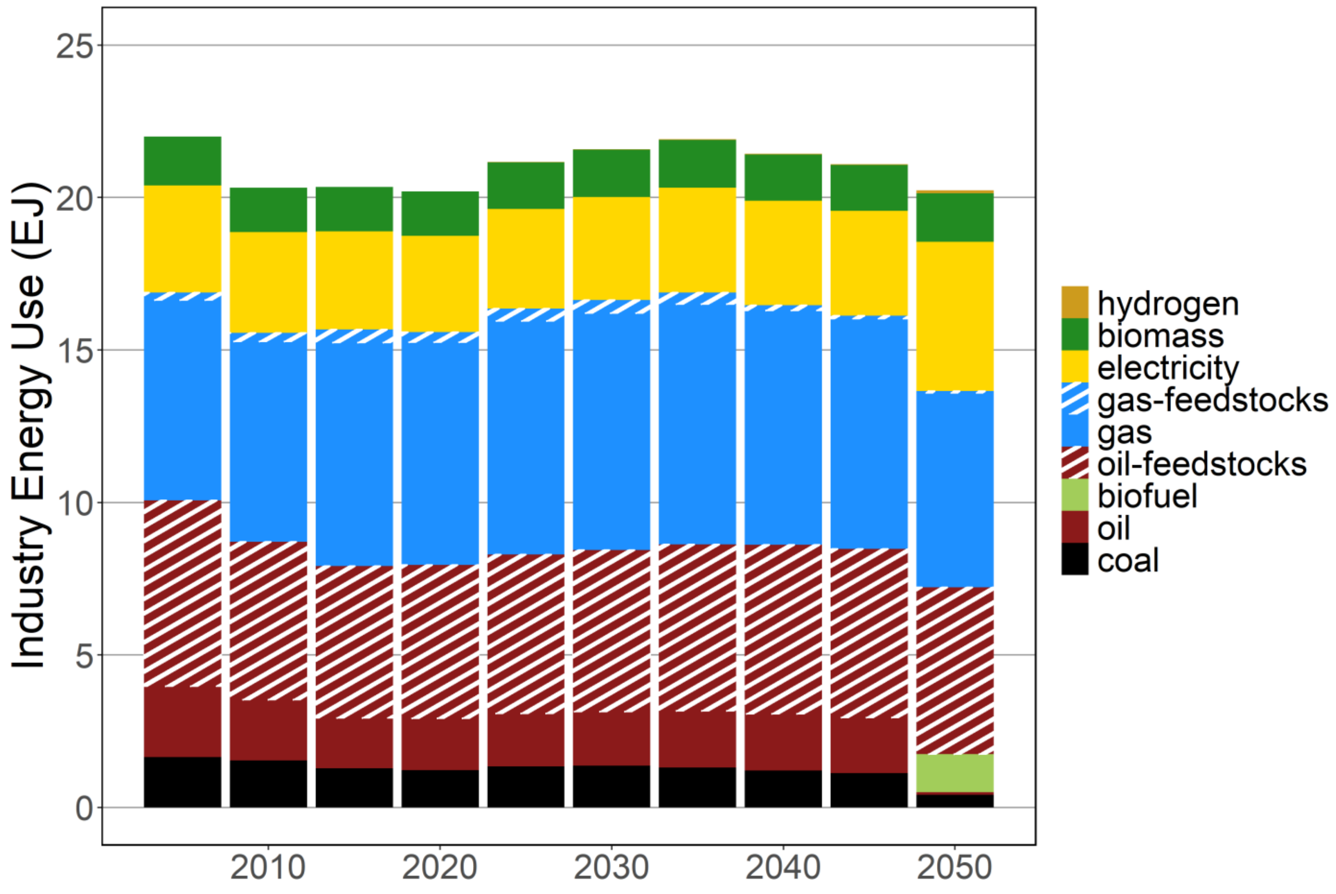


Advanced Buildings

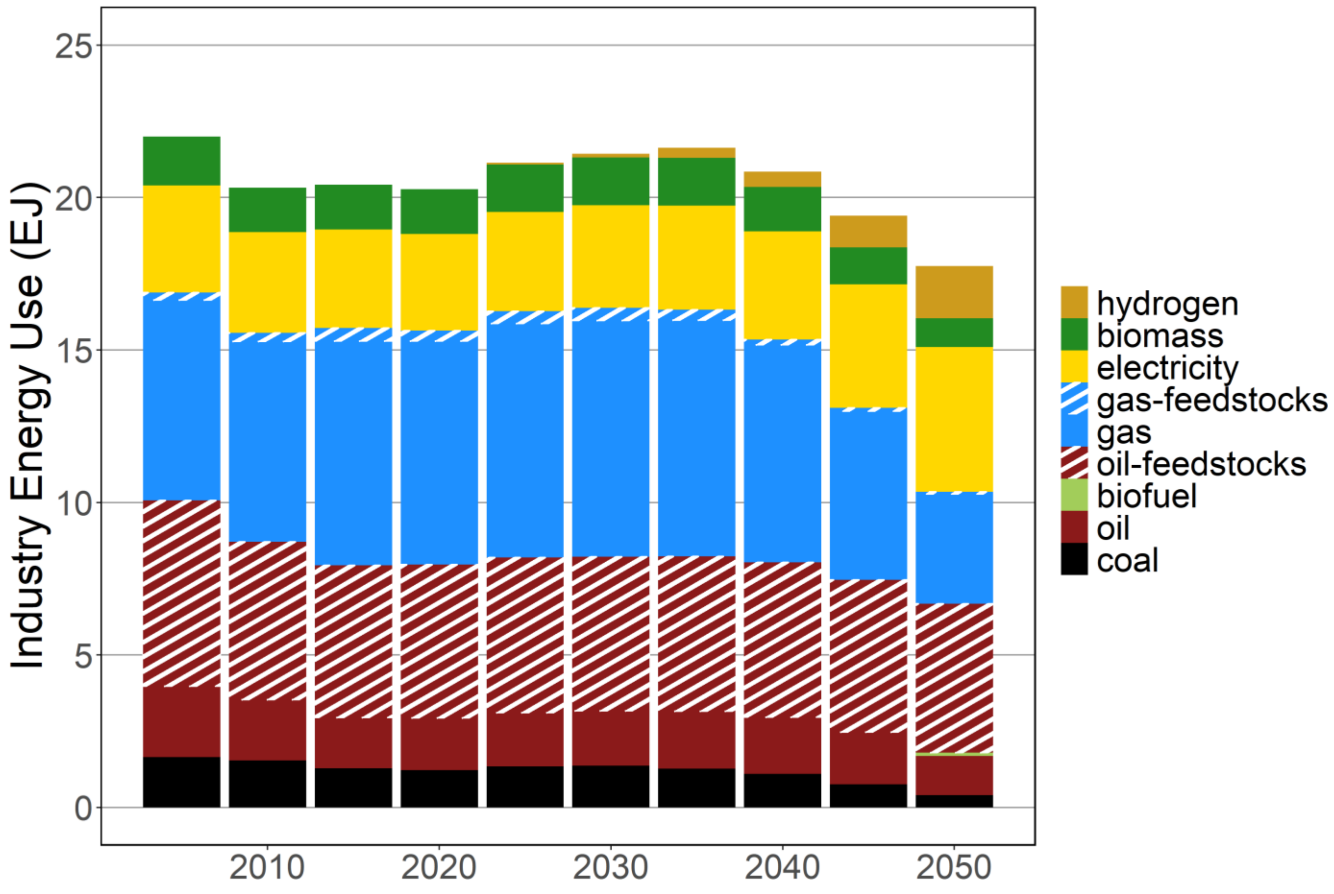


Industry Final Energy

Standard Industry

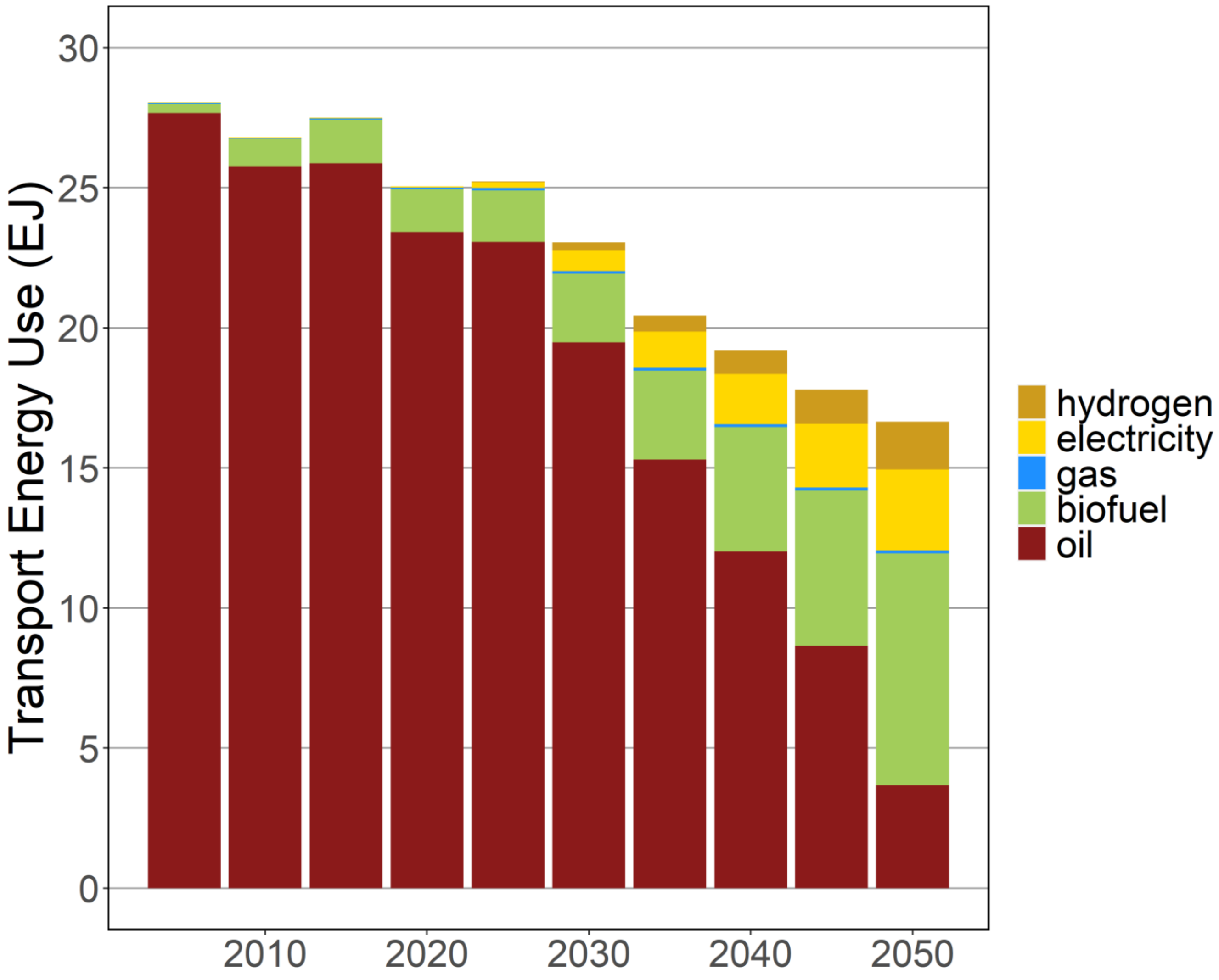


Advanced Industry

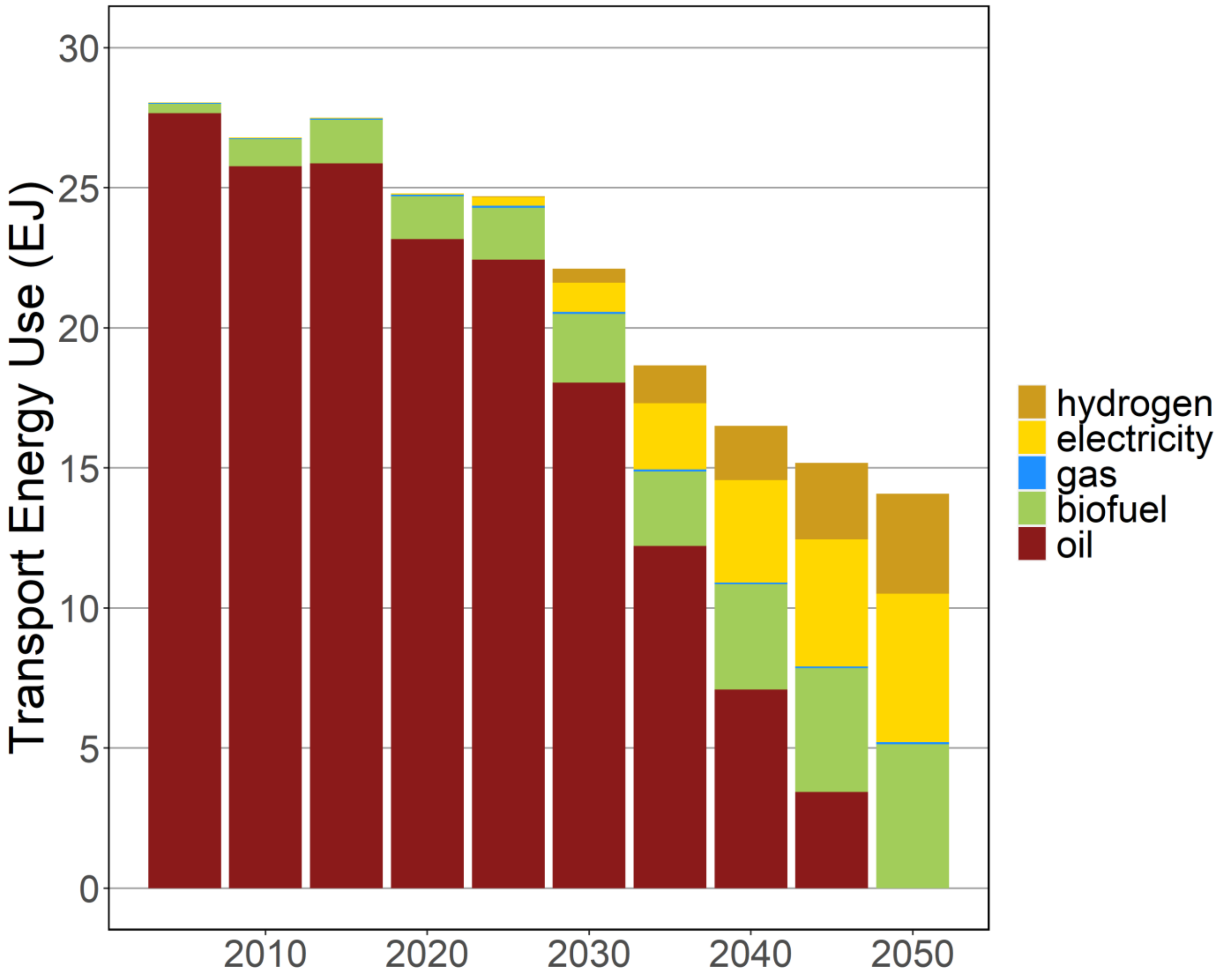


Transport Final Energy

Standard Transport

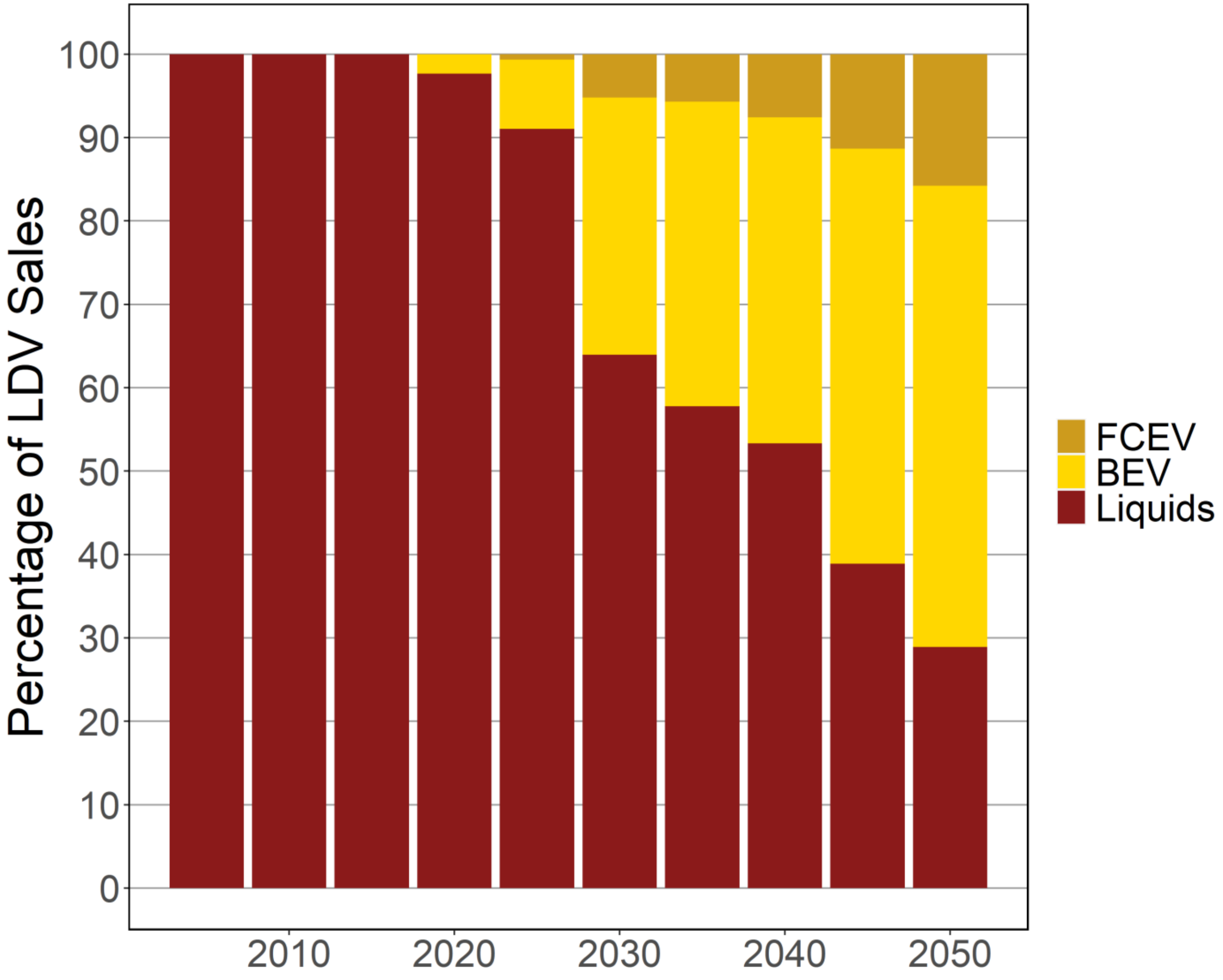


Advanced Transport

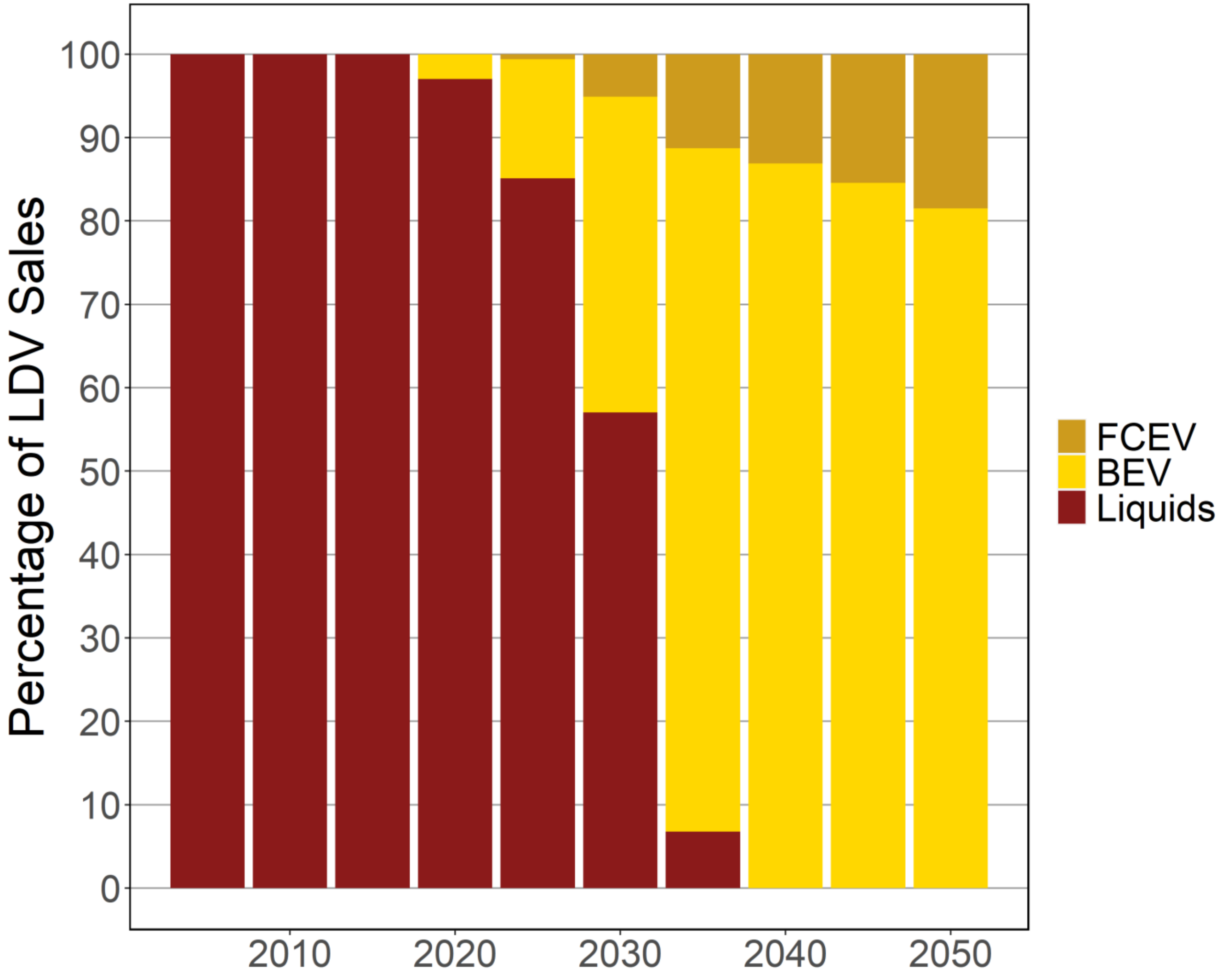


Passenger LDV Sales

Standard Transport

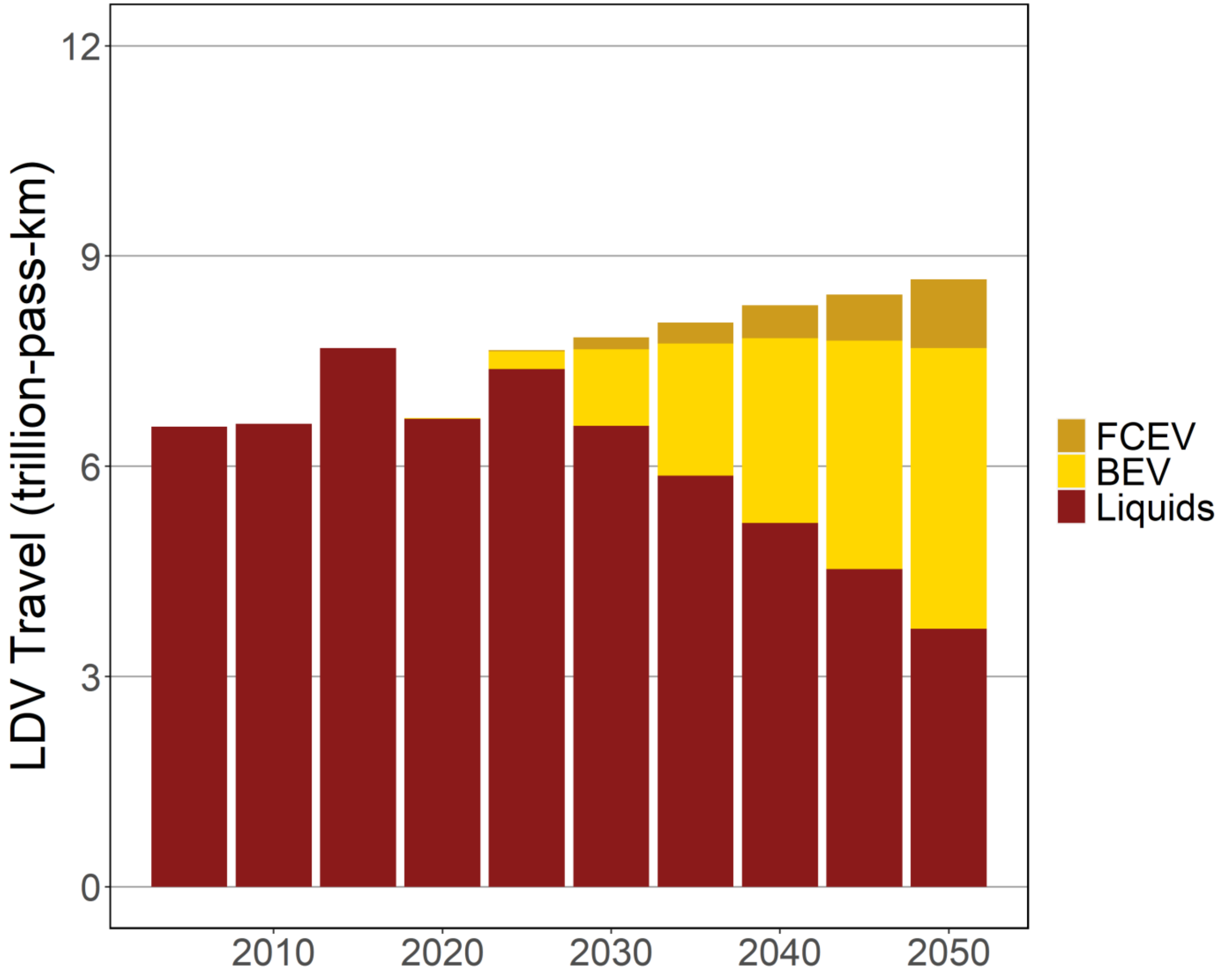


Advanced Transport

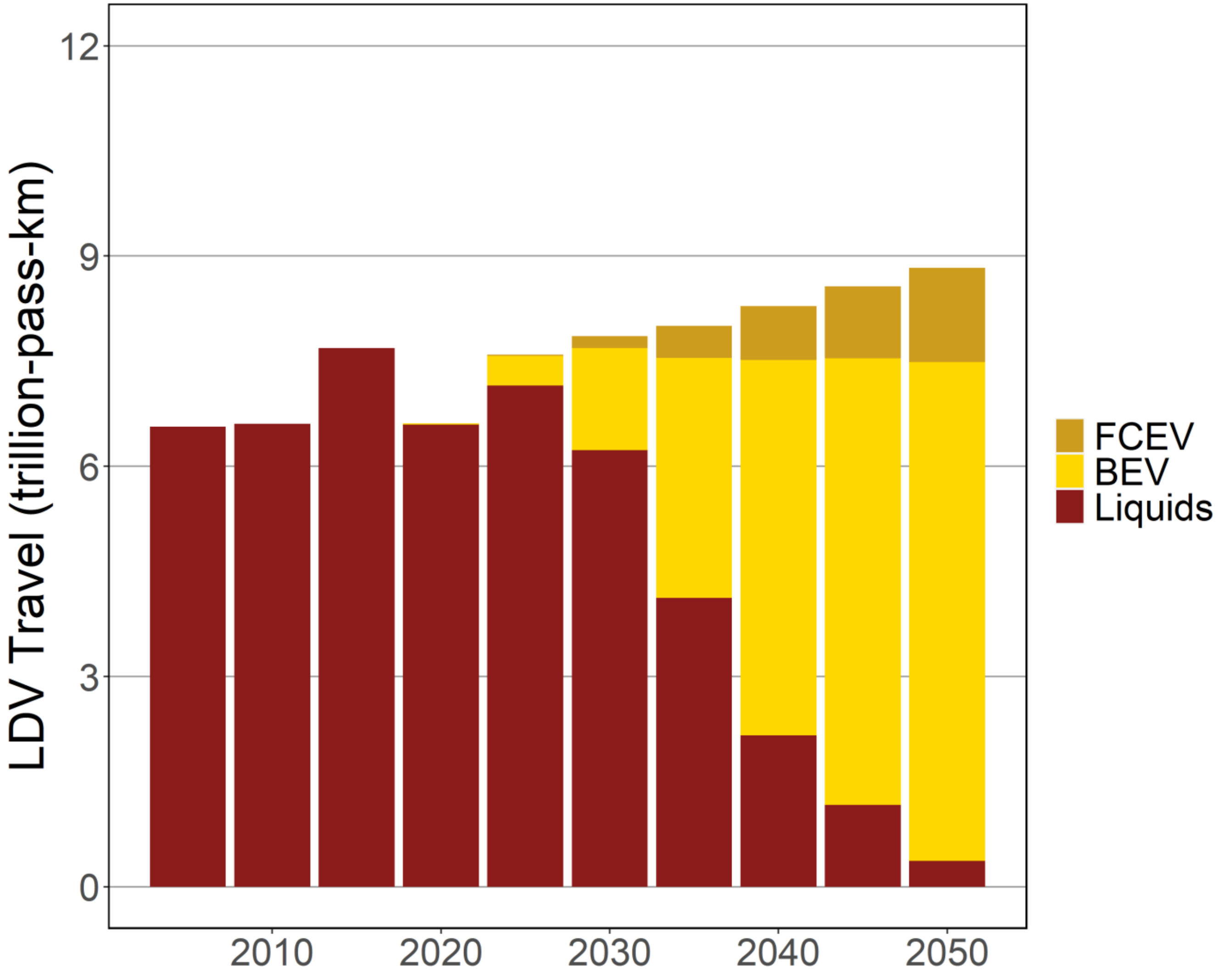


Passenger LDV Service Output

Standard Transport

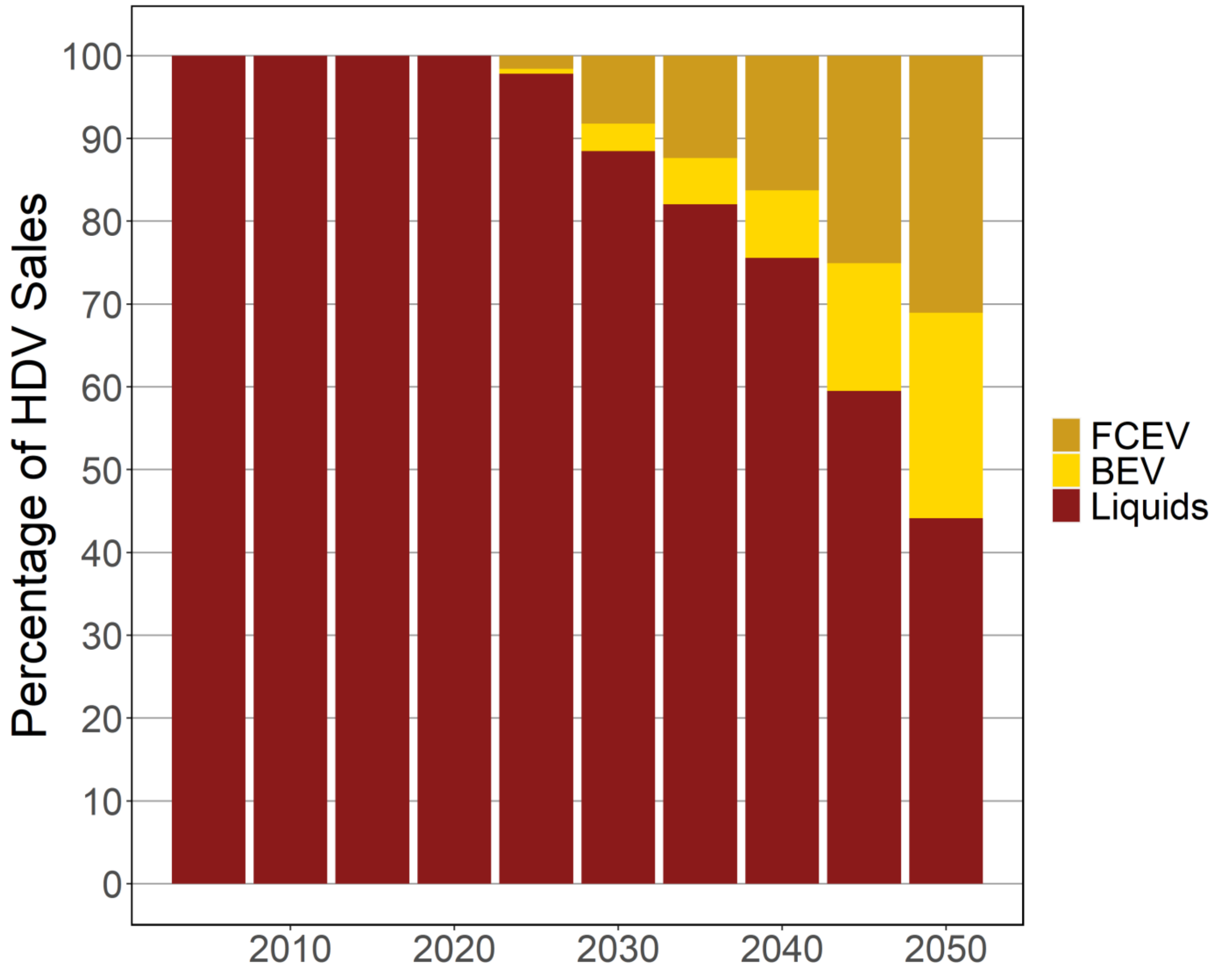


Advanced Transport

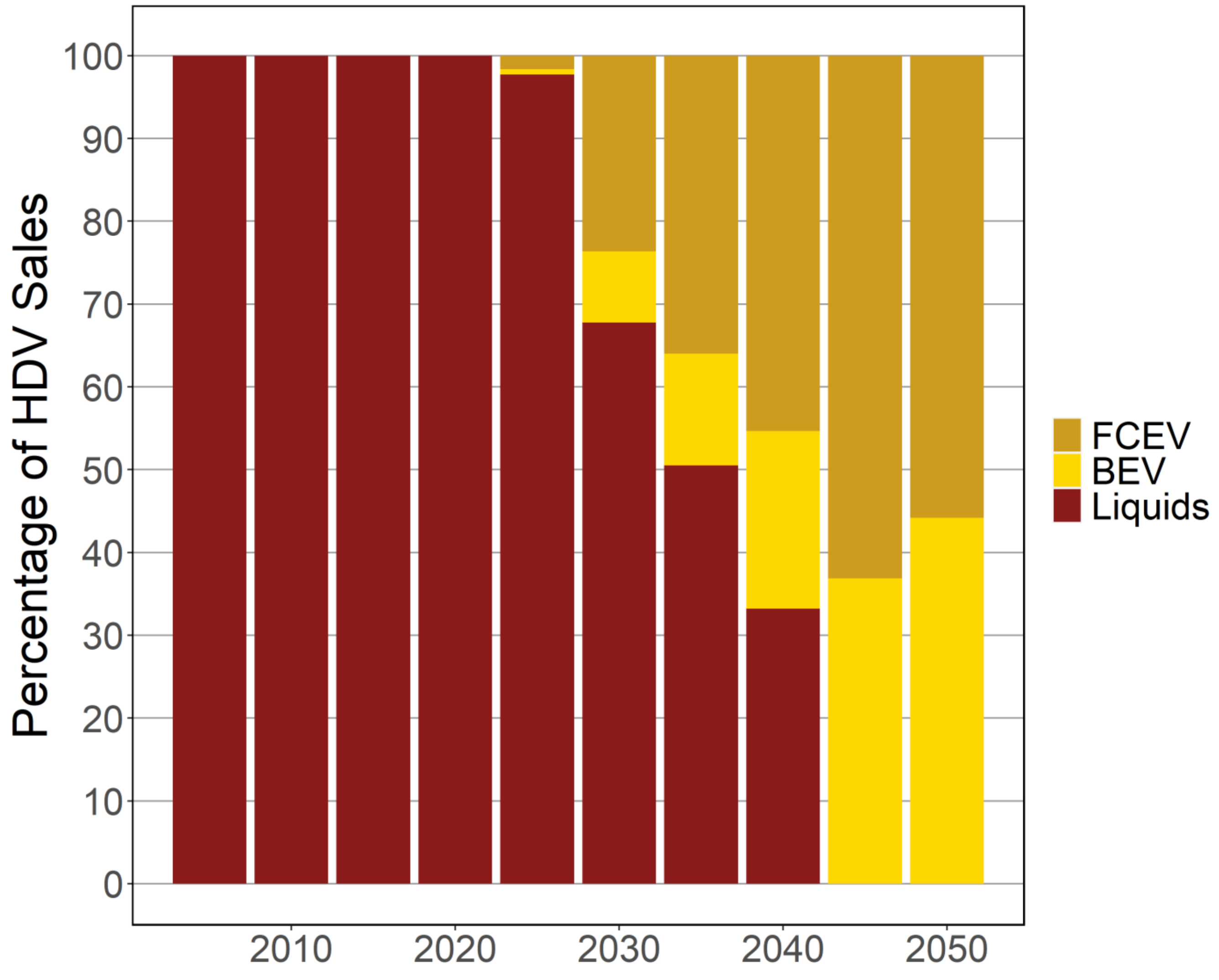


Freight Truck Sales

Standard Transport

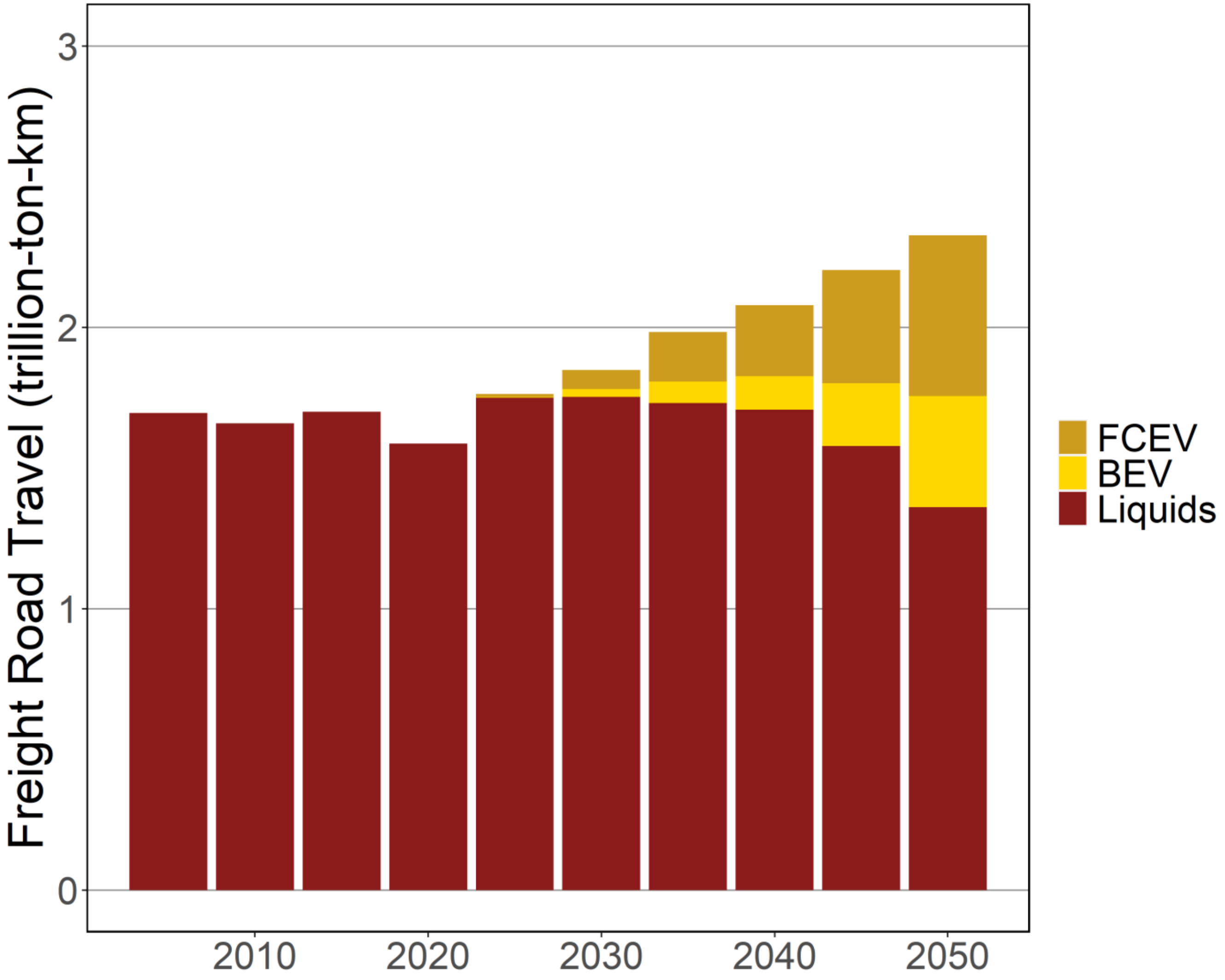


Advanced Transport

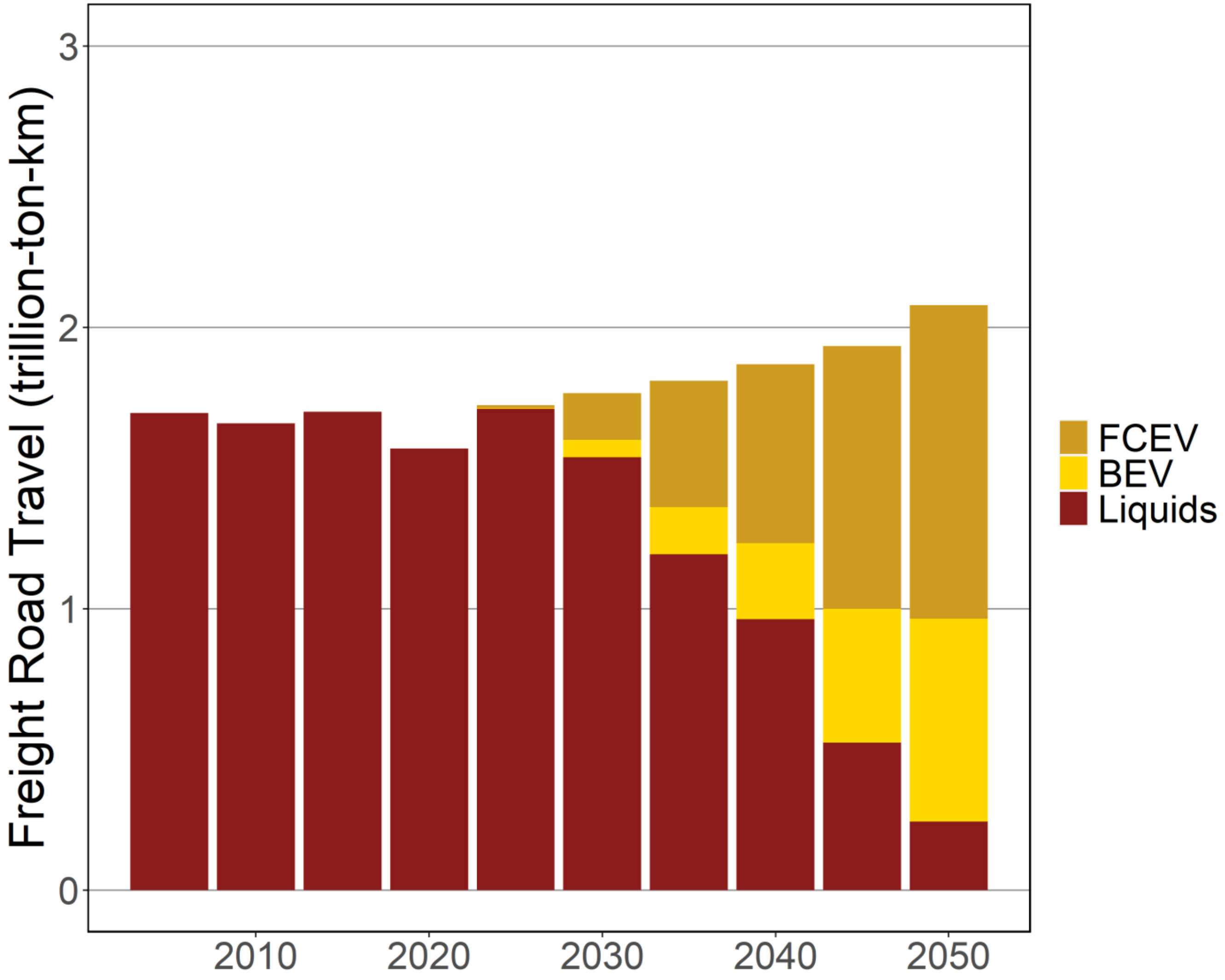


Freight Road Service Output

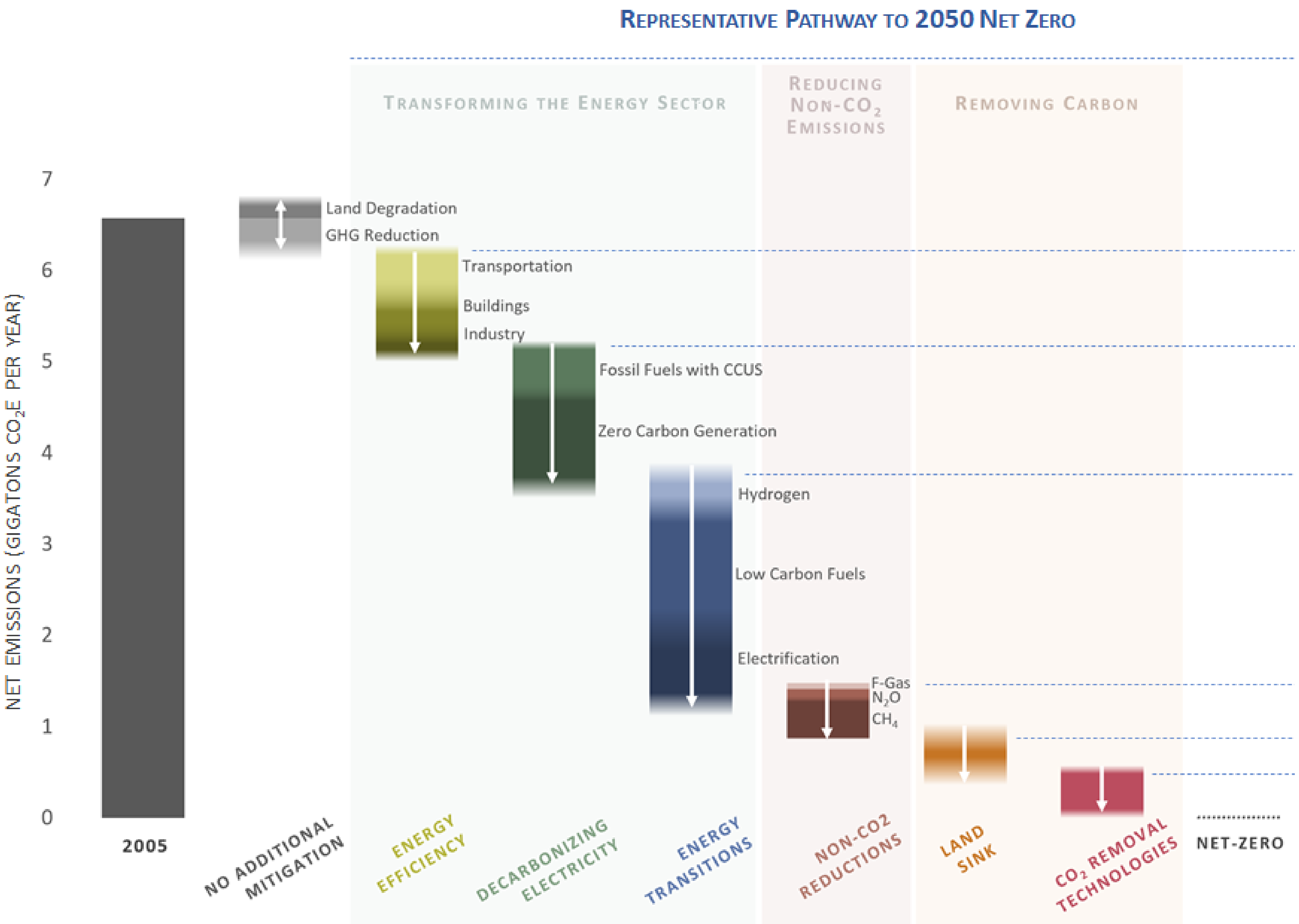
Standard Transport



Advanced Transport



The U.S. Long-Term Strategy



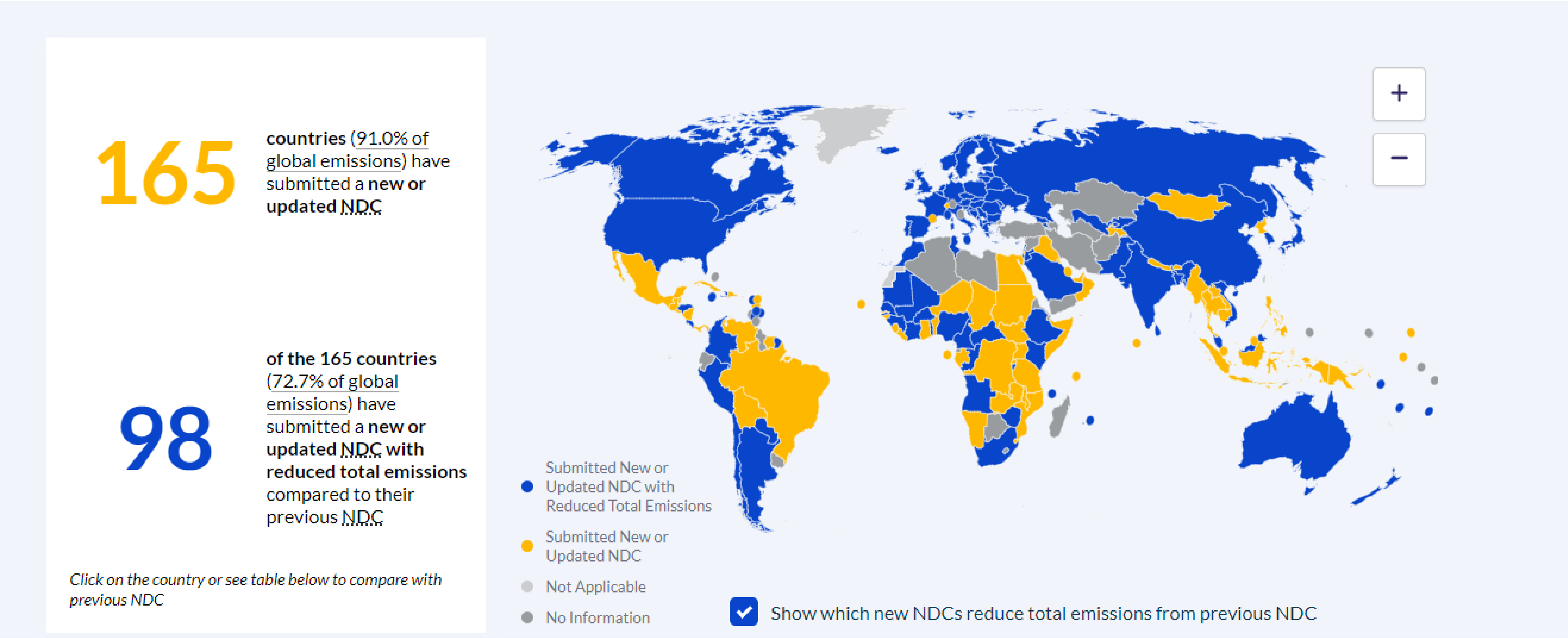
Lessons Learned from the U.S. LTS

1. Net-Zero emission modeling is really hard
2. Net-Zero GHG modeling is really REALLY hard
3. Negative part is just as important as the positive part
4. We can’t just wave a magic wand (carbon tax) and call it done
5. We need to listen to the detailed sector models and experts
6. Getting to net-zero emission is really hard

The 2015 Paris Agreement set up a process to revise countries' emission reduction pledges every five years

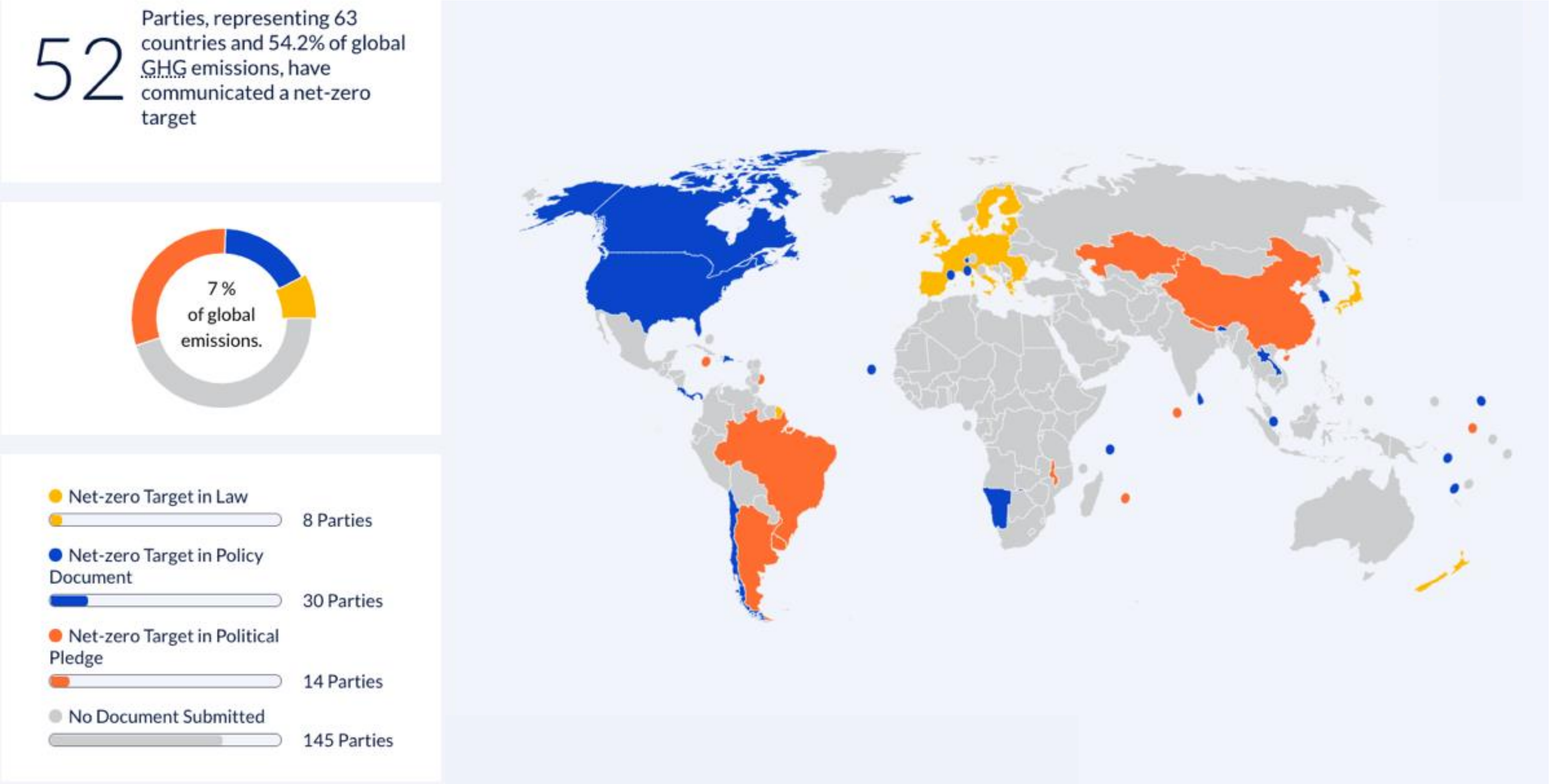
- The United Nations' 26th Conference of Parties (COP) held in Glasgow in November 2021 was a waypoint in the updating process

Over 150 countries submitted updated or new Nationally Determined Contributions (NDCs) outlining actions through 2030



Source: https://www.climatewatchdata.org/

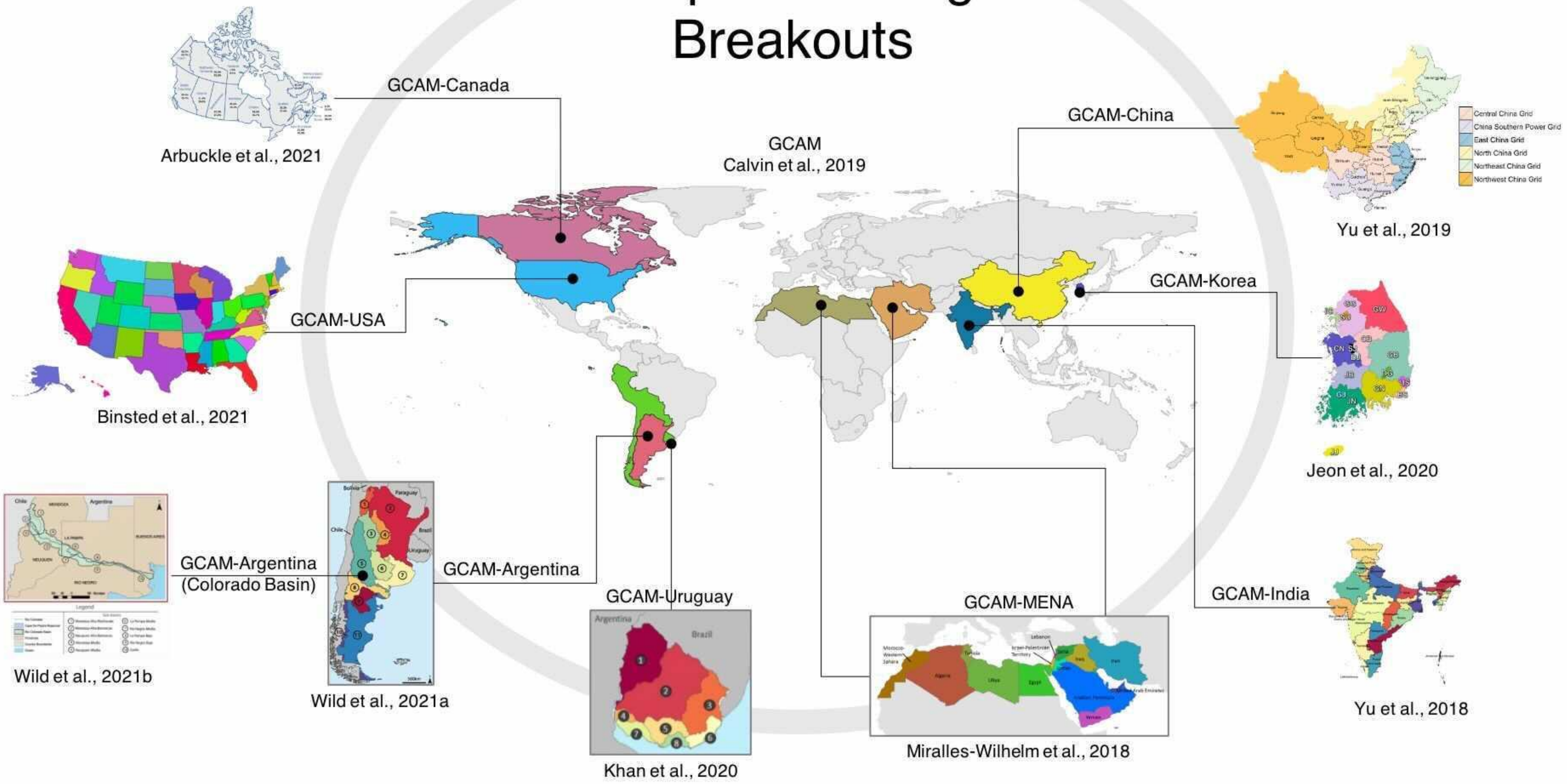
Countries also submitted long-term strategies and net-zero pledges outlining actions through mid-century



Source: https://www.climatewatchdata.org/

The Global Change Analysis Model (GCAM)

32 Geopolitical Regions
Breakouts



Pacific Northwest
NATIONAL LABORATORY

PNNL-10096

Low Emission Development Strategy for Taiwan

An Integrated Assessment of a Low Coal, Low Nuclear Future Energy System

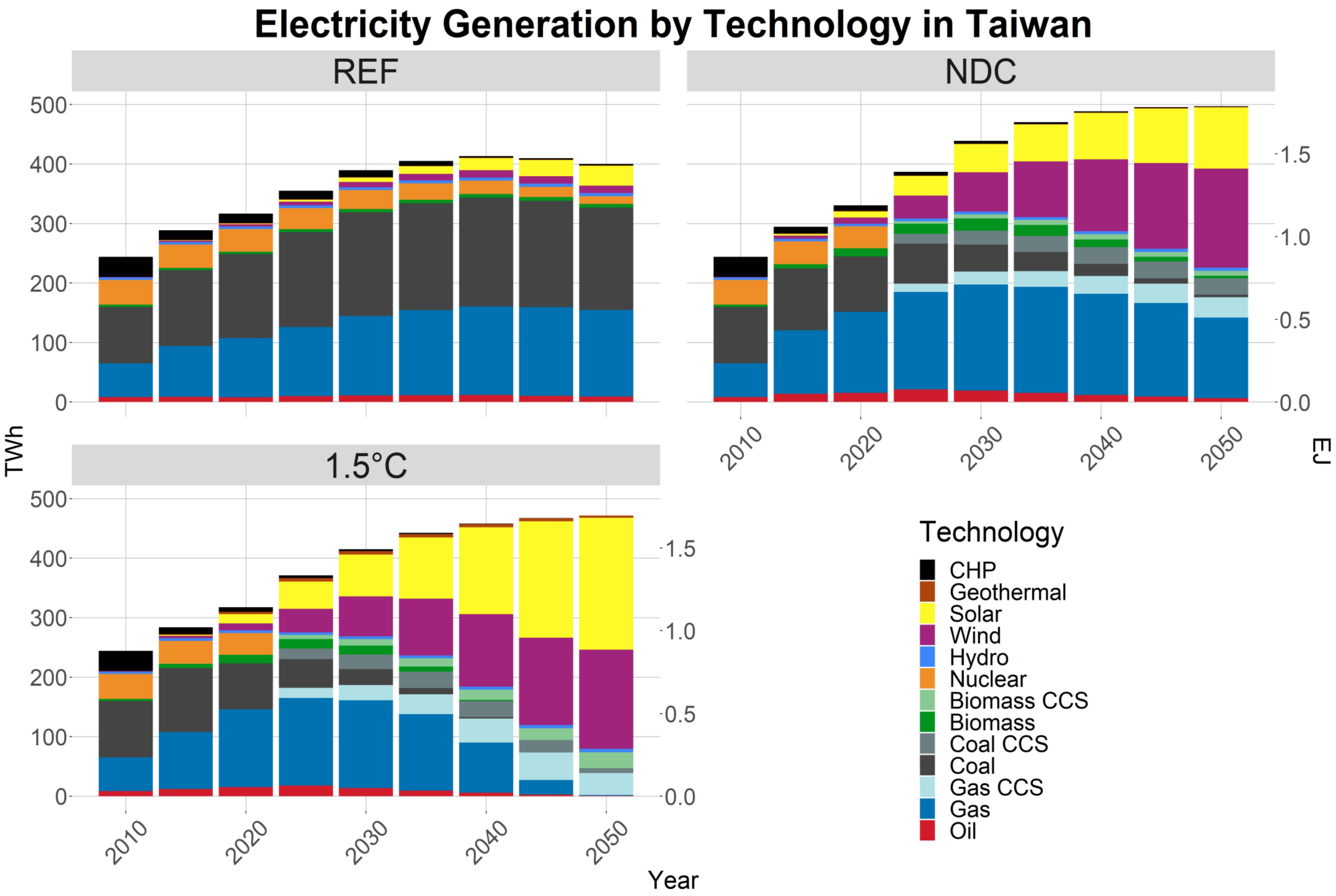
July 2020

Candelaria Bergero
Haewon C. McJeon
Matthew Binsted
Brinda Yarlagadda
Chao Chia-Wei (Risk Society and Policy Research Center, National Taiwan University)
Wu Cheng-Cheng (Green Citizen Action Alliance)
Wei Yang (Green Citizen Action Alliance)
Chou Kuei-Tien (Risk Society and Policy Research Center, National Taiwan University)

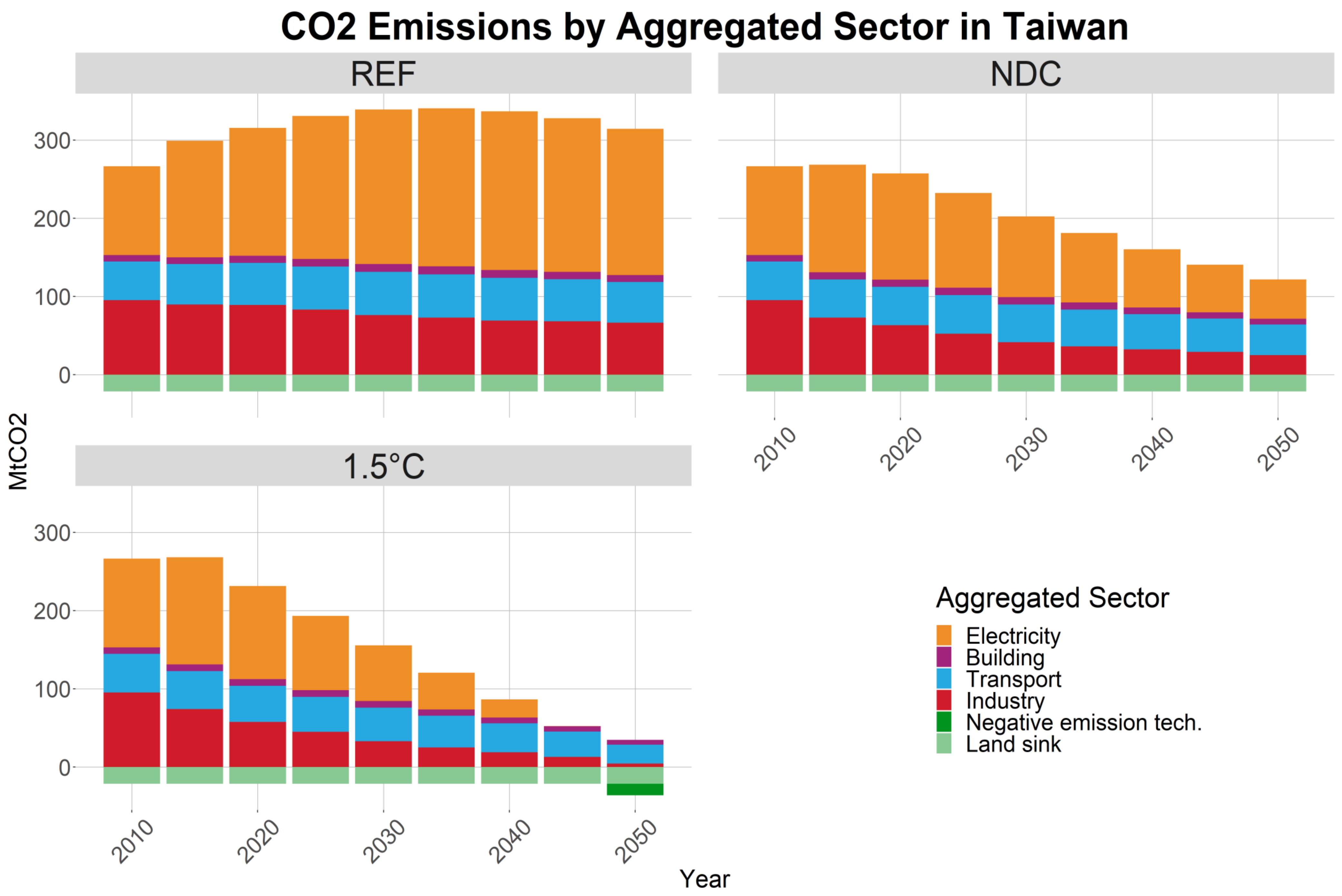
Scenarios

	REF	NDC	1.5°C
Emission Constraints	None. Emissions are determined by unconstrained economic development and population.	Carbon constraints follow Taiwan's NDC until 2030, and Taiwan's mid-century reduction pledge until 2050, linearly decrease to net-zero by 2100. Global carbon emissions net-0 in 2090.	Taiwan carbon emissions net-zero in 2050. Remains constant until 2100. Global carbon emissions net-0 by 2050. Carbon sinks of 1,620 MtC by 2100.
Electricity	No changes in preferences, policy nor costs for different electricity technologies.	Coal and nuclear phaseout. Natural gas decrease. Medium deployment of renewables.	Coal and nuclear phaseout. Natural gas decrease Low costs for renewable energies with high deployment of these technologies
Renewable Electricity Costs	Standard Costs	Standard Costs	Low Costs
Transport Electrification	Low electrification: Passenger 0.3% Freight 0%	Medium electrification: Passenger 21% Freight 17%	High electrification: Passenger 61% Freight 52%
End-use Sector Demand	Medium demand (default GCAM)	Medium demand (default GCAM)	Low demand (0.5% - 1.0 % improvements per time-step)

Electricity Generation



CO2 Emissions



Policy Brief:

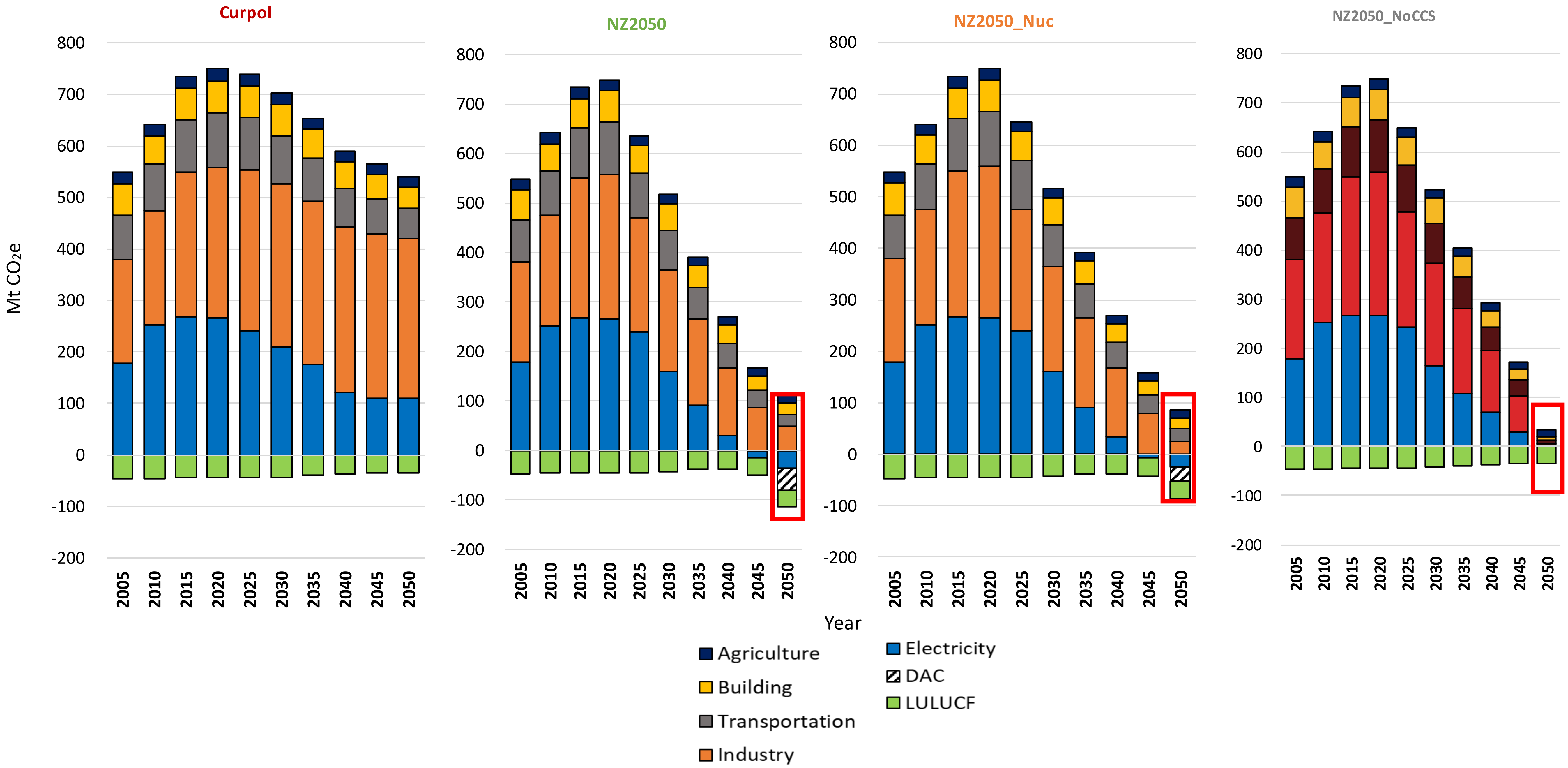
Five Strategies to Achieve China's 2060 Carbon Neutrality Goal

Download now:
go.umd.edu/china2060

27

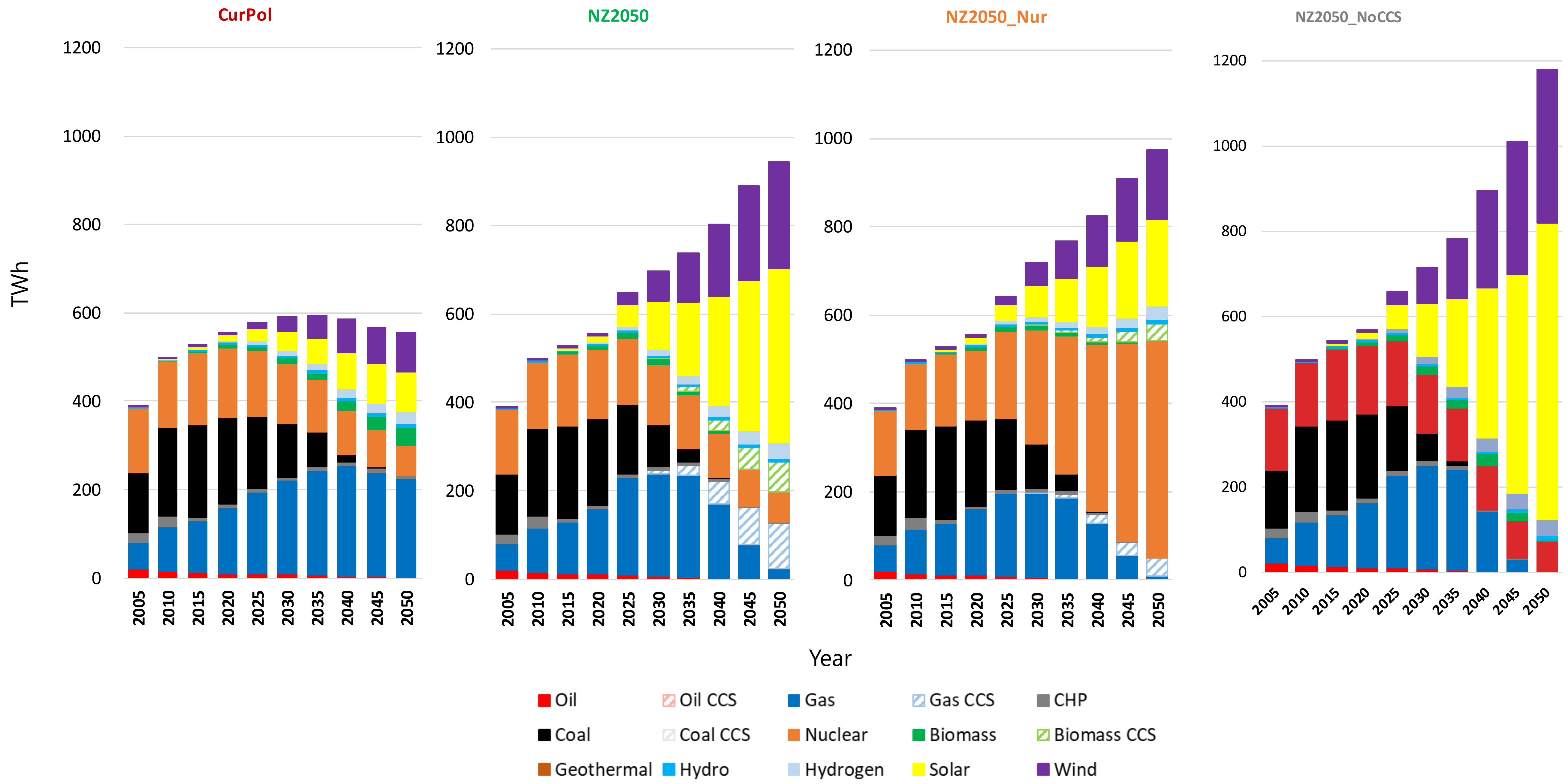
GHG Emission by Sector

- The dramatic GHG reduction demonstrates the need for rapid changes in entire energy system.
- Negative emission technologies are critical to offset hard-to-abate emissions .

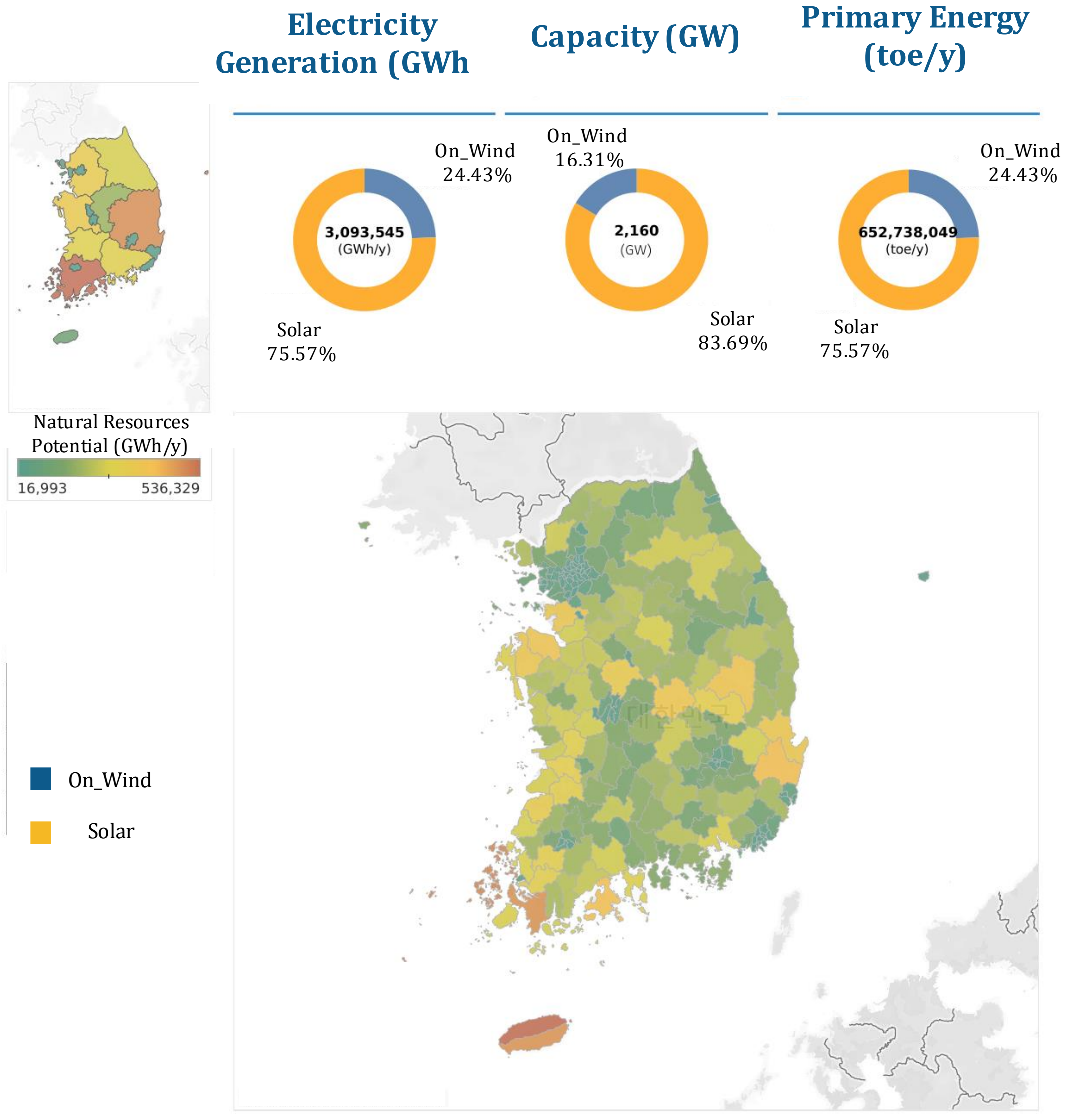


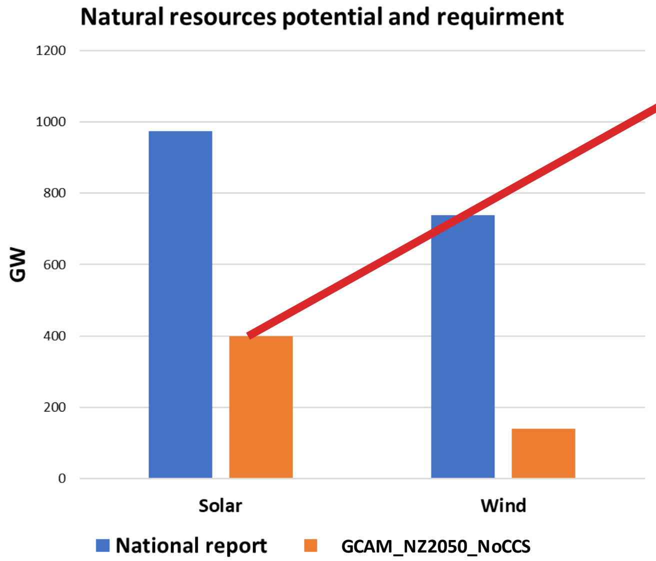
Electricity generation

- Carbon-neutrality require drastic change: Substituting fossil fuels to low carbon sources



Potential resources & land requirement





Solar power plants_NZ2050_NoCCS

X 6

Nuclear power plants_NZ2050_Nuc

10% of the size of Seoul

- 1GW nuclear power plant requires the land size of 0.745km2 (including the geological land and sea area)

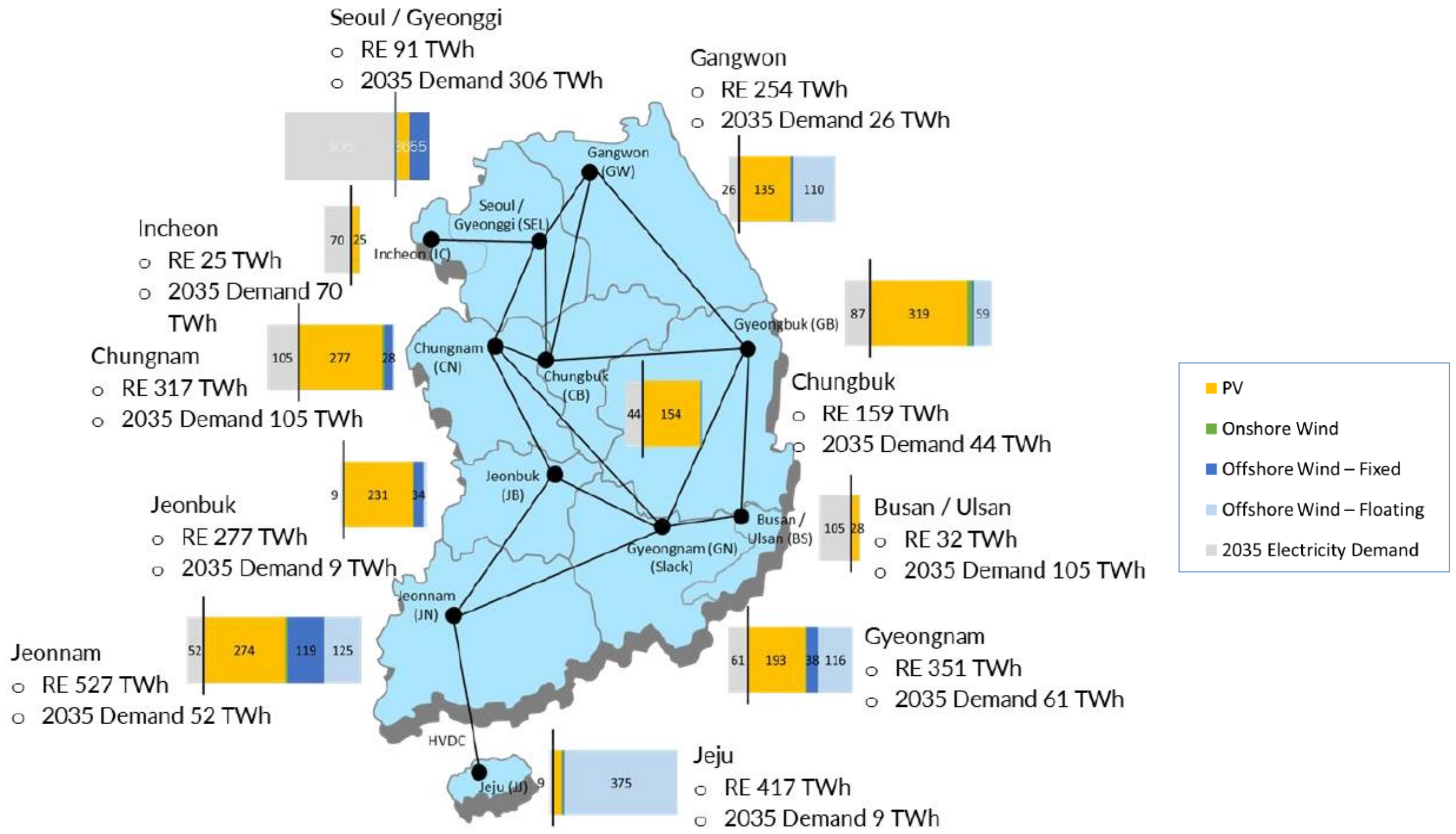
[Source: KIER, Renewable Energy Potential Map, 2022]

[Source: Korea energy agency, Renewable Energy White Paper, 2020]

[Source: KOPIA, A plan to secure locations for each photovoltaic area to achieve carbon]

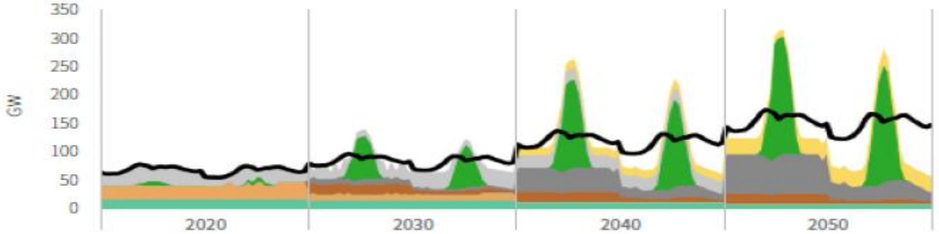
[Source: National Assembly Budget Office "Report on Area Required by Power Generation Source" 2017]

Renewable Energy Potential

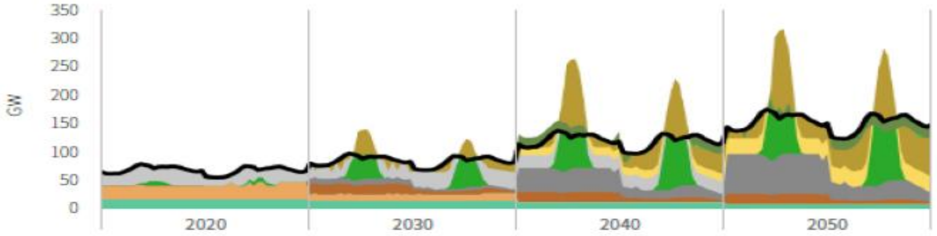


Summer and winter power generation (Storage option)

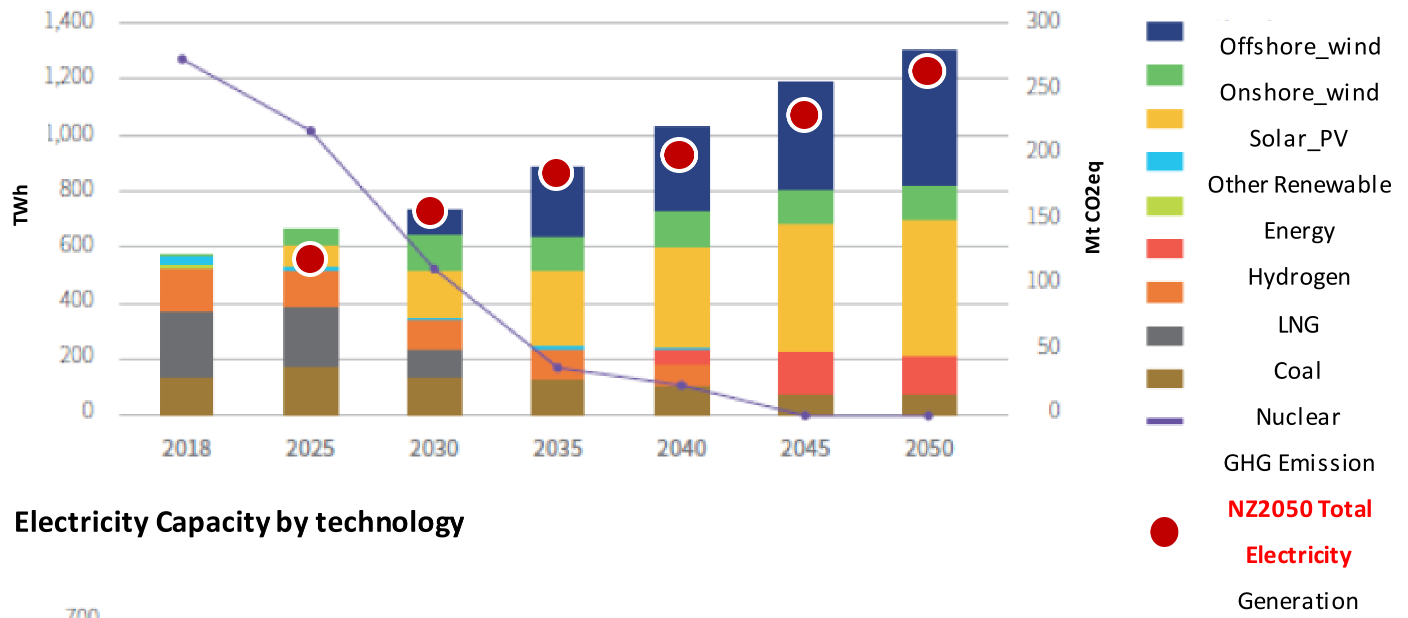
Without Storage



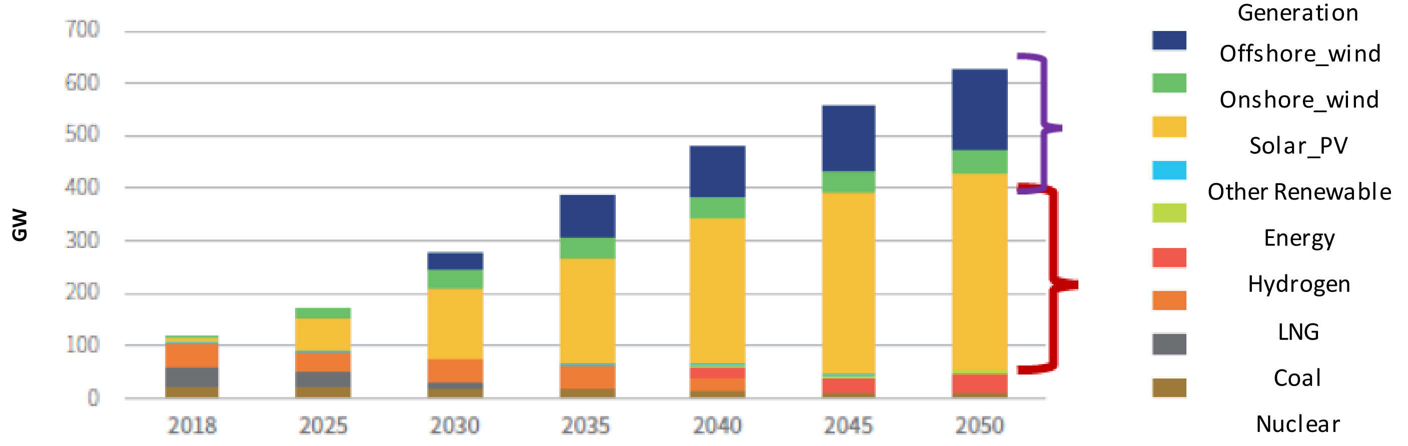
With Storage



GHG emissions pathways and Electricity Generation by technology



Electricity Capacity by technology

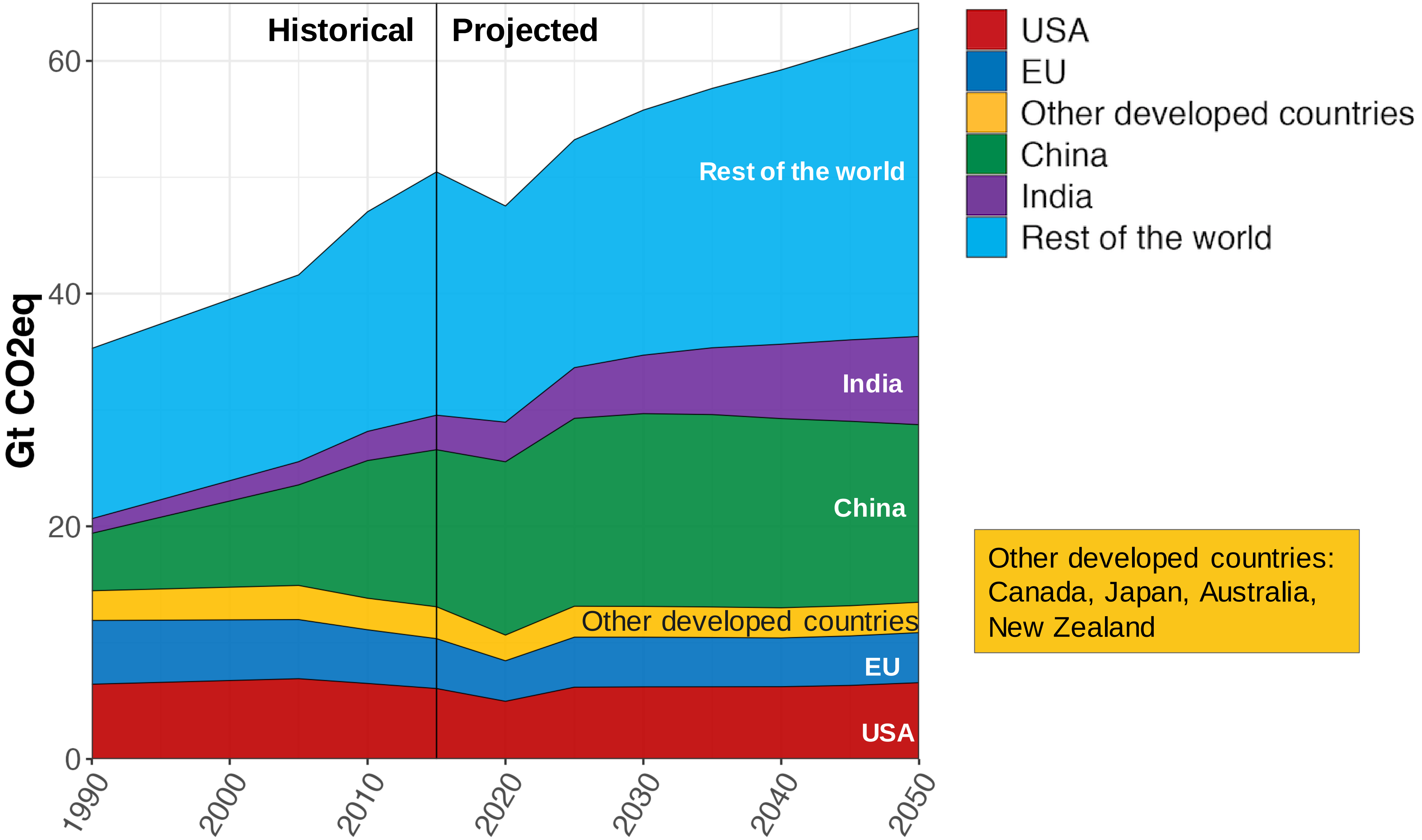


Solar: 370, 300 (NZ2050)
Wind: 200, 110 (NZ2050)

We compiled 100+ NDCs, long-term strategies, and net-zero pledges for modeling in GCAM

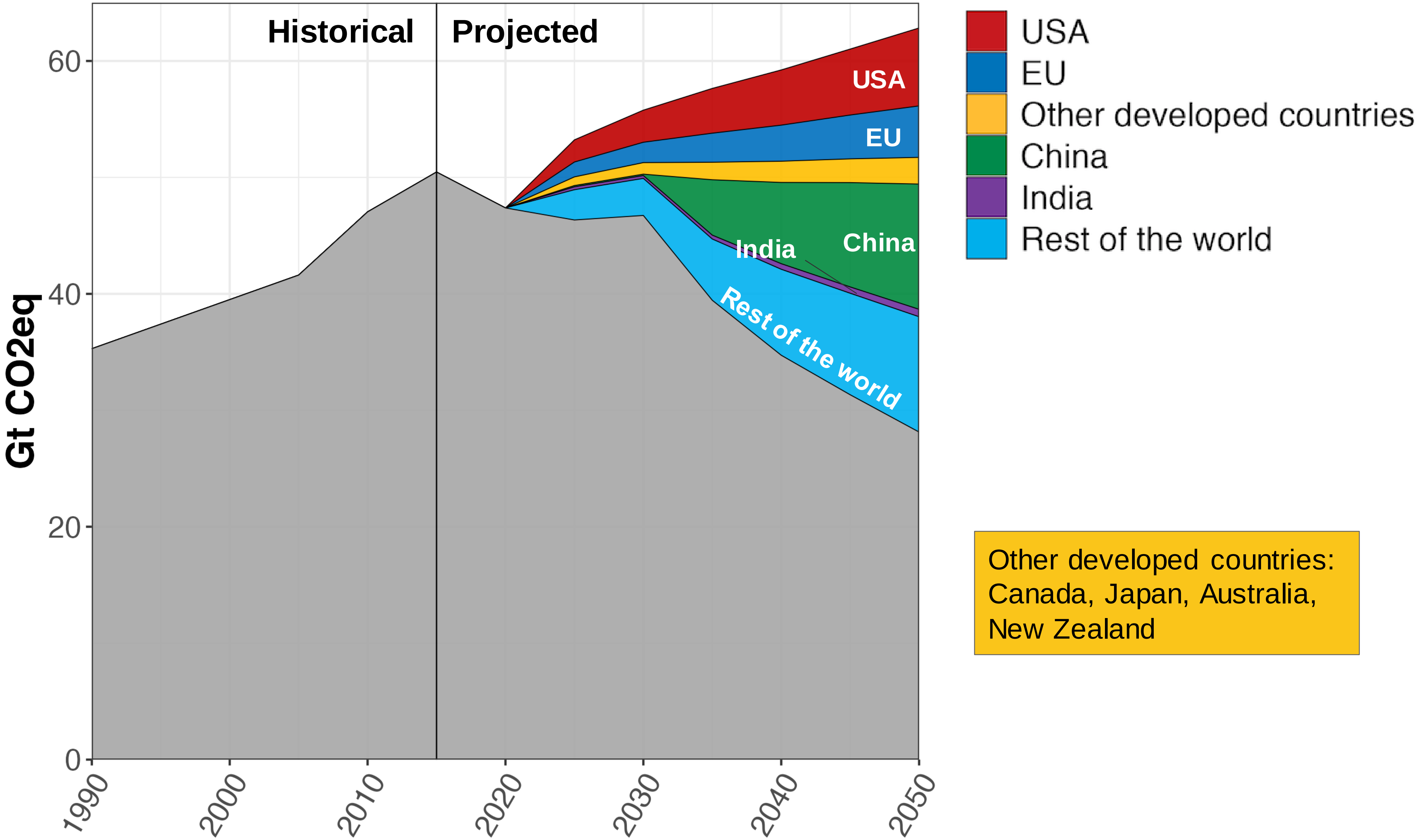
GCAM Region	Country/Region	Representation of NDCs	Source of Historical/BAU emissions	NDC status	Latest submission
	Oman	7% reduction in all GHG (including LUC) below BAU	BAU based on NDC submission	Second NDC	2021-07-29
	Qatar	25% reduction in all GHG (excluding LUC) below BAU	BAU based on GCAM Reference scenario	First NDC (updated submission)	2021-08-24
	United Arab Emirates	23.5% reduction in all GHG (including LUC) below BAU	BAU based on NDC submission	Second NDC	2020-12-29
Russia	Russia	25-30% reduction in all GHG (including LUC) below 1990	Historical emissions based on NDC submission	First NDC	2020-11-25
South Africa	South Africa	Emissions constraint of 420 MtCO2e on all GHG (including LUC)	BAU based on 2000: National Communication; NDC emissions in 2030 based on the upper bound in NDC submission (350-420 MtCO2e)	First NDC (updated submission)	2021-09-27
South America_Southern	Chile	A maximum emissions limit target of 95 MtCO2e GHG emissions (excluding LUC)	2030 NDC target based on NDC submission and Climate Action Tracker assessment	First NDC (updated submission)	2020-04-09
	Ecuador	20.4% reduction in all GHG (excluding LUC) below BAU in 2025	2030 NDC target based on BAU projection of GCAM Reference and NDC partnership assessment	First NDC	2019-03-29
	Paraguay	10% reduction in all GHG (including LUC) below BAU	BAU based on NDC submission	First NDC (updated submission)	2021-07-16
	Peru	30% reduction in all GHG (including LUC) below BAU	BAU based on NDC submission	First NDC (updated submission)	2020-12-18
South Asia	Bangladesh	6.73% reduction in all GHG (excluding LUC) below BAU	BAU based on NDC submission	First NDC (updated submission)	2021-08-26
	Lao Peoples Democratic Republic	60% reduction in all GHG (including LUC) below BAU	BAU based on NDC submission	First NDC (updated submission)	2021-05-11
	Samoa	26% reduction in all GHG (including LUC) below 2007	BAU based on NDC submission	Second NDC	2021-07-30
	Sri Lanka	4% reduction in all GHG (excluding LUC) below BAU in the energy sector	BAU based on GCAM Reference scenario and NDC submission	First NDC (updated submission)	2021-07-30
South Korea	South Korea	24.4% reduction in all GHG (excluding LUC) below 2017	Historical emissions based on NDC submission	First NDC (updated submission)	2020-12-30
Southeast Asia	Brunei Darussalam	20% reduction in all GHG (including LUC) below BAU	BAU based on NDC submission	First NDC	2020-12-31
	Cambodia	41.7% reduction in all GHG (including LUC) below BAU	BAU based on NDC submission	First NDC (updated submission)	2020-12-31
	Fiji	10% reduction in all GHG (excluding LUC) below BAU	BAU based on NDC submission	First NDC (updated submission)	2020-12-31
	Kiribati	12.8% reduction in all GHG (excluding LUC) below BAU	BAU based on NDC submission	First NDC	2016-09-21
	Malaysia	45% reduction in GHG (including LUC) emissions intensity of GDP below 2005	2030 NDC target based on ADVANCE	First NDC (updated submission)	2021-07-30
	Marshall Islands	45% reduction in all GHG (excluding LUC) below 2010	Historical emissions based on NDC submission	Second NDC	2020-12-31
	Philippines	2.71% reduction of cumulative GHG (excluding LUC) below BAU	2030 NDC target based on Climate Action Tracker assessment	First NDC	2021-04-

Global GHG emissions: Reference No New Policy



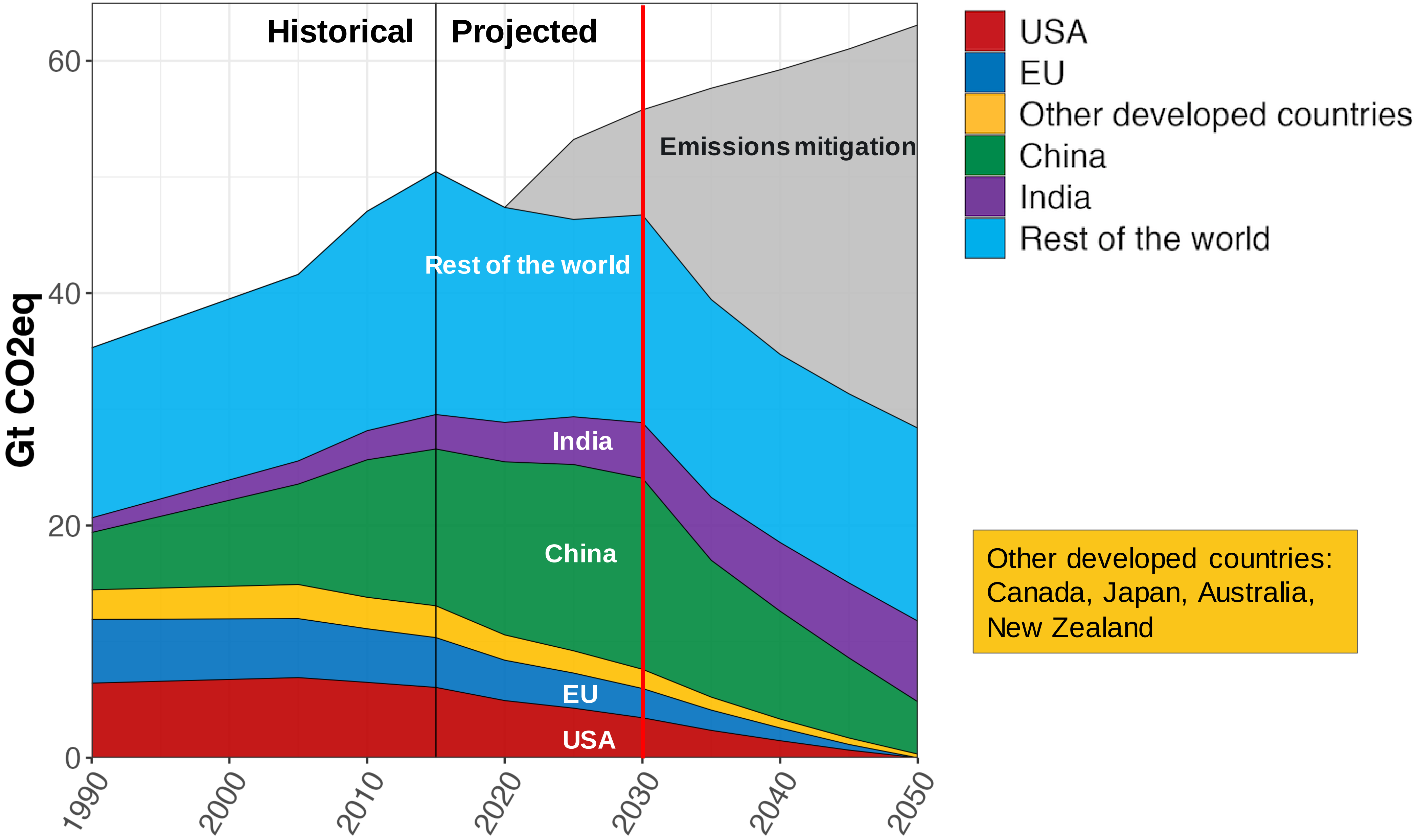
Other developed countries: Canada, Japan, Australia, New Zealand

Global GHG emissions: Updated Pledges Continued Ambition



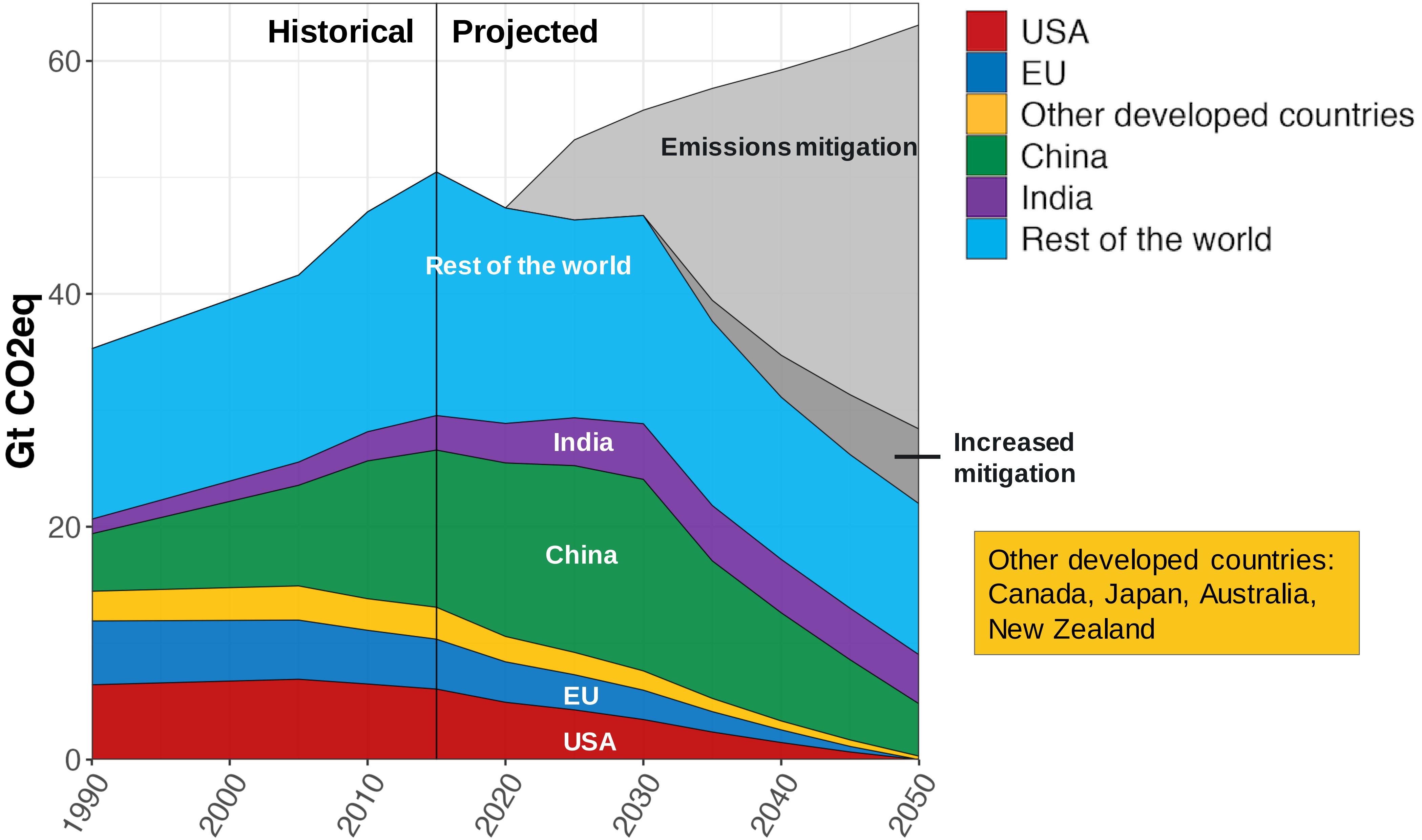
Other developed countries: Canada, Japan, Australia, New Zealand

Global GHG: remaining emissions



Other developed countries: Canada, Japan, Australia, New Zealand

Global GHG emissions: Updated Pledges Increased Ambition



Other developed countries: Canada, Japan, Australia, New Zealand

CLIMATE POLICY

Can updated climate pledges limit warming well below 2°C?

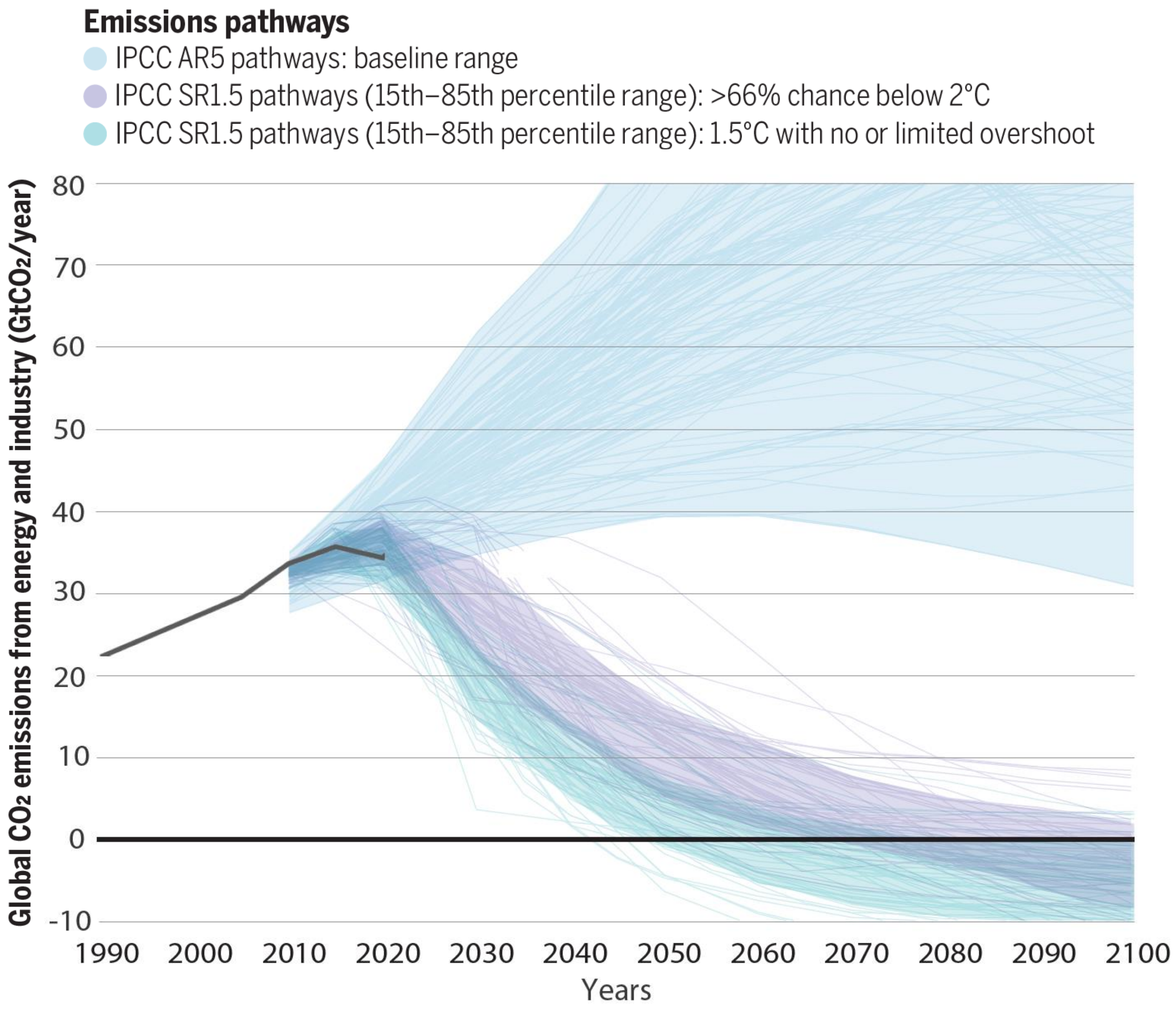
Increased ambition and implementation are essential

By **Yang Ou[1], Gokul Iyer[1]*, Leon Clarke[2], Jae Edmonds[1], Allen A. Fawcett[4], Nathan Hultman[2,3], James R. McFarland[4], Matthew Binsted[1], Ryna Cui[2], Claire Fyson[5], Andreas Geiges[5], Sofia Gonzales-Zuñiga[6], Matthew J. Gidden[5,7], Niklas Höhne[8,9], Louise Jeffery[6], Takeshi Kuramochi[8,10], Jared Lewis[11,12,13], Malte Meinshausen[11,12,13], Zebedee Nicholls[11,12,13], Pralit Patel[1], Shaun Ragnauth[4], Joeri Rogelj[7,14], Stephanie Waldhoff[1], Sha Yu[1], Haewon McJeon[1]**

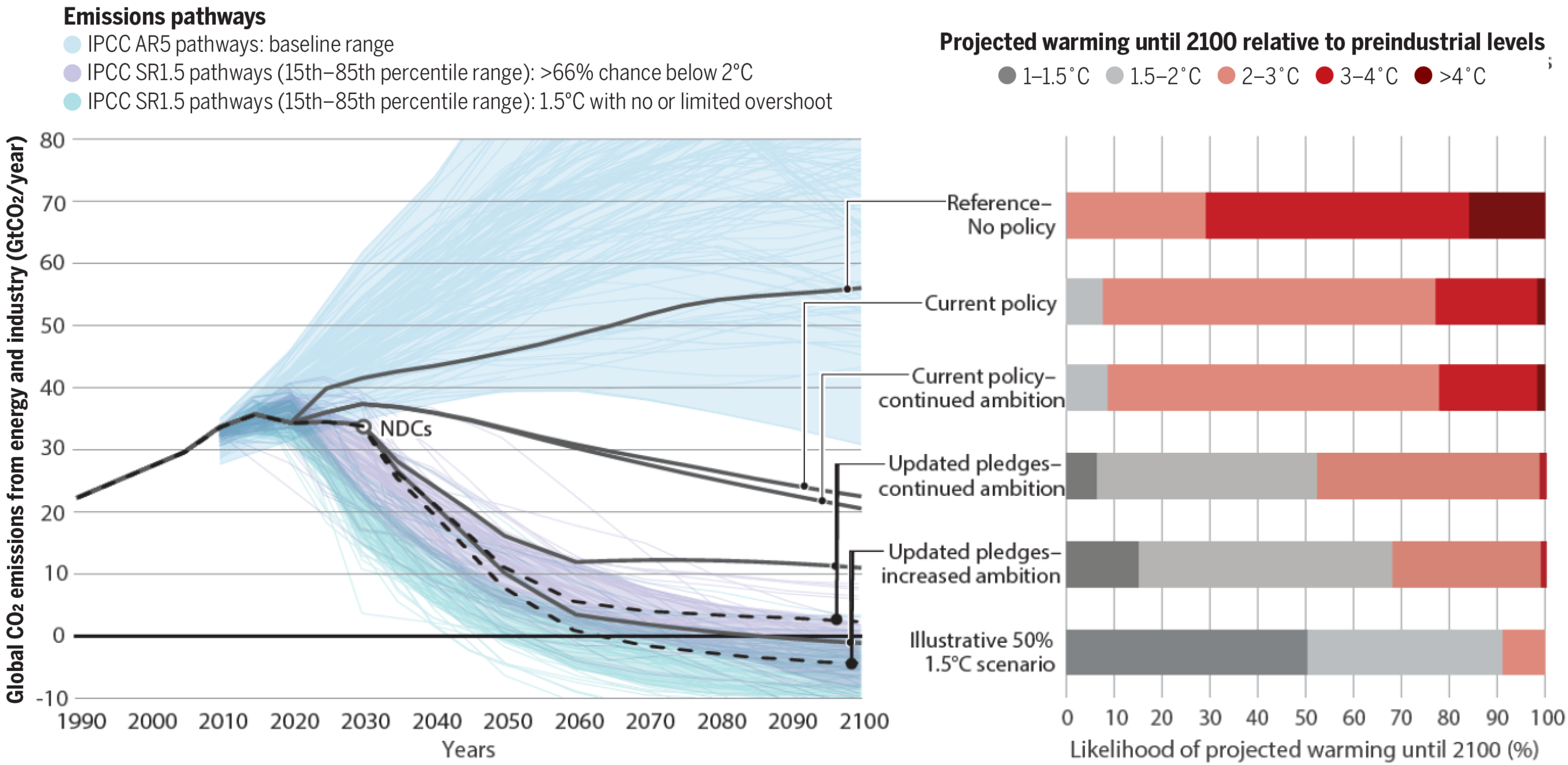
[1]Joint Global Change Research Institute, Pacific Northwest National Laboratory and University of Maryland, College Park, MD, USA. [2]Center for Global Sustainability, School of Public Policy, University of Maryland, College Park, MD, USA. [3]US Department of State, Washington, DC 20520, USA. [4]US Environmental Protection Agency, Washington, DC, USA. [5]Climate Analytics, Berlin, Germany. [6]NewClimate Institute, Berlin, Germany. [7]International Institute for Applied Systems Analysis, Laxenburg, Austria. [8]NewClimate Institute, Cologne, Germany. [9]Environmental Systems Analysis Group, Wageningen University and Research, Wageningen, Netherlands. [10]Copernicus Institute of Sustainable Development, Utrecht University, Utrecht, Netherlands. [11]Australian-German Climate and Energy College, The University of Melbourne, Parkville, Victoria, Australia. [12]School of Geography, Earth and Atmospheric Sciences, The University of Melbourne, Parkville, Victoria, Australia. [13]Climate Resource, Northcote, Victoria, Australia. [14]Grantham Institute, Imperial College London, London, UK. Email: hmcjeon@pnnl.gov

* Co-lead author

Using GCAM, we constructed emissions pathways. Using a simple climate model (MAGICC) in a probabilistic setup, we evaluated temperature distributions in 2100



Temperature distributions after accounting for pledges submitted during and after COP-21 are improved



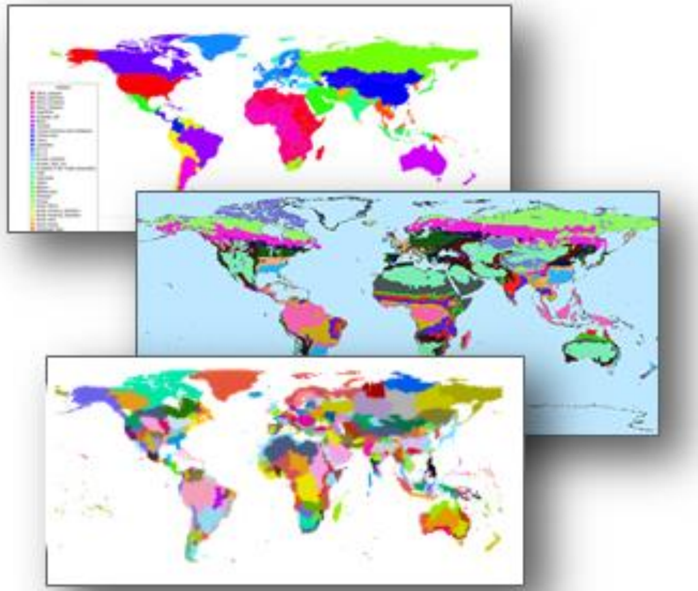
Key Takeaways

- Collectively, the updated and new 2021 climate pledges are stronger than the 2015 pledges
- There's more than 50% chance that the temperature will remain below 2 degrees if these pledges are implemented as stated
- If combined with increased ambition, the probability under 2 degrees can be increased to close to 70%
- However, the pledges still fall far short of achieving 1.5 degrees with a reasonable chance

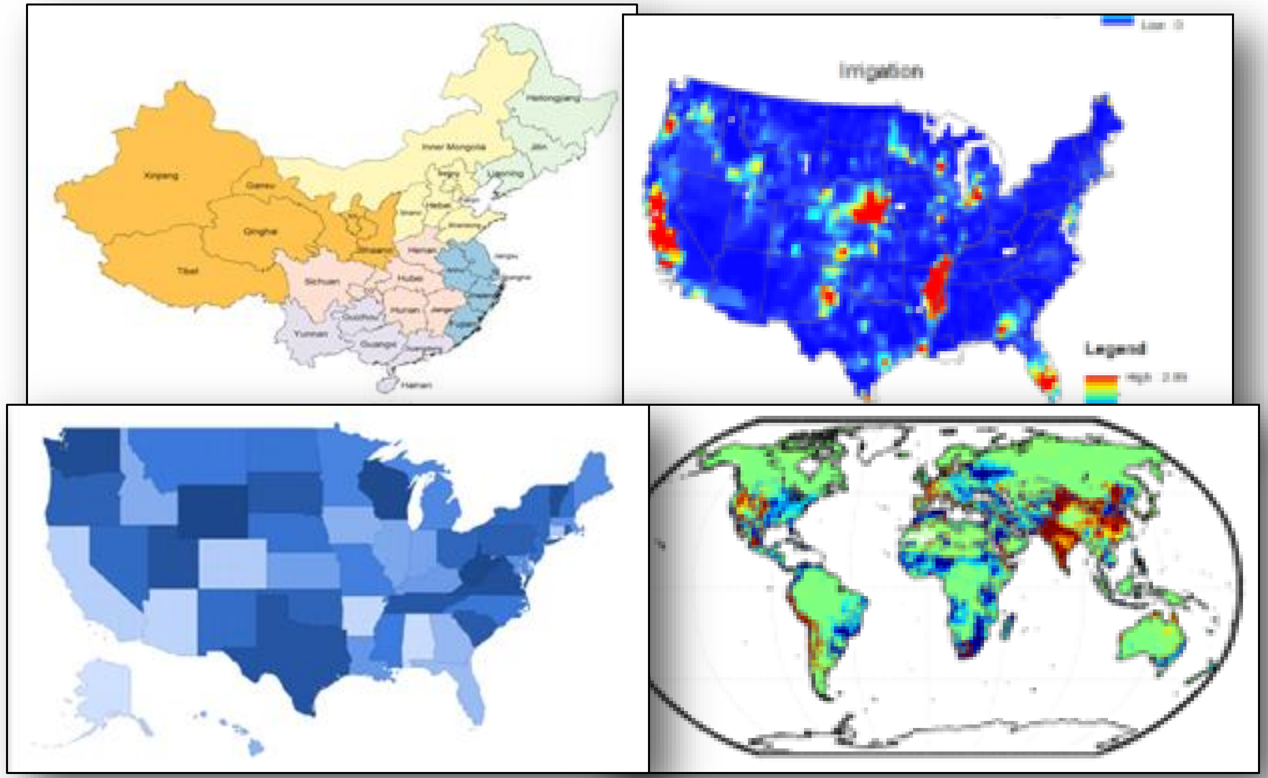
Broad context – increasing details in IAM

- **Regional**
- Temporal
- Sectoral

Global Modeling



Flexible Scale



Current examples

GCAM-USA; GCAM-China; GCAM-Canada; GCAM-India; GCAM-SEAsia; GCAM-LAC; City Scale Modeling

Flexible Time Scale

GCAM Core runs at 5 years; capability to run at one year; ancillary models run at finer scale

Strengths and weaknesses of detailed IAMs compared to global IAMs

Strengths:
- Capture regional heterogeneity within a country
- Analyze subnational policy / action
- Explore interactions between states/provinces
- More policy relevant

Weaknesses

- Data intensive, more difficult to calibrate
- Greater memory requirements
- Longer runtime
- Solution challenges

```
Writing restart file: ./restart/restart.21... Done.
All model periods solved correctly.
Full Scenario 3291.92 seconds.
Bisection solver 2833.1 seconds.
Broyden Solver 1681.44 seconds.
Jacobian calcs 861.19 seconds.
Partial function evaluations 759.77 seconds.
Full function evaluations 338.673 seconds.
Jacobian Preconditioner (overlaps with Jacobian) 5.0112
Jacobian Preconditioner Jacobian overlap 4.09238 second
EDFUN miscellaneous 9.19742 seconds.
EDFUN before world->calc 2.24336 seconds.
EDFUN after world->calc 6.92007 seconds.
EDFUN affected nodes reset 93.8131 seconds.
Model run completed.
Data Readin & Initial Model Run Time: 3431.52 seconds.
Printing output
Starting output to XML Database.
Data Readin, Model Run & Write Time: 3655.42 seconds.
Write time:  223.899 seconds.
Model run completed.
Model exiting successfully.

EDFUN before world->calc 28.8265 seconds.
EDFUN after world->calc 72.6091 seconds.
EDFUN affected nodes reset 713.426 seconds.
Model run completed.
Data Readin & Initial Model Run Time: 31662.1 seconds.
Printing output
Starting output to XML Database.
Data Readin, Model Run & Write Time: 31929.3 seconds.
Write time:  267.178 seconds.
Model run completed.
Model exiting successfully.
```

Unique features of GCAM-China

Socioeconomics at the provincial level

- Population
- GDP

Energy transformation at the provincial level

- Electricity generation and refining by province
- Electricity trade within 6 grid regions

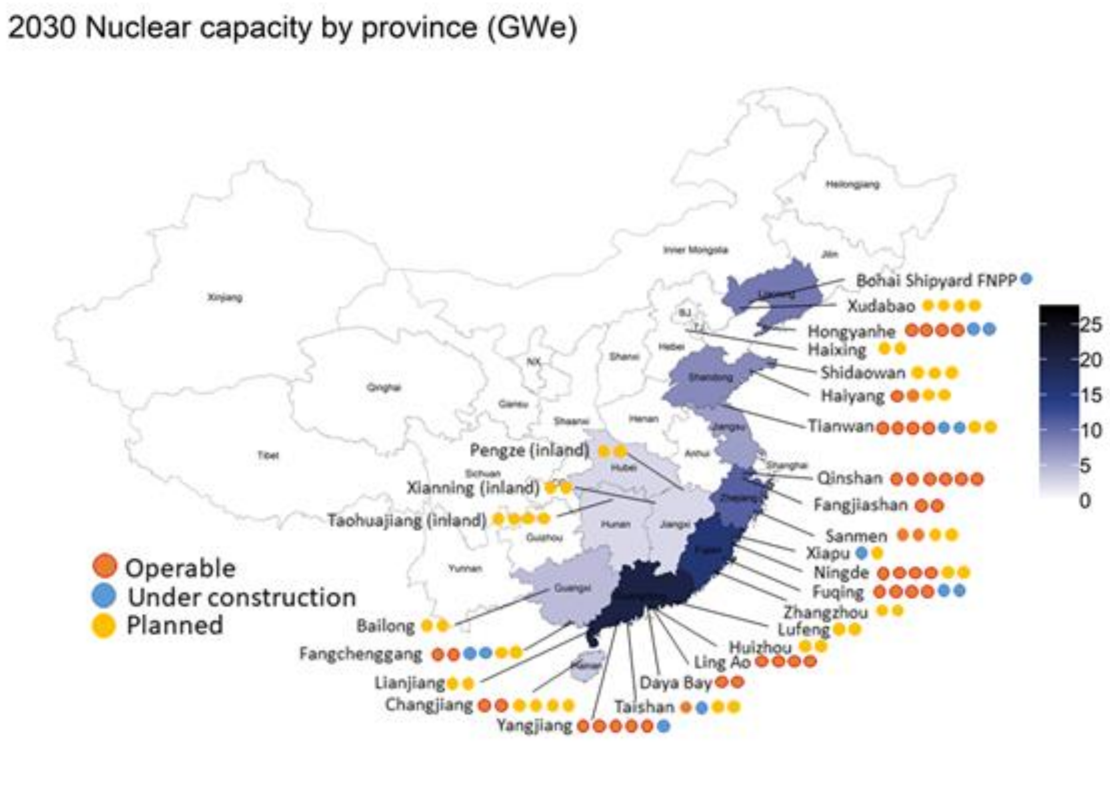
Renewable and carbon storage at provincial level

- Wind and solar
- Carbon storage

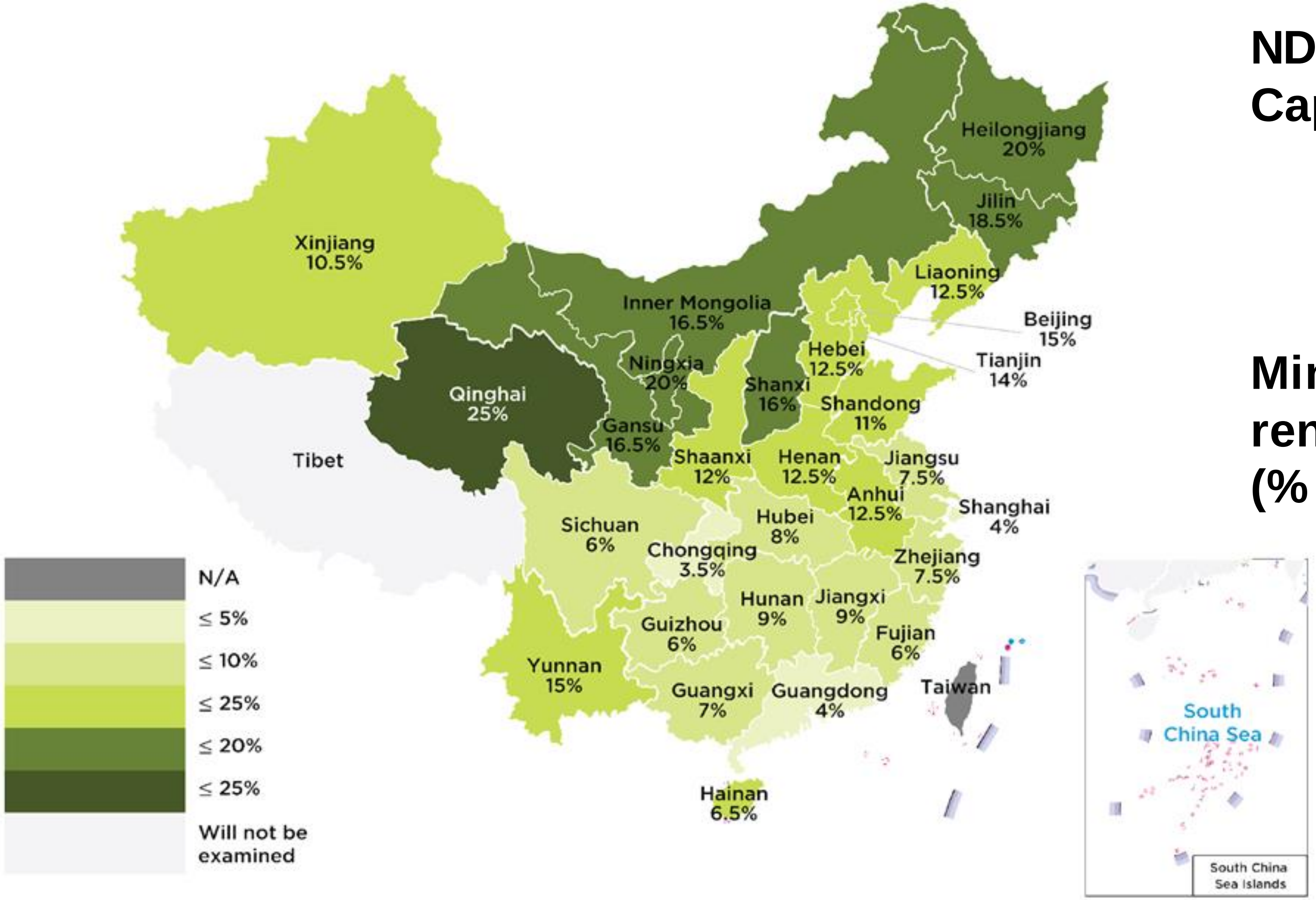
Coal and nuclear power generation at the plant level

Final energy demand at the provincial level

- Buildings: commercial, urban residential, and rural residential
- Transportation: passenger & freight with detailed technologies
- Industry: 9 subsectors



Policies: Renewable deployment in China



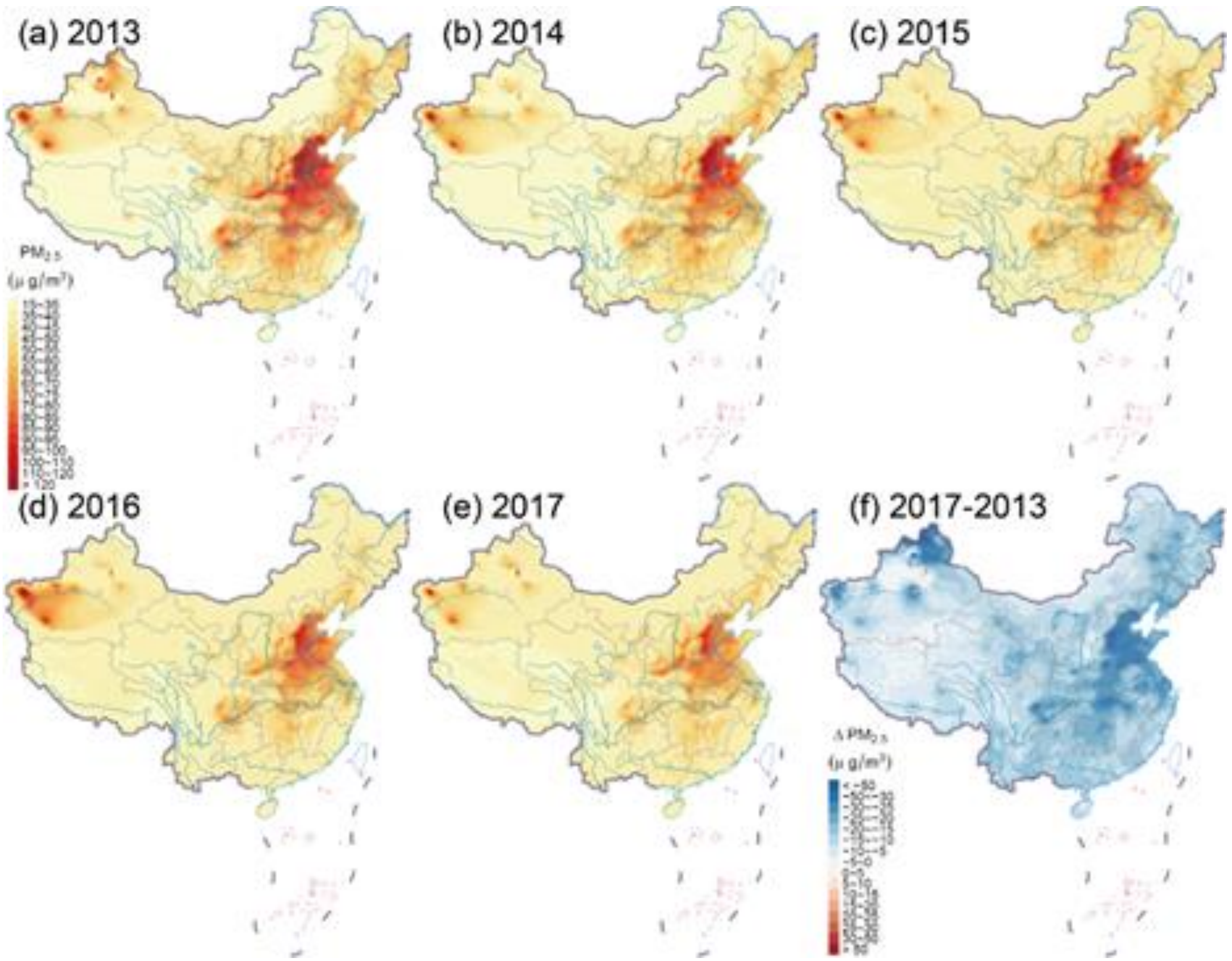
NDC: 1200 GW Solar and Wind Capacity by 2030

Minimum provincial non-hydro renewable obligation (% of generation)

Sources: National Energy Administration, June 2020.
https://www.energypolicy.columbia.edu/research/commentary/trends-and-contradictions-china-s-renewable-energy-policy.

Example: Co-benefits of Air Quality and Climate Policies

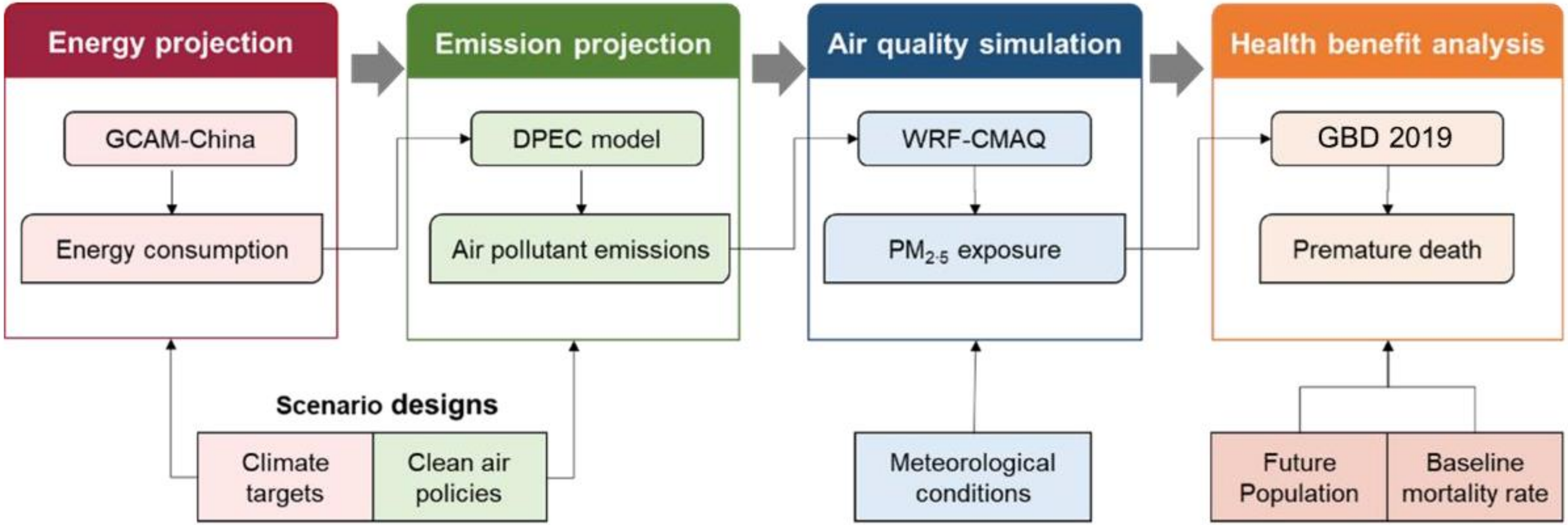
With the implementation of the Clean Air Action, PM2.5 exposure in China has been decreased by 32% during 2013-2017 (from 67 ug/m3 to 45 ug/m3), leading to a 14% reduction in premature deaths due to long-term exposure (from 1.2 million in 2013 to 1.0 million in 2017).



Pollution reductions during 2013-2017 were mainly benefited from strict end-of-pipe control measures by the implementation of the Action Plan. The roles of energy-climate policy are positive but minor.

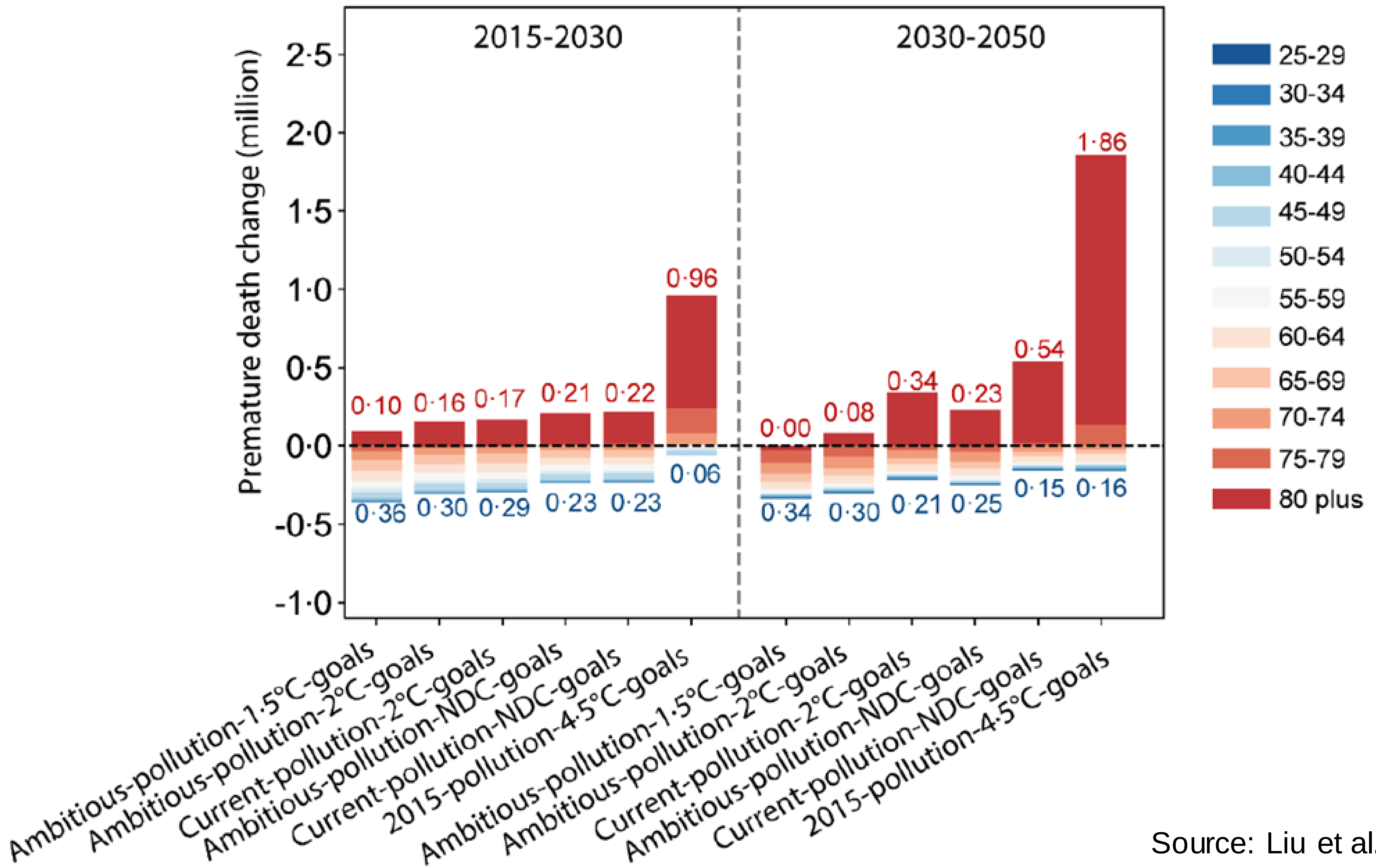
What has worked to reduce emissions and mortality in the past may be less effective in the future.

Example: Model Coupling to Study Health Co-benefits



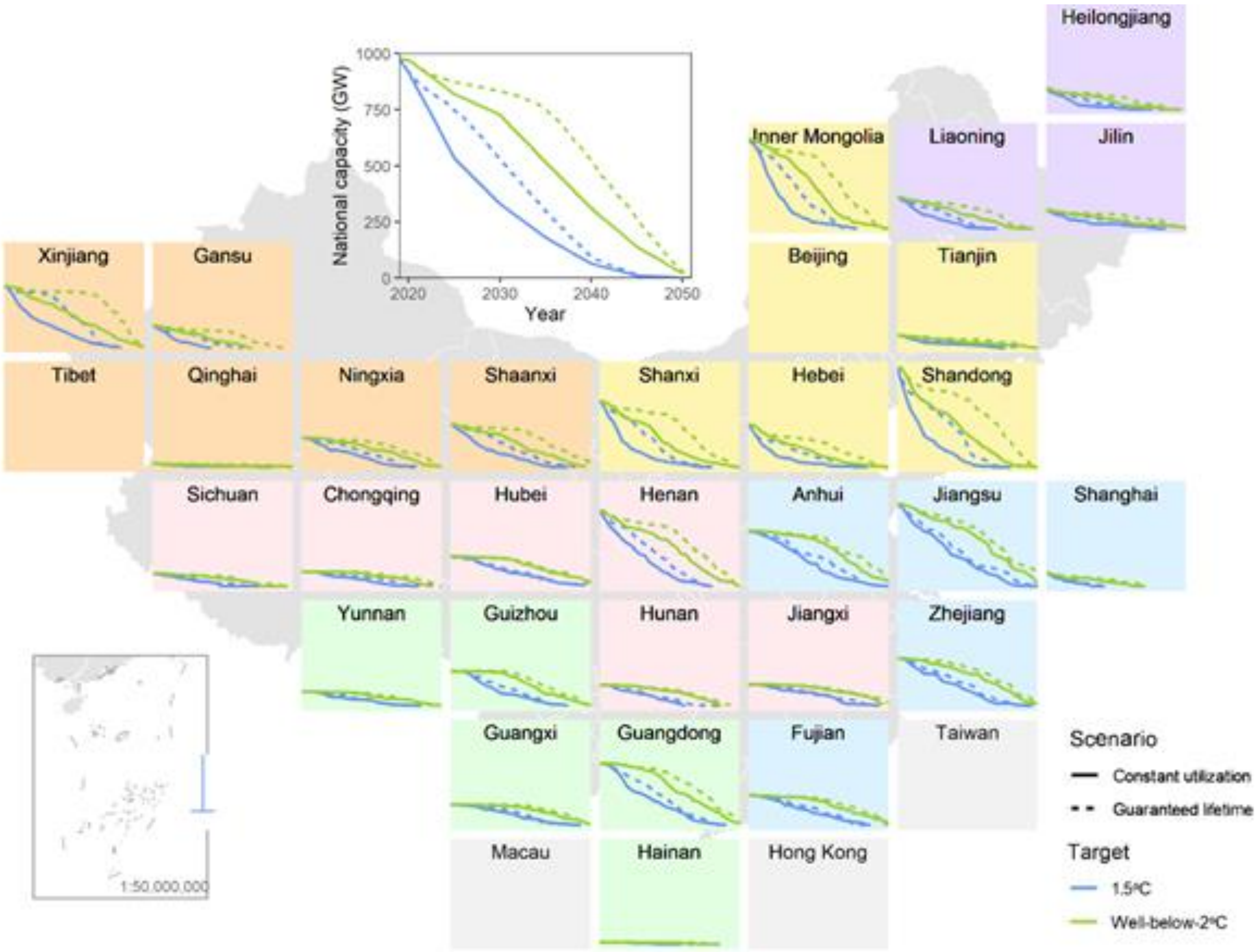
Source: Liu et al. Under Review

Example: Model Coupling to Study Health Co-benefits



Source: Liu et al. Under Review

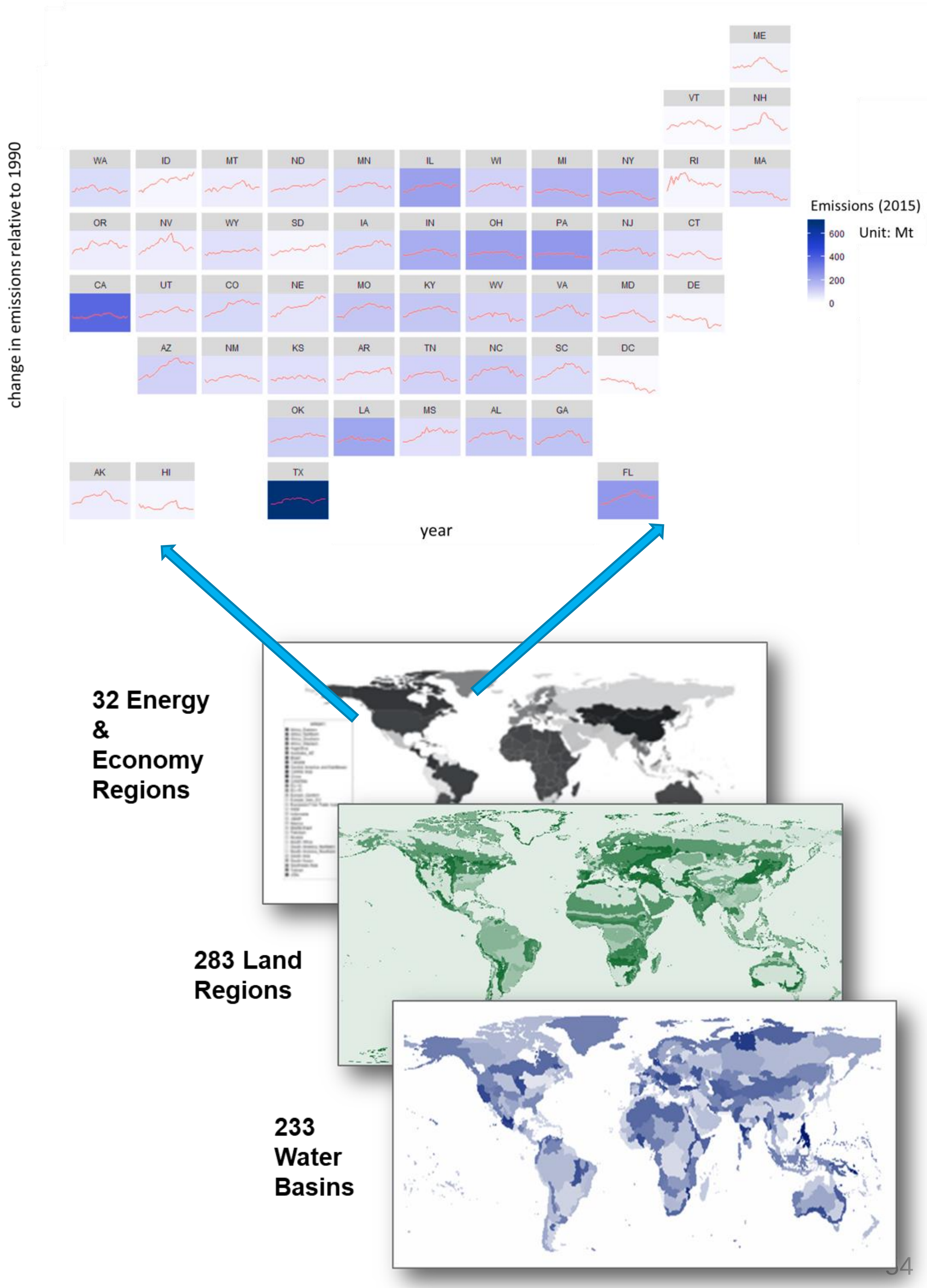
Example: Finding Feasible Coal Phaseout Pathways



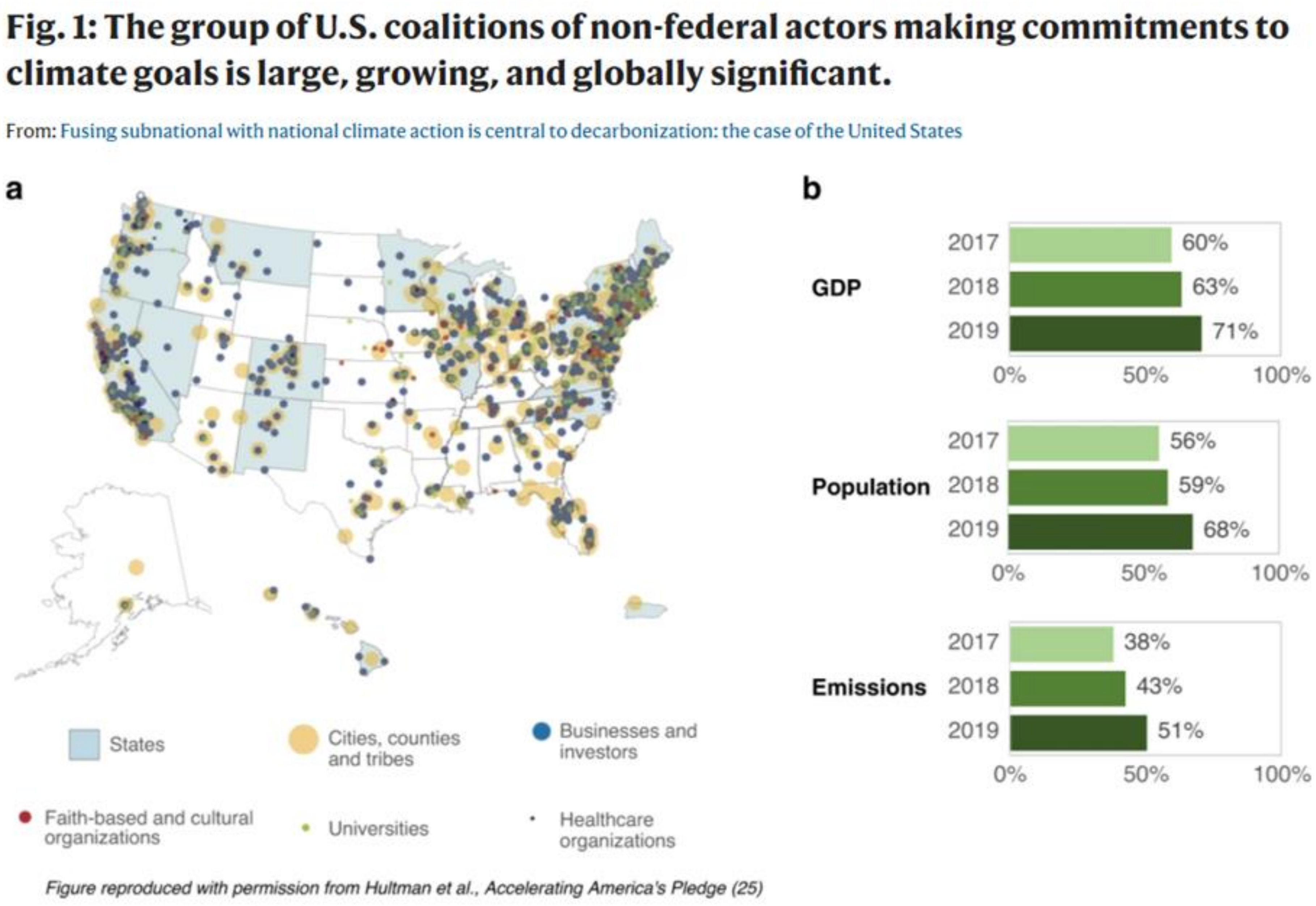
Source: Cui et al. 2021.

GCAM-USA

- GCAM: Global Change Assessment Model
  - Integrated Assessment Model of **Economic, Energy, Land-use, Water, Emissions** and **Climate** systems
  - Modeling of future emissions scenarios to **2100**
  - Emissions of 16 greenhouse gases and short-lived species
  - GCAM is an open-source community model
- GCAM-USA is a version of GCAM with state-level detail in the United States.
- The 50-state version is embedded within the global version of GCAM.
- It is actively being used to explore energy-water-land interactions and conduct policy analysis



Subnational actors in climate mitigation

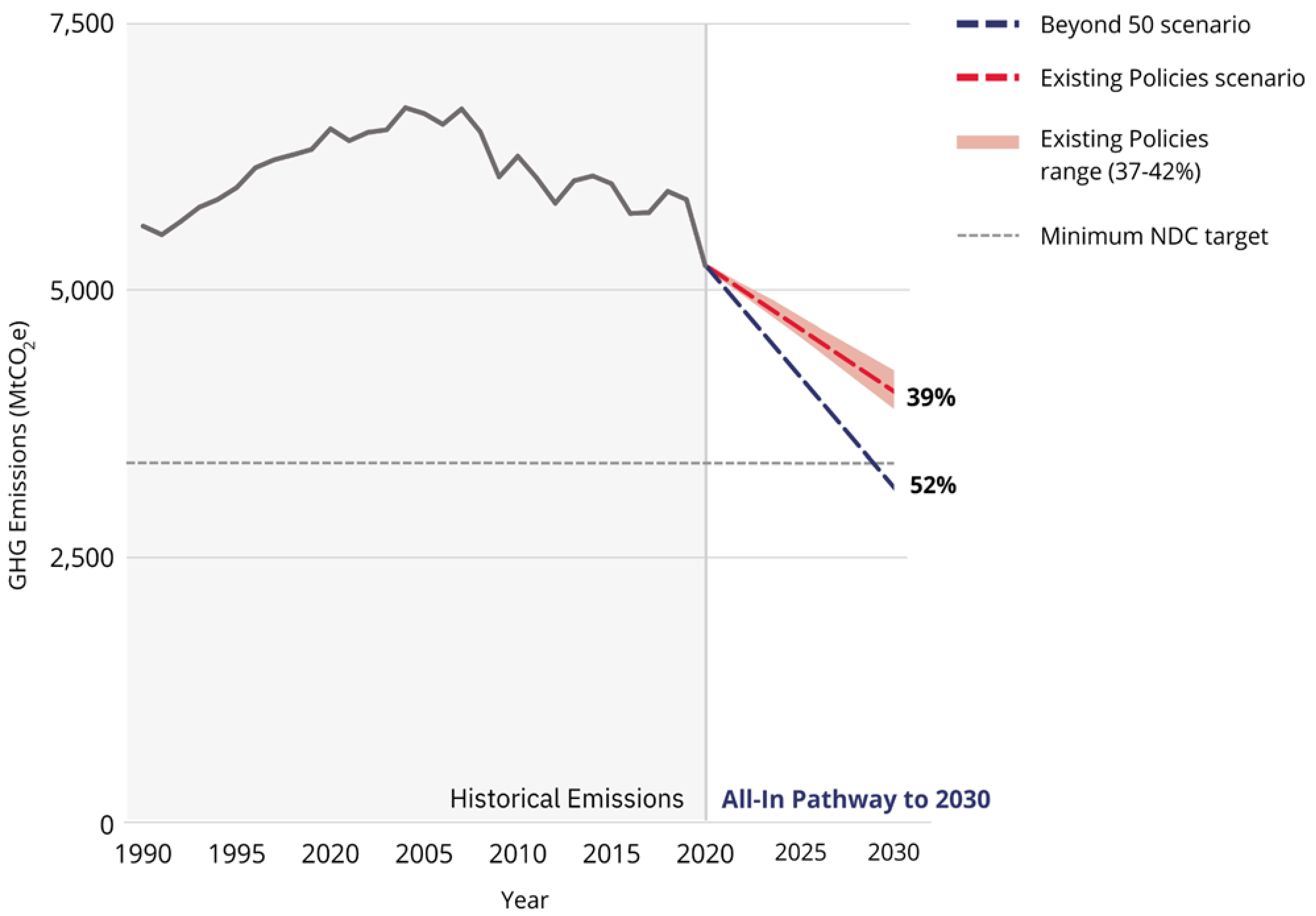


Hultman, N.E., Clarke, L., Frisch, C. *et al.* Fusing subnational with national climate action is central to decarbonization: the case of the United States. *Nat Commun* **11,** 5255 (2020). https://doi.org/10.1038/s41467-020-18903-w. Fig. 1.

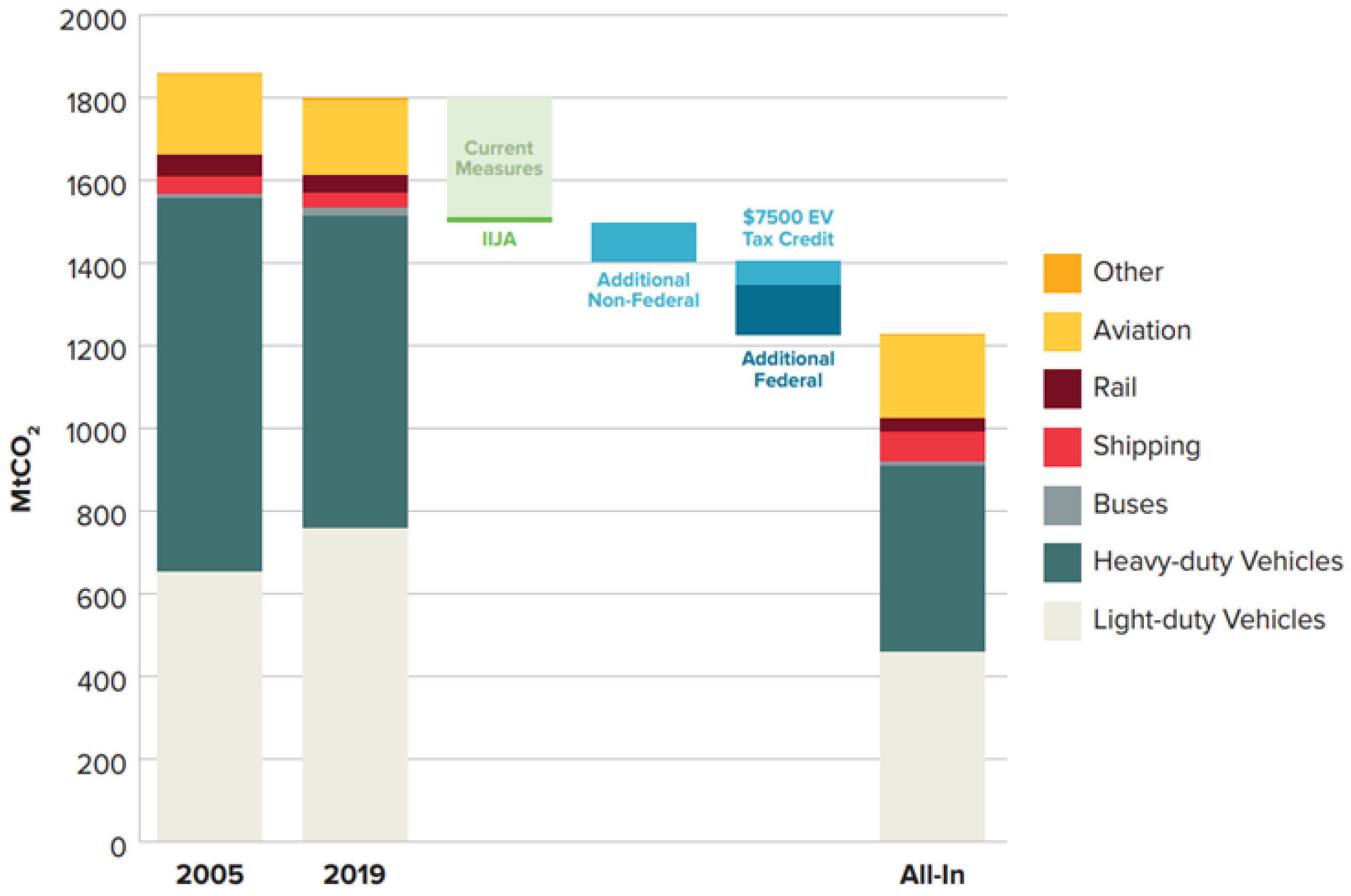
Emissions reductions under an "all-in" climate pathway to achieve the U.S. climate target by 2030

The existing policies scenario shows a majority of reductions from the energy and transportation sectors, with significant additional reductions from methane, largely driven by IRA, **can achieve 39% reductions by 2030** from 2005 levels with potential for 42% reductions with accelerated implementation.

The Beyond 50 scenario incorporates the climate-smart application of IRA from primarily states, with an all-of-society, accelerated approach to a national climate strategy and **shows a pathway for the United States to achieve 52% emissions reductions from 2005 levels by 2030.**



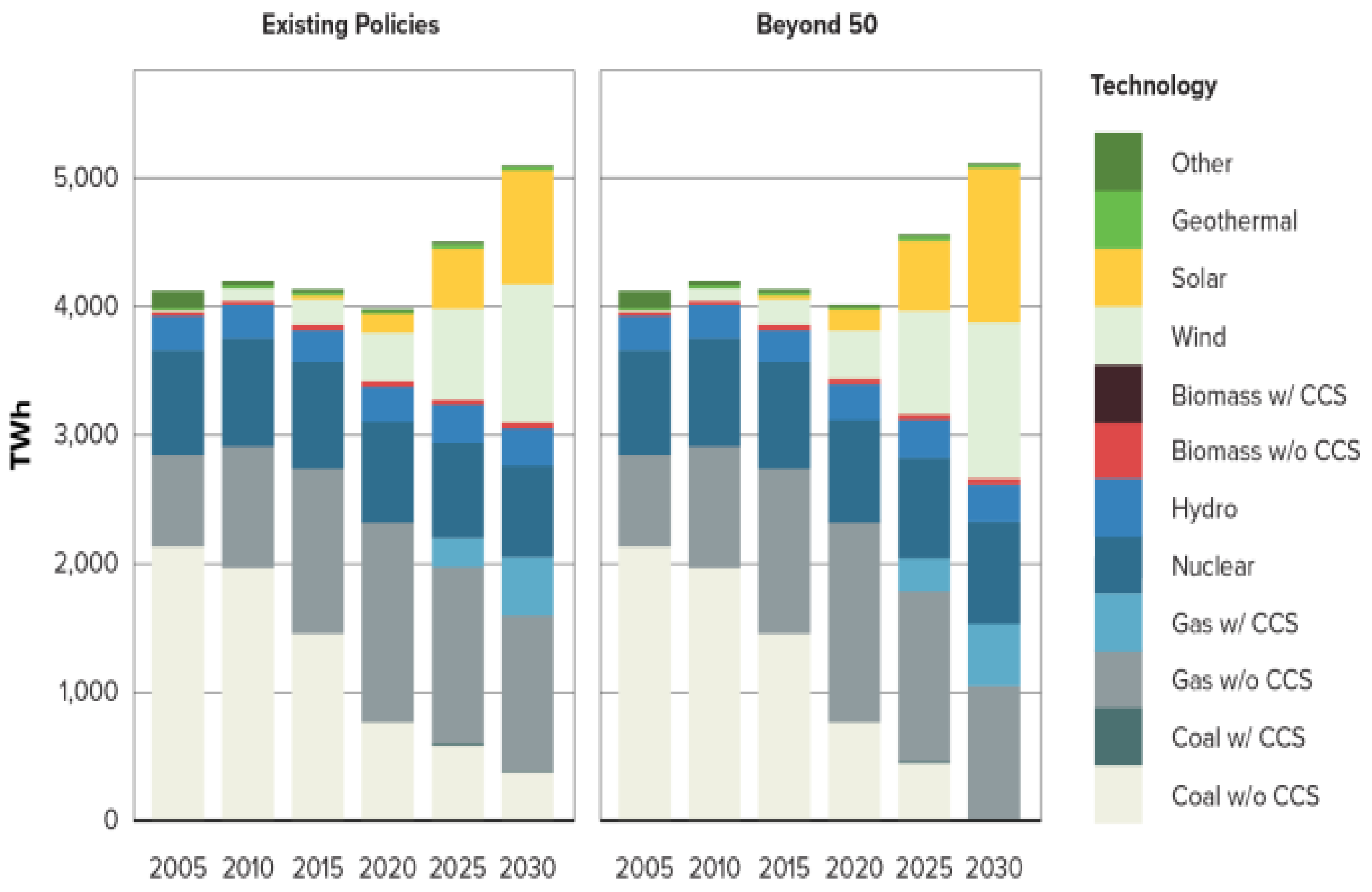
Transport report shows contribution of federal and non-federal actors to achieve NDC



- Transportation emissions need to decrease by 34% to meet the NDC
- Current Measures reduce emissions by 350 $MtCO_2$ (**19%**)
- Remaining 15% must come from non-federal and federal actors
  - Non-federal action: 92 $MtCO_2$ (**5%**)
  - Congressional EV tax credit: 55 $MtCO_2$ (**3%**)
  - Additional federal actions: 120 $MtCO_2$ (**7%**)
- 97% of reductions occur in light-duty and heavy-duty vehicles

Zhao, A., McJeon, H., Cui, R., Cyrs, T., Feldmann, J., Iyer, G., Kathleen Kennedy, Kevin Kennedy, S. Kennedy, O'Keefe, K., Rajpurohit, S., Rowland, L., & Hultman, N. (2022). *An "All-In" pathway to 2030: Transportation sector emissions reduction potential*. Center for Global Sustainability, University of Maryland and America Is All In. Available at www.AmericaIsAllIn.com. 8pp.

Power sector results



Existing policies reaches 71% clean electricity by 2030.

- IRA tax credits for renewables, CCS, hydrogen
- Energy Investment Refinancing program
- State- and city-level renewable energy targets

Beyond 50 reaches 80% clean electricity by 2030

- Coal phaseout
- More ambitious state- and city-level

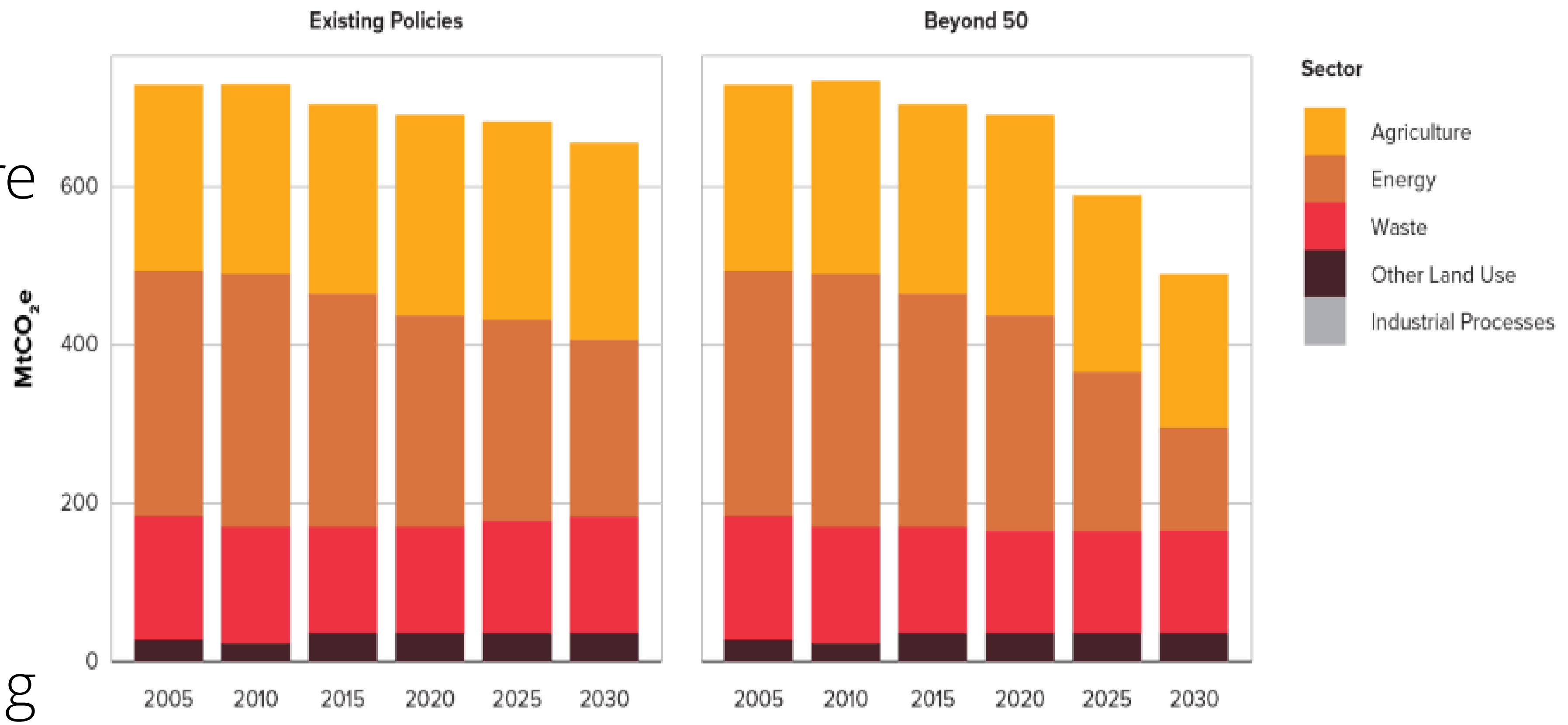
Methane sector results

Existing policies achieves 10% reductions in methane emissions from 2020 levels

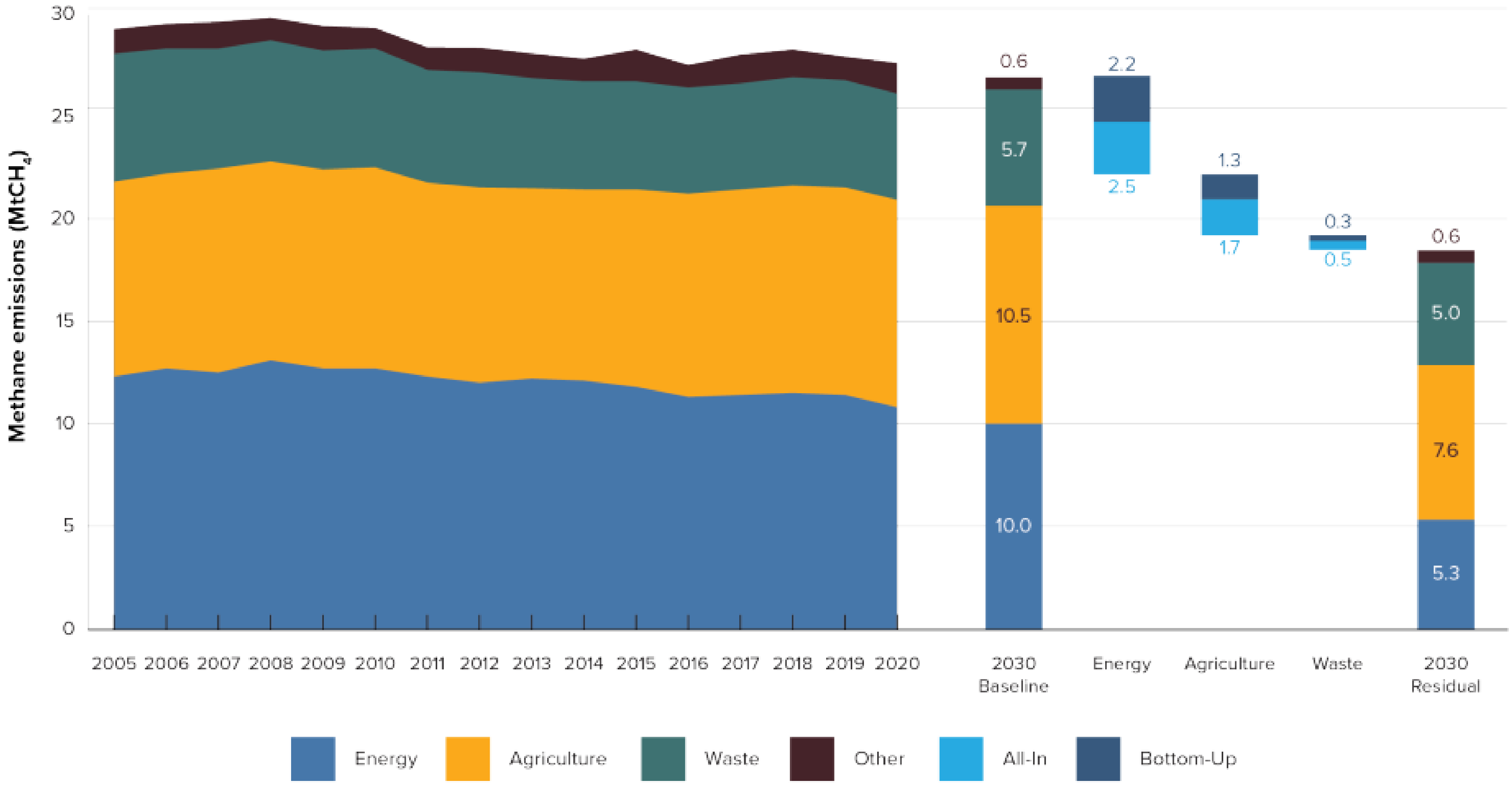
- IRA oil and gas methane fee
- IRA methane-specific agriculture provisions

Beyond 50 achieves over 30% reductions

- Methane fee across all sectors
- Strengthened EPA regulations on oil and gas methane
- State-level standards on existing and new oil and gas sources, emissions standards in the agriculture sector and implementation of agricultural



Methane report shows contribution of federal and non-federal actors to achieve NDC



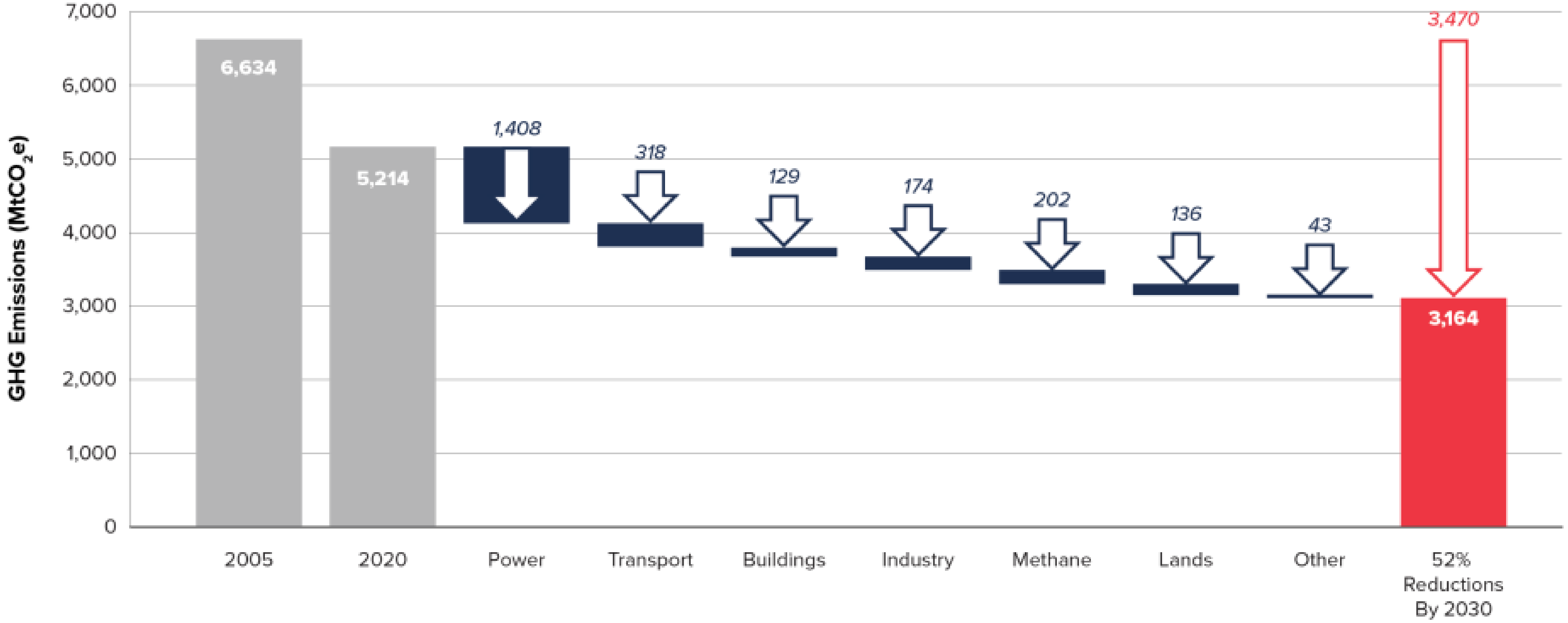
- Non-federal action achieves nearly 16% methane emissions reductions below 2020 levels by 2030
- With federal action, we can achieve over 30%

Zhao, A., K. O'Keefe, H. McJeon, K. Clark-Sutton, R. Cui, J. Feldmann, Kathleen Kennedy, Kevin Kennedy, S. Kennedy, J. Meisel, D. Nilov, S. Rajpurohit, N. Hultman (2022). "An 'All-In' Pathway To 2030: U.S. Methane Sector Emissions Reduction Potential." Center for Global Sustainability, University of Maryland and America Is All In. 16 pp.

GETTING TO 52%: KEY POLICIES				
	FEDERAL GOVERNMENT	STATES	CITIES & TRIBES	BUSINESSES & NGOS
Power	• **Existing Policies:** Production Tax Credit and Investment Tax Credit for renewables • **Beyond 50:** EPA regulations on coal and gas plants	• **Beyond 50:** Accelerated clean energy standards targeting 80% of electricity demand by 2030 • **Beyond 50:** Coal securitization and just transition policies	• **Beyond 50:** City-wide clean electricity goals targeting 100% of demand by 2030	• **Beyond 50:** Utility resource investment and planning to ensure full phaseout of coal generation by 2030
	FEDERAL GOVERNMENT	STATES	CITIES & TRIBES	BUSINESSES & NGOS
Transport	• **Existing Policies:** Clean vehicle tax credits • **Beyond 50:** 100% federal fleet procurement of zero-emission LDVs, light commercial trucks and buses by 2030	• **Beyond 50:** 100% internal combustion engine light-duty vehicle phasedown by 2035 • **Beyond 50:** ZEV mandates for 30-50% new MDV/HDV sales by 2030	• **Beyond 50:** Vehicle miles traveled reductions through planning, low- and zero-emissions zones, decongestion pricing, other mechanisms	• **Beyond 50:** Major auto manufacturers on-track to 100% ZEVs for new LDV sales by 2035
	FEDERAL GOVERNMENT	STATES	CITIES & TRIBES	BUSINESSES & NGOS
Methane	• **Beyond 50:** Methane fee on all sectors • **Beyond 50:** More stringent EPA regulations on oil and gas facilities	• **Beyond 50:** Methane emissions standards on oil and gas sources, with extensive leak detection and repair requirements • **Beyond 50:** Implementation of manure management projects, anaerobic digesters, and enteric fermentation mitigation	• **Beyond 50:** Waste reduction goals and infrastructure • **Beyond 50:** Reduction of methane leakage from distribution infrastructure	• **Beyond 50:** Methane emissions reduction goals

Sectoral reductions to get to 52%

- As of today, the U.S. has achieved 21% in reductions
- From today's levels, power sector contributes an additional 16%, transport sector contributes 5%, and methane sector contributes 3%.
- Industry, buildings, lands, and other sectors contribute the remaining 5%



US Model Comparison Study

Presented by Haewon McJeon

U.S. DEPARTMENT OF ENERGY BATTELLE

PNNL is operated by Battelle for the U.S. Department of Energy

CLIMATE POLICY

Actions for reducing US emissions at least 50% by 2030

Policies must help decarbonize power and transport sectors

By **John Bistline[1], Nikit Abhyankar[2], Geoffrey Blanford[1], Leon Clarke[3,4], Rachel Fakhry[5], Haewon McJeon[3,6], John Reilly[7], Christopher Roney[1], Tom Wilson[1], Mei Yuan[7], Alicia Zhao[3]**

gets. Some models use a top-down approach to identify least-cost emission reduction actions, whereas others use a bottom-up, sector-specific suite of measures and incentives to reflect policy proposals. Comparing

Comparison of Participating Energy Systems Models

Abbr.	Model(s)	Institution	2030 Emissions	Policies Assumed	Study
EDF-NEMS	RHG-NEMS	EDF	51% net GHG reduction from 2005	Suite of sector-specific policies and economy-wide limit on energy CO_2	Link
GCAM-USA-AP	GCAM-USA-AP	PNNL, CGS	50% net GHG reduction from 2005	Bottom-up, sector-specific suite of policies and incentives	Link
LBNL	FACT (transport), ReEDS+PLEXOS (power), EPS (other sectors)	UCB (FACT), NREL (ReEDS), Energy Innovation (EPS)	50% GHG reduction from 2005	▪ 80% federal CES and no new gas in power sector ▪ 100% EV mandates for light-duty and 80% medium-/heavy-duty ▪ Building elec. mandates ▪ CH_4/F-gas reductions	Link
PATHWAYS	RIO (supply-side), EnergyPATHWAYS (demand-side)	Evolved Energy Research	53% net GHG reduction from 2005	State and federal policies on the books as of Q3 2020	Link
REGEN	US-REGEN	EPRI	50% net GHG reduction from 2005	▪ Economy-wide CO_2 cap by 2030 ▪ 2035 electric sector net-zero target	Link
USREP-ReEDS	USREP-ReEDS	MIT, NREL	50% CO_2 reduction from 2005	▪ EE mandates ▪ 50% CO_2 cap by 2030	Link

- Multi-model studies identify which insights are robust and which differ across models
- Models assume different policy pathways to reach the 2030 target

Working list of policies…

- After the publication of the comparison paper, many new climate policies were enacted.
- We're continuously updating the policies to assess the emission impacts.

GETTING TO 52%: KEY POLICIES				
	FEDERAL GOVERNMENT	STATES	CITIES & TRIBES	BUSINESSES & NGOS
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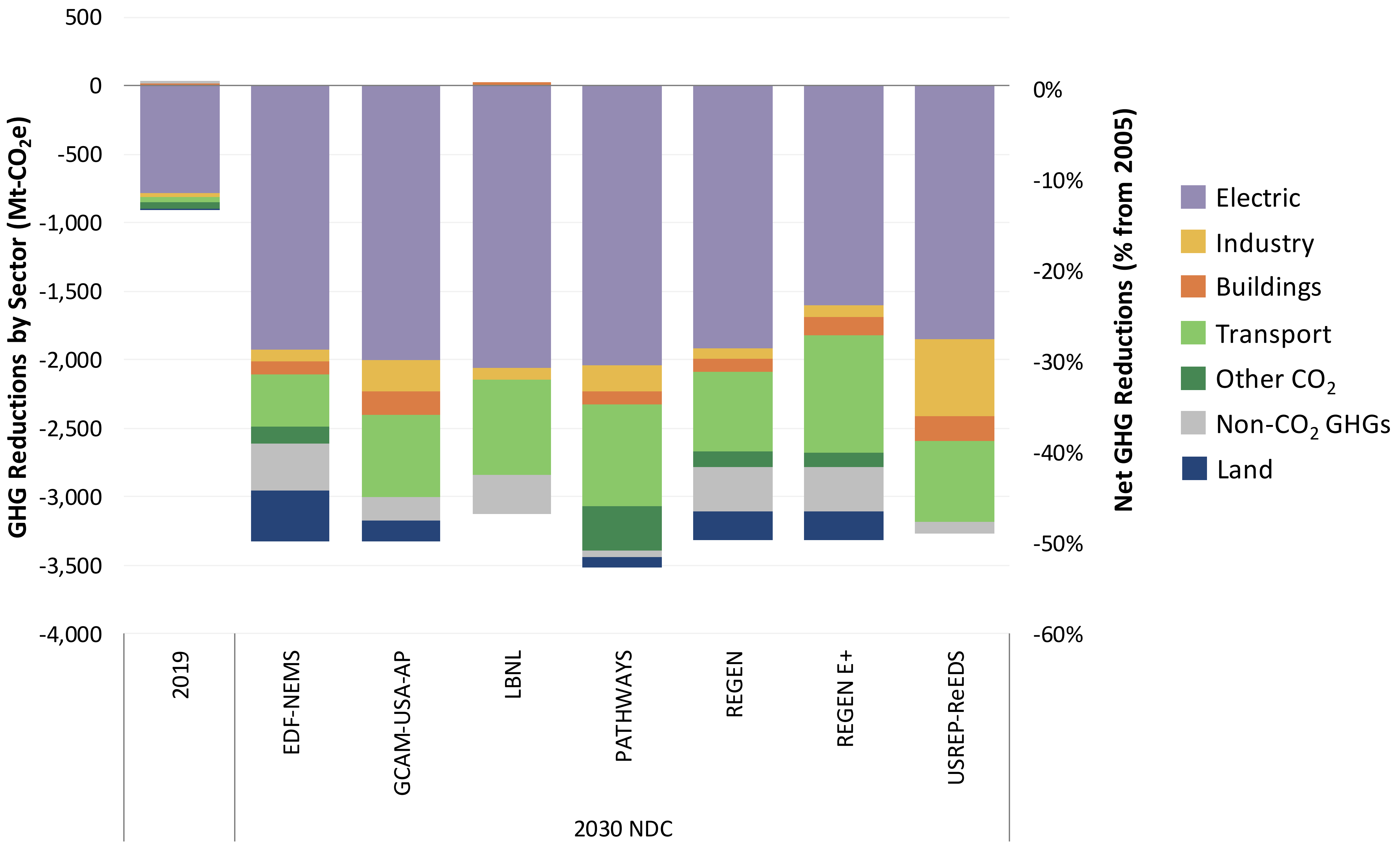
Buildings	• **Existing Policies:** Rebates and incentives to increase efficiency in residential and commercial buildings • **Beyond 50:** Emissions-based building performance standards for federal buildings	• **Beyond 50:** Heightened adoption of stringent EERS standards • **Beyond 50:** Expanded natural gas bans and electrification targets for new buildings	• **Beyond 50:** City stretch codes to accelerate energy savings and phase out gas appliances • **Beyond 50:** Adoption of emissions-based city building performance standards	• **Beyond 50:** Expanded voluntary target setting, benchmarking and other measures • **Beyond 50:** Participation in voluntary ENERGY STAR program
Industry	• **Existing Policies:** 45Q tax credit and hydrogen tax credit to increase use of clean fuels and CCS • **Beyond 50:** "Buy Clean" standards to increase production efficiency, encourage use of clean fuels and CCS	• **Beyond 50:** Heightened Energy Efficiency Resource Standards and International Organization for Standardization 50001 energy management standards • **Beyond 50:** "Buy Clean" standards	• **Beyond 50:** Efficiency targets including industrial facilities/buildings • **Beyond 50:** "Buy Clean"	• **Beyond 50:** Accelerate deployment of green technologies through investments and pilot projects • **Beyond 50:** Electrification goals through retrofits and greenfield projects
Lands	• **Existing Policies:** Investments in forest management, land conservation and ecosystem restoration • **Beyond 50:** Expanded investment in wildfire risk mitigation	• **Beyond 50:** Targeted programs and investment in reforestation, soil carbon sequestration, climate-friendly agricultural practices, and wildfire mitigation • **Beyond 50:** Increased investment in GHG quantification and monitoring	• **Beyond 50:** Expanded urban forestry efforts and fire management practices	• **Beyond 50:** Increased investments in land-based climate mitigation strategies

Results: Sectoral Reductions to Reach 50x30 Targets

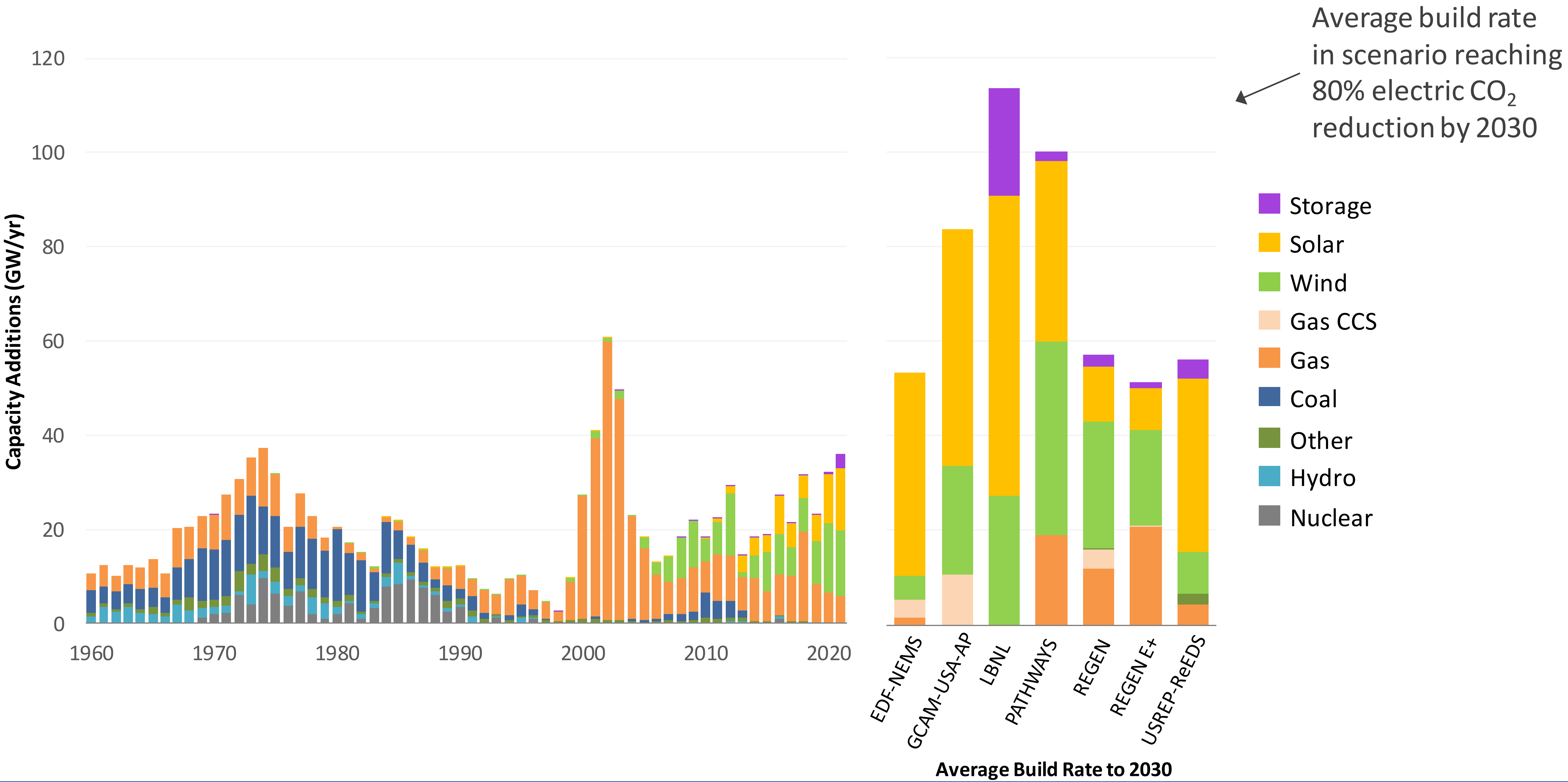


Notes

- Bulk of reductions to reach 2030 target come from the electric sector and transport (~70-90% of 2030 reductions)
- All sectors are involved to varying degrees: Halving GHGs is an "all-hands-on-deck" situation requiring many technology and policy tools

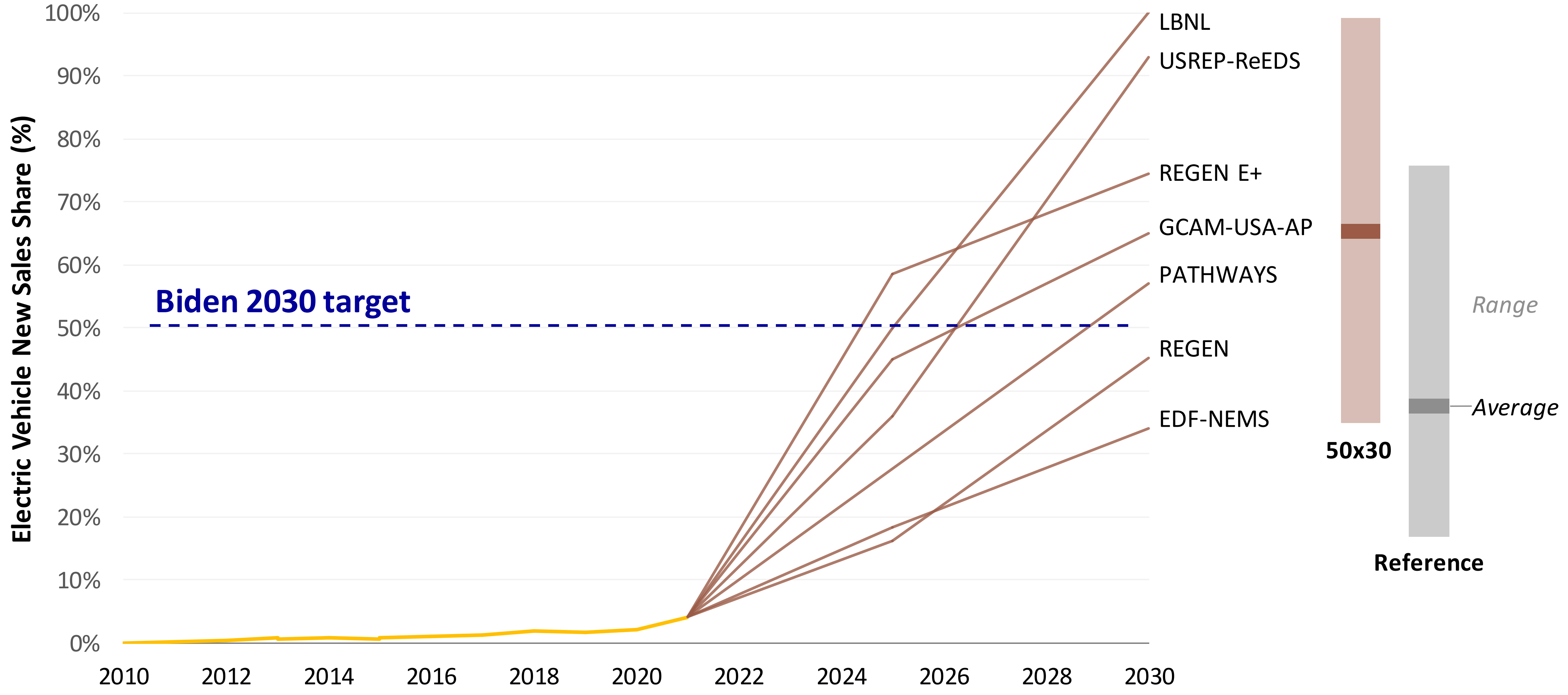
Source: Bistline, et al. (2022), "Actions for Reducing U.S. Emissions at Least 50% by 2030"

What Could It Take? Rapid Buildout of the Grid



Historical maximum additions exceeded each year through 2030, but mix varies across models

What Could It Take? Extensive Electric Vehicle Adoption



EVs projected to reach 34-100% of new sales—10-25x current levels—which is much higher than with current policies and technology trends (i.e., "Reference" scenario)