Energy systems

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PLCY-798K

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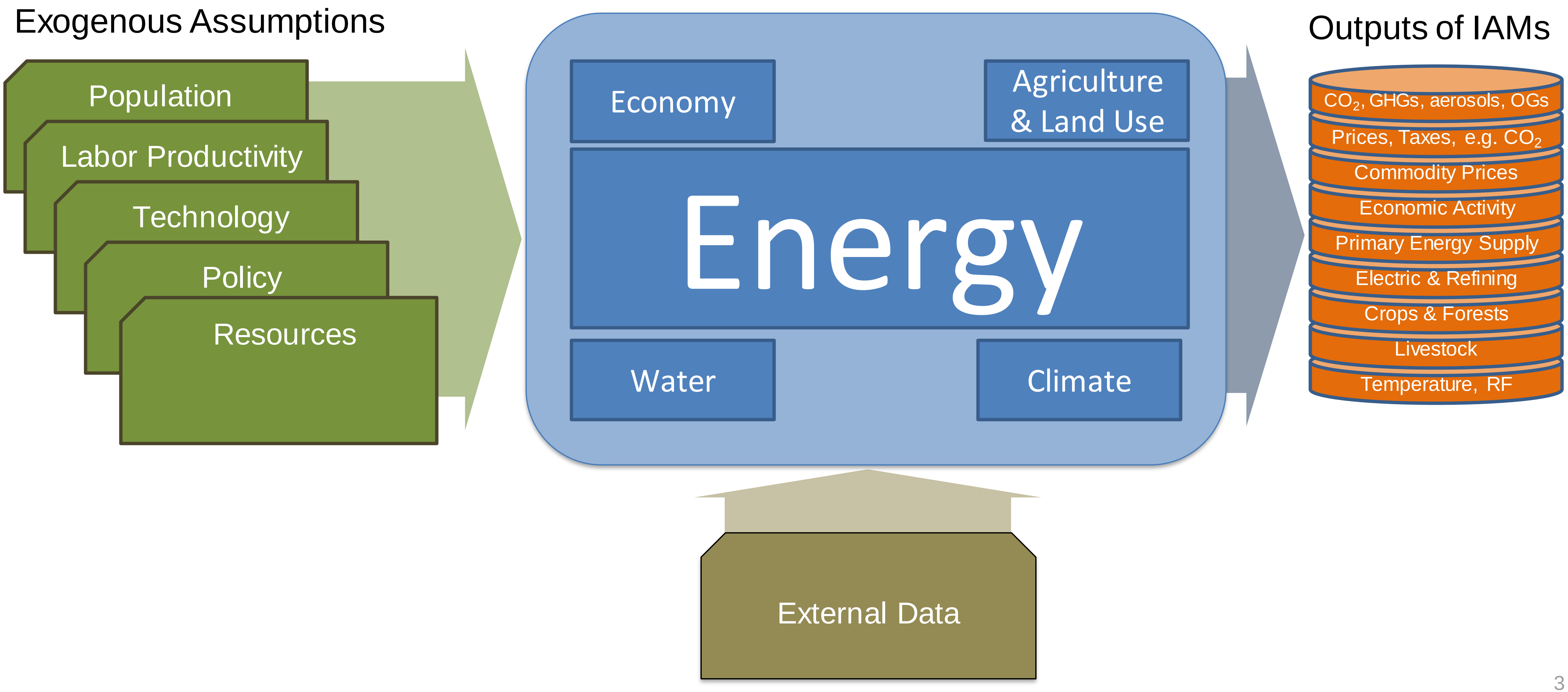
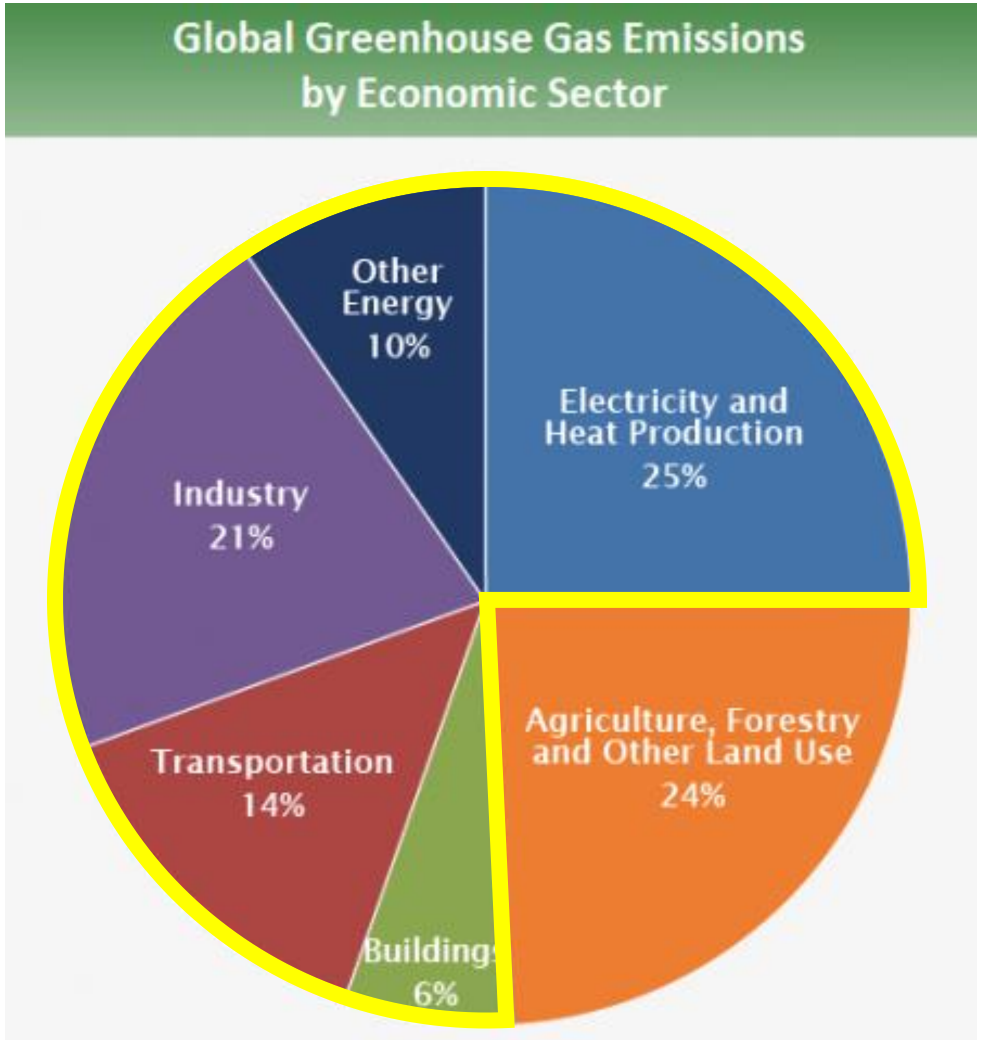
Agenda for today

- Importance of the energy system in integrated assessment modeling
- Components of the energy system
- Quick refreshers
  - Scenarios
  - International climate policy
  - Energy technologies
- Key characteristics of long-term energy system transformations
- Modeling of non-economic factors
- Cutting-edge research in modeling of energy systems in IAMs

The energy system is at the heart of integrated assessment models…

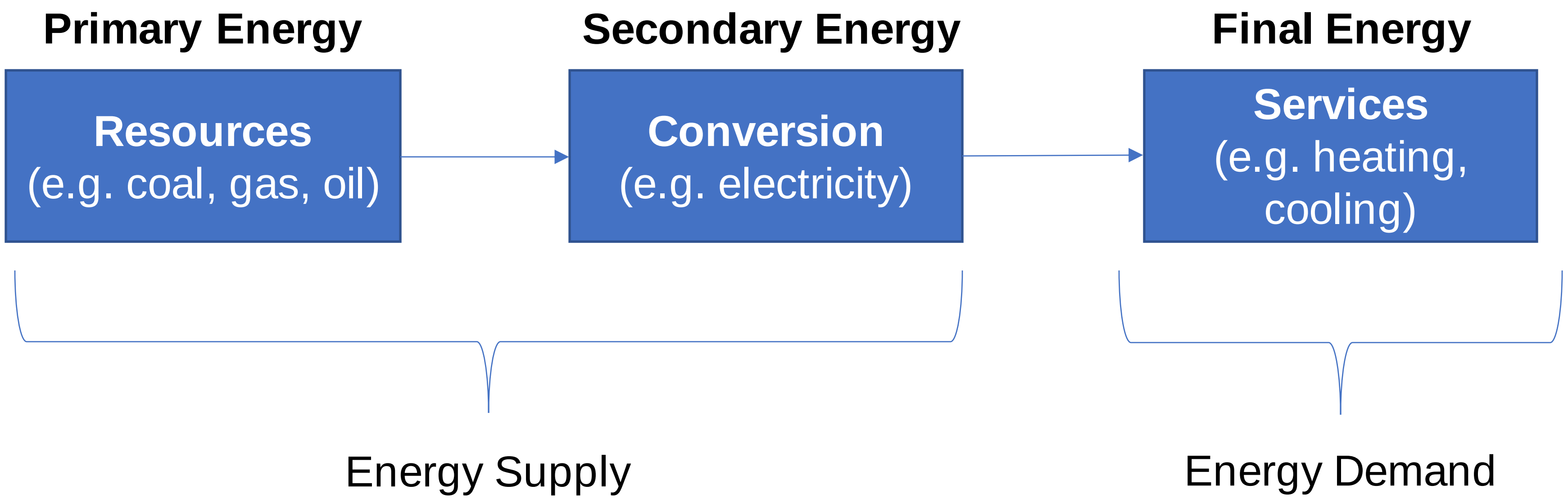


...because the energy system is at the heart of the climate problem…

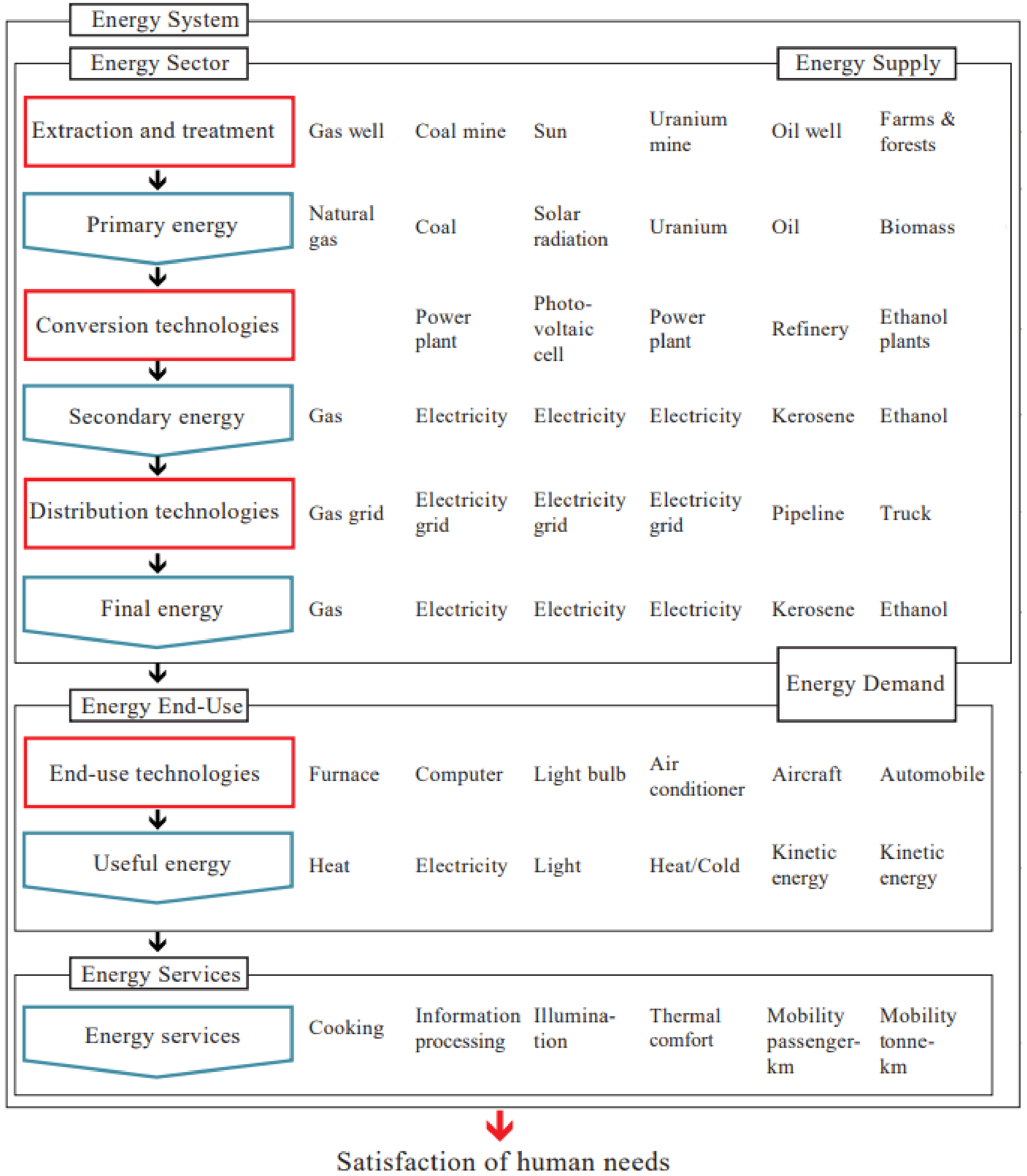


Source: https://www.epa.gov/ghgemissions/global-greenhouse-gas-emissions-data

Three main components of the energy system

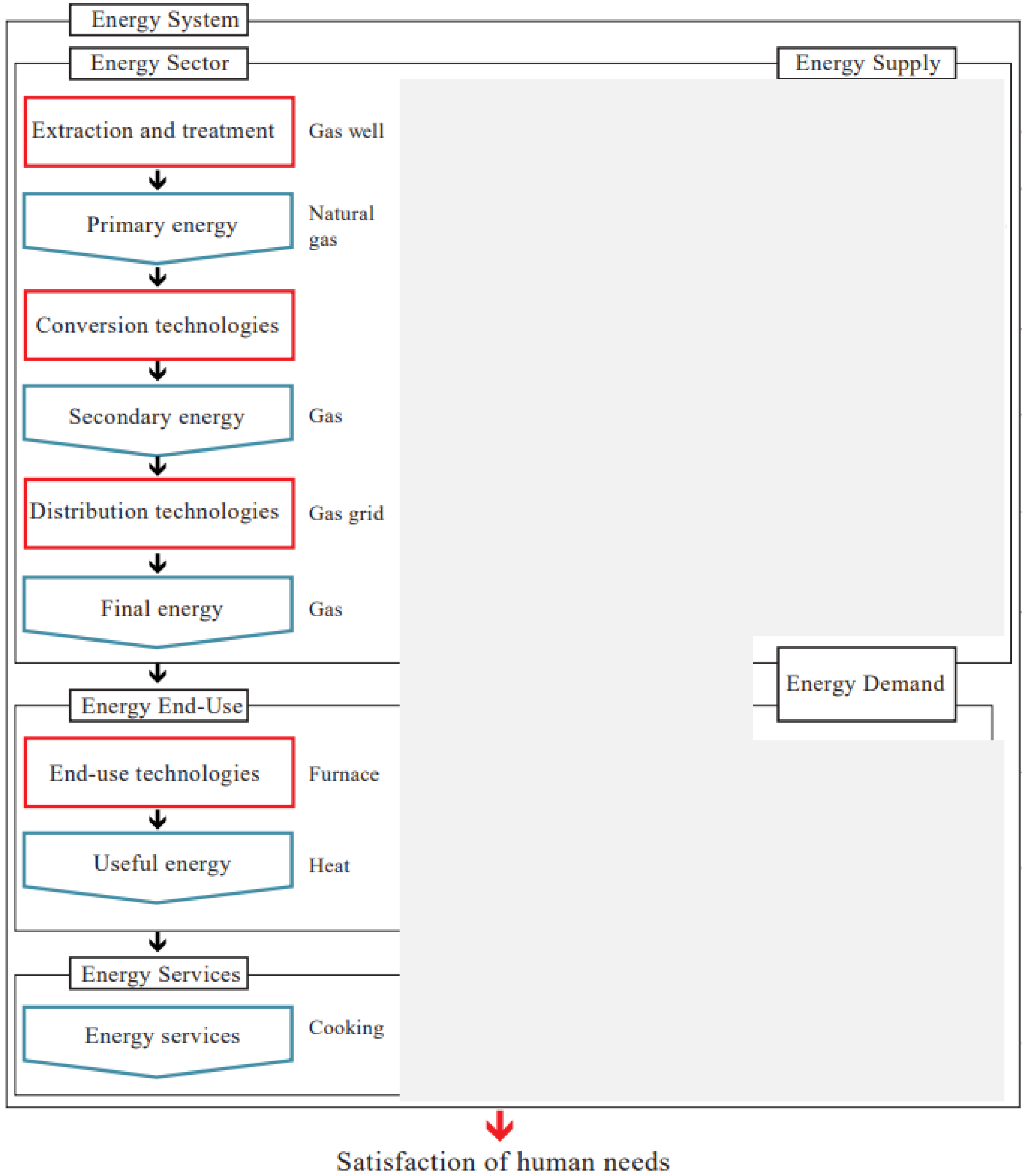


Components of and processes in the energy system: Some details



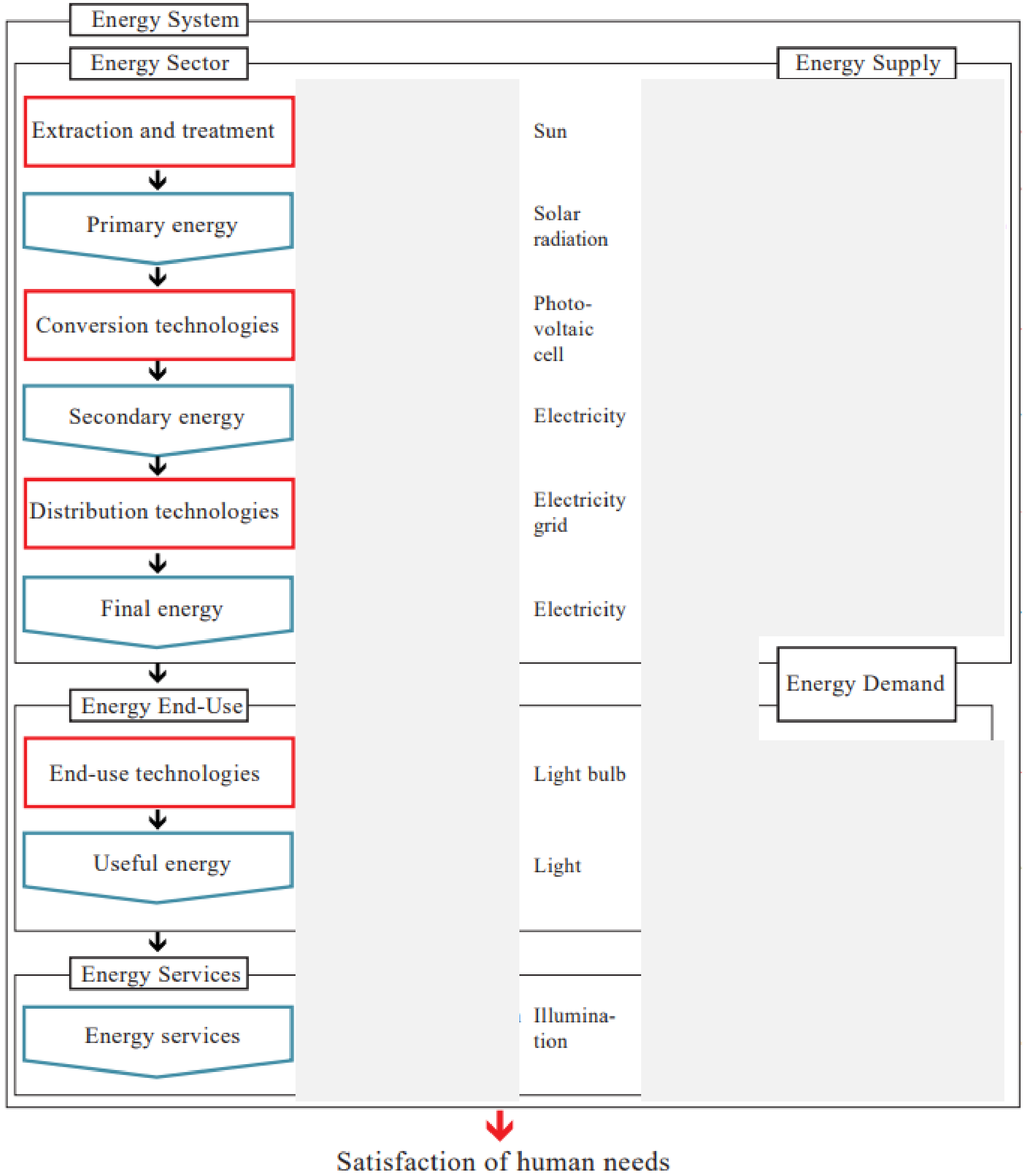
Source: GEA, 2012

Components of and processes in the energy system: Example starting with a fossil resource



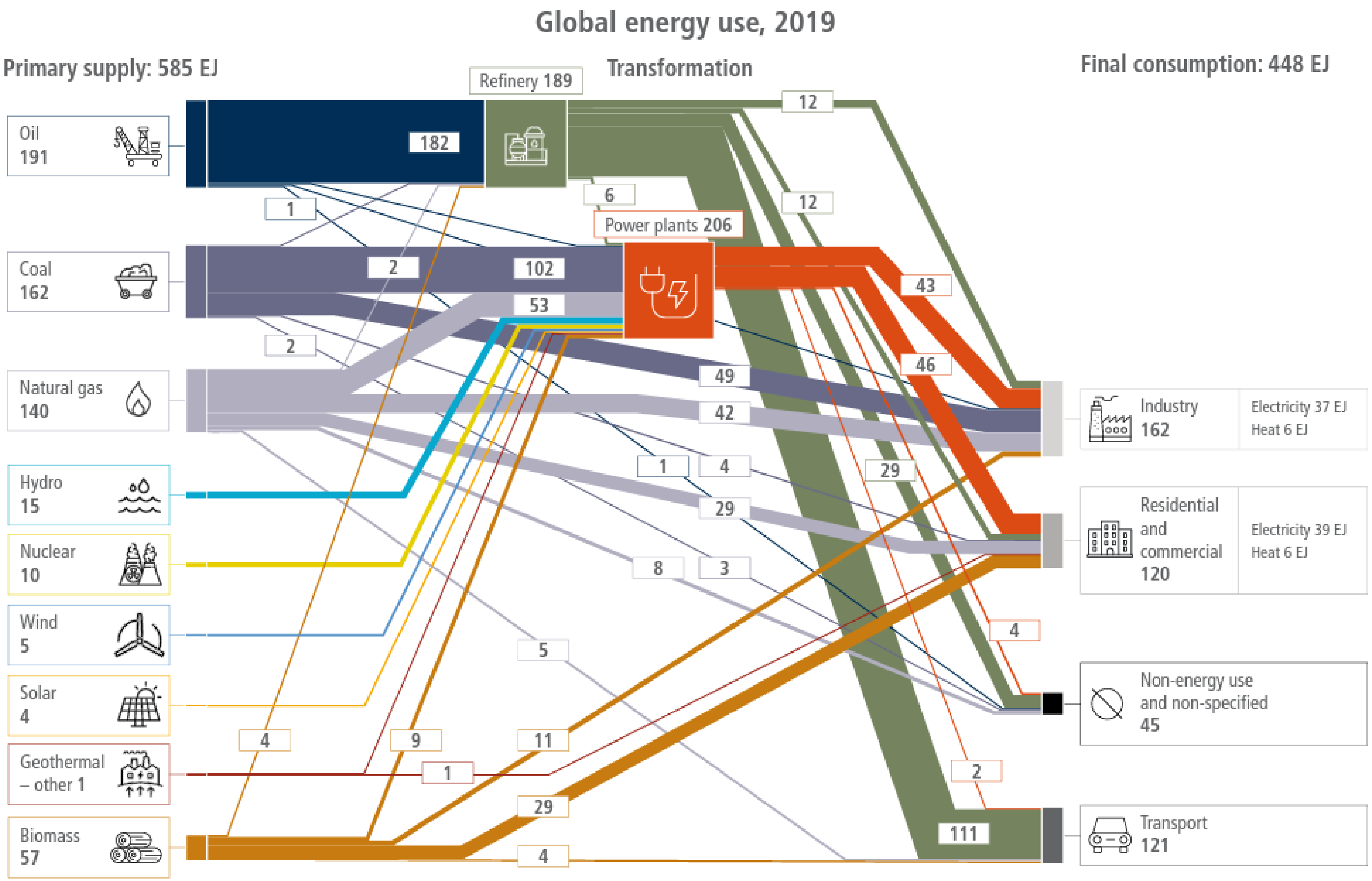
Source: GEA, 2012

Components of and processes in the energy system: Example starting with a ren resource



Source: GEA, 2012

Global flow of energy in 2019

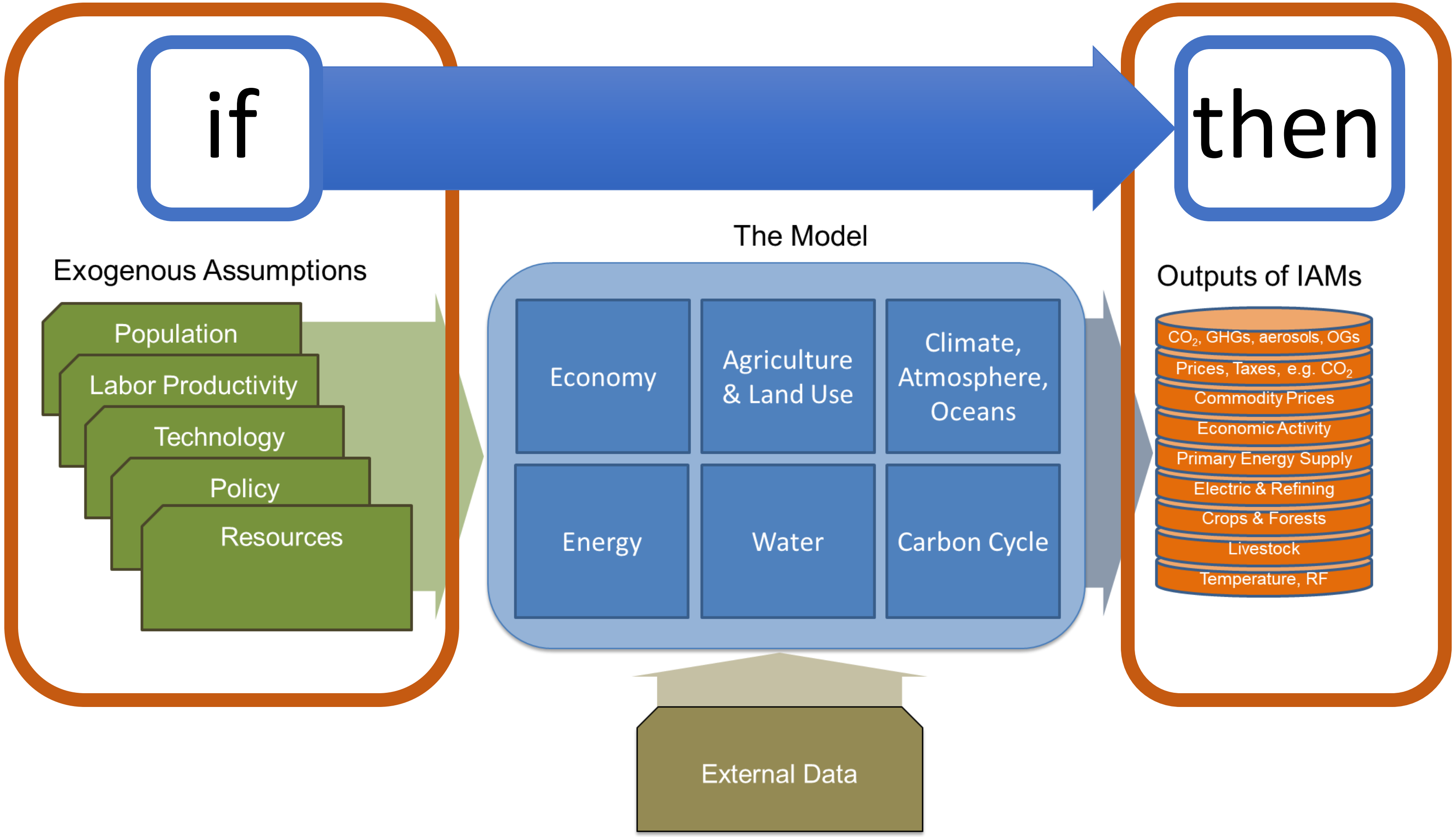


Source: IPCC, AR6

Quick refresher #1: Scenarios

IAMs are used to produce internally consistent "scenarios" or "pathways" of the future

- Simply put, scenarios are conditional forecasts
- Scenarios describe how the future may develop based on a coherent and internally consistent set of assumptions about key relationships and driving forces



A few things to keep in mind about scenarios

- Scenarios do not attach probabilities to the futures they describe and are not predictions nor forecasts of the future
  - Rather, scenarios describe plausible future outcomes that provide a valuable point of reference to aide in analysis and/or decision making

- Scenarios can be used in an explorative manner or for scientific assessment to understand interactions and linkages between key variables related to natural (e.g. land) and/or human (e.g. energy) systems of interest

- Scenarios could also be used to elucidate strategies to address climate change or other issues of societal/policy interest

https://blog.commlabindia.com/elearning-design/scenario-based-elearning-assessments

Quick refresher #2: International climate policy

The international community has established ambitious long-term goals

COP21 • CMP11
PARIS 2015
UN CLIMATE CHANGE CONFERENCE

Holding the increase in the global average temperature to ***well below 2 °C*** *above pre-industrial levels and to pursue efforts to limit the temperature increase to* ***1.5 °C*** *above pre-industrial levels*

How much do we need to reduce global GHG emissions to implement Paris?

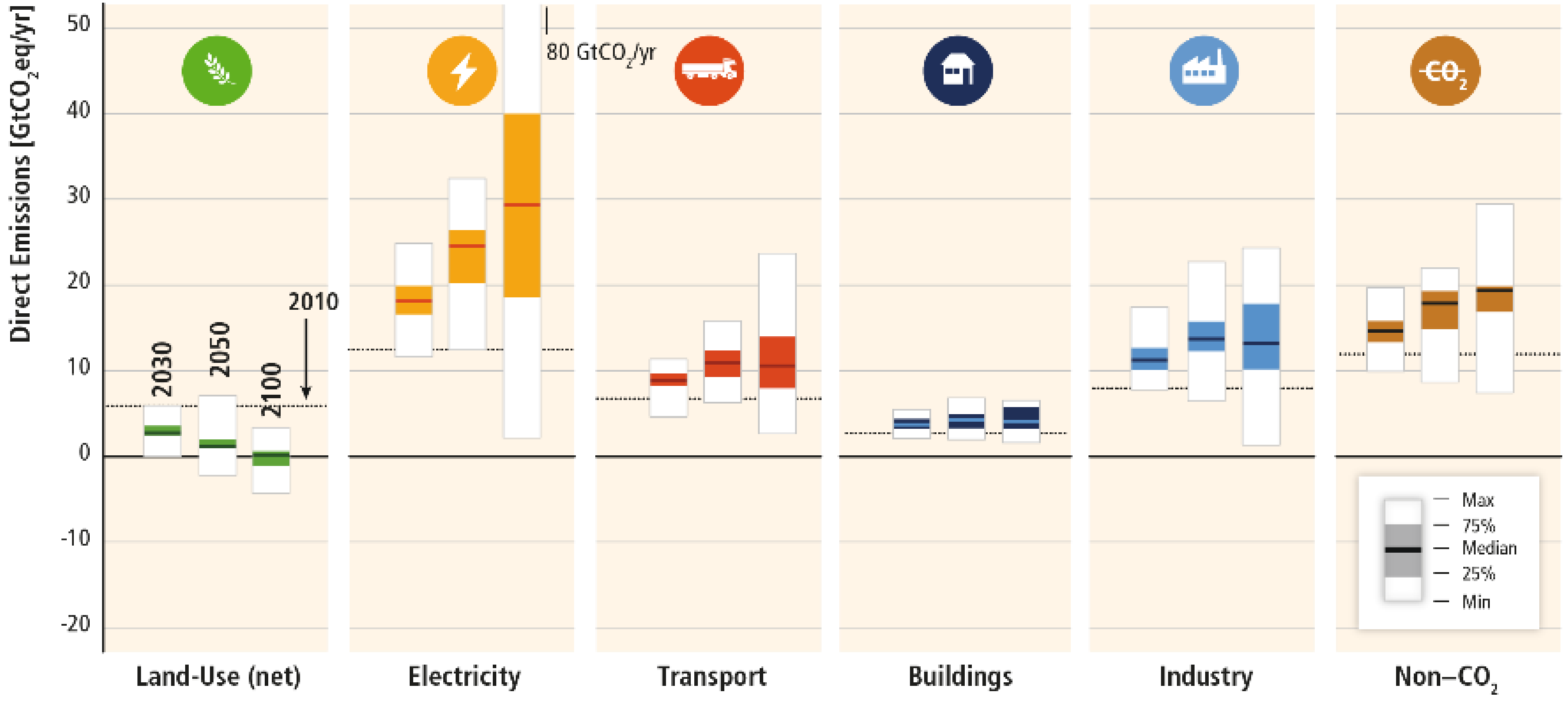
100%

How much should energy-system emissions be reduced?

100% or more

Scenarios produced by IAMs suggest emission increases in the absence of focused policies

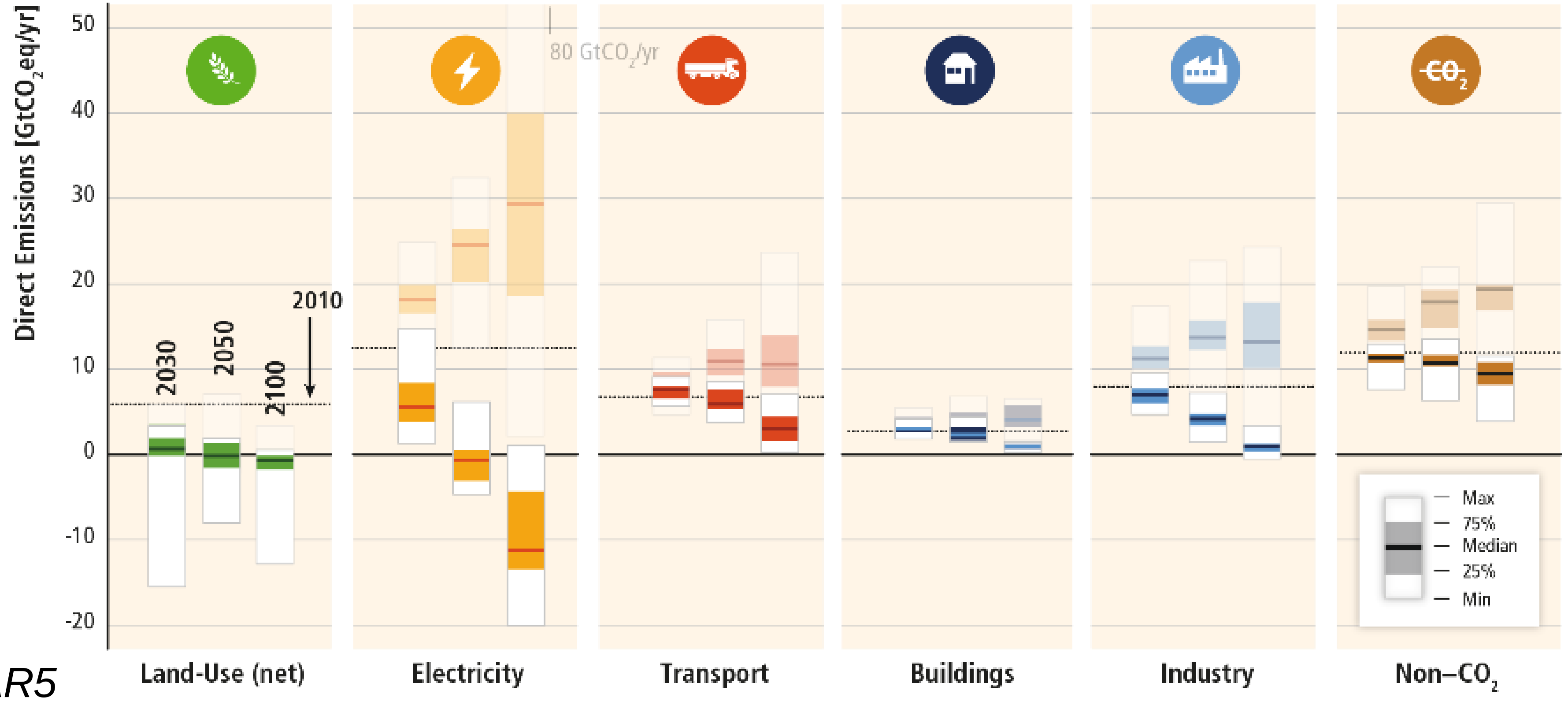
GHG emissions in “No climate Policy” scenarios



Source: IPCC, AR5

Scenarios based on IAMs that incorporate Paris goals are characterized by major emissions reductions in the energy system

GHG emissions in mitigation scenarios (dark) compared to emissions in baseline scenarios (light)



Source: IPCC, AR5

Quick refresher #3: Energy technologies

What kinds of energy technologies result in non-zero emissions?

What kinds of energy technologies result in non-zero emissions?

Coal-fired power plants

Oil refineries, industries

Combustion engines

Building furnaces

What kinds of energy technologies result in low- or zero- emissions?

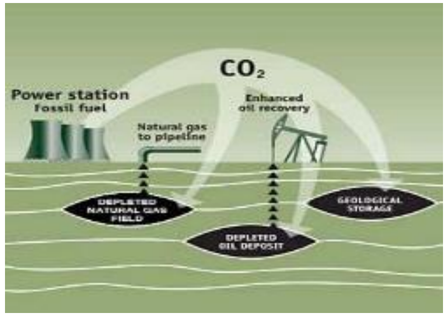
What kinds of energy technologies result in low- or zero- emissions?

Renewables

Nuclear

Biofuels

Carbon Capture Utilization & Storage



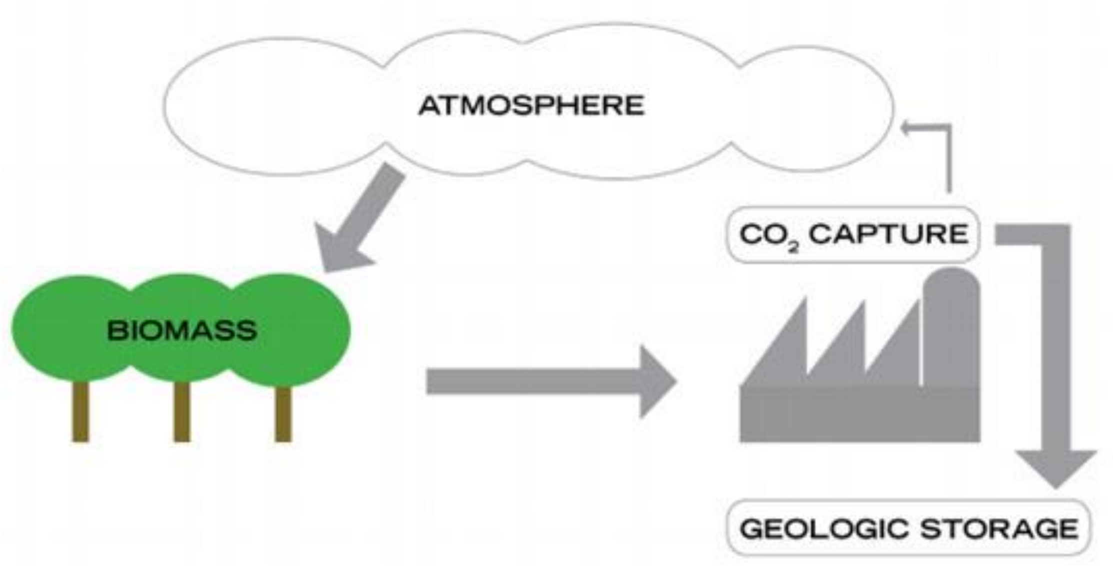
Hydrogen

Electric vehicles

What kinds of energy technologies result in negative emissions?

What kinds of energy technologies result in negative emissions?

Bioenergy + CCUS



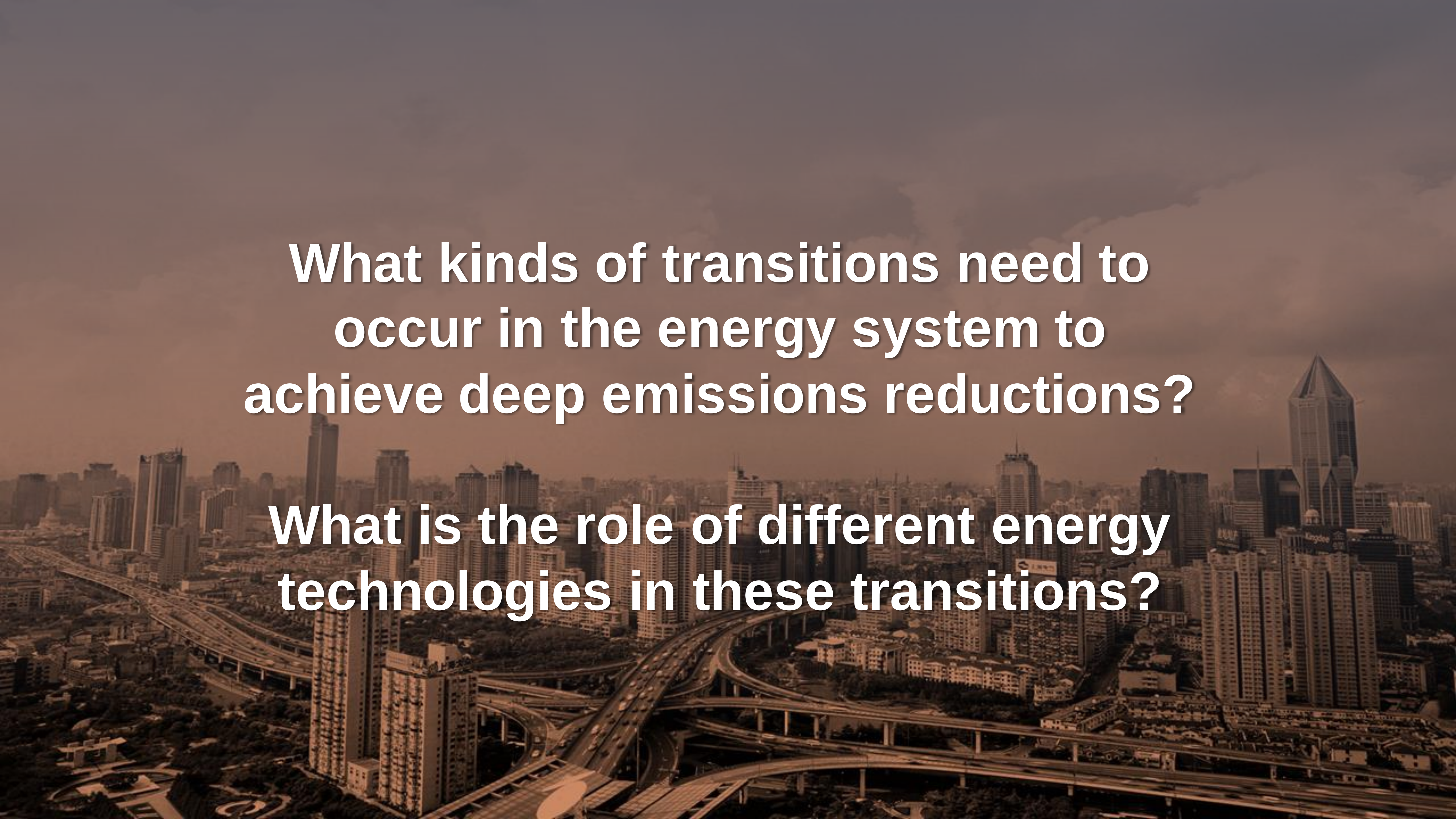
Direct Air Capture

https://www.globalccsinstitute.com/insights/authors/AliceGibson/2015/11/25/importance-bio-ccs-deliver-negative-emissions

Key questions of interest in the energy-climate problem that we will focus on today

- What kinds of transitions need to occur in the energy system to achieve deep emissions reductions? What is the role of different energy technologies in these transitions?

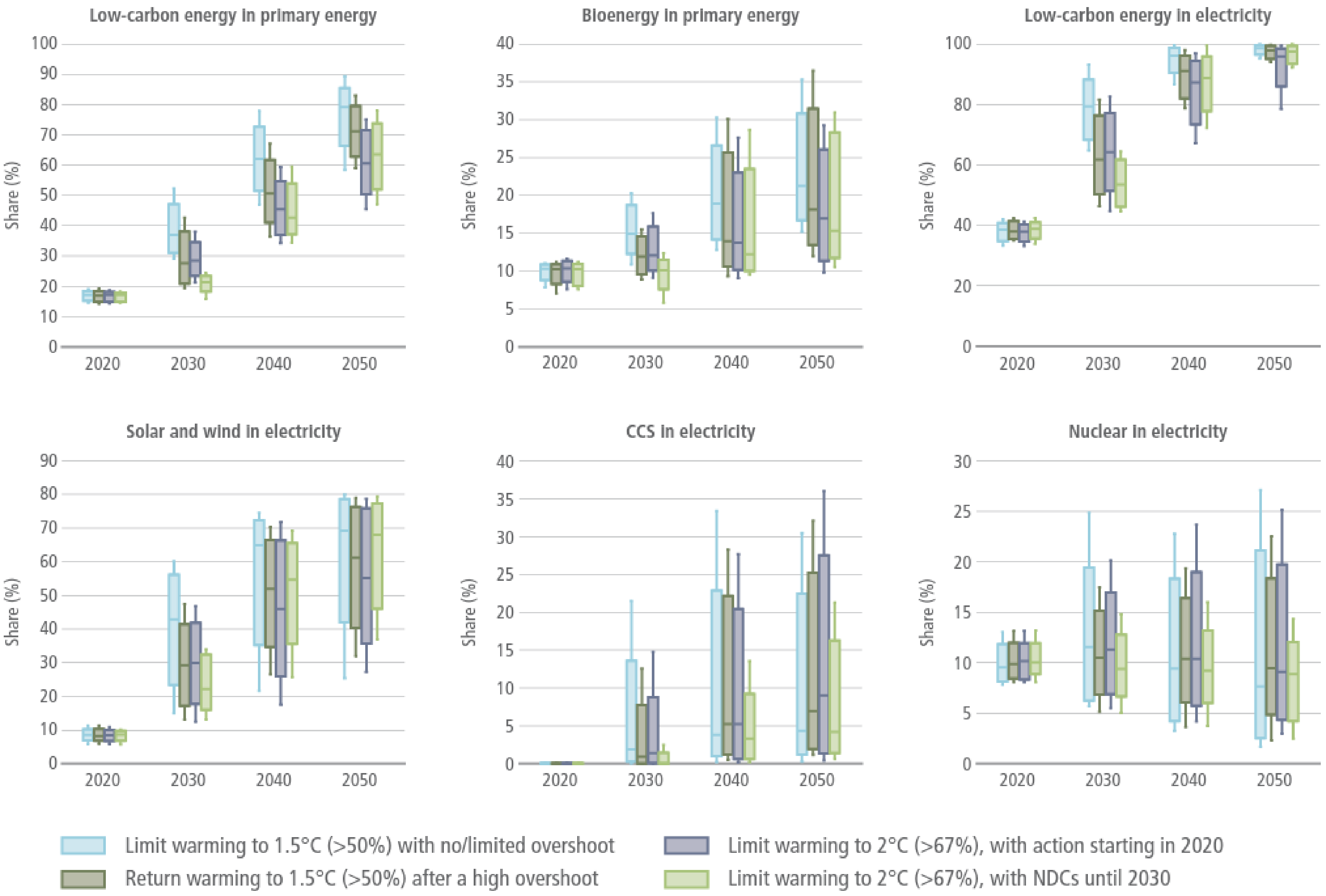
- What is the role of institutions in those transitions?



What kinds of transitions need to occur in the energy system to achieve deep emissions reductions?

What is the role of different energy technologies in these transitions?

Scenarios consistent with Paris goals are characterized by major scaling up of low carbon technologies

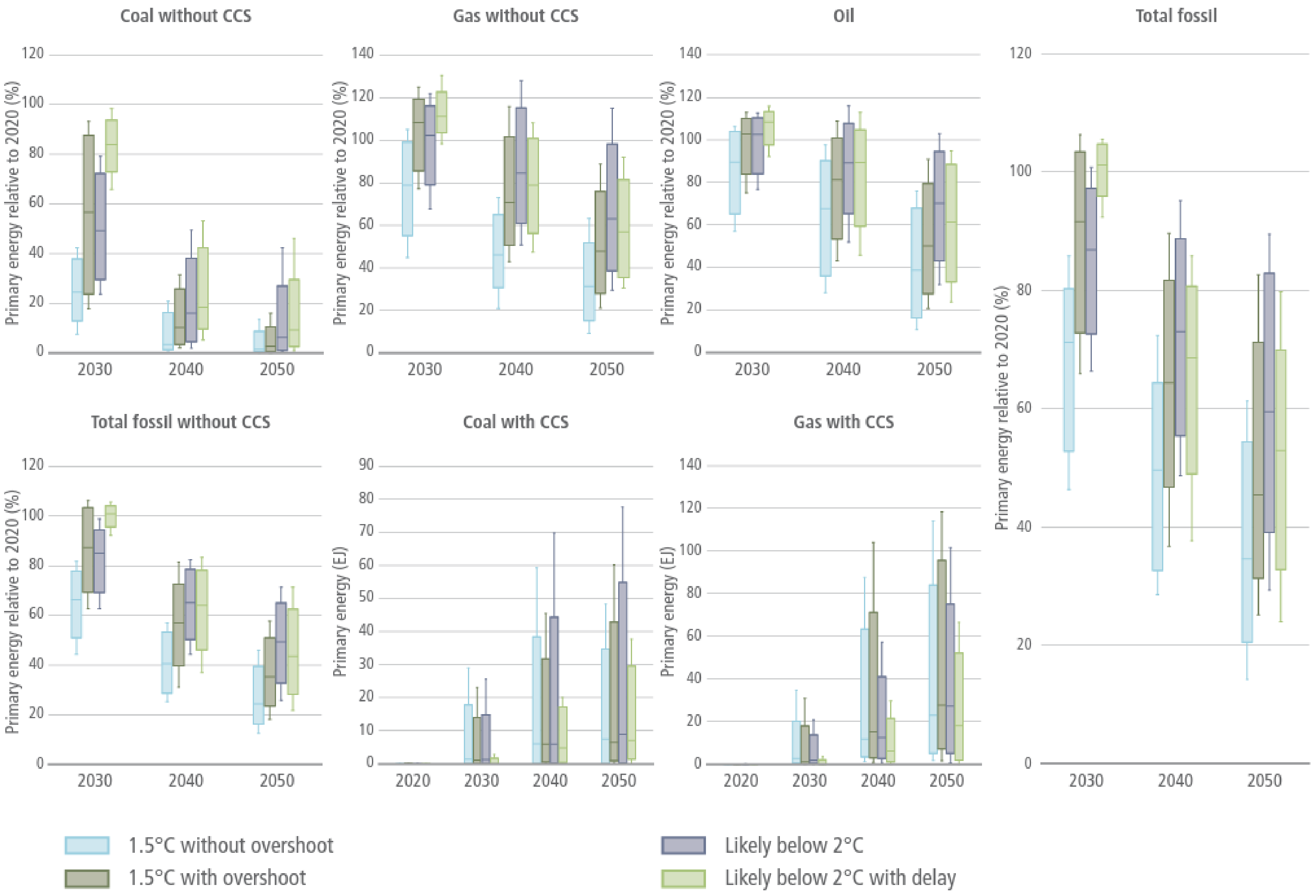


Boxes indicate 25th and 75th percentiles;

whiskers indicate 5th and 95th percentiles

Source: IPCC, AR6

Scenarios consistent with Paris goals are characterized by decreases in fossil production and consumption

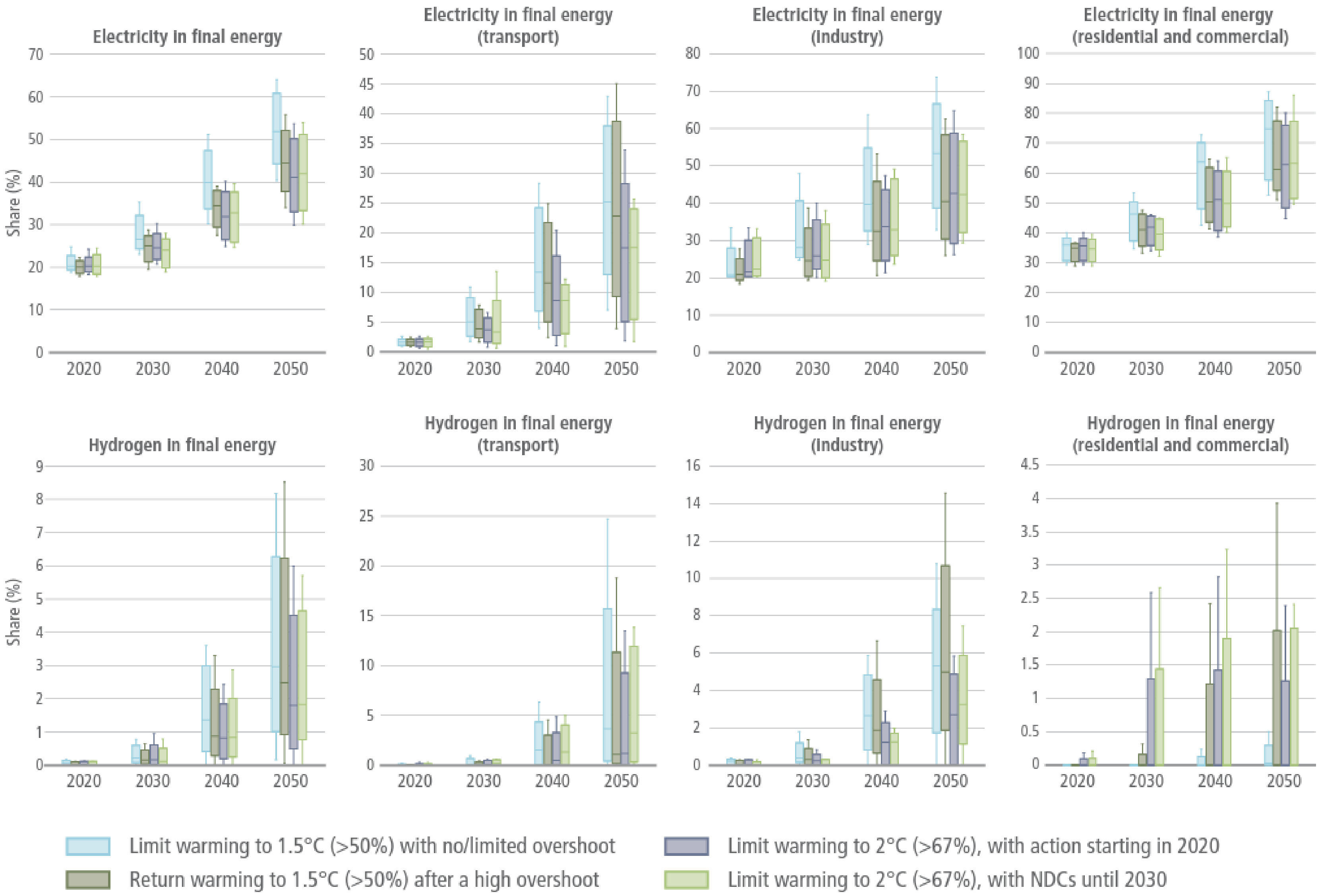


Boxes indicate 25th and 75th percentiles;

whiskers indicate 5th and 95th percentiles

Source: IPCC, AR6

Scenarios consistent with Paris goals are characterized by increases in electricity and H2 in end-use sectors



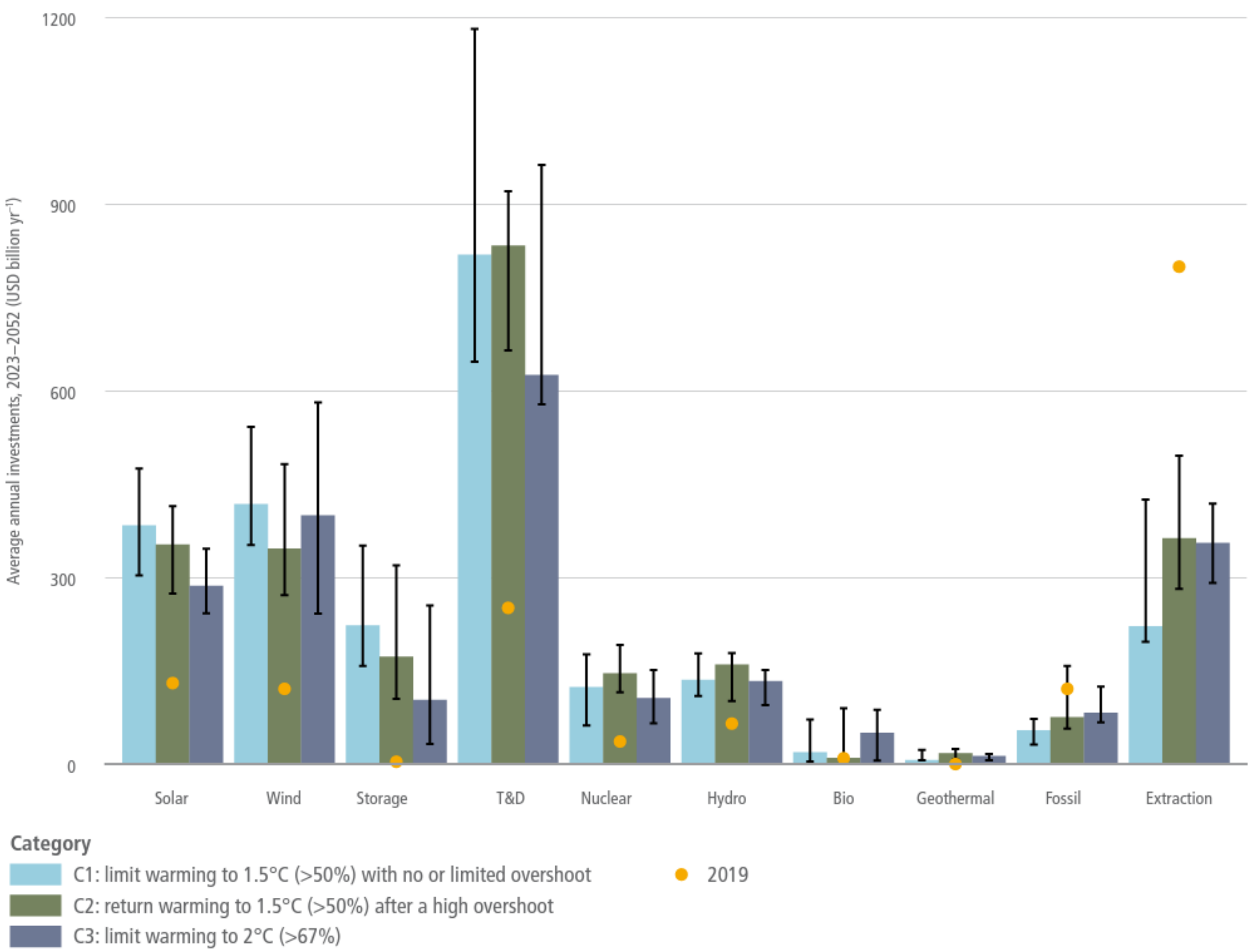
Boxes indicate 25th and 75th percentiles;

whiskers indicate 5th and 95th percentiles

Source: IPCC, AR6

Scenarios consistent with Paris goals are characterized by changes in investment patterns

Global average annual investments (2023–2052) [Billion USD/ yr]

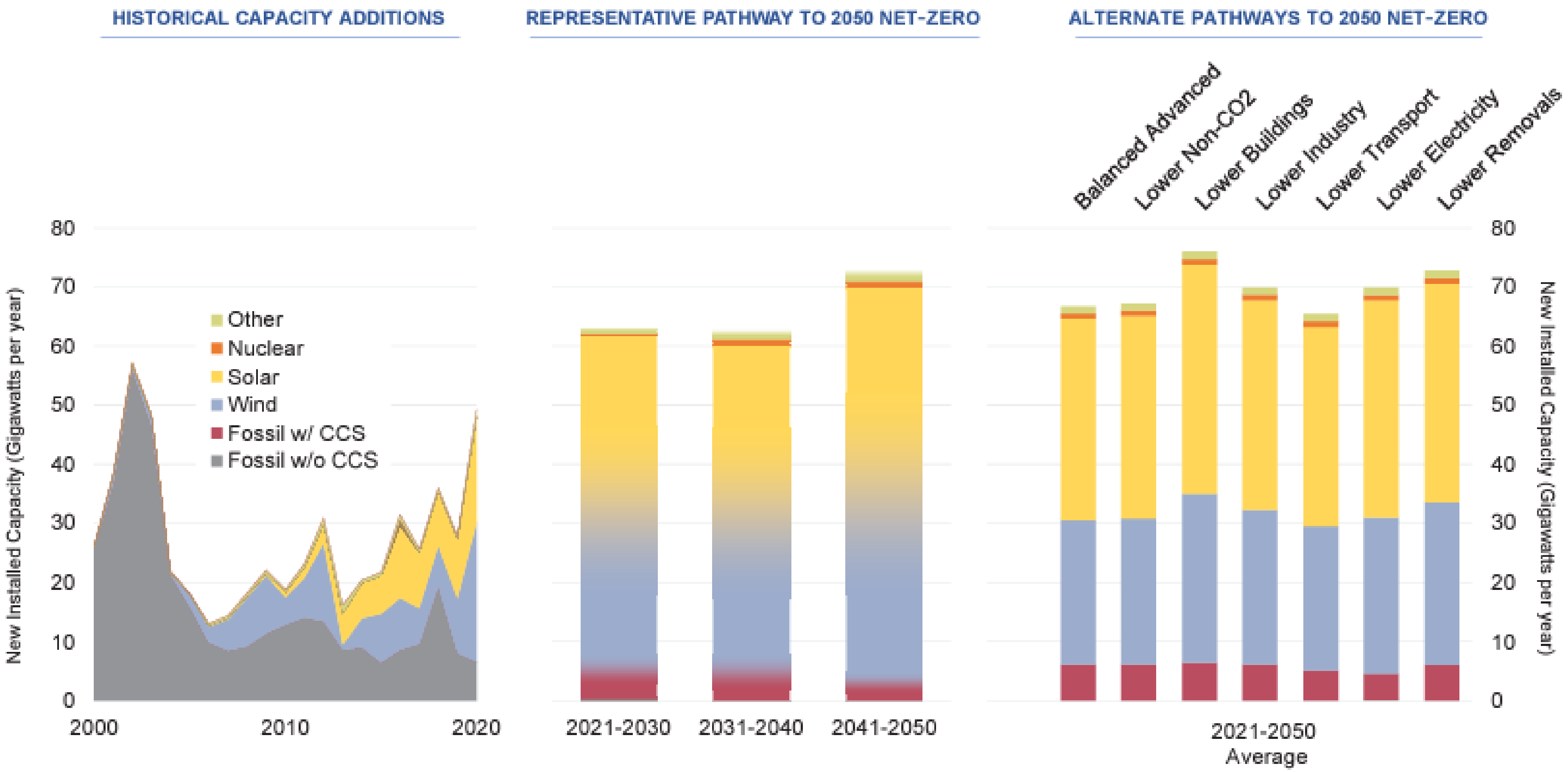


Bars show median values across models-scenarios, and whiskers the interquartile ranges

Source: IPCC, AR6

IAM based pathways toward net-zero emissions in the U.S. by 2050 suggest significant scaling up of investments compared to historical rates

U.S. Electric Generation Capacity Additions



Source:
U.S. LTS 2021

Scenarios consistent with Paris goals are characterized by stranded assets

https://www.greenbiz.com/article/state-green-business-stranded-assets

- Mitigation could result in pre-mature write-downs, devaluations, and conversion to liabilities of carbon-intensive assets, referred to as "**stranding**" of assets.

- In the context of climate change mitigation, stranded assets could manifest in various forms such as:
  - Fossil-fuel resources that cannot be burned in order to maintain a long-term temperature goal
  - Pre-mature retirement of carbon-intensive capital due to climate policies

Why are stranded assets important?

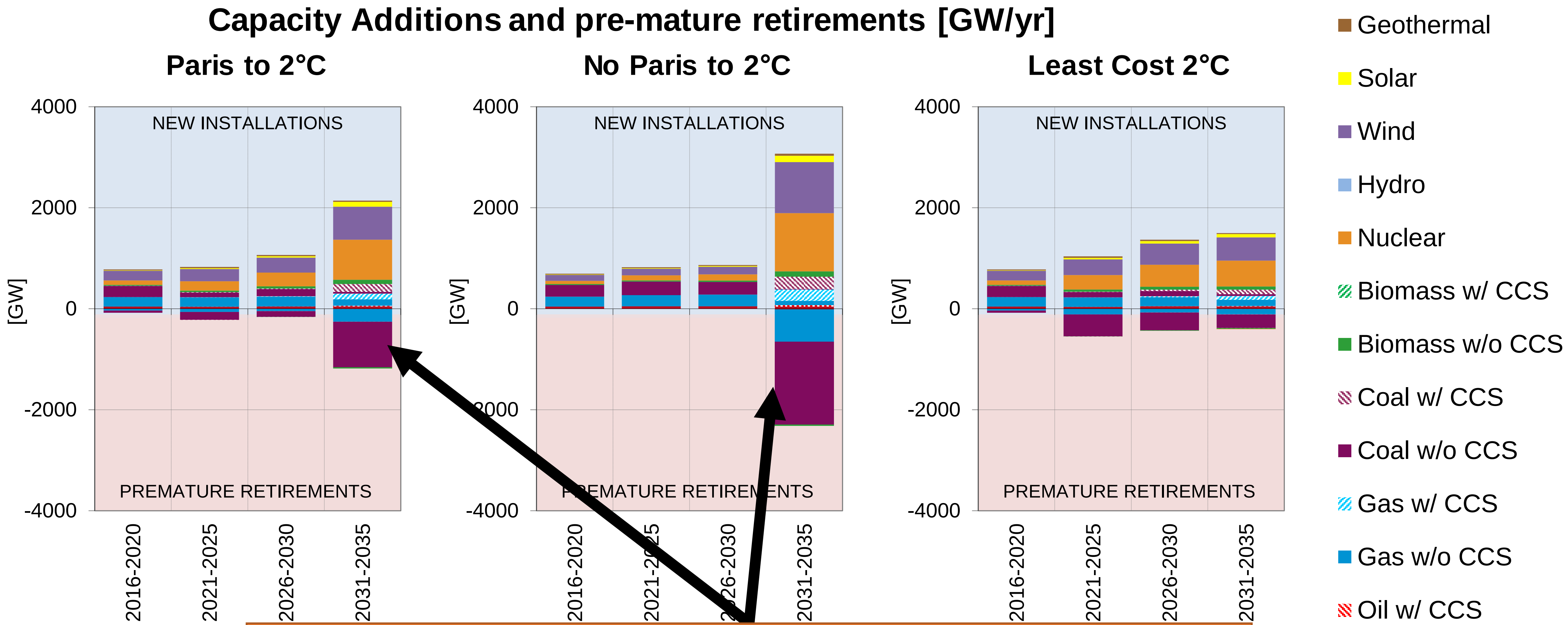
- Stranded assets could create financial and political threats:

  - **Economic risks**: Financial risks that could arise for parties that have suffered loss and damage from climate change mitigation.

  - **Political economy risks**: Stranded assets create loss of wealth for few and could result in lobbying and rent-seeking behavior.

https://www.reminetwork.com/articles/climate-risk-raises-stranded-asset-potential/

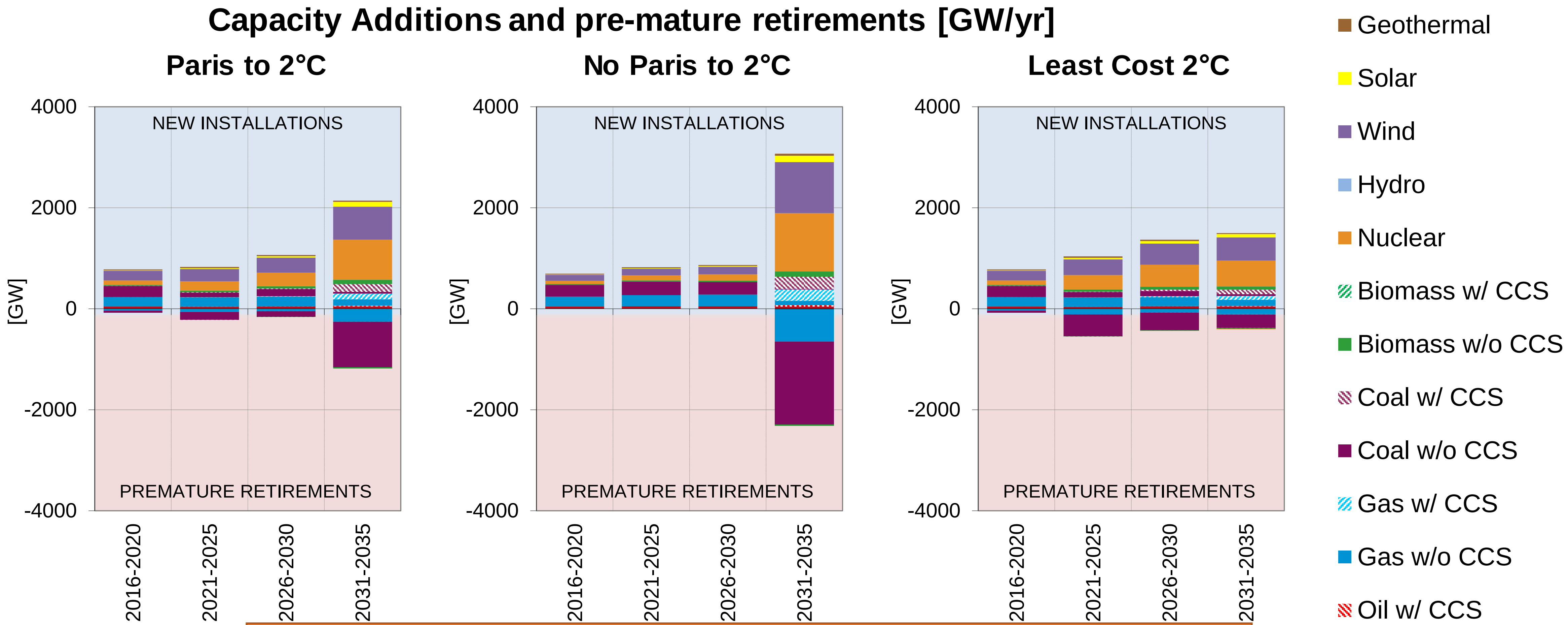
Globally, investments and stranded assets implications of Paris Agreement are non-trivial



Current installed capacity globally is ~8000GW.
The *Paris-* and *No Paris to 2°C* scenarios suggest
pre-maturely retiring 20-25% of this capacity beyond 2030

Source: Iyer et al., 2015, The contribution of Paris to limit global warming to 2°C, Environmental Research Letters

Globally, investments and stranded assets implications of Paris Agreement are non-trivial

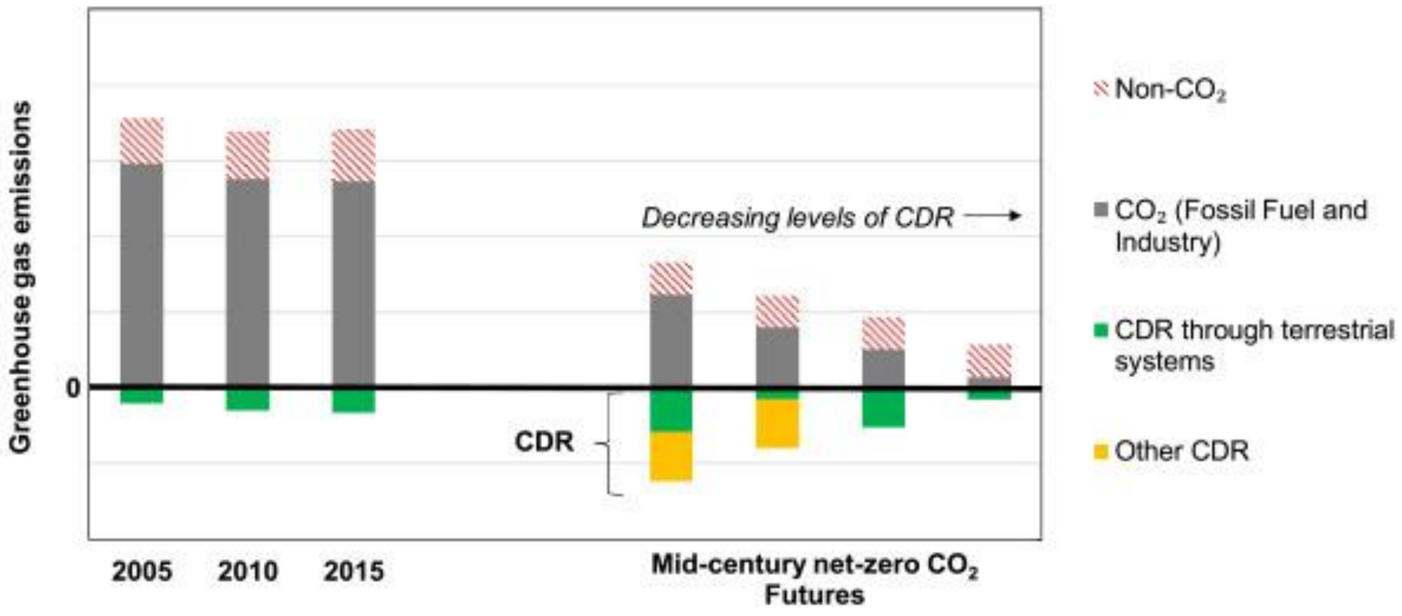


Stranded asset implications under 1.5°C would be even more prominent

Source: Iyer et al., 2015, The contribution of Paris to limit global warming to 2°C, Environmental Research Letters

Looking beyond the energy system: IAM-based research suggests that achieving economy-wide net-zero emissions is a zero-sum game

- Some non-CO2 emissions are hard to reduce (e.g. from cattle)
- Carbon dioxide removal (CDR) will be critical to offset those emissions
- The greater the scale of CDR, the lower is the level of mitigation of CO_2 emissions from fossil fuels and industry and vice versa

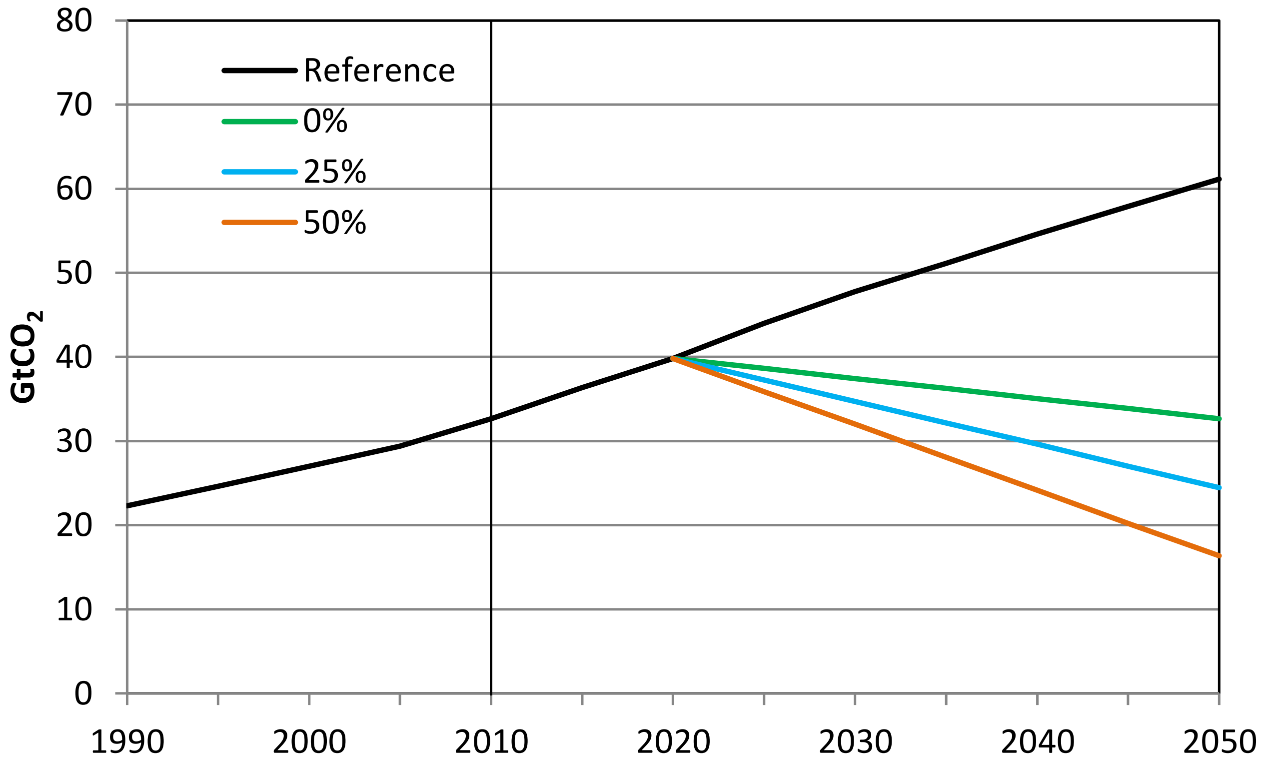


Example diagnostic scenarios based on GCAM

Example using GCAM: Six Emissions Scenarios

Three assumptions about emissions in 2050 *(Energy system CO_2 only)*

- Decline slightly from 2020 to 2010 levels by 2050
- Decline to 25% below 2010 levels in 2050
- Decline to 50% below 2010 levels in 2050 (2°C Scenario)

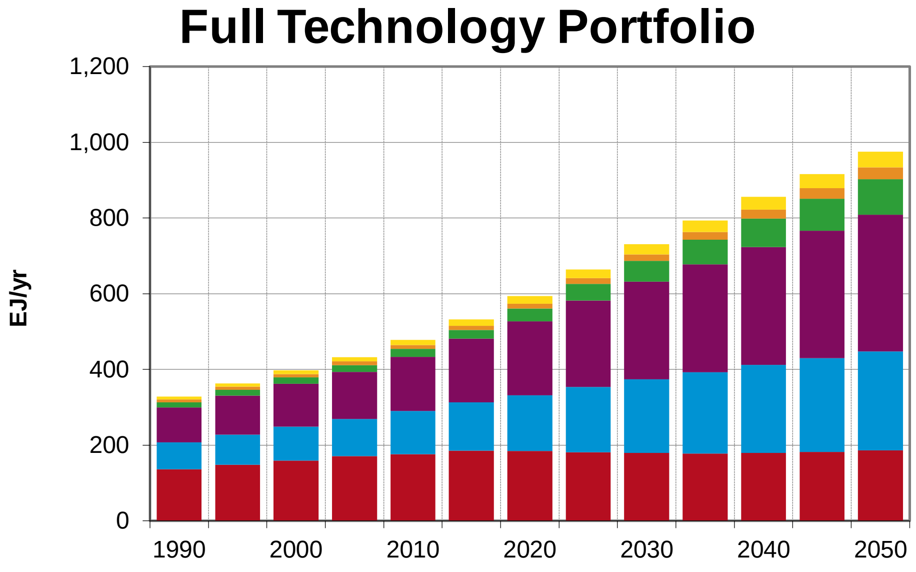


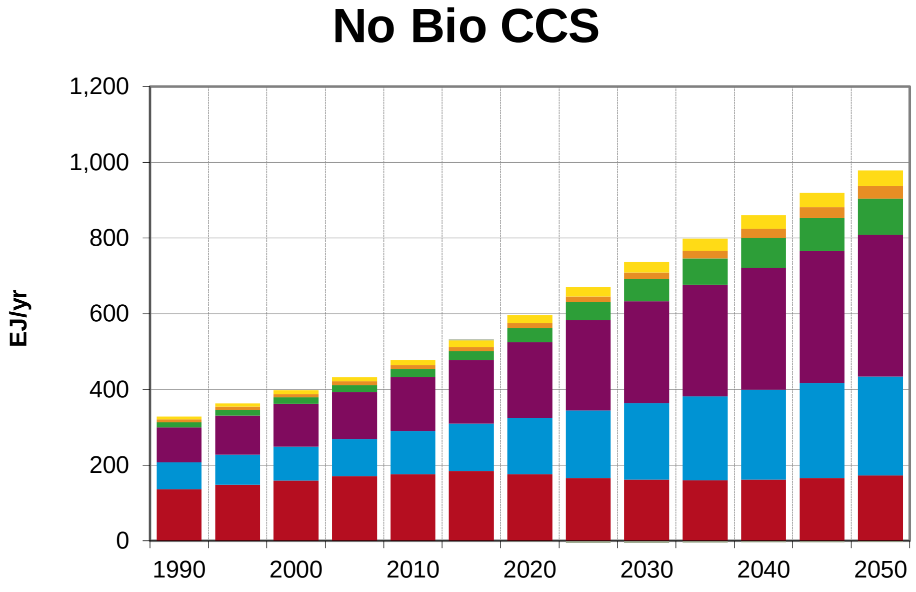
Three technology assumptions

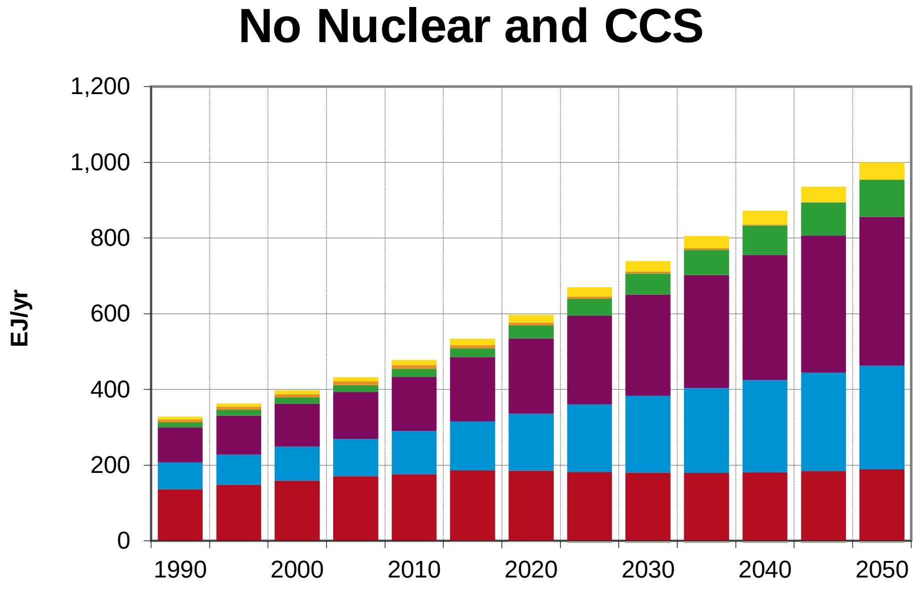
- Full technology
- No BioCCS
- No CCS and Nuclear

Assumptions are consistent with literature

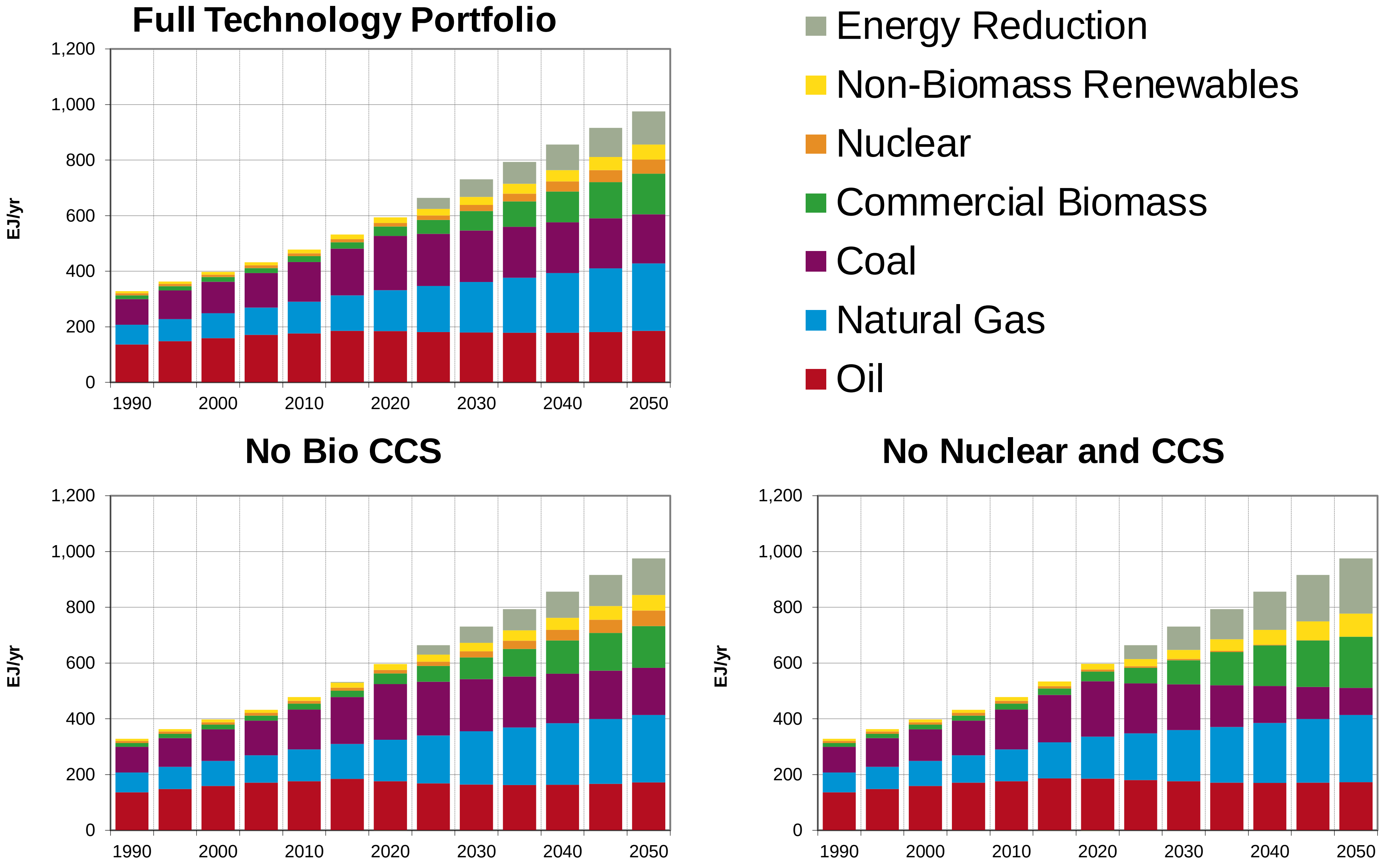
Primary Energy: Reference Scenario



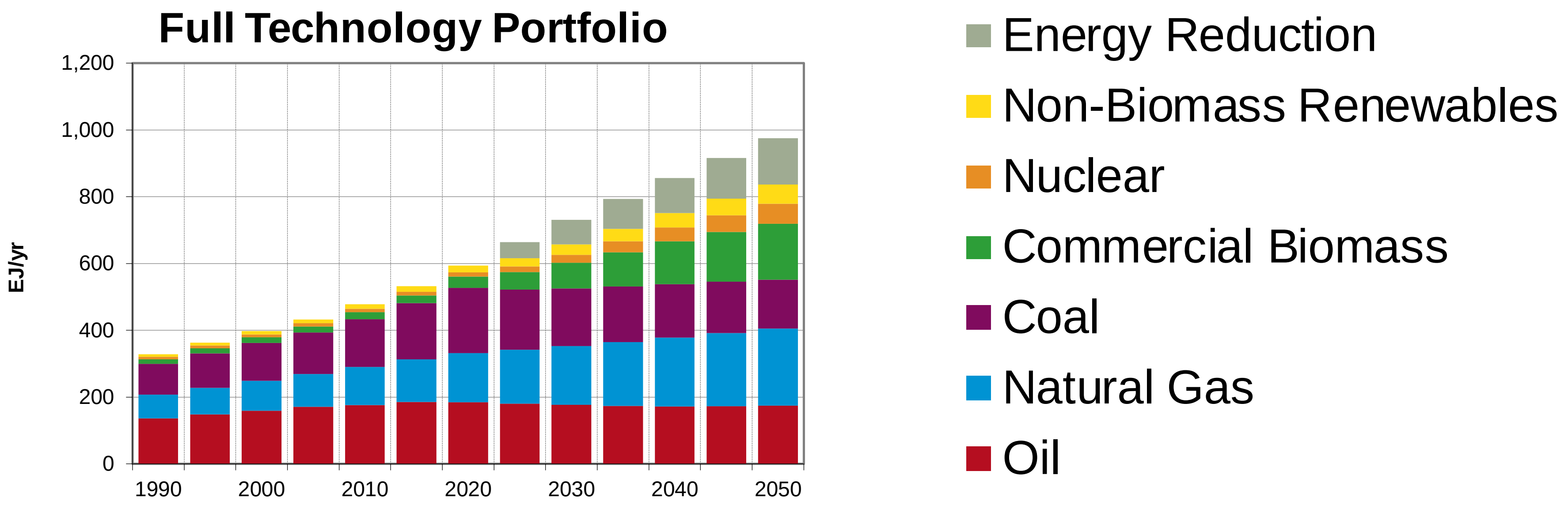


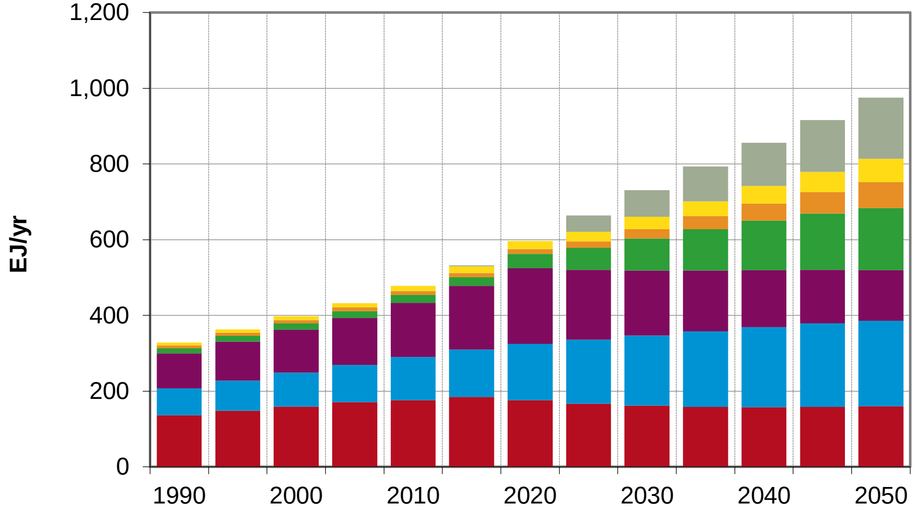


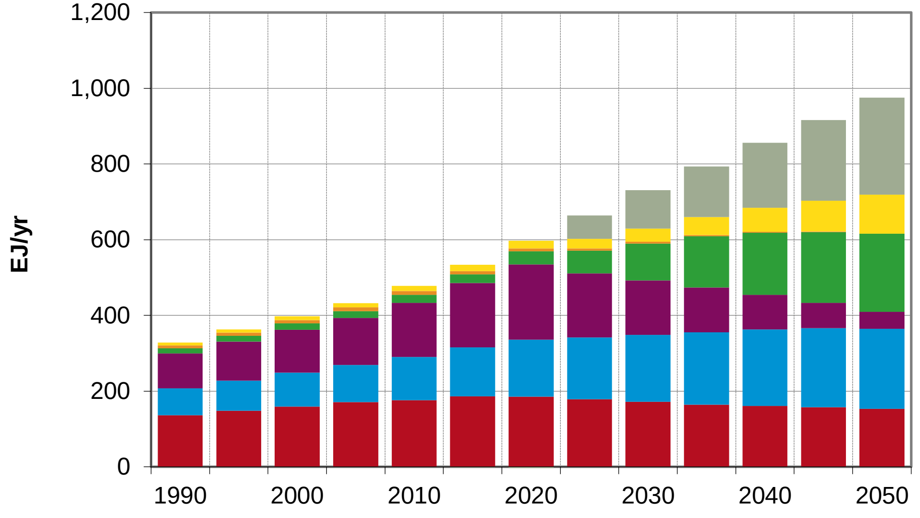
Primary Energy: 2010 Emissions



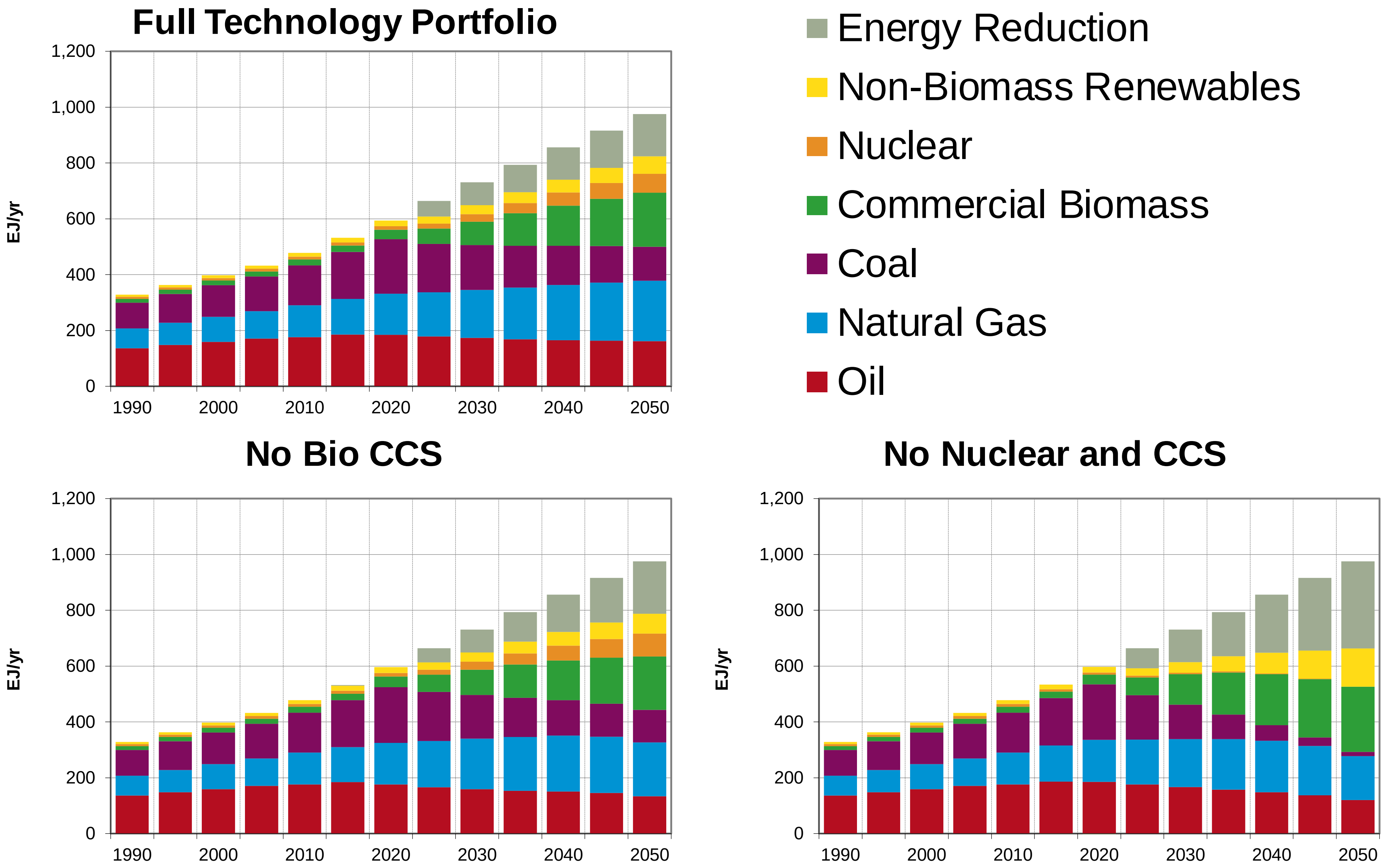
Primary Energy: 25% reduction





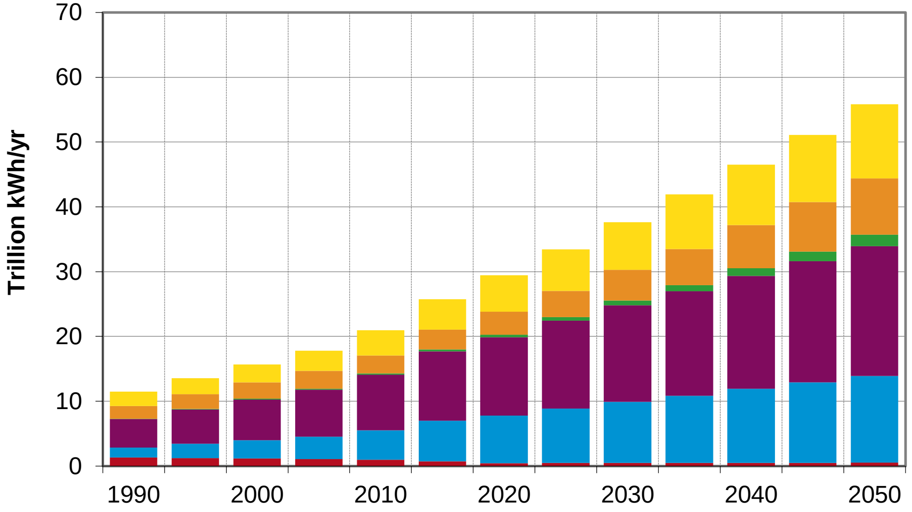


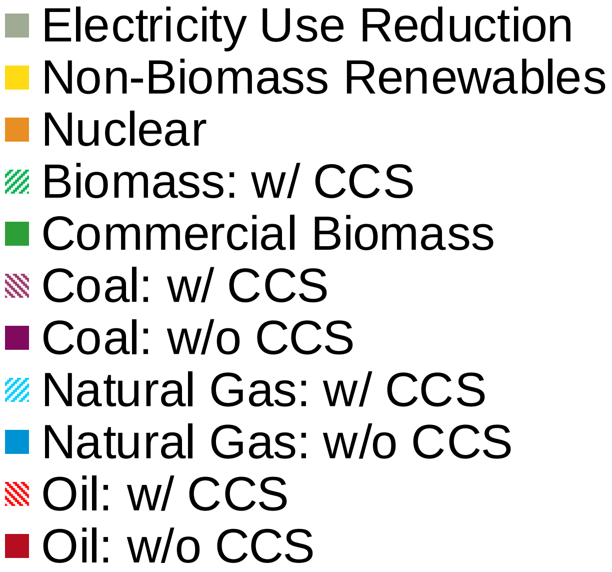
Primary Energy: 50% reduction



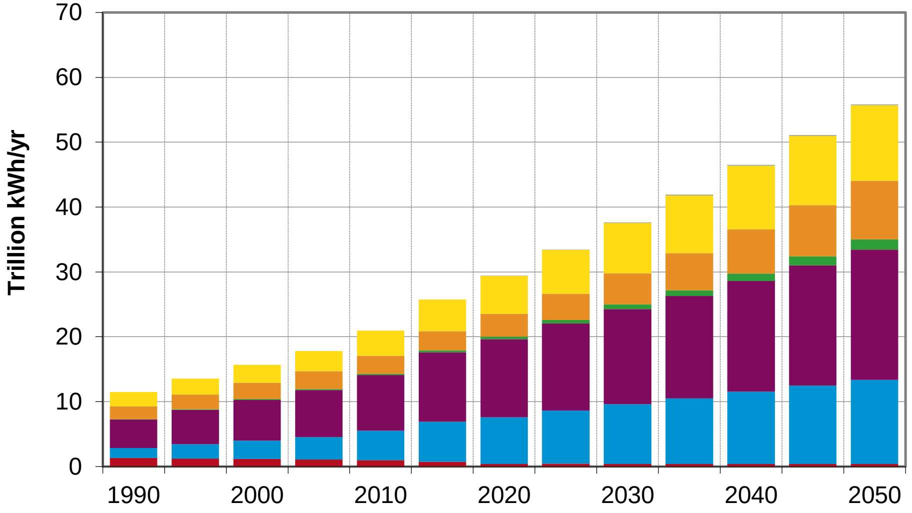
Electricity production: Reference Scenario

Full Technology Portfolio

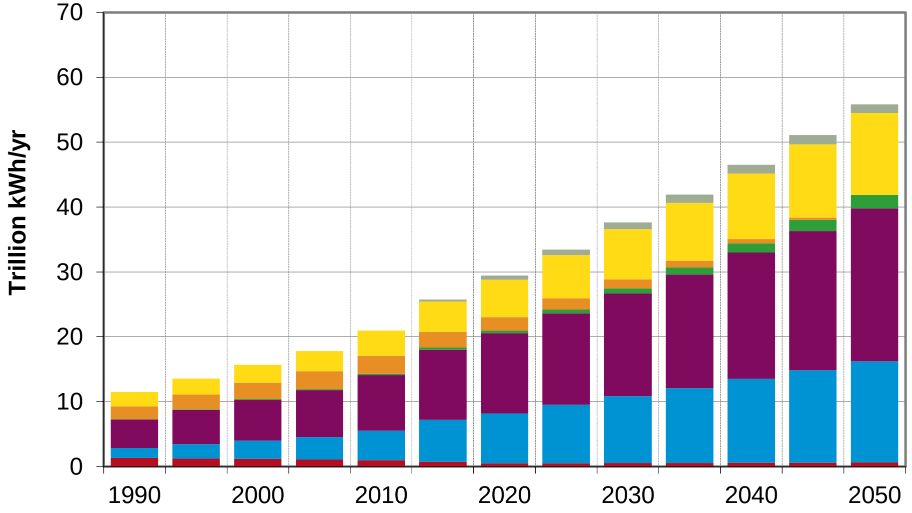




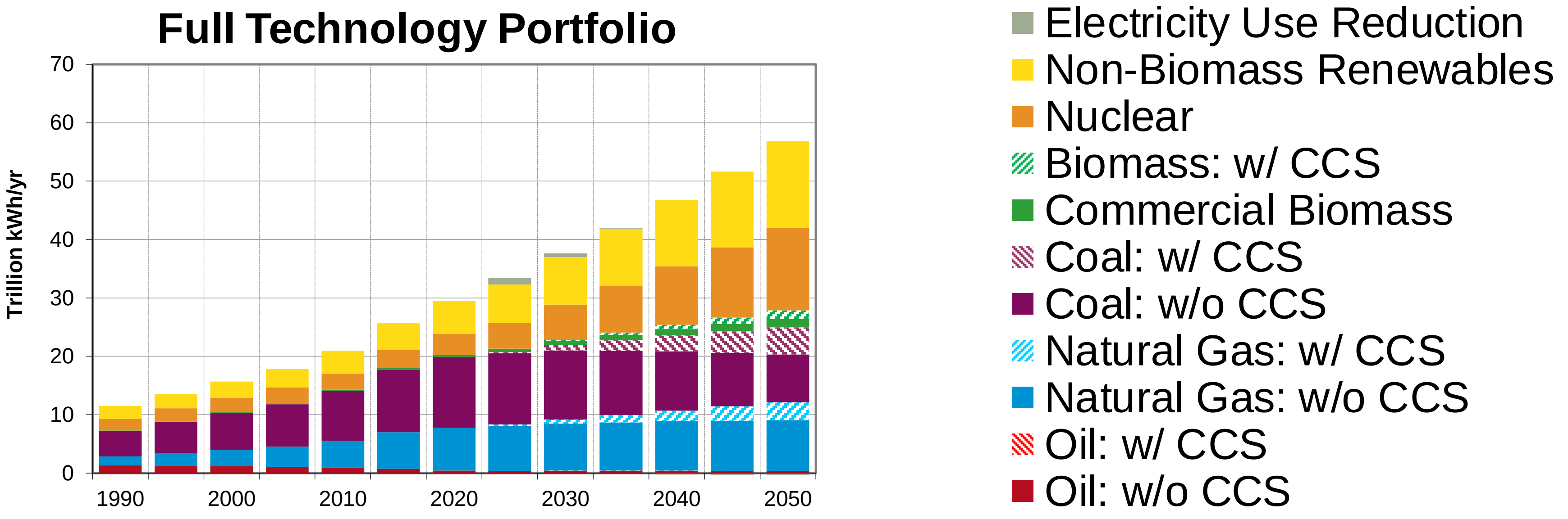
No Bio CCS

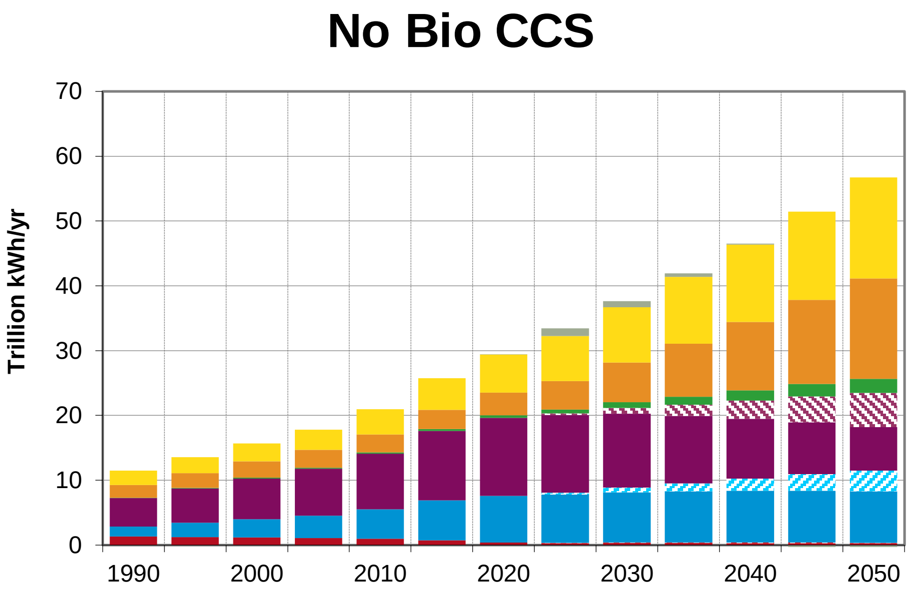


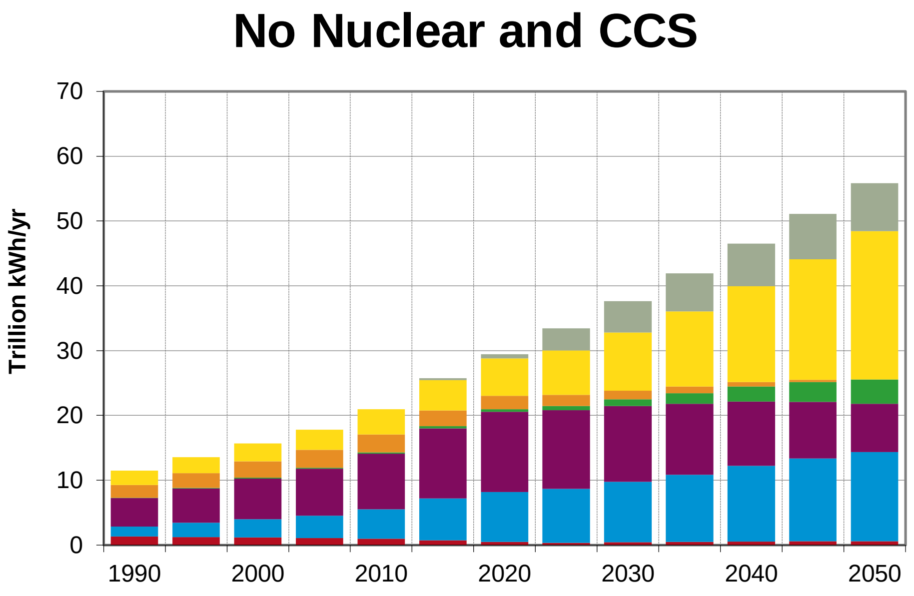
No Nuclear and CCS



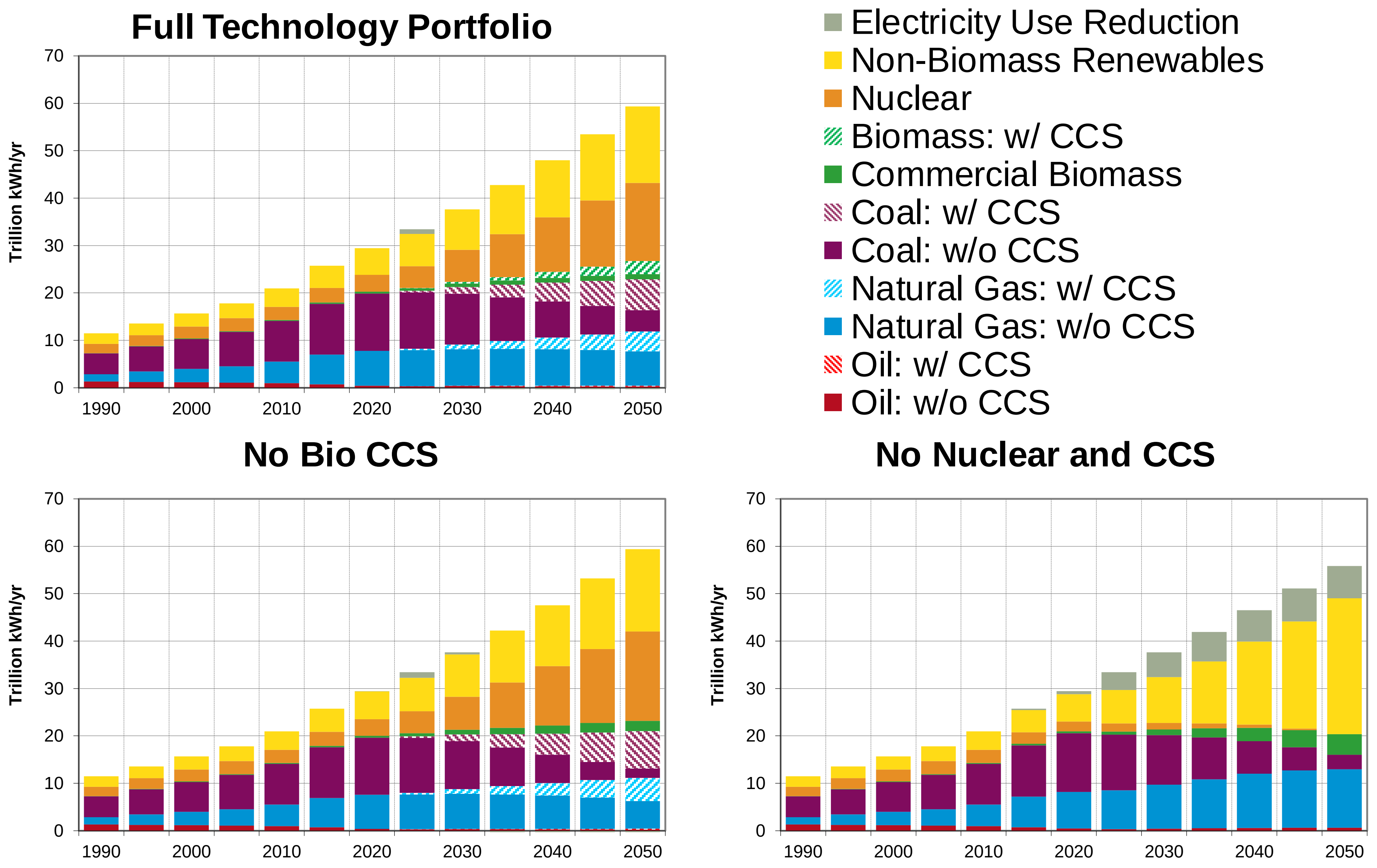
Electricity production: 2010 Emissions



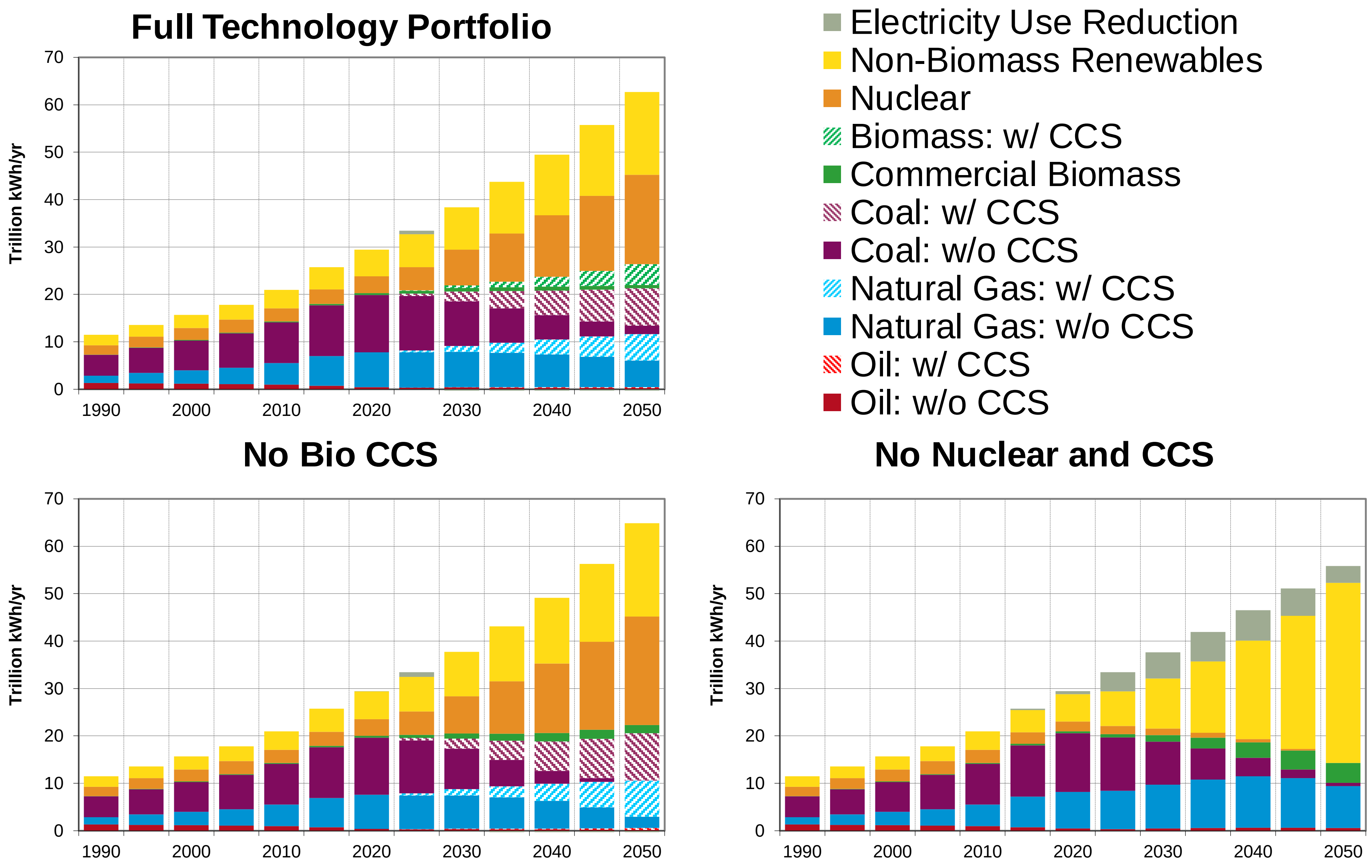




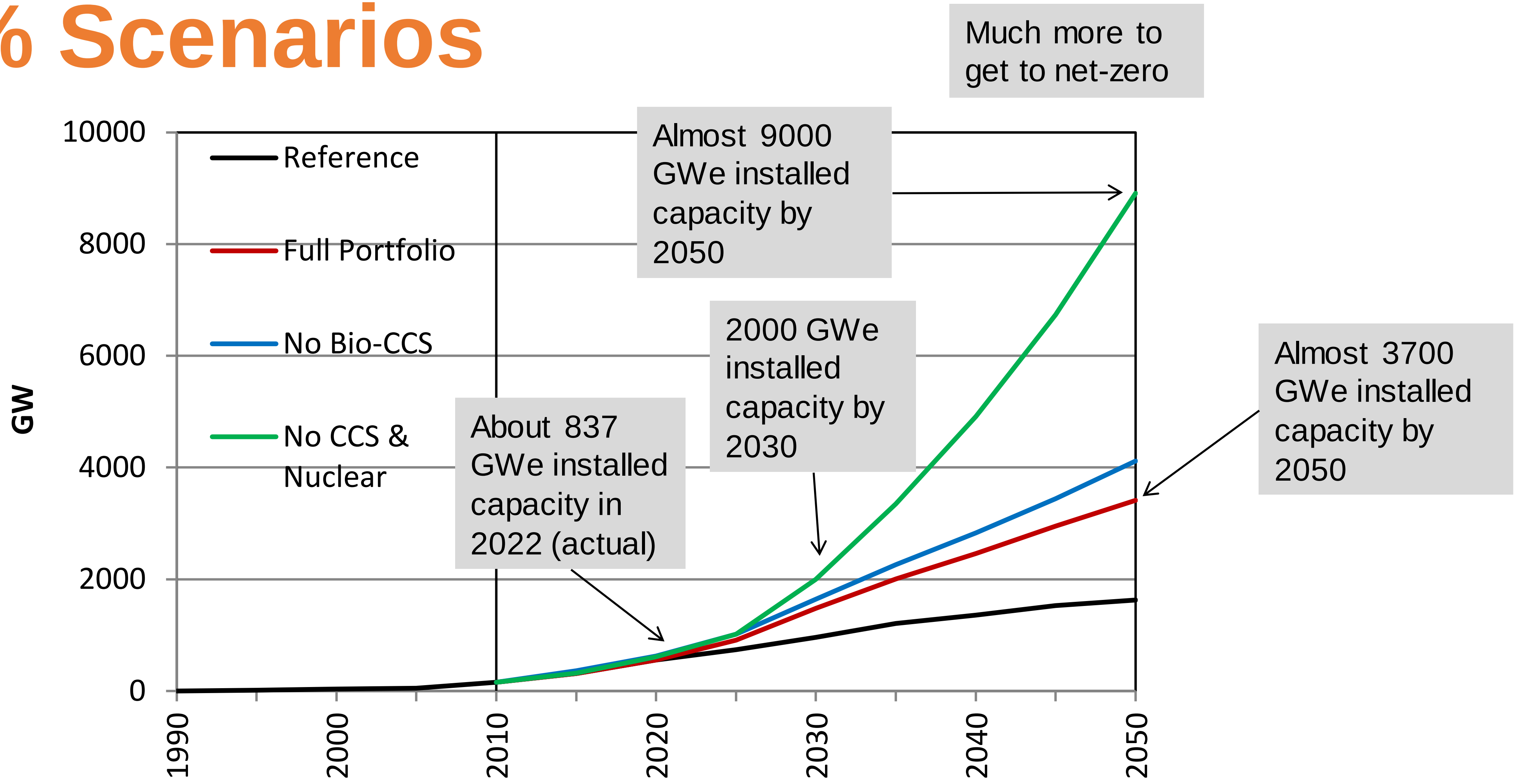
Electricity production: 25% reduction



Electricity production: 50% reduction

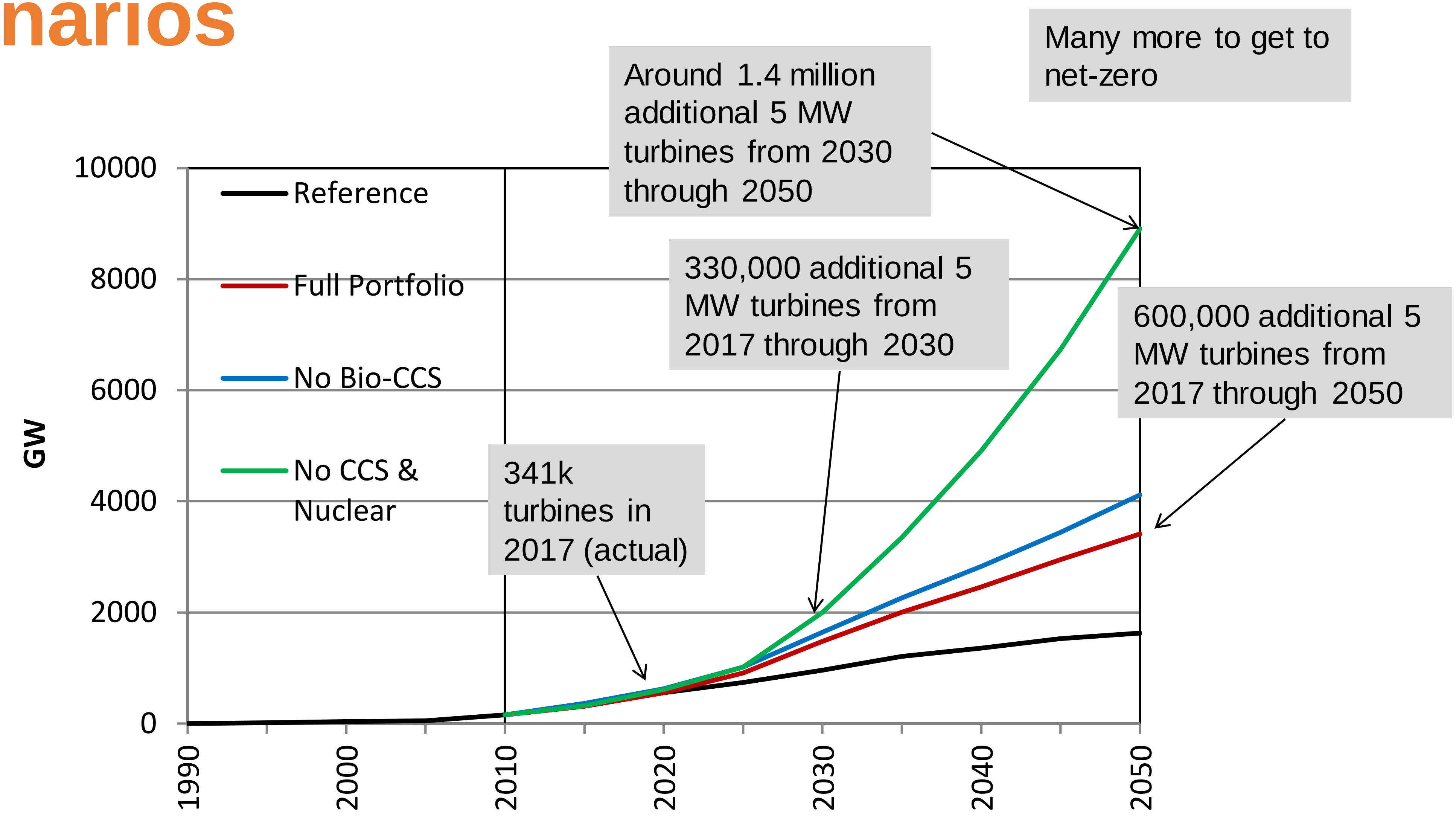


Onshore wind energy capacity in the 50% Scenarios



Note: Assumes a 25% average future global onshore wind capacity factor

Number of wind turbines in 50% reduction scenarios



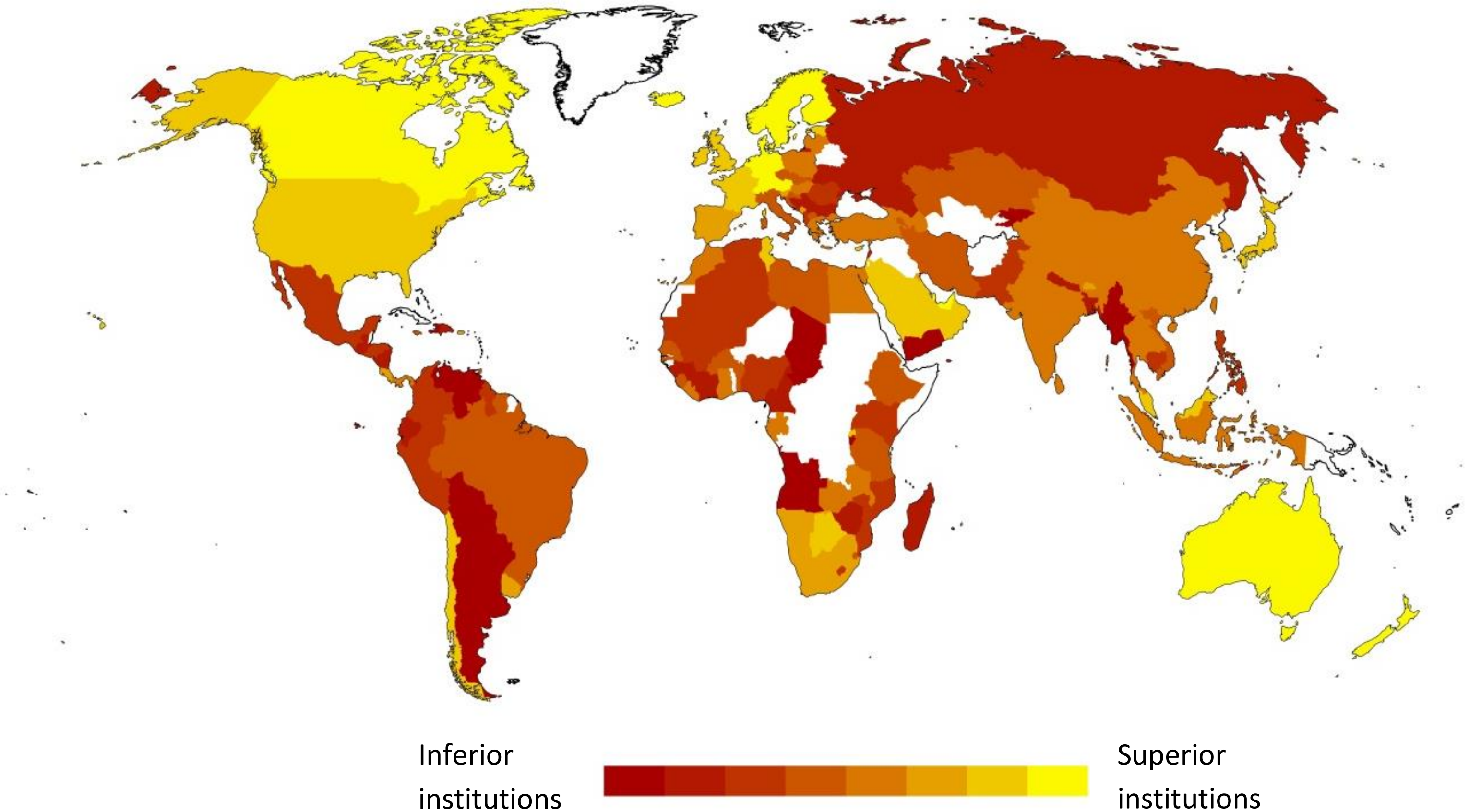
Note: Assumes a 25% average future global onshore wind capacity factor

What is the role of institutions in such transitions?

Many non-economic factors could affect the rate at which technologies deploy

- Institutions
- Policy/regulatory uncertainty
- Public perceptions

Institutional capacities are non-uniform across the globe



Source: World Economic Forum Global Competitiveness Survey

Institutional factors can affect investors' perceptions of risks

AFRICAN WIND FARM
Cost of debt ~ 12-13%

U.S. WIND FARM
Cost of debt ~ 8-9%

Implications of nonuniform investment risks

nature climate change
LETTERS
PUBLISHED ONLINE: 9 MARCH 2015 | DOI: 10.1038/NCLIMATE2553

Improved representation of investment decisions in assessments of CO_2 mitigation

Gokul C. Iyer[1,2*], Leon E. Clarke[2], James A. Edmonds[2], Brian P. Flannery[3], Nathan E. Hultman[1†], Haewon C. McJeon[2] and David G. Victor[4]

Assessments of emissions mitigation patterns have largely ignored the huge variation in real-world factors—in particular, institutions—that affect where, how and at what costs firms deploy capital[1-5]. We investigate one such factor—how national institutions affect investment risks and thus the cost of financing[6-8]. We use an integrated assessment model (IAM; ref. 9) to represent the variation in investment risks across technologies and regions in the electricity generation sector—a pivotally important sector in most assessments of climate change mitigation[10]—and compute the impact on the magnitude and distribution of mitigation costs. This modified representation of investment risks has two major effects. First, achieving an emissions mitigation goal is more expensive than it would be in a world with uniform investment risks. Second, industrialized countries mitigate more, and developing countries mitigate less. Here, we introduce a new front in the research on how real-world factors influence climate mitigation. We also suggest that institutional reforms aimed at lowering investment risks could be an important element of cost-effective climate mitigation strategies.

A number of factors such as national policy environments, quality of public and private institutions, sector and technology specific risks, and firm-level characteristics can affect investors' assessments of risks, leading to a wide variation in the business climate for investment[6,11]. Such heterogeneity in investment risks can have important implications, as investors usually respond to risks by requiring higher returns for riskier projects; delaying or forgoing the investments; or preferring to invest in existing,

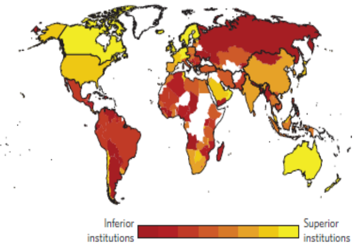


Figure 1 | Quality of national institutions based on the World Economic Forum's Global Competitiveness Index data set[11]. Assuming that non-uniformities in investment risks arise due to differences in institutional qualities, we use these data to represent costs of capital for investing in the electricity generation sector as a function of the quality of a country's institutions. This reflects behaviour of investors in the real world, where investors demand risk-adjusted rates of return that are higher in regions with inferior institutions.

to account for a significant share of future investments in the context of climate change mitigation[2,10].

This paper contributes to the growing literature on climate policy analysis under imperfect circumstances. Our central contribution

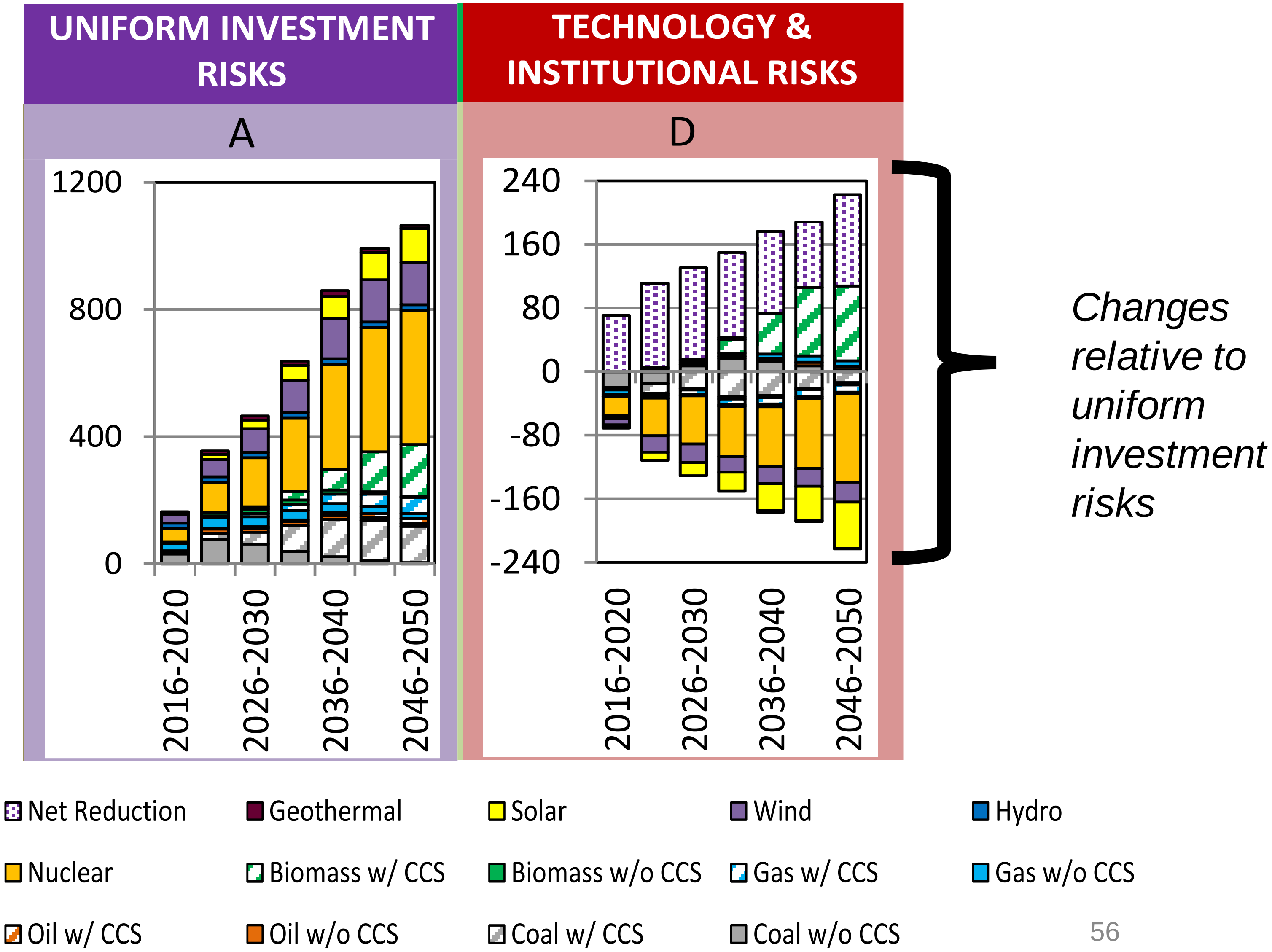
- Nonuniform investment risks can have important implications as investors respond to risks by
  - Expecting higher returns for riskier projects
  - Delaying or forgoing investments
  - Preferring to invest in existing, familiar technologies

How could heterogeneity in investment risks influence cost and distribution of climate change mitigation?

Incorporating risk perceptions in GCAM resulted in three effects

- Reduced investments in high risk low-carbon technologies (e.g. nuclear) and increased investments in BECCS and energy efficiency
- Shift of investments from developing to developed world
- Higher costs for meeting a given emissions goal
  - About 40% higher carbon price for a 50% reduction in CO2 emissions by 2050

Investments in electricity for 50% reduction in CO2 emissions by 2050 (Billion 2012 USD per year)



Key Insights from the study

- Major efforts to improve the institutional environment need to be essential elements of a larger strategy for reducing emissions cost-effectively

- It is plausible that institutional reforms may even be more important than technology-focused policies.

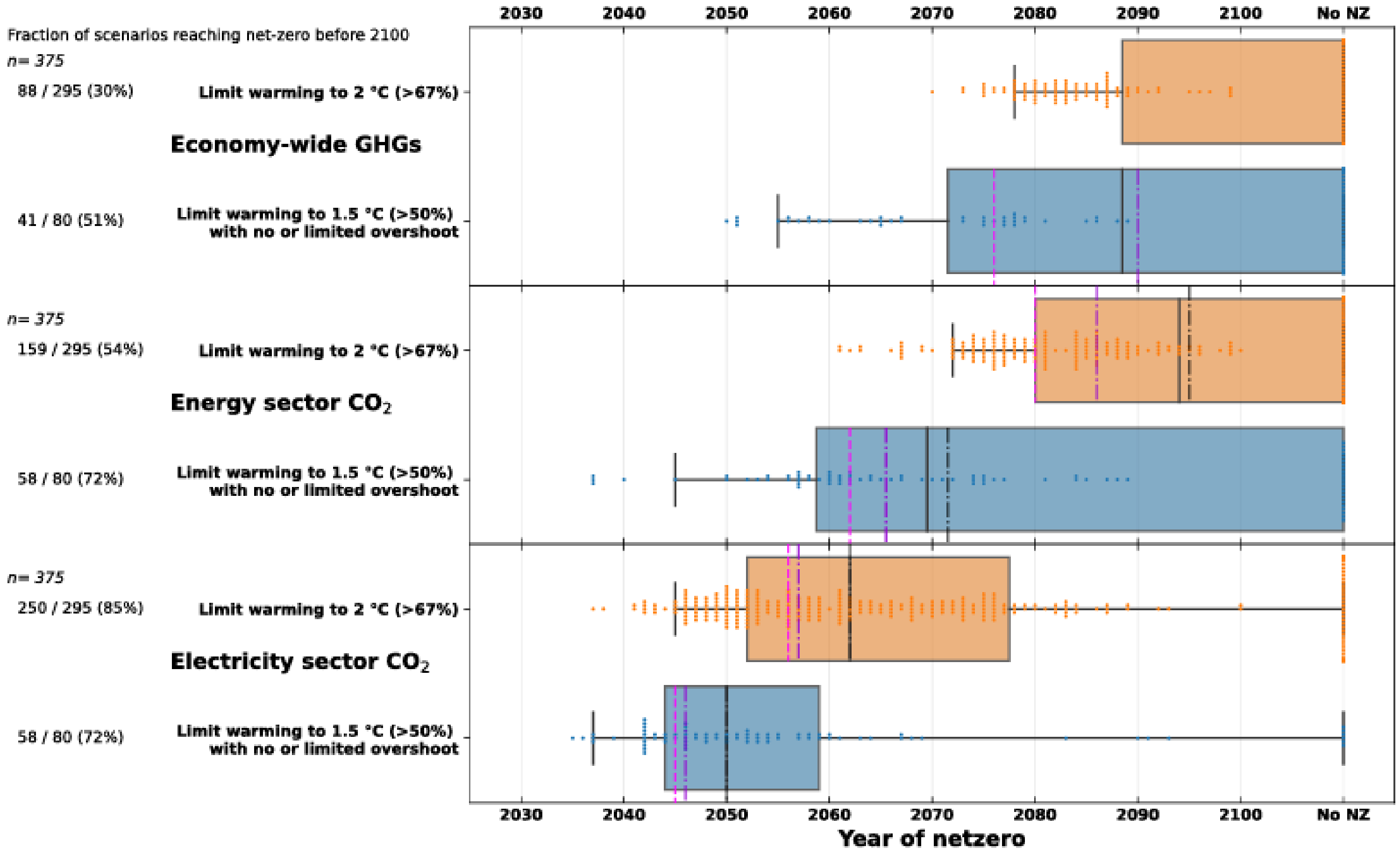
- Absent such reforms, mitigation effort could be disproportionately focused on countries where investment risks are lower.

Some emerging areas of energy systems research in IAMs

- Stranded assets under climate mitigation
- Effect of trade and geopolitical relationships on energy system transitions
- Linkages with mineral supply chains: Implications of mineral supply chains for energy system transitions and vice versa
- Linkages with sustainable development goals
- Spatial and sub-annual details to better capture intra-annual dynamics (e.g. storage in the power sector)
  - Impacts of changing intra-annual load patterns driven by climate, electric vehicle charging, etc.
- Impacts of behavioral changes

Questions

The timing of net-zero varies by sector



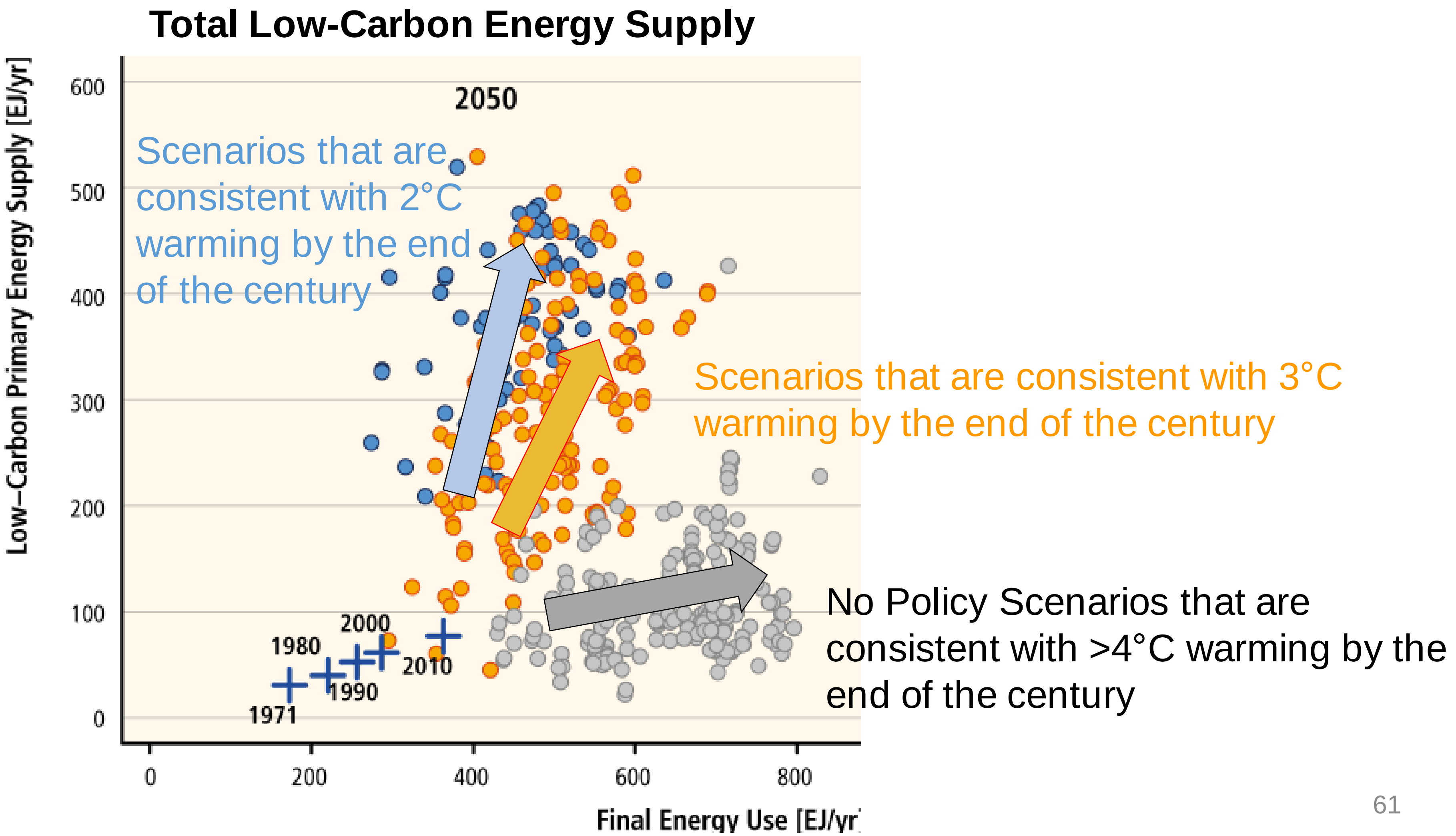
Black vertical line is the median across many IAM scenarios

Note that the range across scenarios is quite wide

Source: IPCC, AR6

Boxes indicate 25th and 75th percentiles, **center black line is the median**, while whiskers indicate 1.5x the inter-quartile range. The vertical dashed lines represent the median point at which emissions in the scenarios have dropped by 95% (pink) and 97.5% (purple), respectively. Dots represent individual scenarios. The fraction indicates the number of scenarios reaching net-zero by 2100 out of the total sample. Source: AR6 Scenario Database.

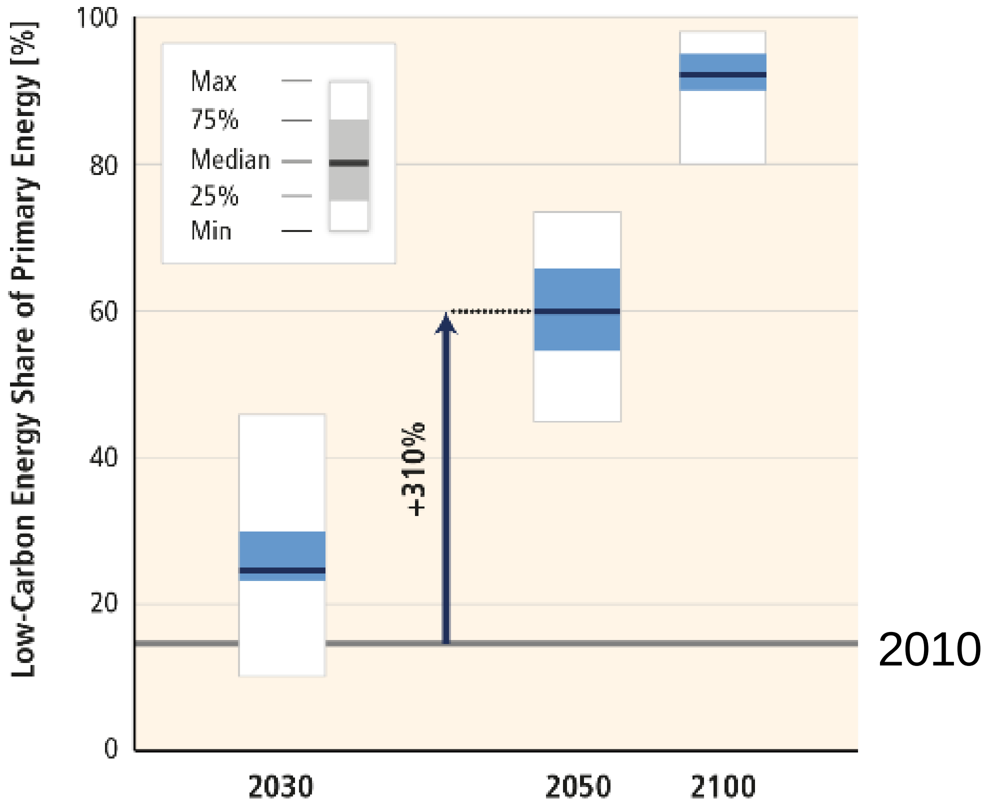
Mitigation scenarios are characterized by a major upscaling of low- and zero- carbon energy



Source: IPCC, AR5

Mitigation scenarios consistent with 2°C warming are characterized by a tripling to nearly a quadrupling of the share of zero- and low-carbon energy supply

Scenarios that are consistent with 2°C warming by the end of the century



Source: IPCC, AR5