Current approaches to modeling long-term climate-economy interactions

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Modeling

Goal of this presentation

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- Show you how long-term macro-climate scenarios are done
- Convince you that you should not invest your time and effort into this
  - I studied this so you don't have to

Long-term = 50+ years, for our purposes.

Long-term scenarios require economy-climate interactions

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Basic idea:

- GHG emissions cause economic harm in distant future
- Mitigating policies reduce GHG, but create disruption in the not so distant future
  - Higher taxes, higher energy prices, asset values decline in certain sectors

Key model ingredients:

- Long-run supply (production function) linked to energy prices / taxes
- GHG emissions linked to economic activity / energy inputs used
- Global temperature linked to accumulated GHG emissions
- Economic activity linked to global temperature

Useful features:

- Sectoral modeling to account for high sectoral heterogeneity

Model combination:

- Useful outputs are usually generated by a combination of models, not one standalone model

This is very complicated.

Long-term scenarios in practice

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Very challenging to develop:

- Completely different modeling tools than we currently use
- Need to account for climate modeling, long time horizons
- Linking GHG emissions to global temperature and economic activity relies on highly uncertain parameters
- Difficult to account for technological progress, adaptation of firms, households, etc.
    - These dimensions are often omitted / held constant.

There are **"benchmark" scenarios available** (discussed further). These can serve as a useful reference point.

From practical standpoint, investing in the long-term modeling makes little sense on the level of individual institutions.

- Unless you advise Biden, Xi, or Modi, you can treat GHG emissions as constant.

IAM Models

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Integrated assessment models are often used to produce long-term climate-economy scenarios.

Usually **do not have sufficient economic detail** to suffice for stress-testing on their own. They do the first step.

A short overview by Nordhaus.

Overview / links to about a dozen IAMs available here.

NGFS uses three IAMs:

- REMIND-MAgPIE
- GCAM
- MESSAGEix-GLOBIOM

IAMs can be quite complicated. Let's have a look.

REMIND-MAgPIE

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REMIND (REgional Model of Investment and Development)
Energy-economy general equilibrium model linking a macro-economic growth model with a bottom-up engineering-based energy system model

Macro: Ramsey-type growth model.

- Production factors: capital, labor, and final energy
- Production function with constant elasticity of substitution determines the final energy demand
- Output split to investment, consumption, trade, and energy system expenditures
- More than 50 technologies for conversion of primary energy into secondary energy and for the distribution of secondary energy carriers into final energy

Energy: Variety of fossil, biogenic, nuclear and renewable energy resource

- Macro and energy linked via the final energy demand and the costs incurred by the energy system
- Economic activity results in demand for final energy

Other:

- Taxes, subsidies
- Technological learning of emergent new technologies

- Adjustment costs
- ...

Solution: Find the welfare-optimal mix of investments in the economy and the energy sectors of each model region, given a set of population, technology, policy and climate constraints

Note: The code is very complicated.

REMIND-MAgPIE Cont.

MAgPIE (Model of Agricultural Production and its Impact on the Environment)
Global land use allocation model, which is connected to the grid-based dynamic vegetation model LPJmL

Agriculture: Land use patterns, yields and total costs of agricultural production for each grid cell

- Food and feed energy for the demand categories can be produced by 20 cropping activities and 3 livestock activities

Energy: Energy demand is defined for an exogenously given population in 10 food energy categories, based on regional diets

- Region-specific

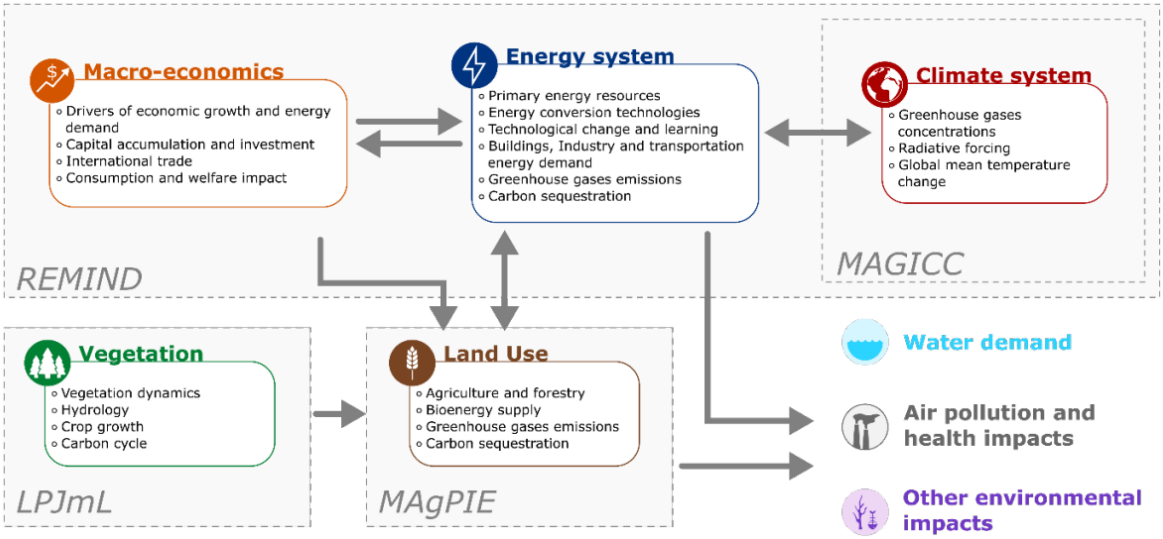
Solution: Minimize total cost of production for a given amount of regional food and bioenergy demand

Combining REMIND and MAgPIE: gi

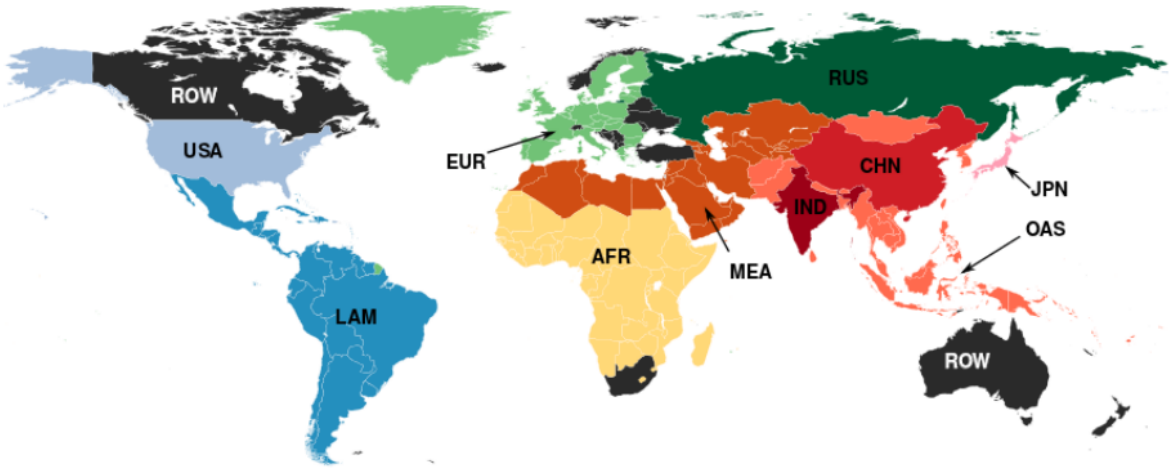
- Iterative mode
- REMIND updates MAgPIE's assumptions regarding bioenergy demand and GHG prices
- MAgPIE updates REMIND's assumptions regarding bioenergy prices and land-use emissions and agricultural production costs
- Iterations continue until changes between iterations become negligible

REMIND-MAgPIE Cont.

REMIND-MAgPIE Structure:



REMIND Regions:

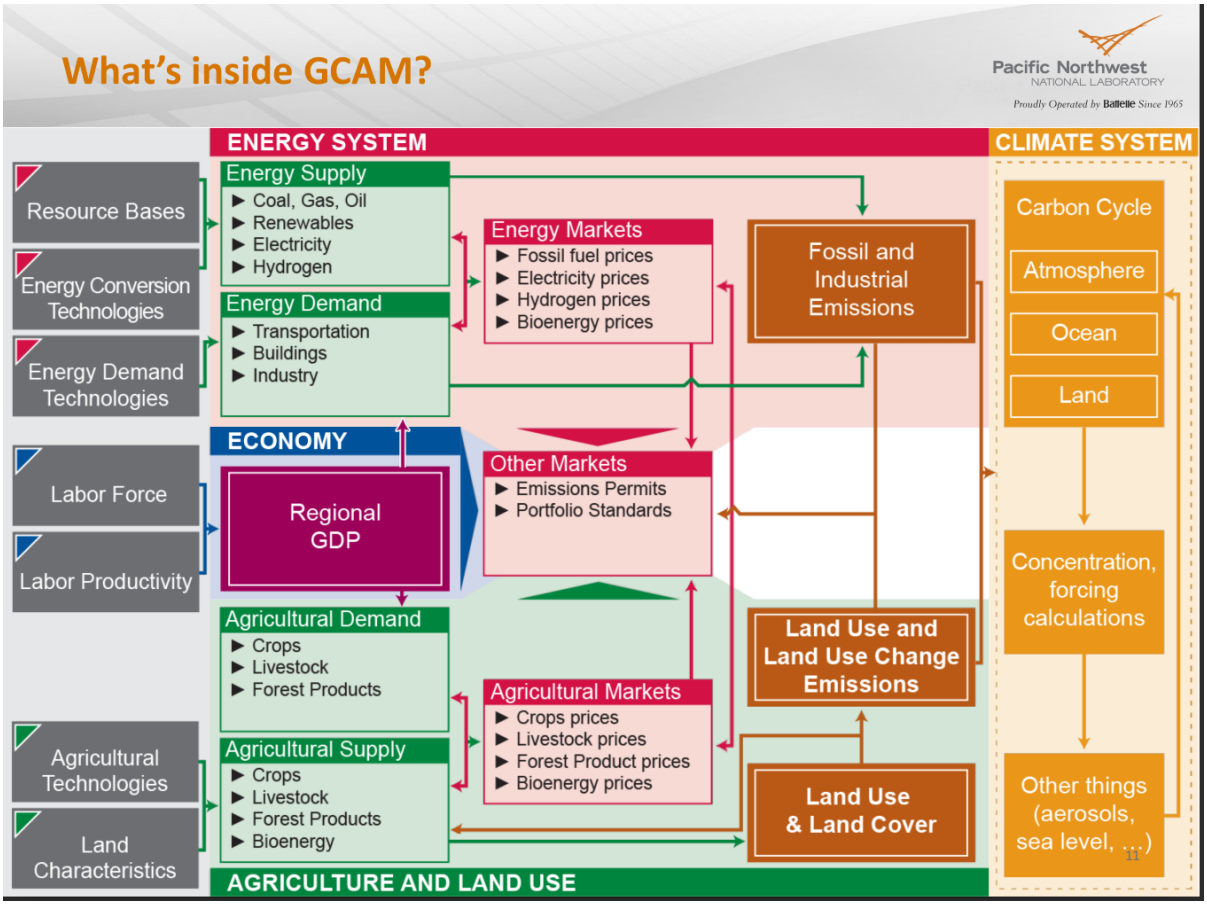


GCAM

GCAM (Global Change Assessment Model):

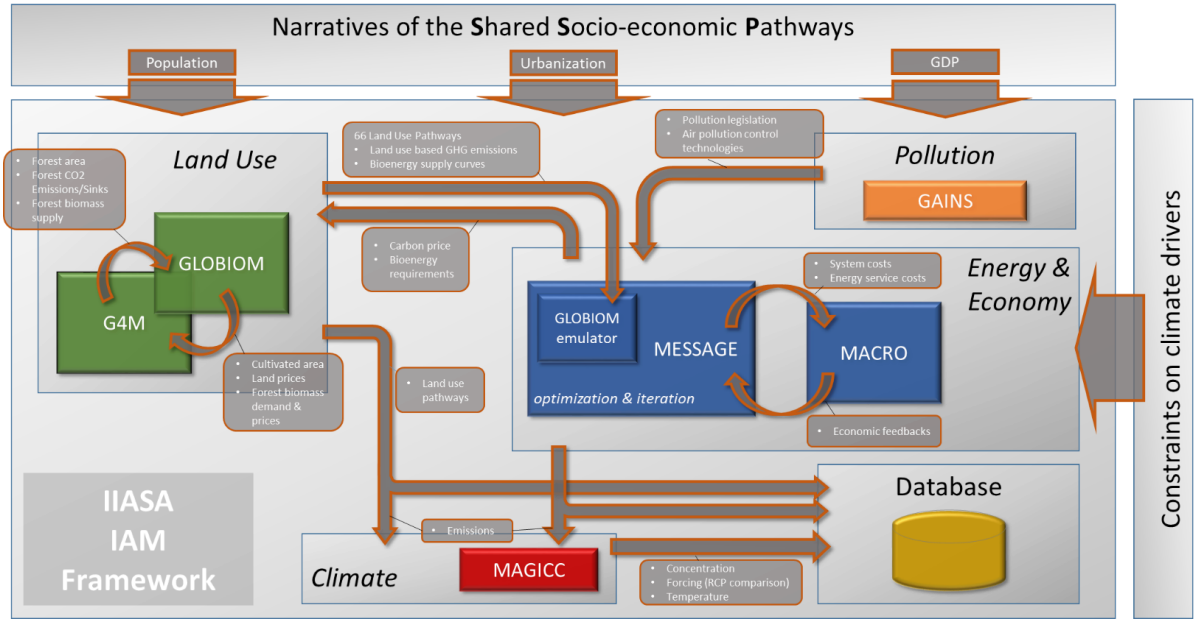
- Behavior and interaction of five systems: energy system, water, agriculture and land use, the economy, and the climate

Also very complex model with dozens of modules.



MESSAGEix-GLOBIOM

- Five modules: energy (MESSAGEix), land use (GLOBIOM), air pollution and GHG (GAINS), macro (MACRO), climate (MAGICC)
- 11 regions
- Also very complicated model



IAMs Summary

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- Very complex models
- Usually combine economy, energy, agriculture, technology, GHG emissions, climate, and other modules
- The modules are often not linked endogenously, but iteratively
- Often work with regions, but not on the level of individual countries
- Most often work in 10-year windows
- Often developed since the 1980s or 1990s, with cross-disciplinary teams behind them
- Macroeconomy described usually by growth model: GDP, consumption, investment, capital, labor, …
- **Not sufficiently detailed outputs for stress-testing**

Some frameworks are less complicated

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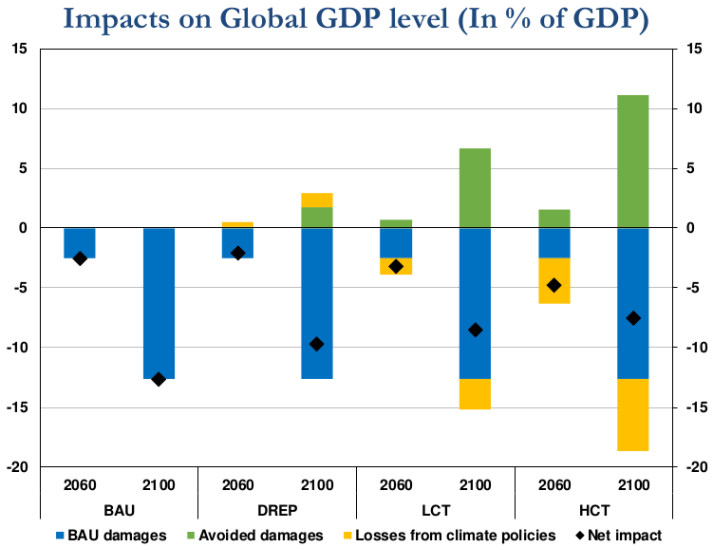
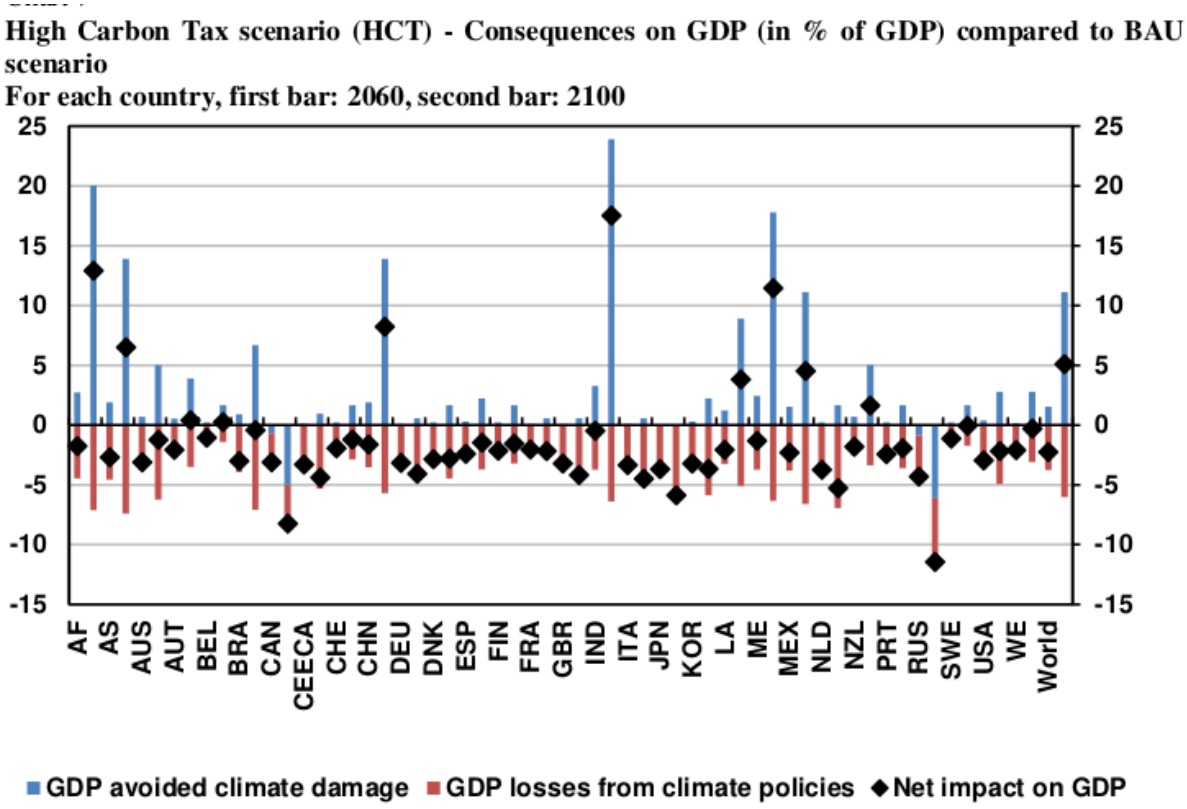
- 2020 Bank of France Working Paper with model of long-term climate-economy interactions
- 30 regions
- Five different types of energy, linked to GDP and GHG emissions
- Endogenous TFP, dependent on energy prices (carbon taxes)
- Authors claim key relationships are estimated from panel data and actually provide a lot of potentially useful estimates of parameters and elasticities
- Much more tractable model than the IAMs presented earlier, but still quite complex
- Scenario inputs: Relative energy prices, relative investment price, years of education, hours worked, employment rate, regulation index, capacity utilization;
  - Building the scenarios is not trivial!
- Note that the results are still not sufficiently rich for stress-testing without utilizing further models

- The paper finds quite substantial impact on global GDP



Scenarios: Business as usual (BAU); Decrease of Renewable Energy relative Price (DREP); Low Carbon Tax (LCT); High Carbon Tax (HCT)



NGFS Scenarios

- Current state-of-the art, **best we have**
- Comprehensive, updated frequently (last update November 2023), comparatively rich in macro, …
- Cover both **physical and transition risks**
- Publicly available, also through IMF Climate Dashboard
- Better than SSPs because they are updated regularly, richer in terms of economic variables

Disorderly

Delayed Transition assumes annual emissions do not decrease until 2030. Strong policies are needed to limit warming to below °2C. Negative emissions are limited.

Too-little too-late

Fragmented World assumes a delayed and divergent climate policy response among countries globally, leading to high physical and transition risks. Countries with net zero targets achieve them only partially (80% of the target), while the other countries follow current policies. NEW

Orderly

Net Zero 2050 limits global warming to 1.5 °C through stringent climate policies and innovation, reaching global net zero CO_2 emissions around 2050.*

Below 2 °C gradually increases the stringency of climate policies, giving a 67% chance of limiting global warming to below 2 °C.

Low Demand assumes that significant behavioural changes – reducing energy demand – in addition to (shadow) carbon price and technology induced efforts, would mitigate pressure on the economic system to reach global net zero CO_2 emissions around 2050.* NEW

Hot house world

Nationally Determined Contributions (NDCs) includes all pledged targets even if not yet backed up by implemented effective policies.

Current Policies assumes that only currently implemented policies are preserved, leading to high physical risks.

* In these scenarios, some jurisdictions such as the US, EU, UK, Canada, Australia and Japan reach net zero for all GHGs.

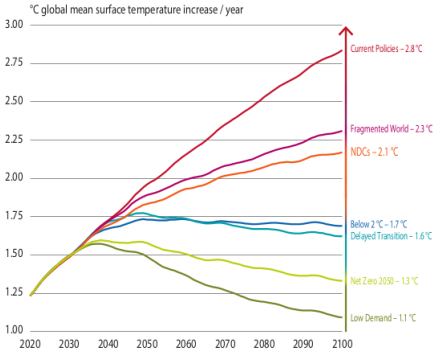
		Physical risk	Transition risk			
Quadrant	**Scenario**	**End of century warming** *(model averages)*	**Policy reaction**	**Technology change**	**Carbon dioxide removal** ⁻	**Regional policy variation** ⁺
Orderly	Low Demand NEW	1.4 °C (1.6 °C)	Immediate	Fast change	Medium use	Medium variation
	Net Zero 2050	1.4 °C (1.6 °C)	Immediate	Fast change	Medium-high use	Medium variation
	Below 2 °C	1.7 °C (1.8 °C)	Immediate and smooth	Moderate change	Medium use	Low variation
Disorderly	Delayed Transition	1.7 °C (1.8 °C)	Delayed	Slow/Fast change	Medium use	High variation
Hot house world	Nationally Determined Contributions (NDCs)	2.4 °C (2.4 °C)	NDCs	Slow change	Low use	Medium variation
	Current Policies	2.9 °C (2.9 °C)	None – current policies	Slow change	Low use	Low variation
Too-little-too-late	Fragmented World NEW	2.3 °C (2.3 °C)	Delayed and Fragmented	Slow/Fragmented change	Low-medium use	High variation

Colour coding indicates whether the characteristic makes the scenario more or less severe from a macro-financial risk perspective ^

- Lower risk
- Moderate risk
- Higher risk

Temperature Evolution by Scenario

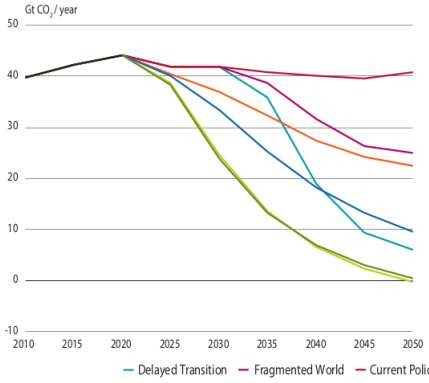
AR6 Surface Temperature (GSAT) increase (50th), MAGICC with REMIND emission inputs



Sources: IIASA NGFS Climate Scenarios Database, MAGICC model

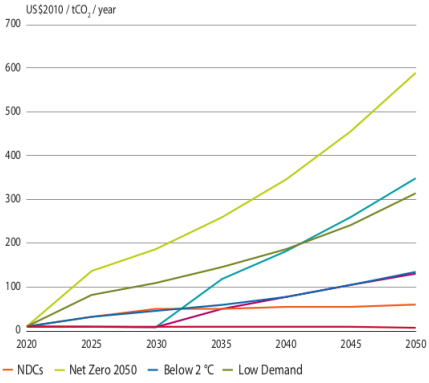
Global Yearly CO_2 Emissions

REMIND



Shadow Carbon Price

REMIND

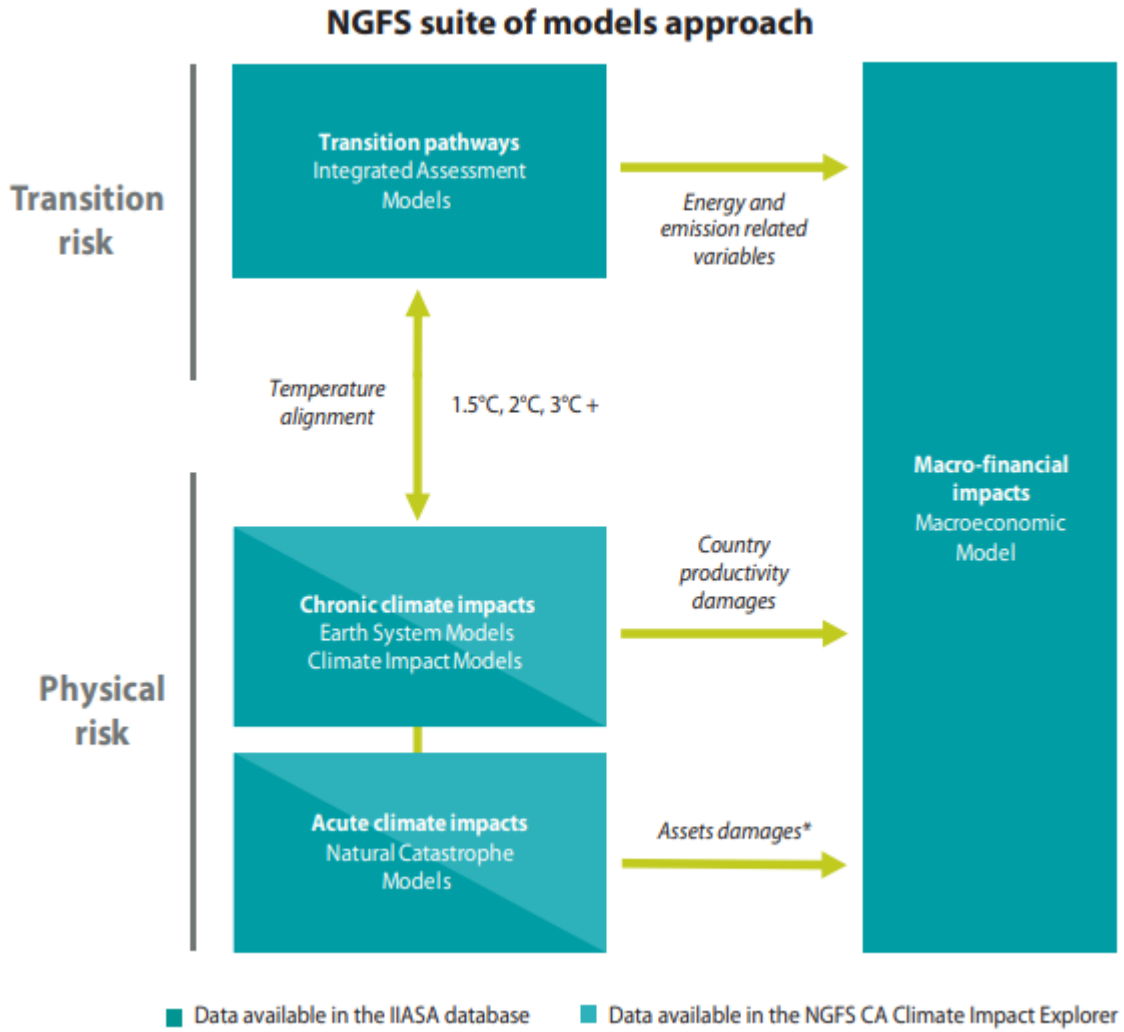


Delayed Transition — Fragmented World — Current Policies — NDCs — Net Zero 2050 — Below 2 °C — Low Demand

NGFS methodology

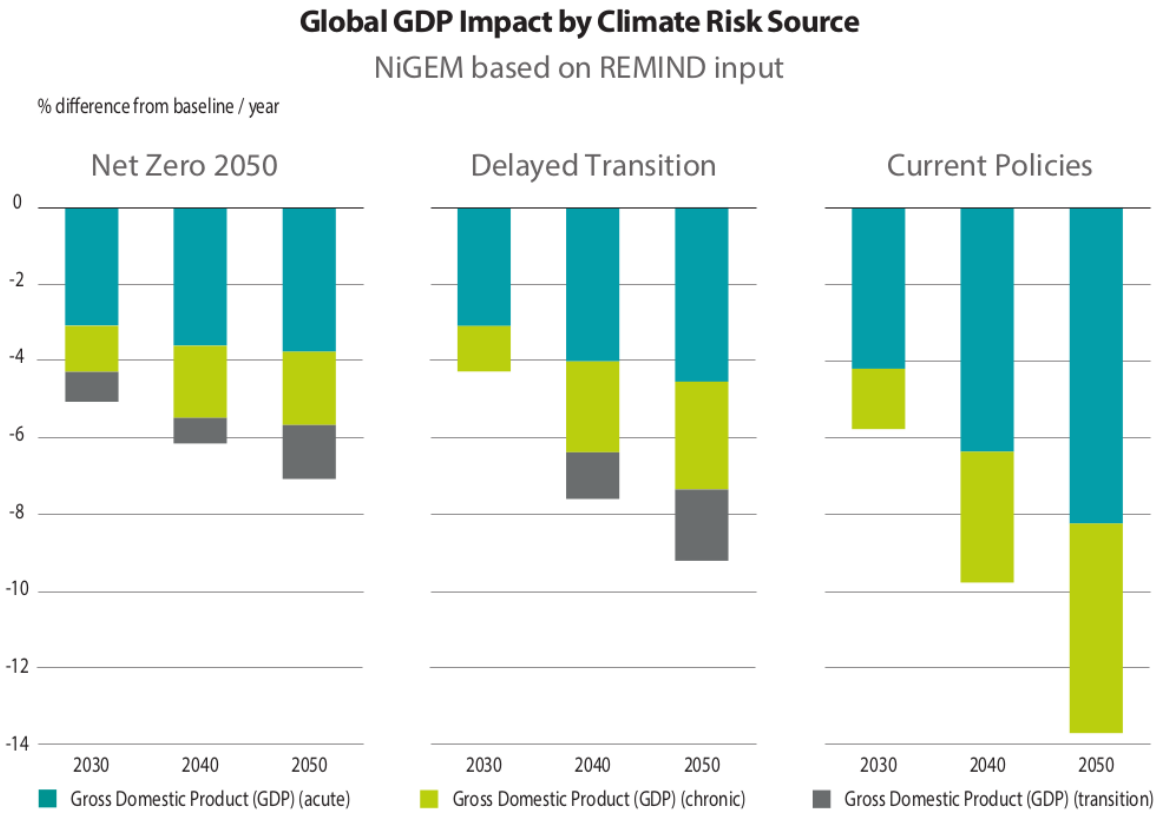
NGFS uses pragmatic approach with a suite of models:

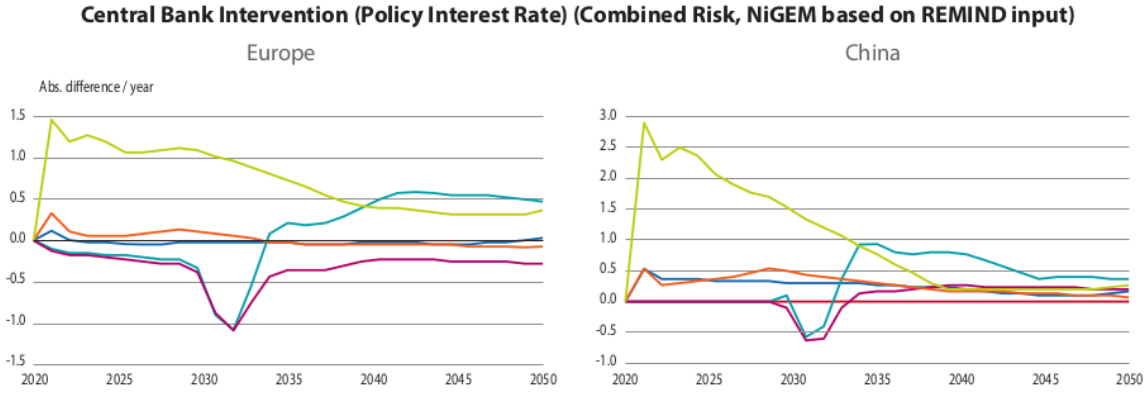
1. Generate "transition pathways" (climate-policy nexus) by **three IAM models**
2. Use **satellite models** to evaluate physical risks consistent with the pathways
3. Use **NiGEM** model to generate economic variables consistent with the pathways and the damages from physical risks

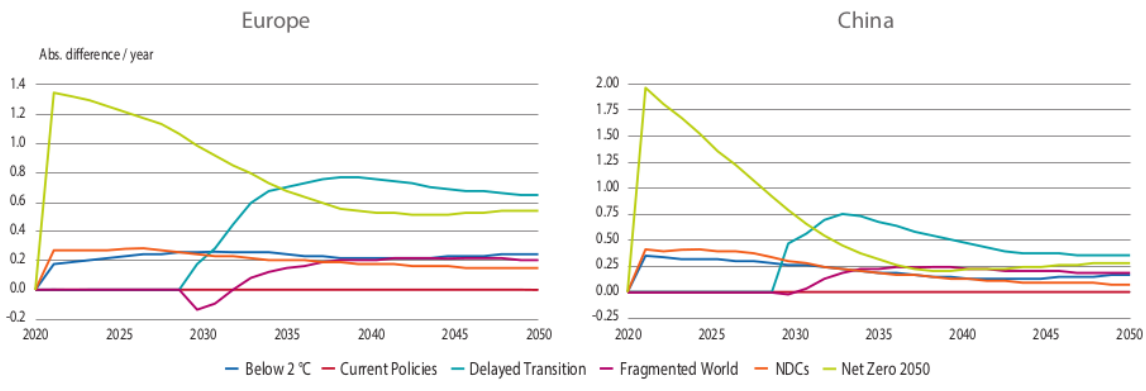


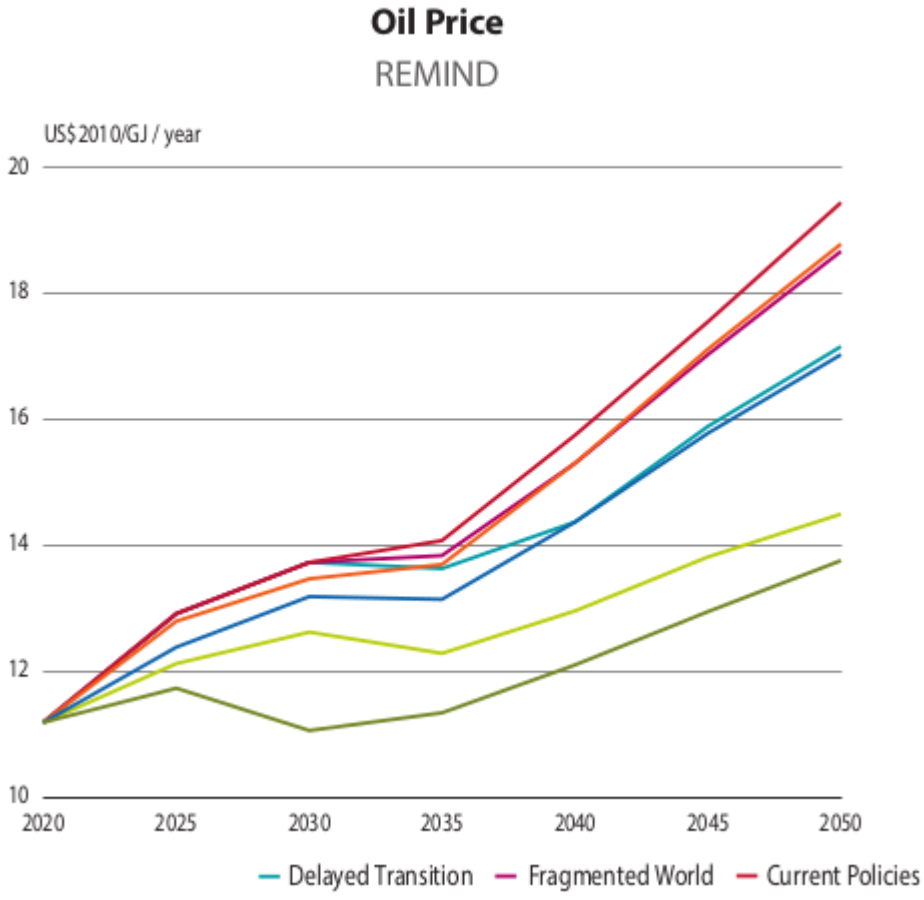
Complete methodology is complicated (240 pages!).

NGFS scenario results








Oil Price
REMIND
US$2010/GJ / year
20
18
16
14
12
10
2020
2025
2030
2035
2040
2045
2050
Delayed Transition
Fragmented World
Current Policies

Accessing NGFS scenarios

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Through the Scenario Explorer.

Where does this leave us?

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- Long-term macro-climate modeling is very complicated exercise
- Requires dedicated team with ample resources
- Outputs are:
  - Surrounded by large uncertainty
    - Some argue that current scenario grossly underestimate risks
  - Not detailed enough (geographically, available variables) => need to use e.g. CGE models which are not policy-invariant
  - Not clear if policy-relevant currently
- Our view: leave this to the experts, utilize what is available for directly relevant work
- NGFS scenarios provide good reference points as to carbon prices, impact on energy prices, demand, ...