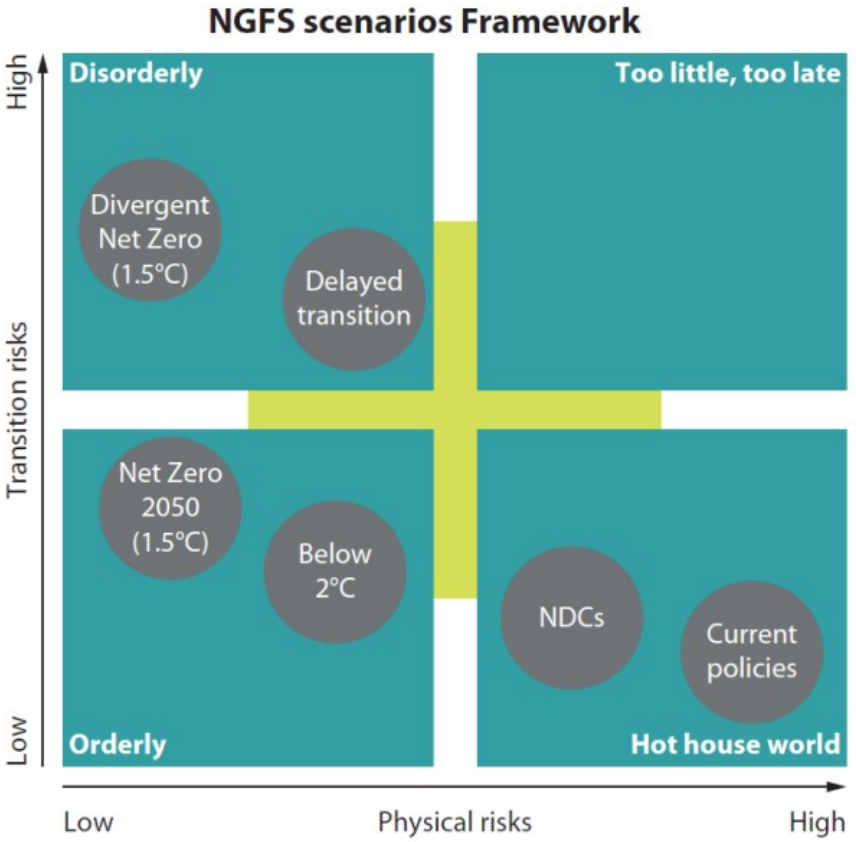
Overview NGFS Data

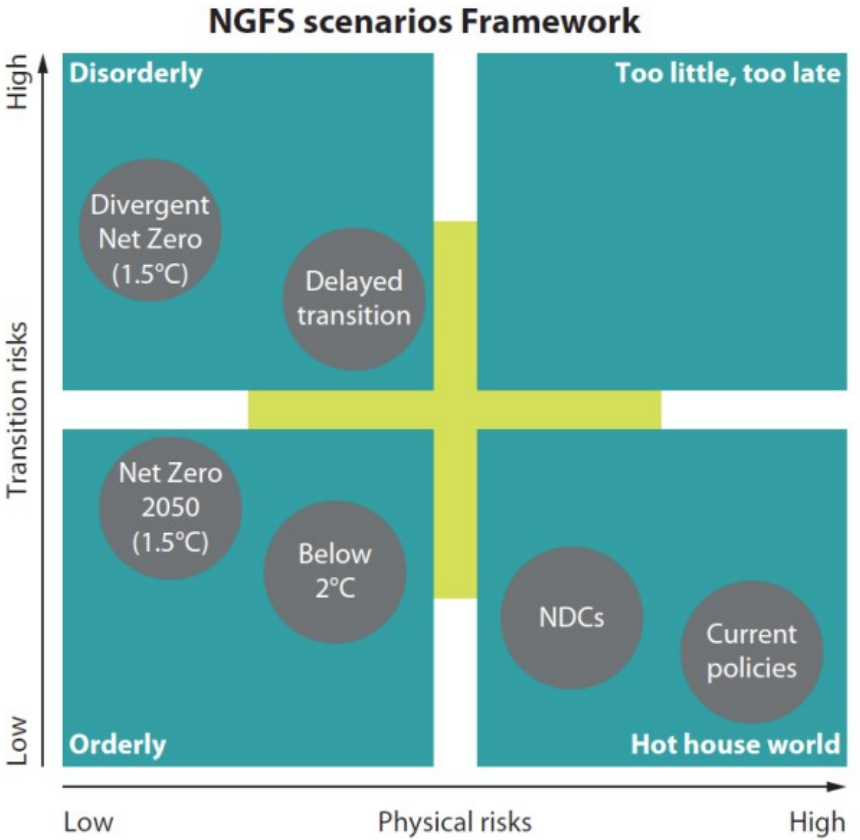
NGFS Reference Scenarios

- 6 scenarios considered by three modelling groups (IIASA, PIK: REMIND-MAgPIE, UMD)
- 18 transition pathways across different scenarios and models
- All share underlying assumption on key socio-economic drivers (population, economic developments, food, energy) from SSP2 (=middle of the road) with IMF adjustments
- 3 approaches: macro-economic damage function, integrated (REMIND-MagPIE), sector-level impact data



NGFS Reference Scenarios

- Divergent Net Zero (Disorderly) (GCAM, MESSAGE-GLOBOIM, REMIND-MAgPIE)
  - This scenario assumes that optimal carbon prices in line with the long-term targets are implemented immediately after 2020 to bring the median temperature below 1.5°C in 2100, after a limited temporary overshoot. Policy pressure and mitigation efforts are unevenly distributed across sectors, with stronger mitigation action taking place in the Transport and Buildings sectors relative to reflect consumer-oriented measured being preferred by policy makers.
- Delayed transition (Disorderly) (GCAM, MESSAGE-GLOBOIM, REMIND-MAgPIE)
  - This scenario assumes that the next 10 years see a "fossil recovery" and thus follow the trajectory of the current policies scenario until 2030, and only thereafter countries with a clear commitment to a specific net-zero policy target at the end of 2020 are assumed to meet the target, representing regional fragmentation. Regionally fragmented CO2 prices converge to global price near 2070 to keep the 67-percentile of warming below 2°C in 2100, which also allows for temporary overshoot.
- Net Zero 2050 (Orderly) (GCAM, MESSAGE-GLOBOIM, REMIND-MAgPIE)
  - This scenario foresees global CO2 emissions to be at net-zero in 2050. Furthermore, countries with a clear commitment to a specific net-zero policy target at the end of 2020 are assumed to meet this target. This scenario assumes that optimal carbon prices in line with the long-term targets are implemented immediately after 2020.
- Below 2°C (GCAM, MESSAGE-GLOBOIM, REMIND-MAgPIE)
  - This scenario assumes that optimal carbon prices in line with the long-term targets are implemented immediately after 2020 and keeps the 67-percentile of warming below 2°C throughout the 21st century.
- Nationally determined contributions (NDCs) (Hot house world) (GCAM, MESSAGE-GLOBOIM, REMIND-MAgPIE)
  - This scenario foresees that currently pledged unconditional NDCs are implemented fully, and respective targets on energy and emissions in 2025 and 2030 are reached in all countries. The long-term policy assumption beyond current NDC target times (2025 and 2030) is that climate policy ambition remains comparable to levels implied by NDCs. This however does not clearly constrain the level of policy ambition, so long-term deviations across models are quite high.
- Current Policies (GCAM, MESSAGE-GLOBOIM, REMIND-MAgPIE)
  - Existing climate policies remain in place, and there is no strengthening of ambition level of these policies.
- NiGEM NGFS v1.21 Base Scenario
  - NiGEM v1.21's starting forecast base calibrated to match the primary fuel consumption differentials from the Current Policies scenario of GCAM5.3_NGFS, MESSAGE-GLOBIOM 1.1., REMIND-MAgPIE 2.1-4.2



NGFS Scenarios

- IIASA
  - Transition
  - 3 modelling groups (IIASA, PIK, UMD)
  - 18 transition pathways
  - Online: NGFS Scenario Explorer
  - RestAPI: Python package pyam
- ISIMIP, CLIMADA
  - Physical impact data collected by the Inter-Sectoral Impact Model Intercomparison Project (ISIMIP)
  - ISIMP – download only
  - Climada – PyPi package
    - https://github.com/CLIMADA-project/climada_python
      - https://climada-python.readthedocs.io/en/stable/tutorial/climada_hazard_RiverFlood.html
      - https://climada-python.readthedocs.io/en/stable/tutorial/climada_hazard_TropCyclone.html

Datasets I

IIASA (NGFS Scenario Explorer)

- Transition Risks
  - 6 models
  - 27 scenarios
  - 1759 variables
  - 400 regions
  - 1 metadata category
- Dowload only, no PyPi package

https://data.ene.iiasa.ac.at/ngfs/#/docs

- Dataset on **transition risk** that comprises transition pathways, including downscaled information on national energy use and emissions and data on macro-economic impacts from physical risks. This dataset also contains scenarios of the economic implications of the combined transition and physical effects on major economies

NGFS-IIASA: MODELS

- GCAM5.3_NGFS - Global Change Assessment Model 5.3
  - **GCAM is a global integrated assessment model** that represents the behaviour of, and complex interactions between five systems: the energy system, water, agriculture and land use, the economy, and the climate.
  - The core operating principle for **GCAM is that of market equilibrium**. Representative agents in GCAM **use information on prices**, as well as other information that might be relevant, and **make decisions about the allocation of resources**. These representative agents exist throughout the model, representing, for example, regional electricity sectors, regional refining sectors, regional energy demand sectors, and land users who have to allocate land among competing crops within any given land region. Markets are the means by which these representative agents interact with one another. All markets are solved simultaneously. Agents pass goods and services along with prices into the markets. Markets exist for physical flows such as electricity or agricultural commodities, but they also can exist for other types of goods and services, for example tradable carbon permits.
- MESSAGEix-GLOBIOM 1.1 - https://github.com/iiasa/message_ix
  - MESSAGEix-GLOBIOM is an **integrated assessment framework** designed to assess the **transformation of the energy and land systems** vis-a-vis the challenges of climate change and other sustainability issues. It consists of the **energy model MESSAGE**, the **land use model GLOBIOM**, the **air pollution and GHG model GAINS**, the aggregated **macro-economic model MACRO** and the simple **climate model MAGICC**.
  - **Hybrid model** (energy engineering and land use partial equilibrium models soft-linked to macro-economic general equilibrium model)
- NiGEM NGFS v1.21
  - The **National Institute Global Econometric Model, NiGEM,** is a transparent, peer reviewed global econometric model that has developed over 30 years of regular use. It is available from the Institute with a user-friendly ‘front-end’ specifically designed to facilitate forecasting and simulation analysis. The model is used by policymakers and private sector organisations around the world for economic forecasting, scenario analysis and stress testing.
  - From a theoretical perspective, NiGEM can be classed among **global general equilibrium macroeconomic models,** which are fundamentally grounded in **Walrasian general equilibrium theory.** It therefore strikes a balance between theoretical underpinnings that guide economies towards long-run market clearing equilibria, and data-driven individual country characteristics that fit the main characteristics of real-world data outturns.
- REMIND 2.1 – MAgPIE 4.2 Potsdam Institut für Klimafolgenforschung (PIK)
  - REMIND: (**Regionalized model of investment and development**) is a **global multi-regional model incorporating the economy, the climate system and a detailed representation of the energy sector**. It allows analysing technology options and policy proposals for climate mitigation, and models regional energy investments and interregional trade in goods, energy carriers and emissions allowances.
  - REMIND: **Hybrid model** that couples an economic growth model with a detailed energy system model and a simple climate model.
  - MAgPIE: (**Model of Agricultural Production and its Impact on the Environment**) is a **global land use allocation model**. MAgPIE derives future projections of spatial land use patterns, yields and regional costs of agricultural production.
  - MAgPIE: **Gridded land use model with economic regions**. Coupled to the grid-based dynamic vegetation model LPJmL providing gridded input on potential crop yields, water availability and terrestrial carbon content under various climate conditions.

NGFS-IIASA: MODELS

- REMIND 2.1 with integrated damages – MAgPIE 4.2
  - REMIND: (**Regionalized model of investment and development**) is a global multi-regional model incorporating the economy, the climate system and a detailed representation of the energy sector. It allows analysing technology options and policy proposals for climate mitigation, and models regional energy investments and interregional trade in goods, energy carriers and emissions allowances.
  - REMIND: **Hybrid model** that couples an economic growth model with a detailed energy system model and a simple climate model. In this version of the model, macro-economic climate damages are endogenised via the labour productivity channel. This model considers high level of physical damages corresponding to the 95th-percentile projected increase in global mean temperature (GMT-P95).
  - MAgPIE: (**Model of Agricultural Production and its Impact on the Environment**) is a **global land use allocation model**. MAgPIE derives future projections of spatial land use patterns, yields and regional costs of agricultural production.,
  - MAgPIE: In this version of the model framework, we used an **emulator of the MAgPIE model**
- REMIND 2.1 with integrated damages – MAgPIE 4.2
  - REMIND: (**Regionalized model of investment and development**) is a global multi-regional model incorporating the economy, the climate system and a detailed representation of the energy sector. It allows analysing technology options and policy proposals for climate mitigation, and models regional energy investments and interregional trade in goods, energy carriers and emissions allowances.
  - REMIND: **Hybrid model** that couples an economic growth model with a detailed energy system model and a simple climate model. In this version of the model, macro-economic climate damages are endogenised via the labour productivity channel. This model considers medium level of physical damages corresponding to the median projected increase in global mean temperature (GMT-MED).
  - MAgPIE: (**Model of Agricultural Production and its Impact on the Environment**) is a global land use allocation model. MAgPIE derives future projections of spatial land use patterns, yields and regional costs of agricultural production.
  - MAgPIE: In this version of the model framework, we used an emulator of the MAgPIE model.

- **REMIND** - Regionalized model of investment and development is a global multi-regional model incorporating the economy, the climate system and a detailed representation of the energy sector
- **MAgPIE**: (Model of Agricultural Production and its Impact on the Environment) is a global land use allocation model.
- **MESSAGEix**-GLOBIOM 1.1 - energy model MESSAGE, the land use model **GLOBIOM**, the air pollution and GHG model **GAINS**, the aggregated macro-economic model **MACRO** and the simple climate model **MAGICC**
- **NiGEM** - NiGEM (**short-term** macro-economic effects) is the econometric macroeconomic model for economic forecasting, scenario building and stress testing. It consists of individual country models for the major economies, which are linked together through trade in goods and services and integrated capital markets.
- **GCAM** - integrated tool for exploring the dynamics of the coupled human-Earth system and the response of this system to global changes. http://www.globalchange.umd.edu/gcam

Variables for PD Modeling

- **Price|Carbon** is an endogenous variable (iteratively adjusted to meet the climate targets) which denotes the economy-wide carbon price that is the main policy instrument in all scenarios (though additional sectoral policies are implemented in the “Current Policies” and “NDC” scenarios), and whose value is set so to reach the specified emission targets in the respective scenario. Carbon prices are differentiated across regions, and in the “Divergent NetZero” scenario also across sectors. The (global) aggregate is calculated as a weighted average, with (regional and/or sectoral) gross emissions as weight. The general equilibrium models REMIND-MagPIE and MESSAGEix-GLOBIOM recycle the revenues from carbon pricing via the general budget of each region. This cannot be done in the partial equilibrium model GCAM which, by design, does not have a representation of the whole economy.
- All economic assumptions are taken from the shared socio-economic pathway 2 (SSP 2), designed to represent a “middle-of-the-road” future development. All 3 models have Population as a fully exogenous input assumption. **GDP|PPP,** denominating the gross domestic product in power-purchasing parity terms, is an exogenous input assumption in the GCAM model, but a semi-endogenous output for REMIND-MAgPIE and MESSAGEix-GLOBIOM

- The consumption of fossil primary energy is separated into **Primary Energy|Coal**, **Primary Energy|Oil** and **Primary Energy|Gas** (all of which - and any other related variables - are computed endogenously). These three primary energy categories are aggregated into the category **Primary energy|Fossil.** Primary energy carriers can be used directly or converted to secondary fuels (electricity, gases or liquids, see below), and the use of primary energy carriers in the power sector is reported under Primary **Energy|Coal|Electricity** (similar for oil and gas). The generation of electricity can take place with or without capturing the CO2, which is reported separately **Primary Energy|Coal|Electricity|w/ CCS** and **Primary Energy|Coal|Electricity|w/o CCS** (similar for oil and gas).

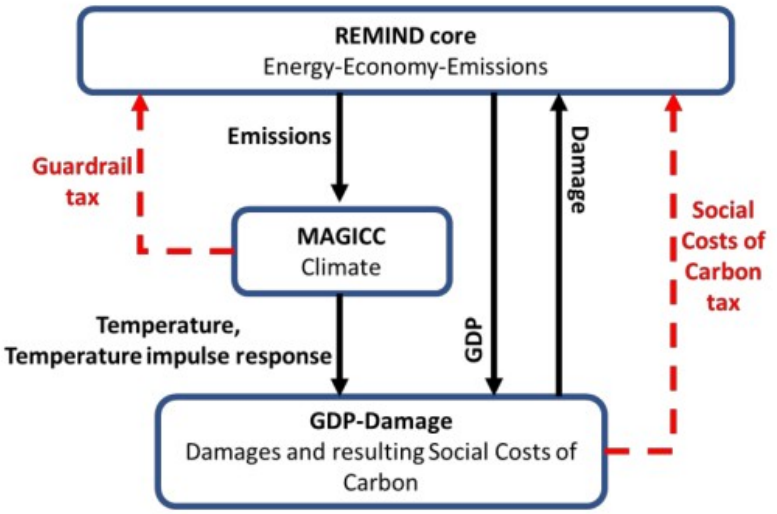
Country Level Data

- The original downscaling tool aims at providing a range of pathways at the country level based on different criteria, in order to explore the feasibility space of low-carbon scenarios. However, for the application to the NGFS scenarios, we have **developed a single pathway for each country** that is consistent with the philosophy of the underlying scenario.
- Several basic quantitative elements for the SSPs are available at the country-level, including Population (Samir KC et al 2017), GDP (Dellink et al 2017, Crespo 2017, Leimbach et al 2017), and governance indicators (Andrijevic et al. 2019). The GDP and population data refer to baseline scenarios (absent of climate policies) and are available in the SSP online database , whereas the governance indicators are available on a github repository. We use those country-level scenario data as inputs to the downscaling tool.
  - https://tntcat.iiasa.ac.at/SspDb/dsd?Action=htmlpage&page=welcome
  - https://github.com/marina-andrijevic/governance2019

- For each **downscaled final energy variable**, we applied the conversion factors listed in table 4 and sum them up in to a new variable called Useful energy. The R script developed and used to compute useful energy:
  - https://gitlab.pik-potsdam.de/hilaire/ngfs_estimate_usefulenergy/
- The global mean temperature pathways provided by the MAGICC postprocessing have to be downscaled to country-level for the calculation of country-level macroeconomic damages as described in the previous section. For this we use a statistical downscaling approach based on the multi-model climate data set from Phase 5 of the Coupled Model Intercomparison Project of global climate models
  - https://esgf-node.llnl.gov/search/cmip5/

Integrated Scenarios

- **Transition and physical risks should be modelled together** in an integrated framework, to capture feedback effects properly. With the REMIND-MAgPIE model we provide an additional set of such integrated scenarios for the NGFS framework, integrating climate damages based on the empirical specification by Kalkuhl & Wenz (2020) into the transition scenarios directly, while the default scenarios with REMIND-MagPIE and the other two IAMs do not include damages internally.



NiGEM (short-term macro)

- Based on a New Keynesian structure, individual country models are grounded in **textbook macroeconomic foundations,** with features such as sticky prices, rational or model-consistent expectations, endogenous monetary policy based on a Taylor rule or other standard specifications, and long-run fiscal solvency. The structure of **NiGEM is designed to correspond to macroeconomic policy needs**. Country models are built around the national income identity, and contain the determinants of domestic demand, trade volumes, prices, current accounts and asset holdings. They also incorporate a **well-specified supply-side,** which underpins the sustainable growth rate of each economy in the medium term.
- Both the integrated assessment models and NiGEM **produce endogenous GDP estimates** (though the GCAM GDP estimate is based on the endogeneous carbon price response, see section 3.1.3 above). NiGEM estimates of short-term GDP utilize integrated assessment model long-term reference GDP trajectories from the three IAMs as a point of departure. The IAMs' reference scenario GDP pathway is a counterfactual long-term asymptotic GDP pathway that would emerge in the absence of either physical or transition shocks. **NiGEM replicates the long-term, reference GDP pathways produced by the three IAMs**, as well as the associated population and primary energy consumption pathways.

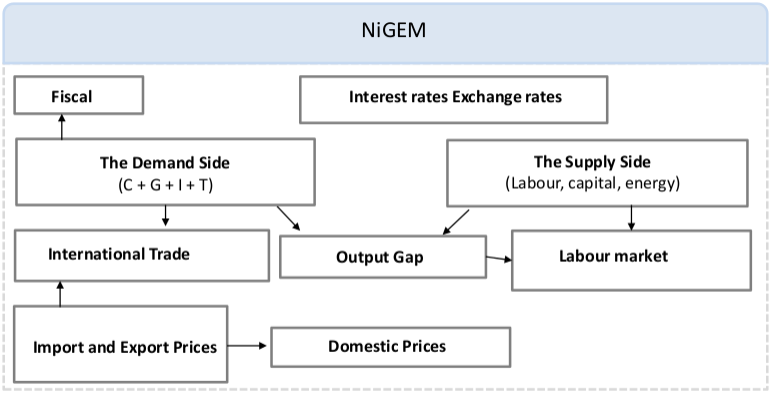


Figure 10 Typical country structure in NiGEM

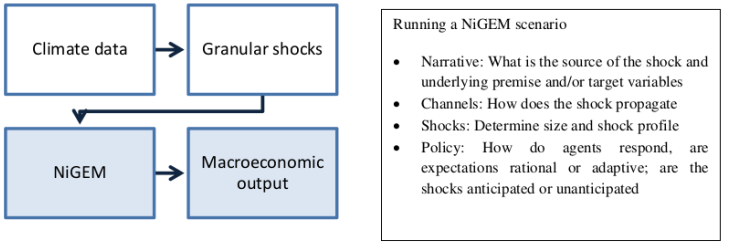


Figure 11 Sequence for translating climate scenarios into NIGEM

NiGEM

Table 5 Differences between scenarios

NGFS scenario	Physical	Transition	Fiscal rule and notes
Current policies	The P95 temperature profile is used for the GDP damage target	None	Fiscal rule: N/A Note: With only physical damage considered, the energy sector is endogenous for the physical shock.
NDC	The P95 temperature profile is used for the GDP damage target	Current Nationally Determined Contributions • Limited carbon pricing	Fiscal rule: Income tax is cut, boosting private consumption.
Net Zero 2050	Expected temperature profile is used for GDP damage target	• Global carbon pricing • Energy mix changes • Energy efficiencies	Fiscal rule: Carbon tax revenues channeled back via government investment.
Below 2°C	Expected temperature profile is used for GDP damage target	• Global carbon pricing • Energy mix changes • Energy efficiencies	Fiscal rule: Income tax is cut, boosting private consumption.
Divergent Net Zero	Expected temperature profile is used for GDP damage target	• Global carbon pricing • Energy mix changes	Fiscal rule: Income tax is cut, boosting private consumption.
			Note: Additional negative shock to business confidence
Delayed transition	Expected temperature profile is used for GDP damage target	• Global carbon pricing • Energy mix changes • Energy efficiencies	Fiscal rule: Income tax is cut, boosting private consumption. Note: Additional negative shock to business confidence

NiGEM output variables are the following:

General economic outputs

- Gross domestic product (GDP)
- Consumption, investment, government expenditure
- Technological innovation and capital productivity
- Unemployment rate
- Corporate profits, household income
- International trade flows
- Gross domestic income
- Trend capacity
- Energy prices and consumption

Specific economic outputs in the context of financial risk analysis

- Consumer price inflation
- Energy and commodity prices
- Interest rates
- Government bond yields
- Exchange rates between countries
- Equity market indices
- Real estate price indices (residential)

Models

Table 6 **Time steps across models**

Model	Time steps
GCAM	• 5-year time steps from 2005 to 2100
MESSAGEix-GLOBIOM	• 5-year time steps from 2005 to 2060 and 10-year timesteps over the period 2050-2100
REMIND-MAgPIE	• 5-year time steps from 2005 to 2060 and 10-year time steps over the period 2050-2100

Datasets II

ISIMIP, CLIMADA

- Climada
  - open-source catastrophe risk modelling framework, is used to estimate the damages from
  - extreme events by modelling their likelihood of occurring and the hazard associated with them

- **Physical impact data** collected by the Inter-Sectoral Impact Model Intercomparison Project (ISIMIP), as well as data from CLIMADA
- These datasets are generated with a suite of models including integrated assessment models, a **macro-econometric model, earth system models, sectoral impact models, a natural catastrophe damage model and global macroeconomic damage functions**. They are linked together in a coherent way by aligning global warming levels and by explicit linkage via defined interfaces in case of the integrated assessment models and the macro-econometric model

Climate Impact Explorer

- The Climate Impact Explorer is meant to provide information about projected changes in various climate impact indicators for several levels of global warming, and how they may unfold over time according to various scenarios of greenhouse gas emissions.
- This information is provided at the country level, both in the format of time series with 5-year time steps until 2100 and as maps visualizing projected changes for distinctive global warming levels (1.5°C, 2°C, 2.5°C, and 3°C).

- The CIE displays **climate impacts** on biophysical systems, extreme events and resulting economic damages **for three of the six NGFS scenarios:**
  - **Net-Zero 2050** is an ambitious scenario that limits global warming to 1.5°C through stringent climate policies and innovation, reaching net zero CO2 emissions around 2050. This scenario is thus compatible with the long-term temperature goal of the Paris Agreement.
  - **Delayed transition** assumes annual emissions do not decrease until 2030. Strong policies are then needed to limit warming to below 2°C.
  - **Current Policies** assumes that only currently implemented policies are preserved, leading to a global warming by up to 3°C by 2100 and high associated climate impacts.
- The derivation of the GMT trajectories resulting from these scenarios was done using MAGICC6 (see Section 1.2). More information on these scenarios is available on the NGFS Scenarios Portal or the NGFS IIASA Scenario Explorer.