CMIP Coupled Model Intercomparison Project
Climate Forcings

Pathway to regular and sustained delivery of climate forcing datasets workshop: 28-31 October 2024, ECMWF Reading

Session 2: Scenario forcings and harmonisation for ScenarioMIP

15:30–18:00

Chairs: Jarmo Kikstra, Steven Smith

Agenda

- Status, plans and timeline
  (Jarmo Kikstra) - 10 mins + 10 mins Q&A
- Lessons learned from RESCUE
  (Matt Gidden) - 10 + 5
- Emissions: historical and harmonization
  (Steve Smith) - 15 + 10
- Land use: historical and harmonization
  (Louise Chini) - 15 + 10
- CDR in CMIP7 scenarios
  (Ben Sanderson) - 10 + 10
- ScenarioMIP
  (Brian O'Neill) - 10 + 10

————————————————————————

- General discussion - 25 mins

Lots of Q&A, but also add to Slido:

- Add questions using slido, with upvoting,

Three ways to join:

1) Scan QR code
2) Go to slido.com + Enter code: #2618796
3) Click on: https://app.sli.do/event/aEKsZcVCxwo1dWhpr1EkFP

Status, plans and timeline

Content

- Overview: inputs and outputs
- Timeline
- Recommendation on 2100-2125 extension
- Q&A

Overview of harmonization process

Inputs:

- IAM scenarios; Emissions
  - Modelling all major emissions
  - For each model, only changes *after 2025* (2025 extensions provided by each model)
  - Across models, differences (due to different historical emissions estimates, or potentially missing minor processes)
- IAM scenarios; Land-use:
  - Modelling regional land-use change, different per model.
- Historical emissions:
  - Anthro: CEDS (currently until 2022)
  - Burning: BB4CMIP (currently until 2023)
  - + a few other global sources (until 2022-2023)
- Historical land-use
  - LUH (currently until will be extended until 2025).

Outputs:

- 6 scenarios
- Each scenario consistent with historical data
- Each scenario with complete spatial emissions, global concentrations, and detailed land-use change information
- Across scenarios, as much consistency as possible (at least up to 2023, attempt until 2025)

Comparing to CMIP6

- IAM scenarios:
  - new design (Brian)
- Emissions and Land-use harmonization:
  - Similar process
  - **Start-year**: was 2015, now will be 2023 or later (Steve)
  - **End-year**: need your recommendation (end of presentation)
  - Process **more automated** (especially emissions gridding; Matt)
  - New **land-use** (Louise) and **CDR** (Ben) information

Overview of CMIP6 harmonization process

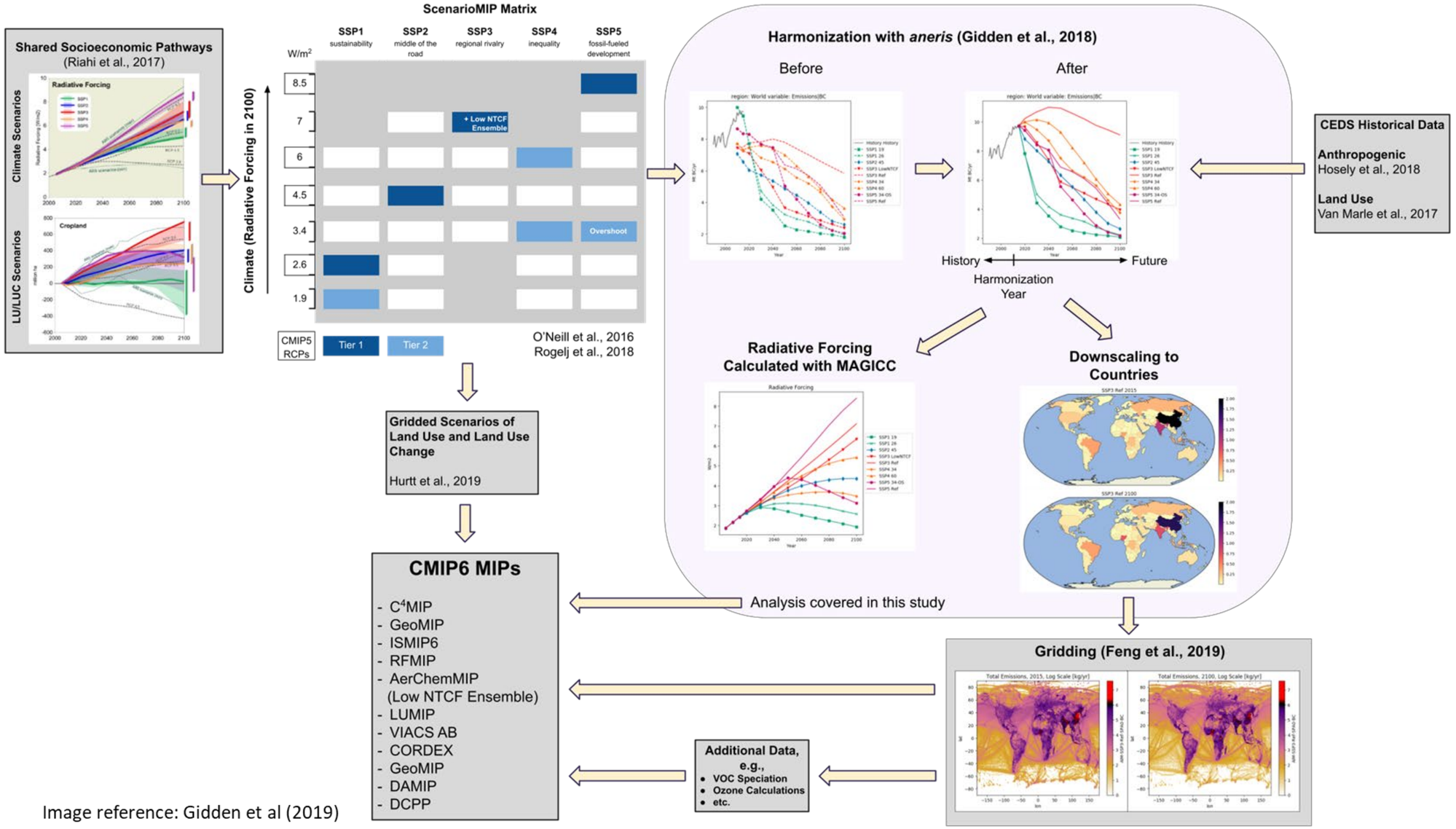
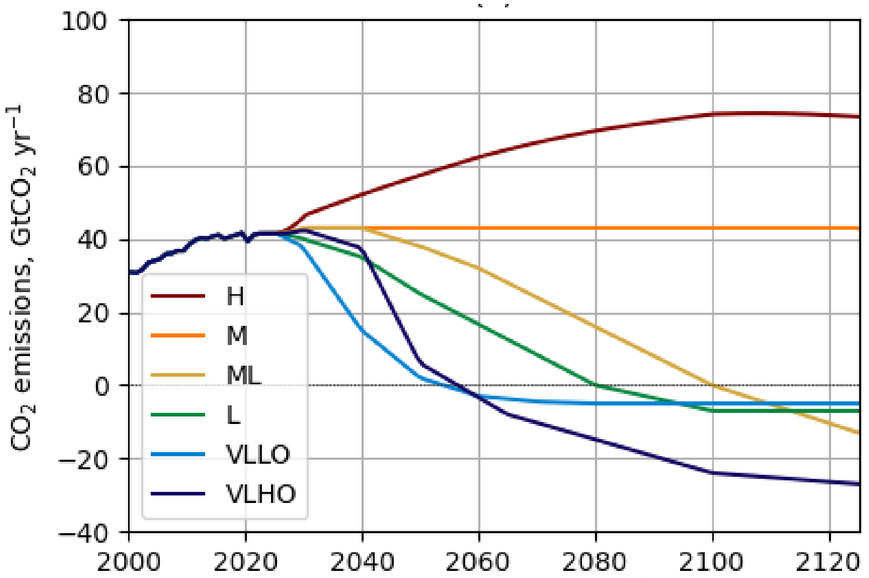


Image reference: Gidden et al (2019)

Overview of CMIP7 harmonization process



Gridded Scenarios of Land Use and Land Use Change

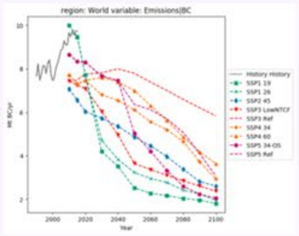
Hurtt et al., 2019

CMIP6 MIPs

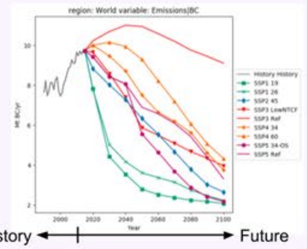
- C⁴MIP
- GeoMIP
- ISMIP6
- RFMIP
- AerChemMIP (Low NTCF Ensemble)
- LUMIP
- VIACS AB
- CORDEX
- GeoMIP
- DAMIP
- DCPP

Harmonization with *aneris* (Gidden et al., 2018)

Before



After



History ◄ | ► Future

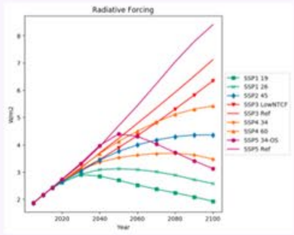
Harmonization Year

CEDS Historical Data

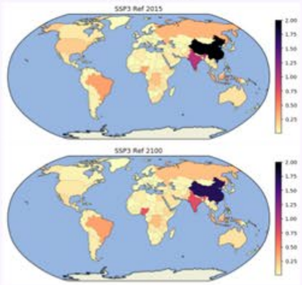
Anthropogenic
Hosely et al., 2018

Land Use
Van Marle et al., 2017

Radiative Forcing Calculated with MAGICC

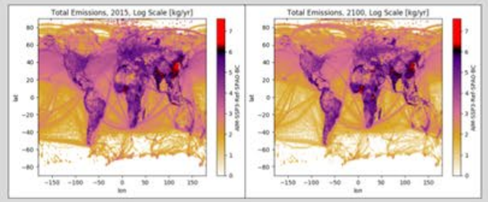


Downscaling to Countries



Analysis covered in this study

Gridding (Feng et al., 2019)

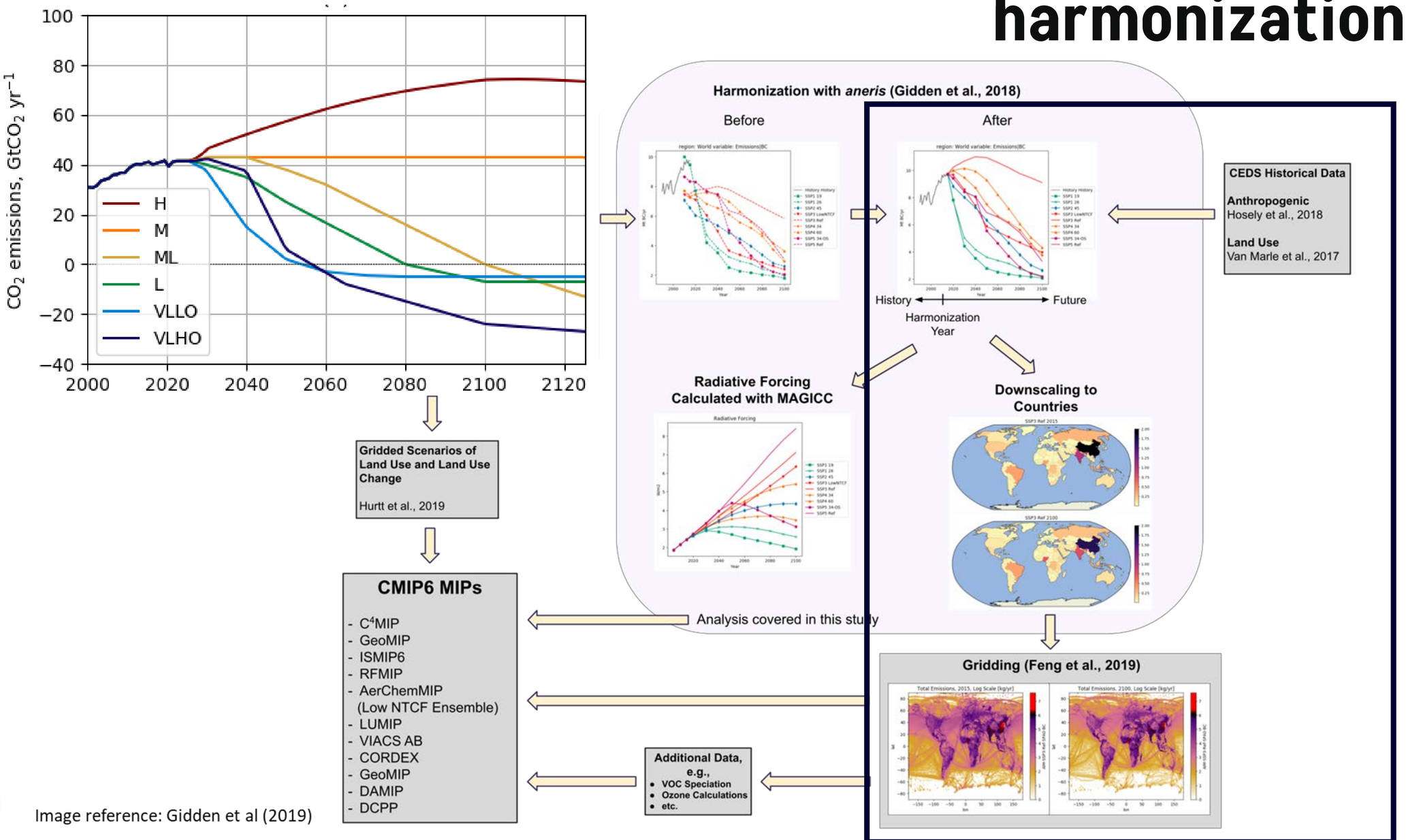


Additional Data, e.g.,

- VOC Speciation
- Ozone Calculations
- etc.

Image reference: Gidden et al (2019)

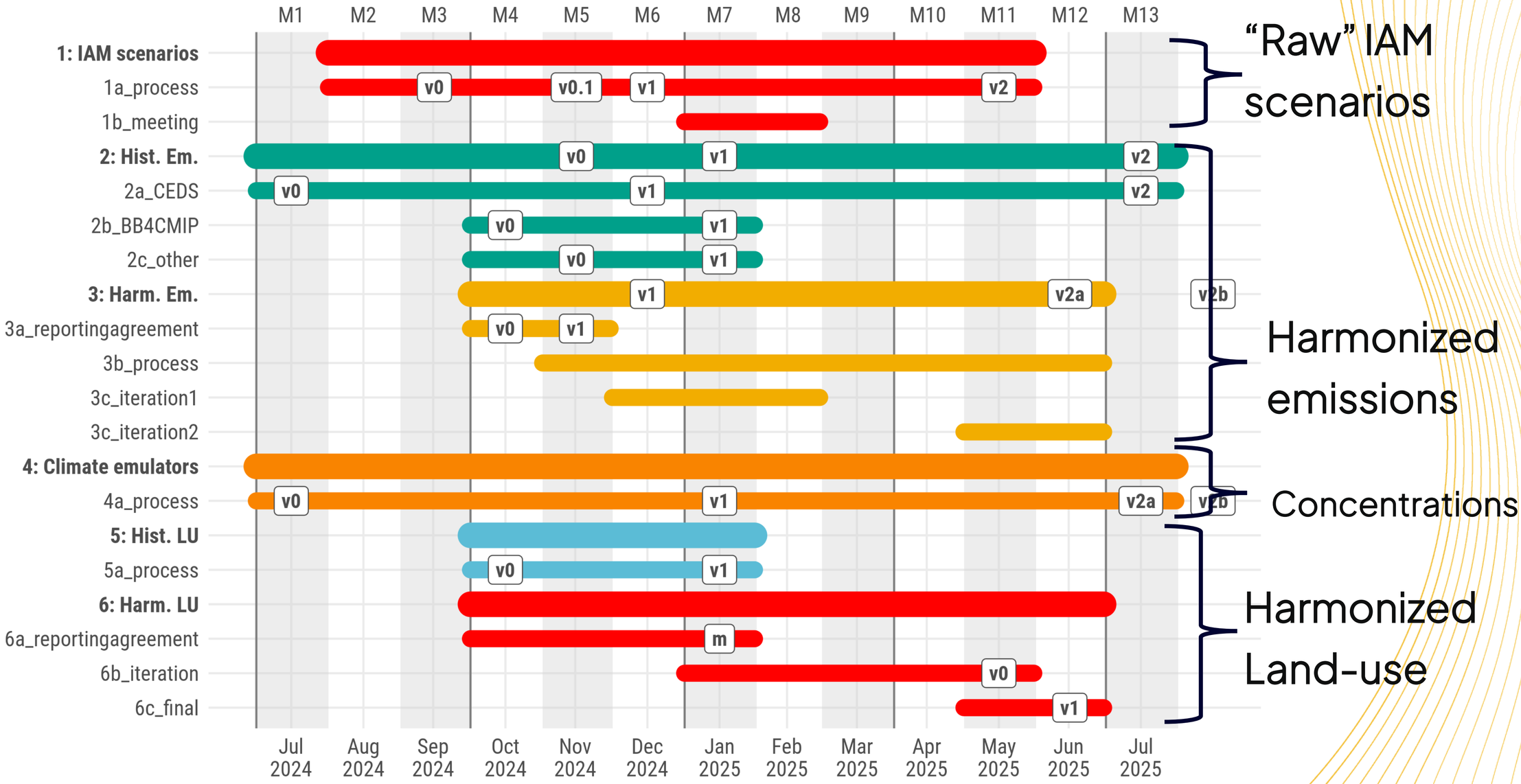
Overview of CMIP7 harmonization process



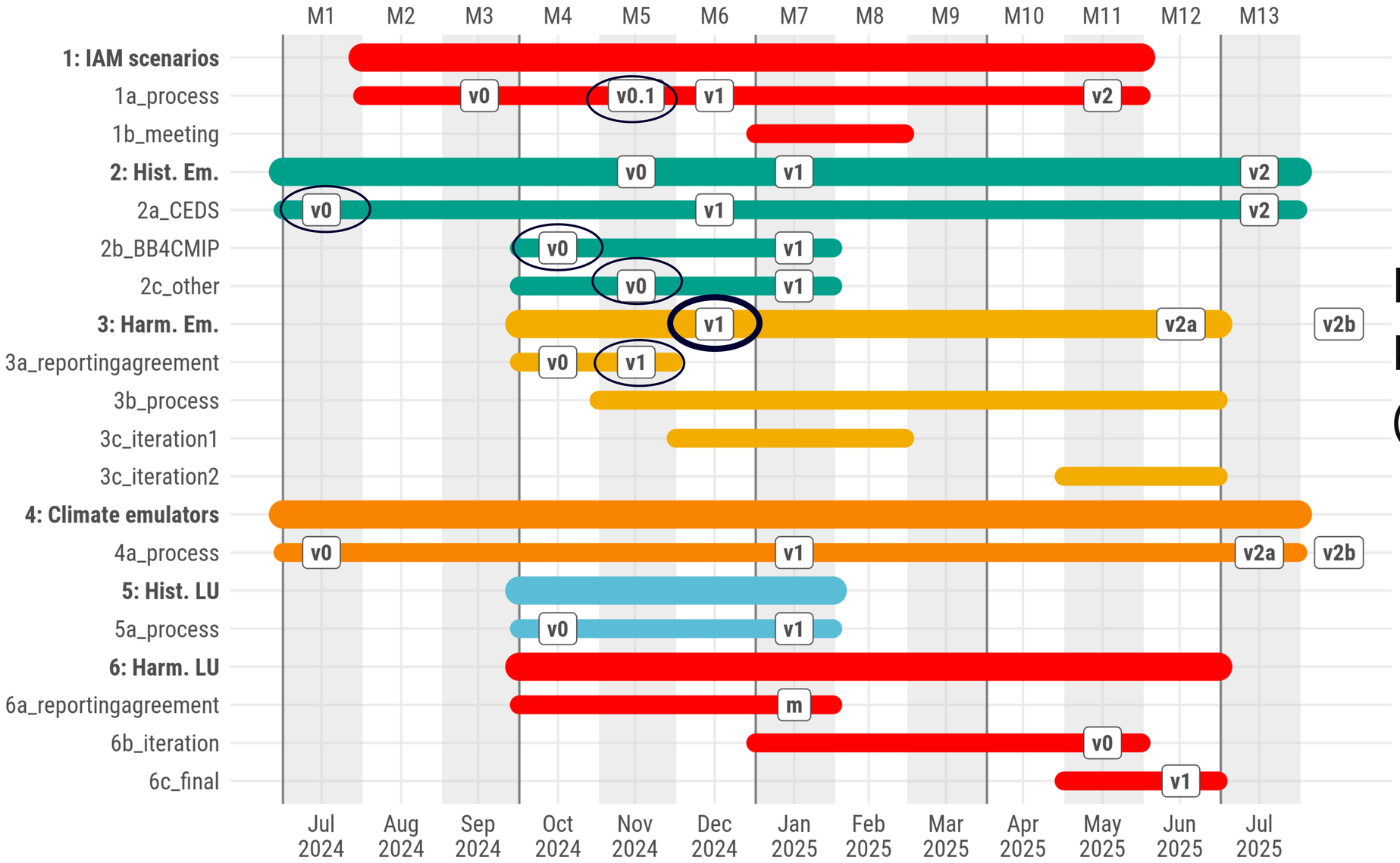
Single workflow

Image reference: Gidden et al (2019)

Dependency chart of harmonization process

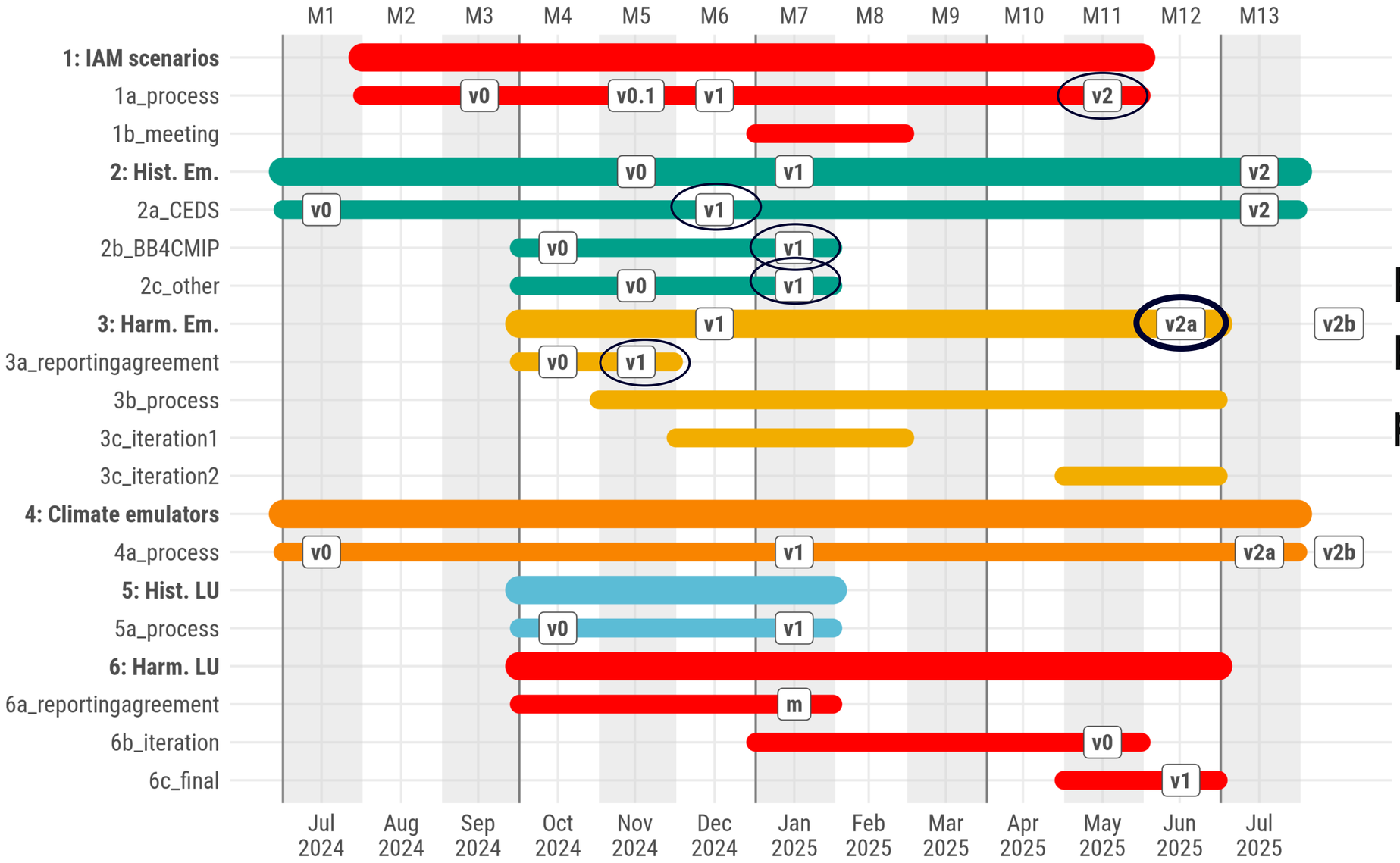


Dependency chart of harmonization process



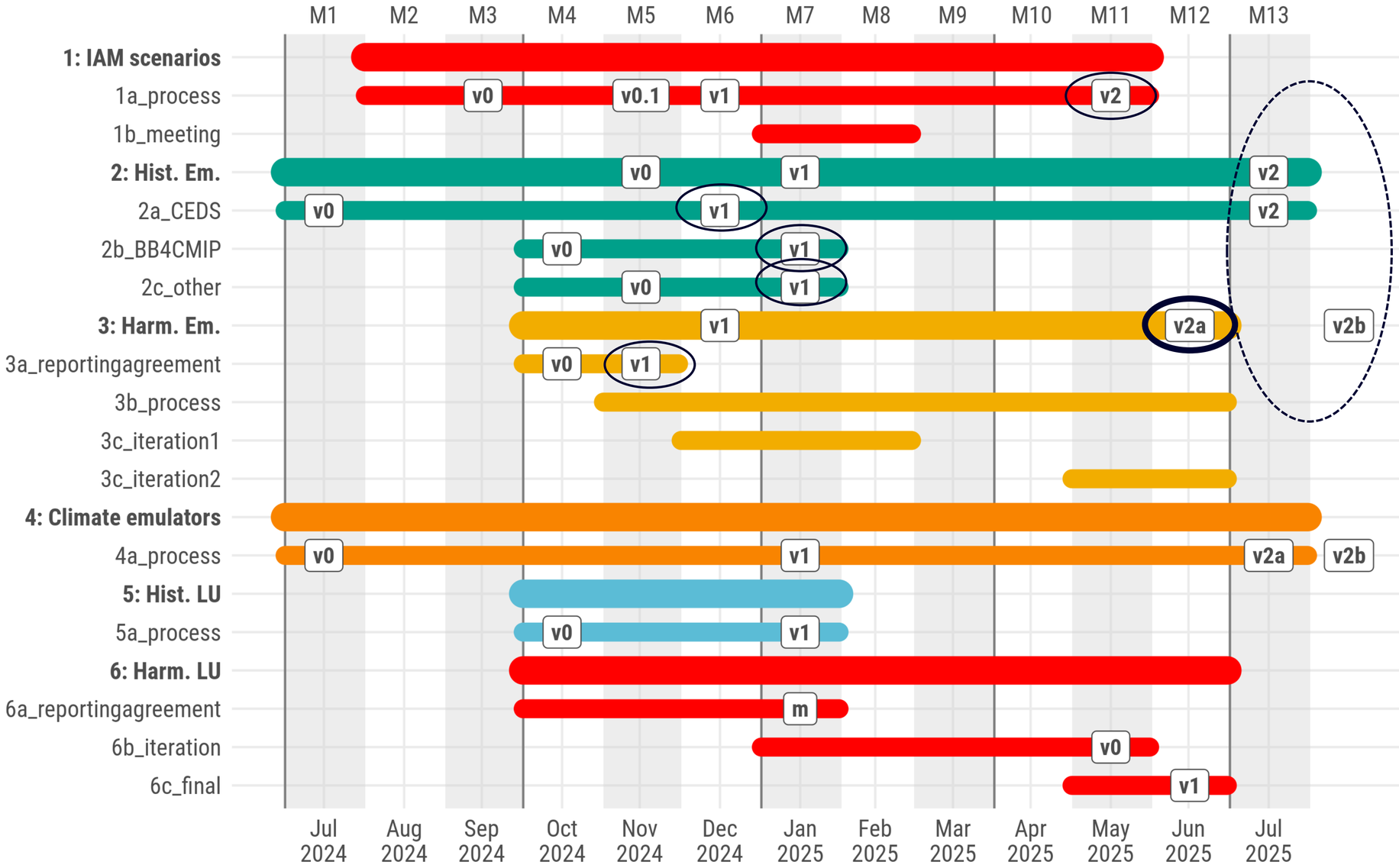
Harmonized Emissions (iteration)

Dependency chart of harmonization process



Harmonized Emissions product

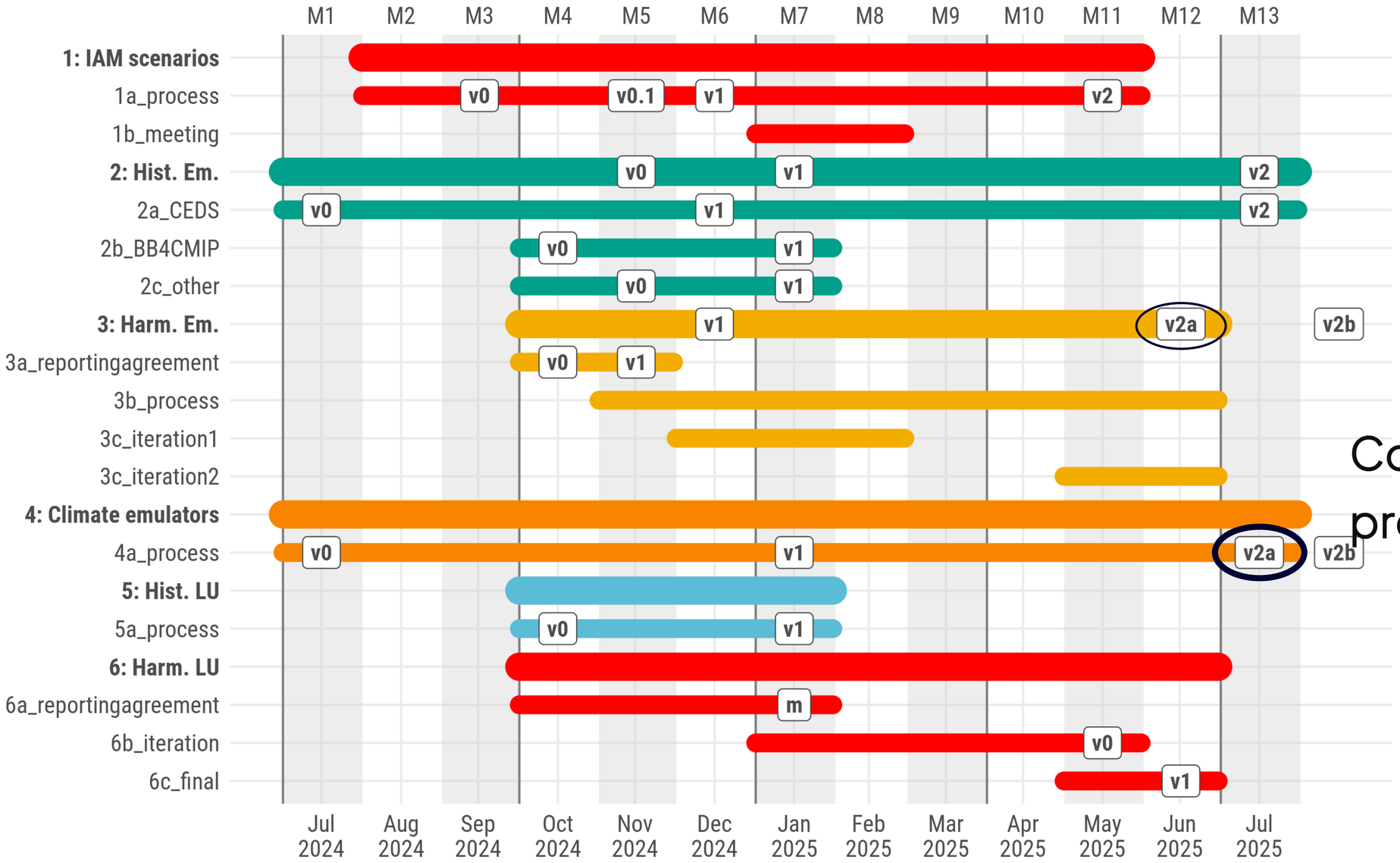
Dependency chart of harmonization process



Harmonized Emissions product

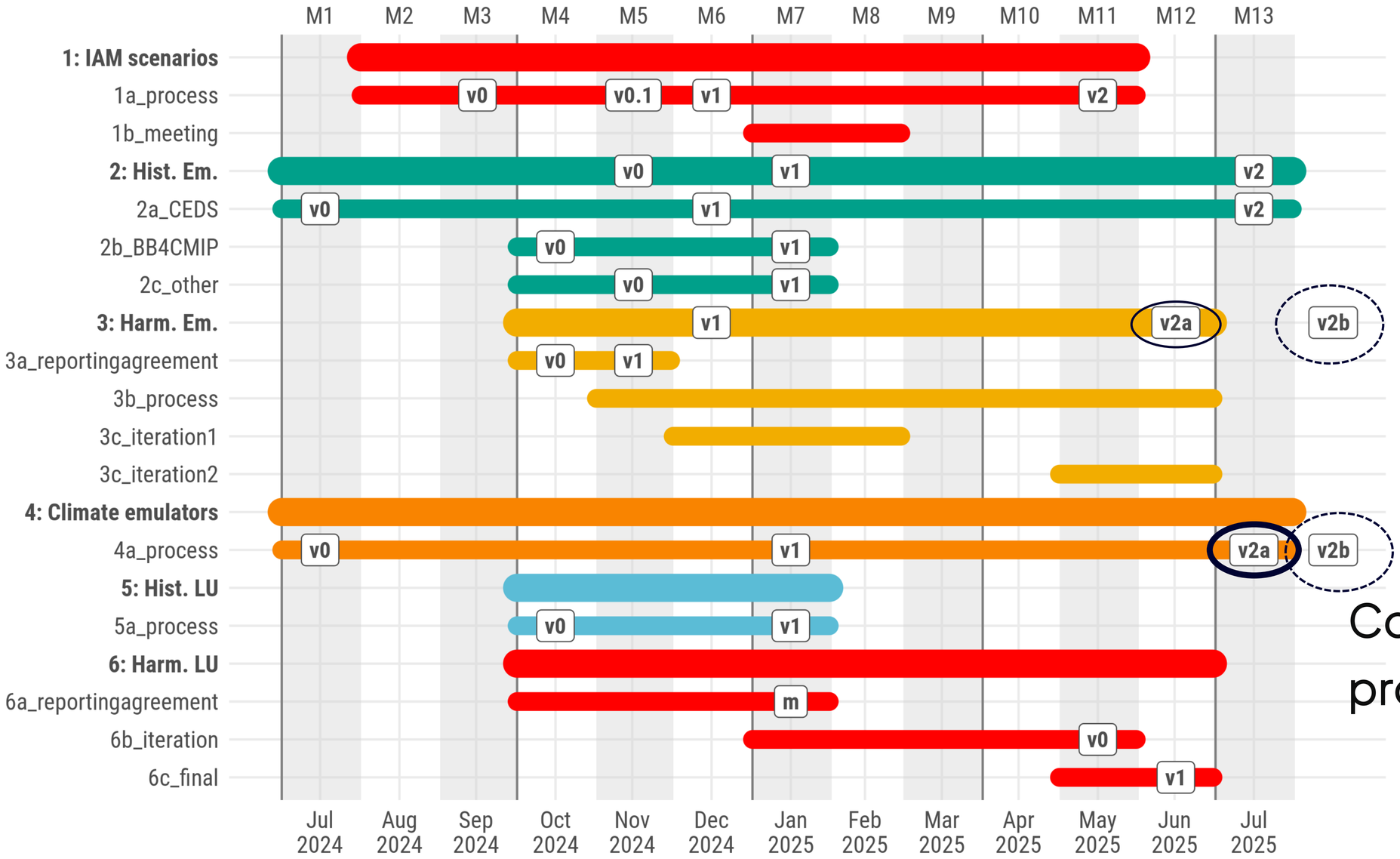
Potential update in summer with new anthro emissions data (if process not yet finished and time left)

Dependency chart of harmonization process



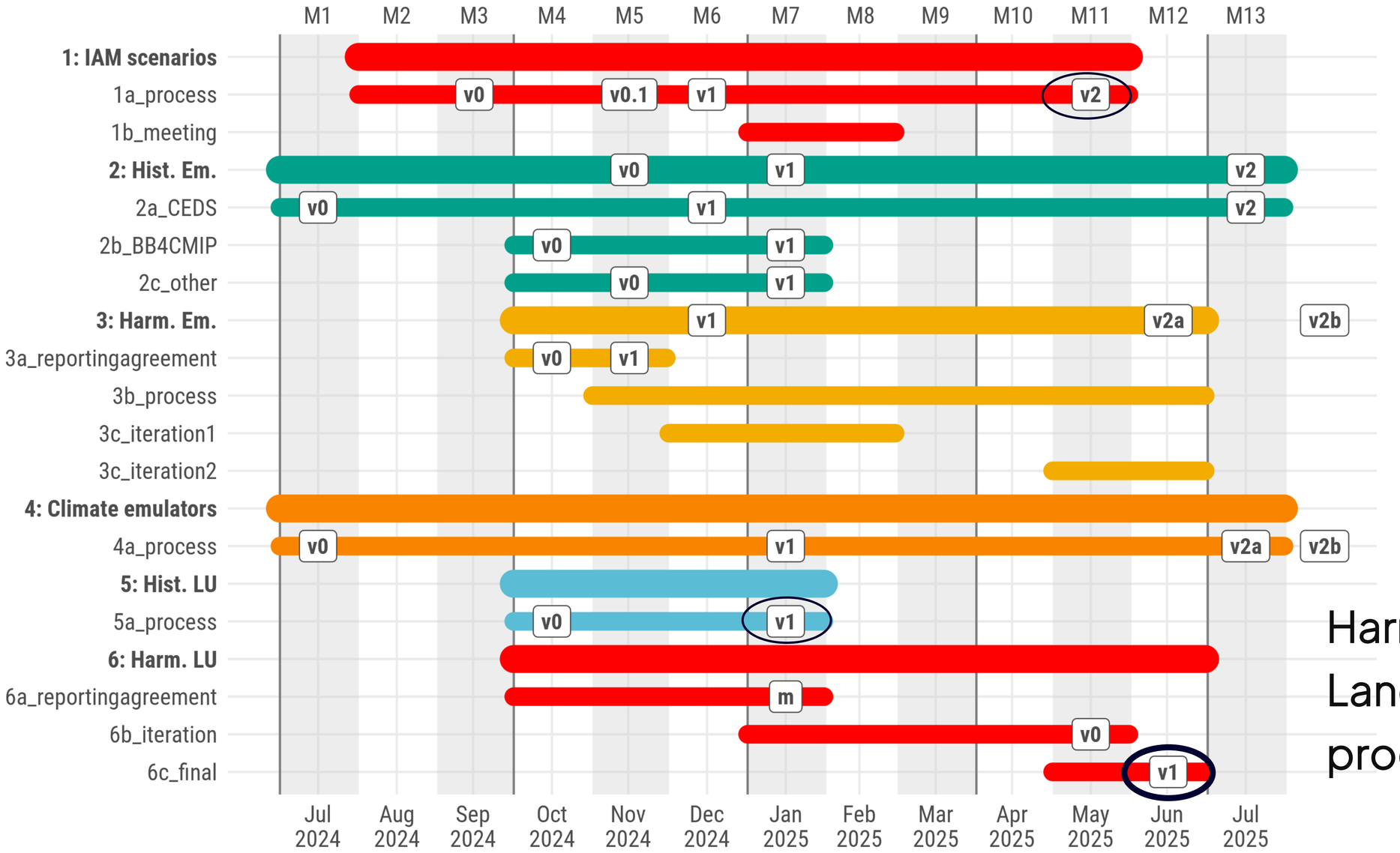
Concentrations product

Dependency chart of harmonization process



Concentrations product

Dependency chart of harmonization process



Harmonized Land-use product

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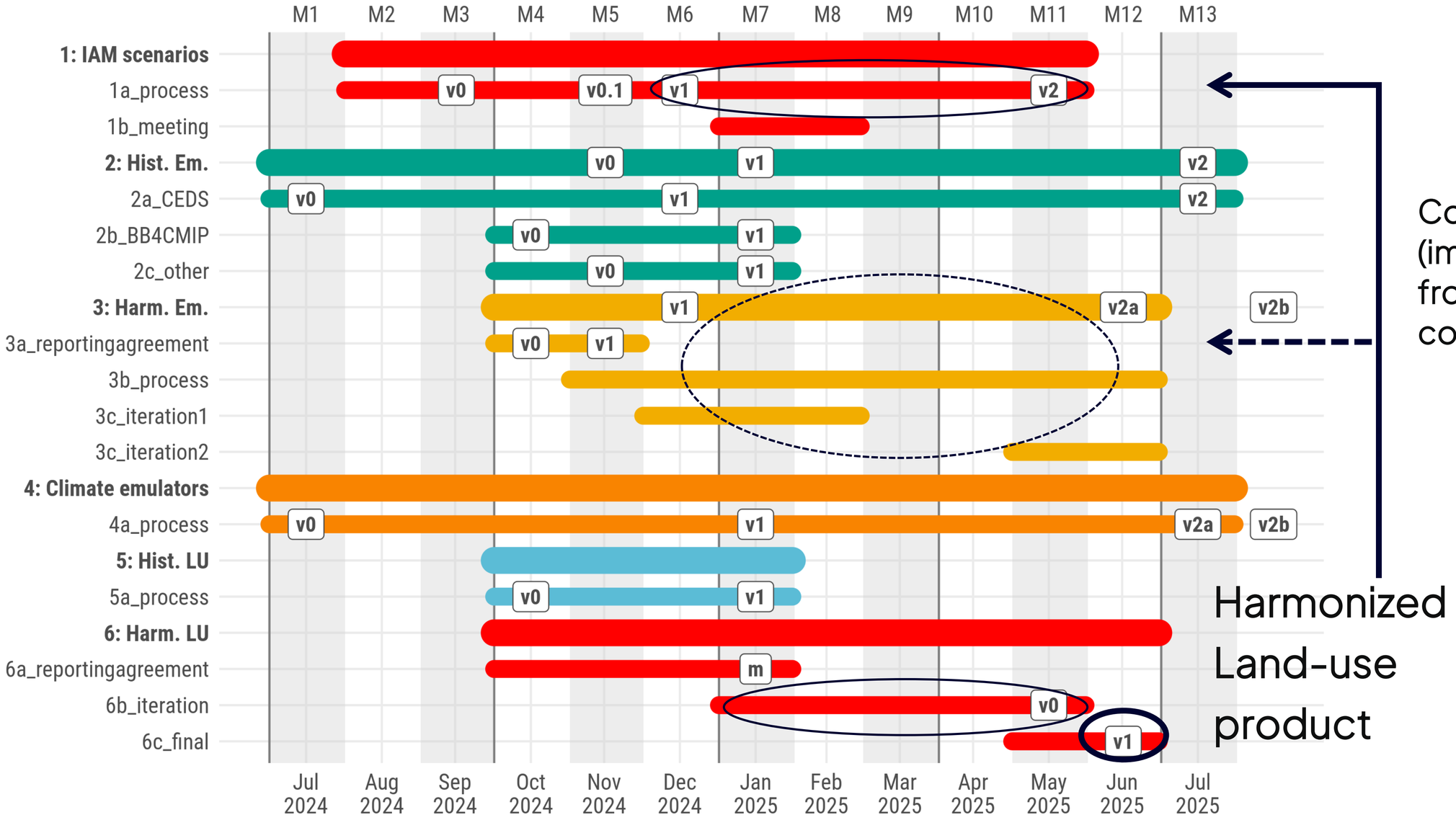
Dependency chart of harmonization process



Consistency checks (implied emissions from land-use conversion)

Harmonized Land-use product

Scenarios: extension beyond 2100 to 2125 (for Q&A)

- IAM teams would all like to do this. However, the time investment is large, and therefore the teams focus on other parts to get the scenarios right in the tight timeline. Full IAM results will thus be available only until 2100.
- Need a recommendation on how to continue

Two options:

- Using the long-run extensions; starting 2100 (instead of 2125)
- Is a 2100-2125 regional emissions extension (extrapolating IAM results) absolutely needed by the community?
  - Note: Land-use information for the same timeframe may be particularly difficult still.

Scenarios Timeline

- Until December/January:
  - New scenarios: update.
  - Iteration with IAM teams on format for products
- Jan-May:
  - Iterative process between harmonization teams and IAM teams
  - Investigation of uncertainties, robustness, exploring methods
- June:
  - New scenarios: final scenarios.
  - Start harmonizing scenarios

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Status, plans and timeline: discussion

- Add questions using slido, with upvoting,

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Lessons learned from RESCUE

RESCUE

CMIP7 Forcings Workshop
28 October 2024

Lessons learned for generating scenario forcings for emissions-driven ESM simulations with explicit consideration of CDR

Matthew Gidden on behalf of the RESCUE Team

Data Preparation: Jonas Hörsch, Pascal Sauer, Daria Kuznetsova, Leon Merfort, Nico Bauer, Jan Dietrich, Etienne Tourigny, Thomas Gasser

ESM Teams: Momme Butenschön, Jörg Schwinger, Lars Nieradzik, Timothée Bourgois, Lina Teckentrup, Sabine Bischof, Julia Pongratz, Shraddha Gupta, Nadine Mengis, Etienne Tourigny, Raffa Bernadello

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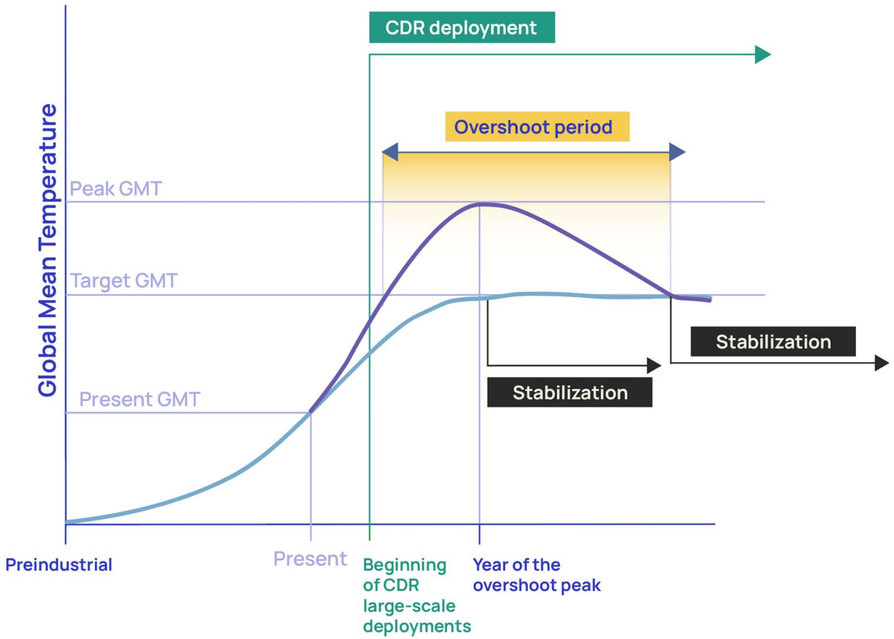
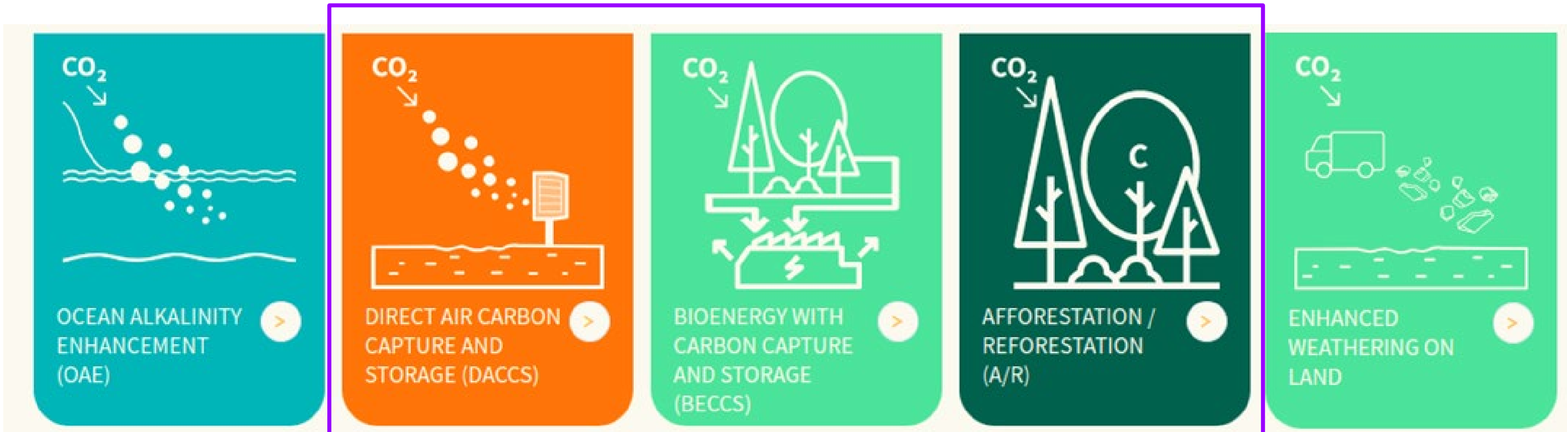
The sole responsibility for the content of this document lies with the RESCUE project and does not necessarily reflect the opinion of the European Union.

An Introduction to RESCUE

A Horizon Europe research project advancing 5 ESMs from emission to activity-driven configuration forced by new REMIND-MAgPIE scenarios to explore the climate effectiveness of different CDR methods



CDR in ScenarioMIP



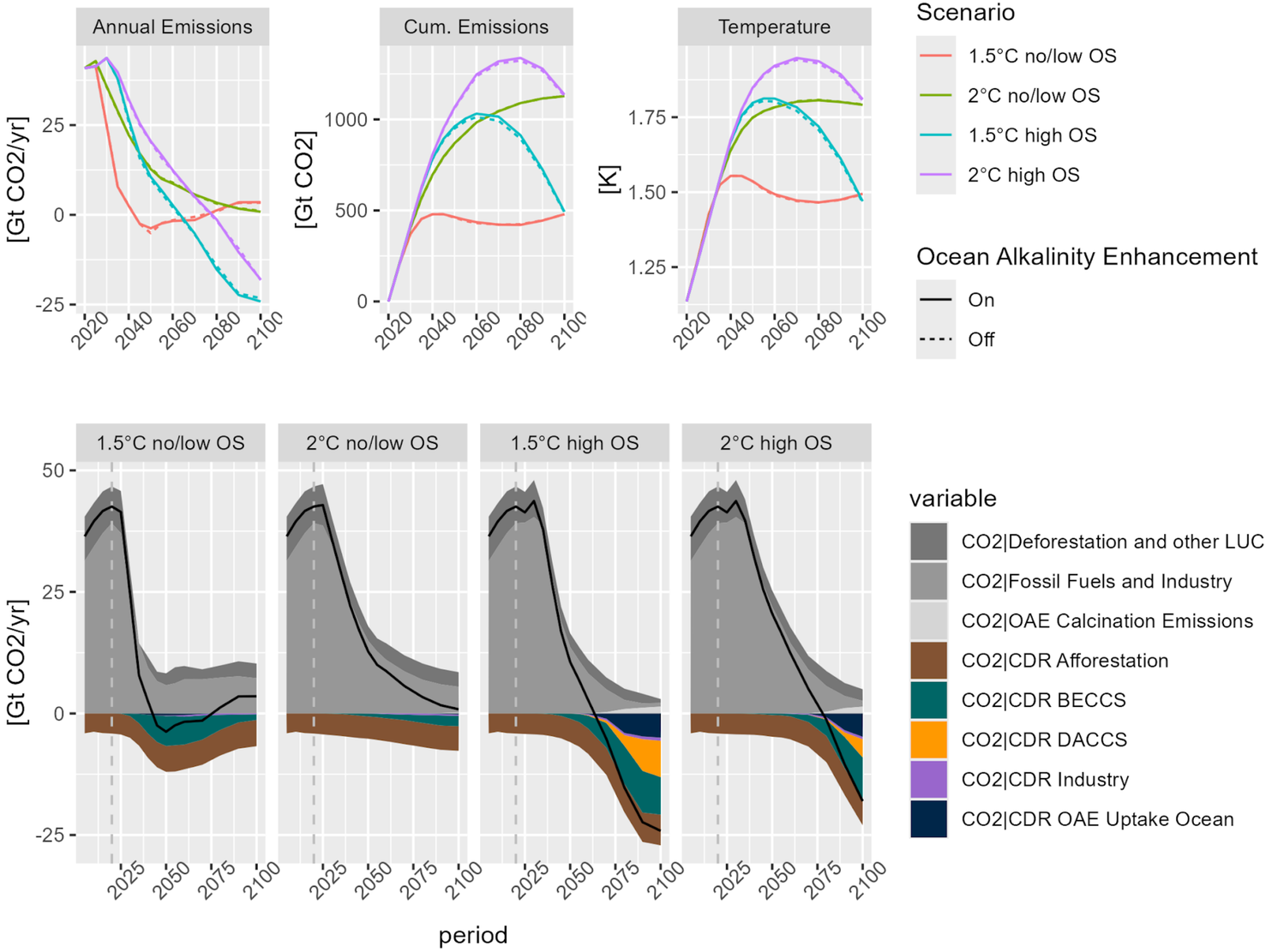
Core research questions:

1. What is the effect of a single and a portfolio of CDRs on the carbon cycle (atmospheric CO_2, ocean and terrestrial carbon stocks)
2. What is the amount of carbon sequestered (efficiency) and what are the feedbacks?
3. What are the biophysical feedbacks and impacts?

RESCUE Scenarios

- Target temperature
  - **1.5°** (500 $GtCO_2$ budget)
  - well below **2°** (1150 $GtCO_2$ budget)
- Target type
  - **no/low OS** (only minimal overshoot)
  - **high OS** (climate policy starts only in 2035)
- Sensitivity: Ocean Alkalinity Enhancement (OAE)
  - **on**
  - (off)

OAE & DACCS only used in overshoot scenarios

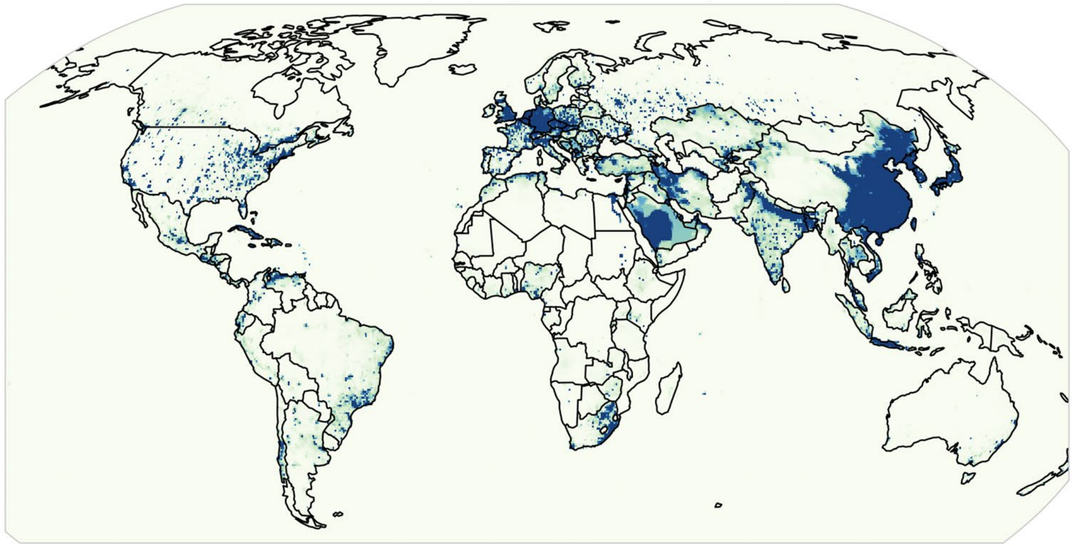


Moving beyond CMIP6 scenario data

Emissions time-series are spread onto a 0.5º x 0.5º - grid proportional to proxies

- As in CMIP6 recent historical patterns compiled by CEDS are used for most sectors, population where not available (details)
- Updates are:
  - International shipping from MariTeam (Kramel and Muri, et al, 2021)
  - New CDR proxies
- Compatibility with input4MIPS conventions (CF conventions/cdo)

Industrial sector proxy for year 2050 from CEDS (EDGAR)



▼ Coordinates:

lon	(lon)	float64	-179.8 -179.2 ... 179.2 179.8
lat	(lat)	float64	-89.75 -89.25 ... 89.25 89.75
time	(time)	object	2015-01-16 00:00:00 ... 2100-12-...
sector	(sector)	object	'Agriculture' ... 'CDR OAE Uptak...

▼ Data variables:

CO2_em_anthro	(time, sector, lat, lon)	float32	0.0 0.0 0.0 0.0 ... 0.0 0.0 0.0 0.0
time_bnds	(time, bound)	object	...
lon_bnds	(lon, bound)	float64	...
lat_bnds	(lat, bound)	float64	...

▶ Indexes: (4)

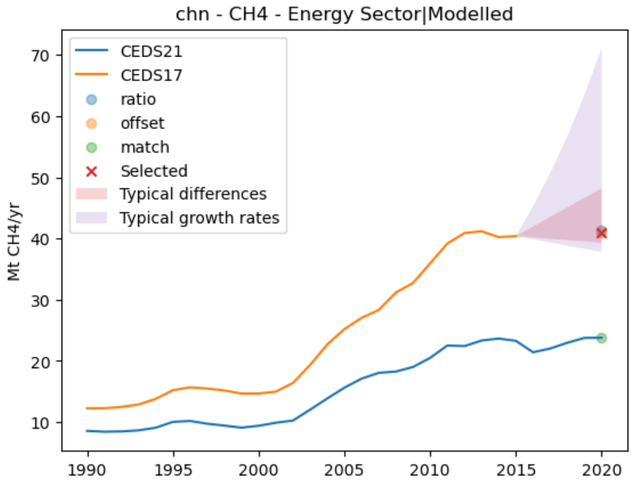
▼ Attributes:

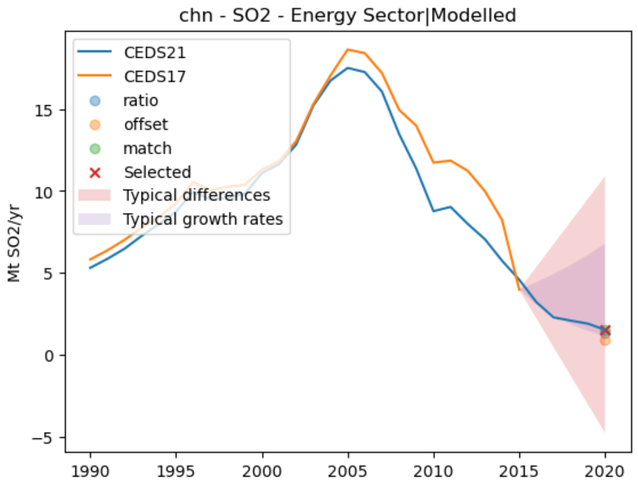
Conventions :	CF-1.6
activity_id :	input4MIPs
comment :	Gridded emissions produced after harmonization and downscaling as part of the RESCUE project. See https://github.com/IAMconsortium/concordia and https://github.com/iiasa/aneris for documentation on the processes.
contact :	Matthew J. Gidden (gidden@iiasa.ac.at)
data_structure :	grid
dataset_category :	emissions
external_variables :	gridcell_area
frequency :	mon
further_info_url :	https://rescue-climate.eu/
grid :	0.5x0.5 degree latitude x longitude
grid_label :	gn

Moving beyond CMIP6 historic data

RESCUE

Species	Sectors	Data source	Gridded variables
CO2, CH4, NH3, SO2, BC, OC, CO, NOx, VOC	Aircraft	CEDS – Hoesly et al (2018) CMIP6 version 2016 and v_2021_04_21	_em_AIR_anthro
	Agriculture		_em_anthro
	Energy		
	Industrial		
	International Shipping		
	Residential, Commercial, Other		
	Solvents Production and Application		
	Transportation		
	Waste		
CO2	Deforestation and other LUC	GCB - Le Quéré, C. (2016) & Friedlingstein et al. (2023)	_em_anthro
	CDR Afforestation		
CH4, NH3, SO2, BC, OC, CO, NOx, VOC	Agricultural Waste Burning	GFED CMIP6 version and GFED4	_em_openburning
	Forest Burning		
	Grassland Burning		
	Peat Burning		
N2O	Total	Gütschow et al. (2016) v2.0 & v.2.3.1	
HFC		Velders et al. (2015) & Velders et al. (2020)	
C2F6, CF4		Carpenter et al. (2014) & Say et al. (2021)	
SF6		Carpenter et al. (2014) & Simmonds et al. (2020)	





CDR in RESCUE: Emissions/Removals

- New sectors of gridded CO2 anthropogenic emissions/removals, which can be used for forcing input if activity/driver not implemented:

Process	Emission/Removal Variable	Spatial	Gridding Pattern	Used in ESMs?
A/R	CDR Afforestation	global	non-urban land mask	Verification only
	Deforestation and other LUC	global	non-urban land mask	Verification only
BECCS	CDR BECCS	region	LIGNO biomass potential	Verification only (possibly Forcing input)
DACCS	CDR DACCS	country	RESCUE DACCS potential	Forcing input
Industry	CDR Industry	country	RESCUE DACCS potential	Forcing input
OAE	CDR OAE Uptake Ocean	region	EEZs	Verification only
	OAE Calcination Emissions	region	Land mask	Forcing Input
	Alkalinity Addition	region	EEZs	Forcing input
EW	*CDR EW*	*region*	*Non-urban land mask*	*Verification only*
	Weathering Addition	*region*	*Non-urban land mask*	*Forcing input*

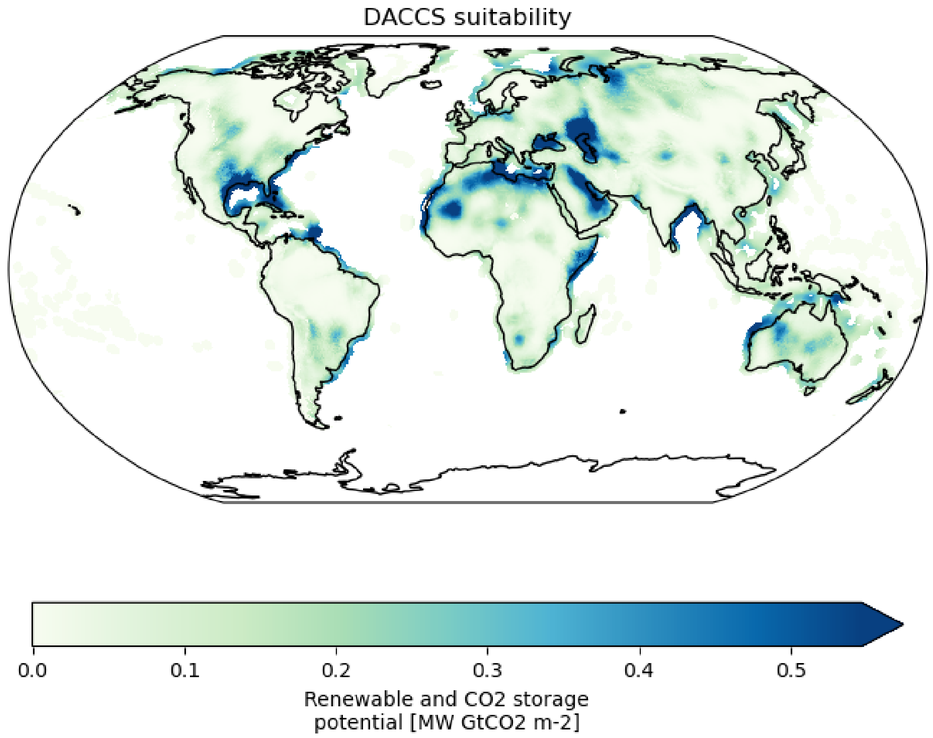


Fig: RESCUE DACCS potential by overlaying sedimentary basins with renewable economic potential

CDR in RESCUE: Land use/management

RESCUE

states

c3ann
c3nfx
c3per
c4ann
c4per
pastr
primf
primn
range
secdf
secdn
urban
secma
secmb

management

crpbf_c3ann
crpbf_c3nfx
crpbf_c3per
crpbf_c4ann
crpbf_c4per
crpbf2_c3per
crpbf2_c4per
irrig_c3ann
irrig_c3nfx
irrig_c3per
irrig_c4ann
irrig_c4per
manaf
fulwd
rndwd
fertl_c3ann
fertl_c3nfx
fertl_c3per
fertl_c4ann
fertl_c4per
combf
flood
fharv_c3per
fharv_c4per

manaf: Share of secdf considered managed

crpbf2_c[3,4]per: Share of c3per/c4per for 2nd gen biofuels

transitions

all transitions

legend

implemented
not reported
new variable

All data processing with OS Tools

Tools

- Aneris: https://github.com/iiasa/aneris

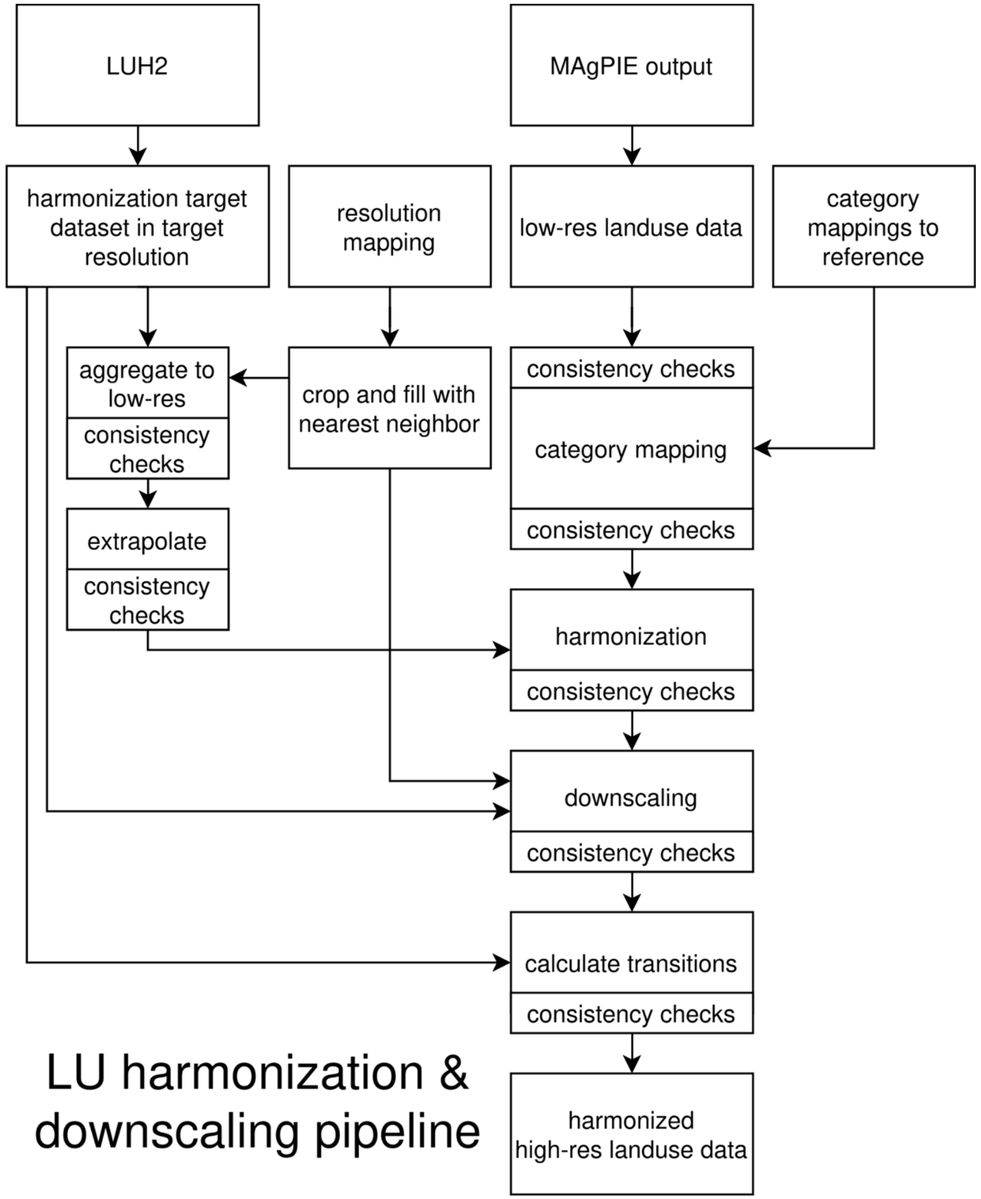
  Emissions harmonisation, downscaling & gridding (expanded from CMIP6 times)

- mrdownscale: https://github.com/pik-piam/mrdownscale

  LU harmonisation & gridding

- Concordia: https://github.com/IAMconsortium/concordia

  RESCUE-workflow and input4MIPS compliancy



LU harmonization & downscaling pipeline

Implementing CDR in ESMs - DACCS

RESCUE

ESM	Approach
CMCC-ESM2	Implemented atmospheric CO2 sink from external forcing
EC-Earth3	Implemented atmospheric CO2 sink from external forcing
MPI-ESM	plans to be implemented as removal from the atmosphere based on provided negative DACCS emissions
FOCI	plans to be implemented as removal from the atmosphere based on provided negative DACCS emissions
NorESM2	atmospheric CO2 sink from provided negative DACCS emissions; available and tested;

Implementing CDR in ESMs - A/R

ESM	Approach
CMCC-ESM2	implementation of CLM-specific tools to convert land use data into CLM surface files
EC-Earth3	LPJ-GUESS is a dynamic vegetation model, hence trees, shrub, grass will grow and compete where climate is suitable. LUC will add/remove areas of potential forests. Wood harvest follows a self-thinning approach optimising Carbon storage in forests.
MPI-ESM	increase the fraction of the existing forest PFTs in targeted grid cells based on land use changes from the forcing data set
FOCI	increase the fraction of the existing forest PFTs in targeted grid cells based on land use changes from the forcing data set
NorESM2	driven by land use changes from the forcing data set

Implementing CDR in ESMs - BE(CCS)

RESCUE

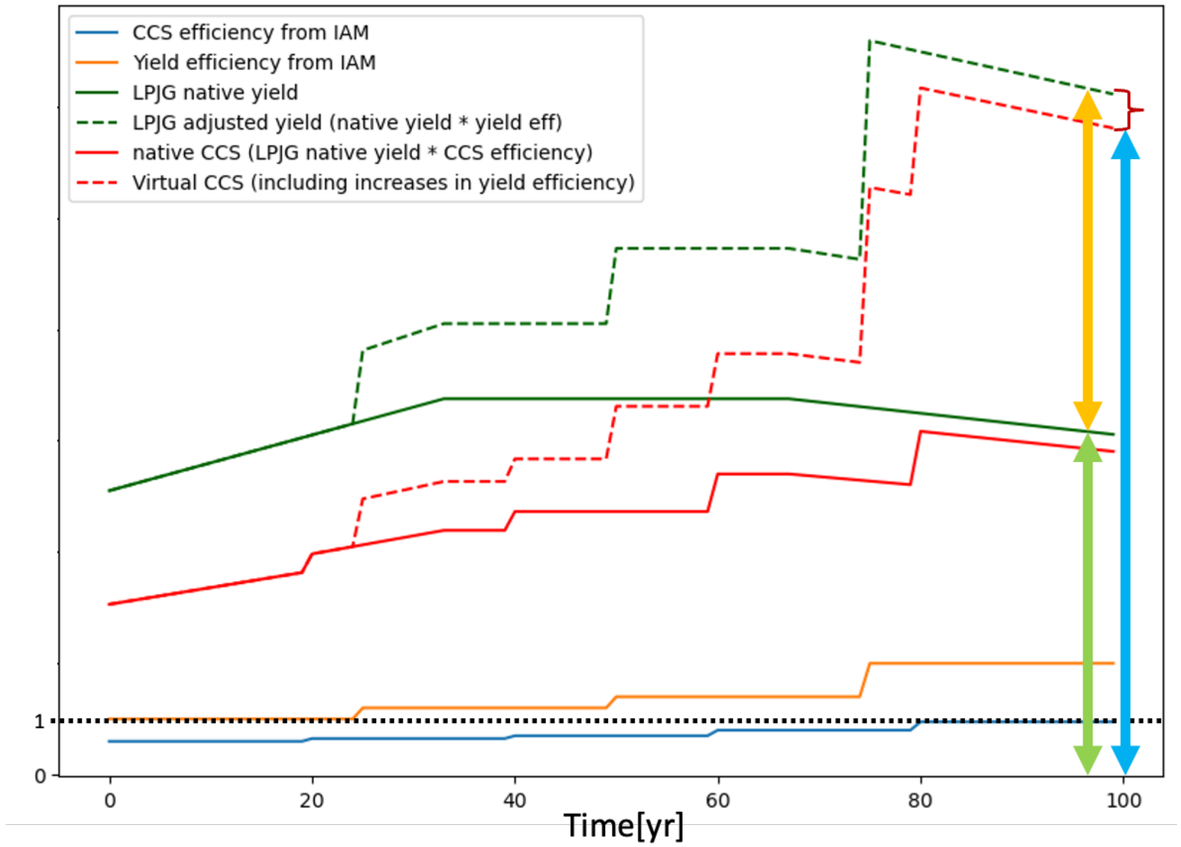
ESM	Approach
CMCC-ESM2	finalising porting of dynamic crops from CLM5 to CLM4.5 (as this was used in our CMIP6 configuration), backup solution is providing the crop changes as annual external forcing
EC-Earth3	Implemented new high productive biomass crops (e.g. Miscanthus, Switchgrass, Sugar cane) with nitrogen fixation based on Ma et al. (GMD, 2022) Also introduced nitrogen fixing crops (soy) and cover-crops (e.g. clover)
MPI-ESM & FOCI	Additional plant functional type for 2nd gen bioenergy crops (Miscanthus) implemented in JSBACH 3.2 with optimized parameter choices. A fraction of the bioenergy crop harvest is allocated to a CCS pool with an option to specify leakage fraction.
NorESM2	CLM5 functional for energy - food - feed crops (e.g. corn, sugarcane ++), not yet energy specific crops like miscanthus, switchgrass.

Novel Data used by ESMs

- **Global data: Fraction of bioenergy used for CCS** (CCS fraction per kg DM of BE yield)
- **Better description of C3/C4 second-generation bioenergy crops**
- **Managed forest fraction can be useful for ESMs implementing this**
- **Partition of total negative emissions into separate activities (e.g. BECCS, DACS) allows for ESMs to potentially simulate the different CDR technologies, but still allows for models to not simulate them internally**
- **New inputs allow to simulate CDR interactively (BECCS storage, alkalinity addition, etc)**

Additional implementation considerations

- **Energy Crop Trade loss** (%) - depending on IAM implementation
- **Agricultural yield increases** (%) - depending on IAM implementation



CCS-efficiency and yield efficiency are delivered by the IAMs.

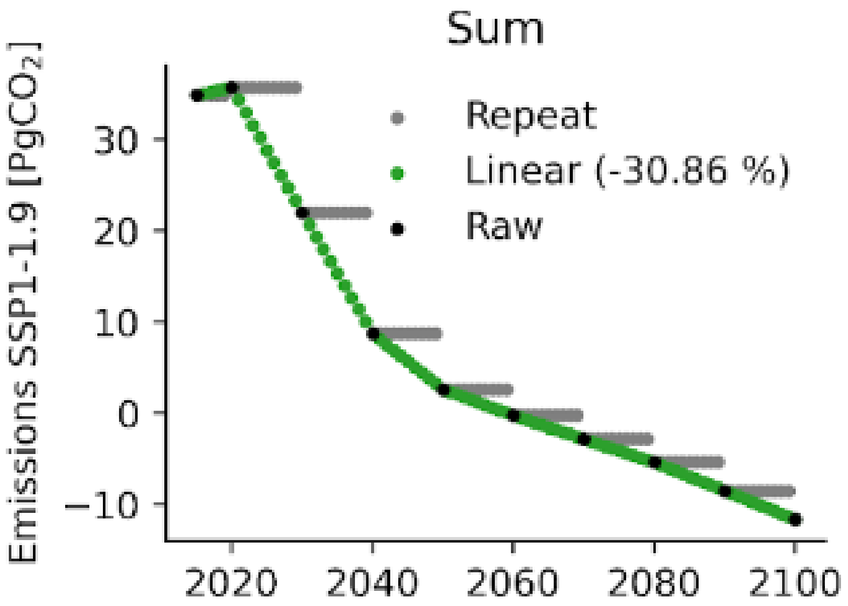
The virtual CCS is computed from LPJG's crop-yields upscaled to a total (virtual) CCS by applying both factors.

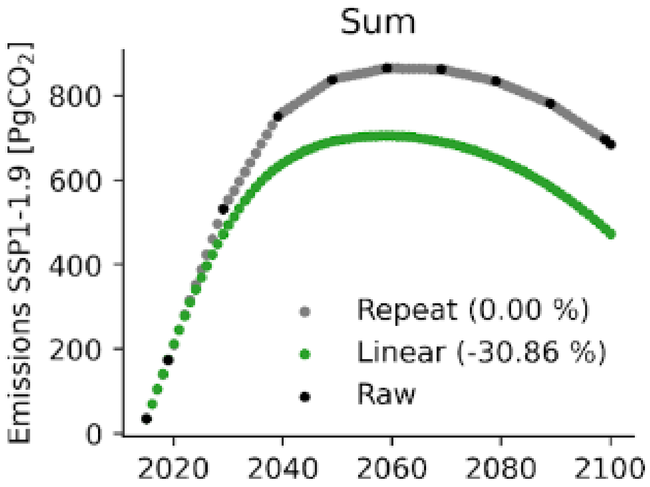
Virtual CCS will be removed from the atmosphere to be in line with IAM.

What LPJG sees
What EC-Earth sees
LPJG – C-Uptake
Virtual C-uptake (incr. yield_eff)
Total CCS (incr. CCS_eff)
Rereleased to ATM

Additional implementation considerations

- Interpolation (!!!)
  - Linear interpolation performed via CDO commands
  - Some variables could require constant-step interpolation
  - **IAM values should be processed to guarantee linear interpolation!**
- Global values are easy to implement (e.g., CCS fraction of BE). Otherwise they need to be gridded.





Final Thoughts

- Teams are running short-term simulations (~10 years) using all scenario forcing files and beginning simulations
- New gridded variables were added to communicate more detailed information on bioenergy crops and other CO2 removal fields
- New non-gridded fields are needed to communicate some CDR parameterizations
- Many IAM CDR fields are used for *verification only* - e.g. BECCS for which production/consumption reporting cannot be consistent. Models which can not run “activity driven” simulations can use these as forcings.
- Still known inconsistencies to decide on in CMIP7 (e.g., Ag yield improvements)

CMIP Climate Forcings | WCRP

Learning from RESCUE: discussion

- Add questions using slido, with upvoting,

Three ways to join:

1) Scan QR code
2) Go to slido.com + Enter code: #2618796
3) Click on: https://app.sli.do/event/aEKsZcVCxwo1dWhpr1EkFP

CMIP Climate Forcings | WCRP

Emissions: historical and harmonization

Emission Updates

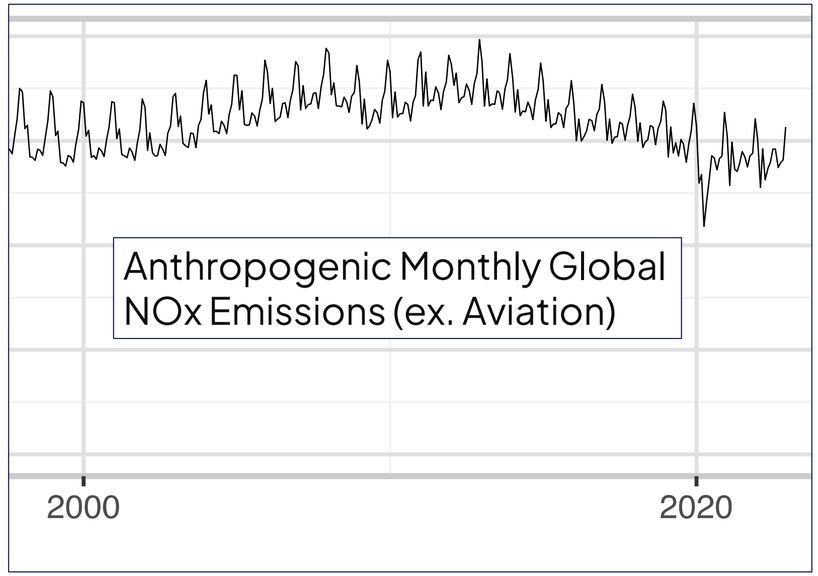
- CEDS v2024_07_08 Release (1750-2022)
  - Aggregate emissions
    - A number of updates from the CMIP6 release
    - More modest updates from previous v2021_04_21 release
      - Lower global CO and NMVOC emissions
  - Gridding updates
    - Major point sources more accurately located
    - Update to seasonality (incorporates COVID)
    - Core gridded data should be in ESGF queue this week

- Next Release (1750-2023) (in winter 2024) – "v2024_12_31"
  - Entire time series updated to 2023
    - For example, there are significant changes in biomass consumption for a number of countries in the latest IEA data.

- CMIP7 Extension (2022-2024) (in July 2025)
  - Will be anchored to the last historical year value (*e.g.*, 2021) in the "v2024_12_31" release

CEDS 0.5° gridded data
same format as in CMIP6

0.1° data from 1980



- Open Biomass Burning (BB4CMIP)
  - We are not anticipating a further update at this time
- F- Gases - Are exploring several sources
  - WMO?, AGAGE [Rigby&Western], US EPA, EDGAR

Date typos corrected

New Data Protocol

1850	historical	2021

CMIP7 Simulations

2022	harmonization	2025?	scenario-low	2125
2022	harmonization	2025?	scenario-mid	2125
2022	harmonization	2025?	scenario-hi	2125

CMIP7 defined experiments:

DECK/CMIP historical (or esm-hist) 1850-2021

ScenarioMIP scenario-? 2022-2125

Future Near-term Extensions of CMIP7 simulations

2021	historical-ext	~2030

historical-ext (or esm-hist-ext) allow groups to run and publish simulations using alternate forcings extending beyond CMIP7:CMIP:historical period

Additional non-CMIP7 datasets (“provisional”) can be used in historical-ext simulations,
Observed period forcing datasets that extend beyond 2021- have larger uncertainties and considered “unstable”

Why are recent emission estimates uncertain?

Data characteristics that lead to additional uncertainty over the most recent years *(e.g., in Fall 2024)*

- Activity data
  - Energy consumption in 2023 is based on EI Energy Statistics.
    - Many of the 2023 data points are likely to be revised next year (Hoesly and Smith 2018)
    - For 2023, we only have aggregate energy consumption from EI (total coal, some liquid fuel breakout) and only for large countries. So we have to assume the distribution across sectors is constant from 2022.
    - We are extrapolating the sectoral breakdown from IEA data out to 2022, and that 2022 data may also change in the next release
    - Activity data is not available at all for the most recent ~2 years for many non-combustion sources
- Emission Inventories
  - Where we have country-level emission inventories to calibrate to, they generally lag about 2 years behind
  - In limited cases (e.g. USA) we have some emission data out to 2023 for selected sectors (electric power, road), plus estimates for large point sources in 2022, but complete data only for 2021
- Satellite Data
  - We have satellite-based estimates of SO2 emissions for large point sources out to 2023.
    - We don't have similar time series for other emission species however

We want historical CMIP simulations to stop at a year where emission data are relatively stable

Hoesly R.M. and S.J. Smith. 2018. "Informing energy consumption uncertainty: an analysis of energy data revisions." *Environ. Res. Lett.* **13** 124023.

New CMIP Forcing Dataset Protocol

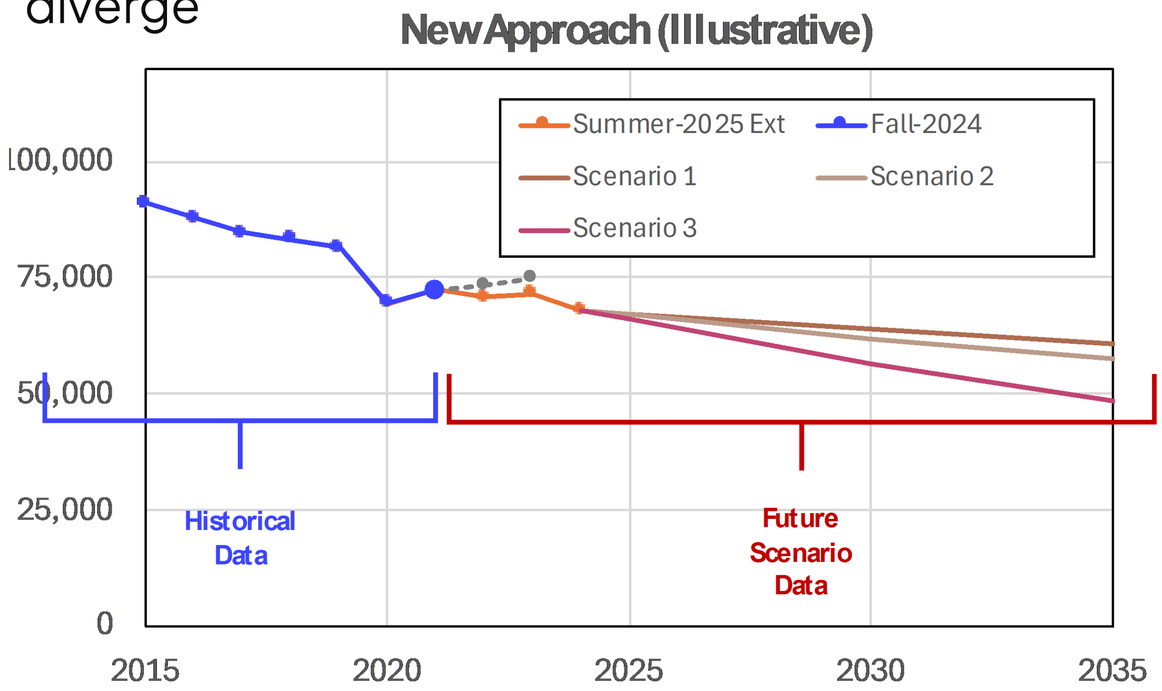
Advantages

The last historical data years are the most uncertain.

- This new approach allows additional time and data collection for refinement. So more accurate data over the most recent few years.
- This will facilitate more robust extensions of the CMIP historical data in the future by using a more robust starting point.
- ESMs saving restart files at the last common hist year (*e.g.* 2021) enables ESMs to perform future extension simulations of the historical period as data is updated. (A common request)
- As historical data is updated, emulators (and ESMs) can evaluate the impact of any data changes.

Key Characteristics

- "Historical" ESM forcing runs now extend to a "recent" common year but NOT the most recent year possible
- Scenario forcing data contains several annual data points in common until data starts to diverge



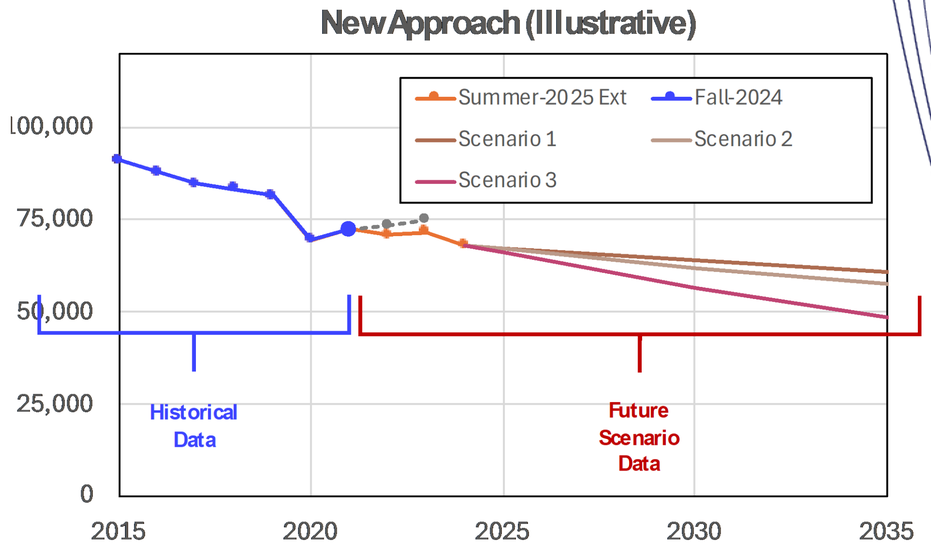
What end-year should we use for the historical simulations?

The historical/scenario split year needs to be a compromise between data stability and being relatively recent.

- A more recent split year means that there are fewer years with identical forcing data in the future scenarios.

  For efficiency, don't want this year to be too far back

- The closer we get to the last possible year, the less reliable estimate will be



With 2023 as the last year for which we can provide historical data this fall/winter:

we suggest 2021 as the last year for the historical forcing simulations

Note that historical CEDS emissions data will be provided out to 2023, however:

- The historical scenario data submission will only accept data out to 2021
- The future scenario data must start in 2022
- Therefore, models can run with hist forcing data past 2021, but **must save restart files for 2021**, since 2022 data will be updated in the scenario data.

Pros and Cons of 2025 fixed across scenarios

- Pro (*i.e.*, common 2025 point across scenarios)
  - Consistent with IAM data; GDP inputs, IAM 5-year storylines;
    No arbitrary deviation created by the harmonization algorithm
    (which may be countering the different storylines in 2025);
    Enables more consistent comparisons of data (e.g. IAV community)
  - Land-use: extension to 2025 possible.
  - Emissions: requires f someone provides solid guidance for 2024/2025, then we can use it.
- Con (*i.e.*, allow some divergence in 2025 values)
  - We have no data yet for 2025; presenting a unified number can be misleading (as the "common scenario year" 2024/2025 will be somewhat arbitrary)
  - Confusing: would mean having three types of "common trajectory"
    - Historical (up until 2021)
    - Historical CMIP7 fast-track (up until 2023/2024)
    - Common scenario year (2024/2025)
  - IAM-based averages are generally not meaningful guidance.
    Other variables (like energy, etc.) are also differing between models.

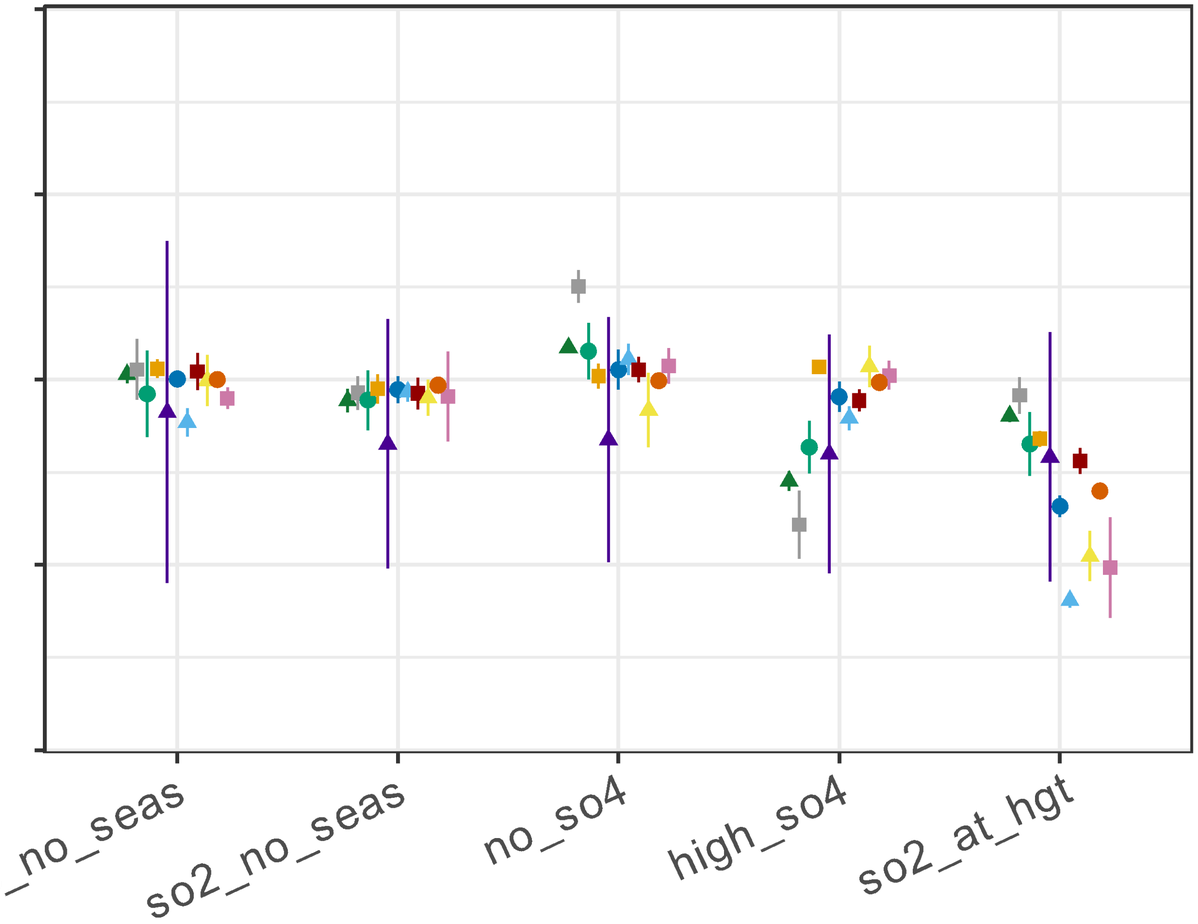
Whatever is done needs to be clearly, and repeatedly, communicated.

Note this is only for CMIP7-ScenarioMIP. In principle, later studies can use updated historical data and updated reharmonized data too for other non-ESM analyses.

The assumed emissions injection height matters

Injecting all anthropogenic emissions into the model surface layer biases model results for: concentrations, deposition rates, and radiative forcing. Sometimes quite substantially.

Note that a fraction of SO2 emissions should also be injected into the atmosphere as SO4.

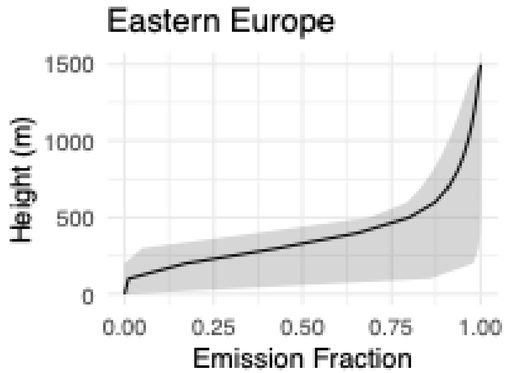


Ahsan et al: The Emissions Model Intercomparison Project (Emissions-MIP): quantifying model sensitivity to emission characteristics, Atmos. Chem. Phys., 23, 14779–14799, https://doi.org/10.5194/acp-23-14779-2023, 2023.

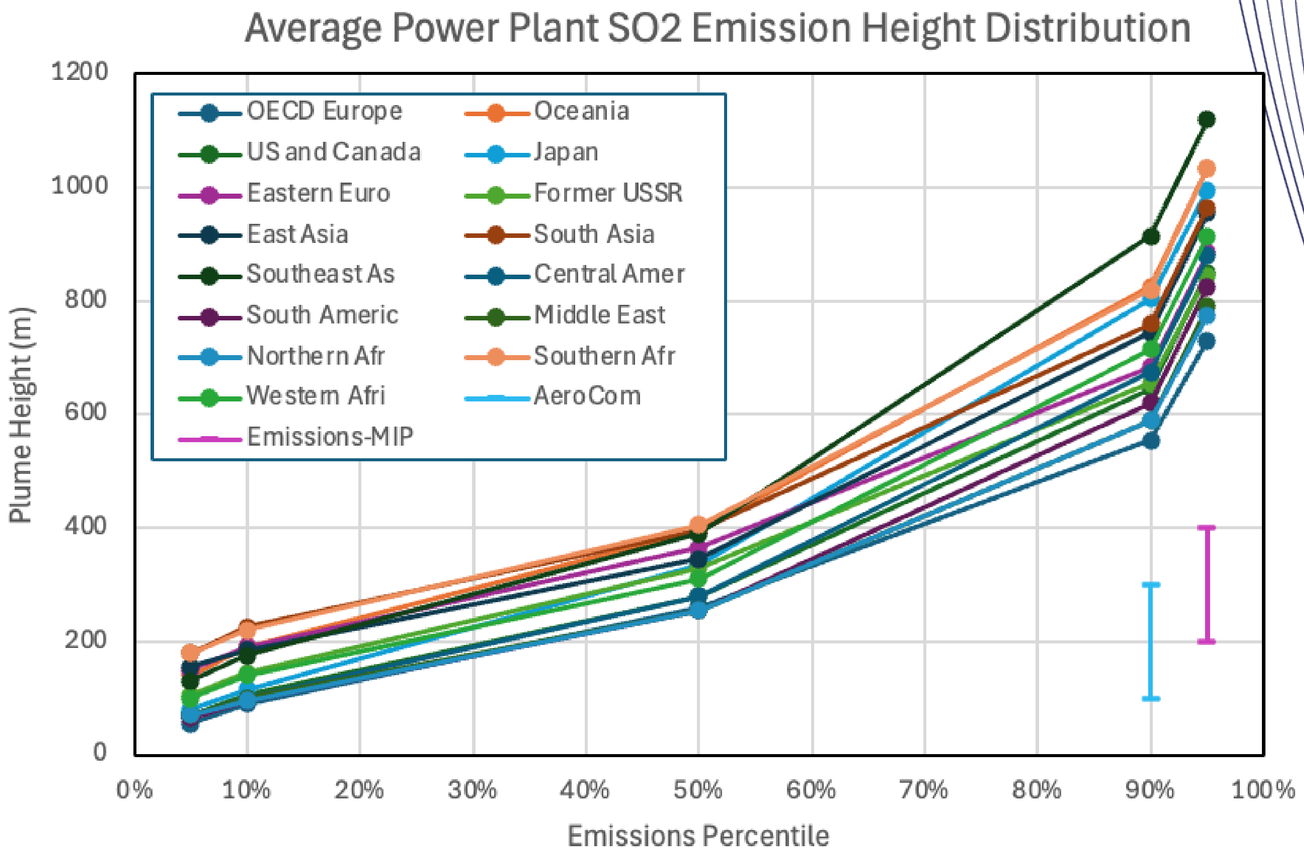
Recent Results

A recent global analysis by Guevara et al. (2024) has found that power plant emission plumes are much higher than assumed in global models.

- Many models use the AeroCom protocol (ENE and IND emissions injected between 100-300m)
- Plume height varies by region, and (generally a bit less) by emission species
- Emissions MIP assumptions were also too low (but were also applied to all SO2 emissions).
- In some instances, the plumes are even higher – median height ~1k in one case.



Effective Injection Height = Stack Height + Plume Rise



Guevara, M., Enciso, S., Tena, C., Jorba, O., Dellaert, S., Denier van der Gon, H., and Pérez García-Pando, C.: A global catalogue of CO_2 emissions and co-emitted species from power plants, including high-resolution vertical and temporal profiles, Earth Syst. Sci. Data, 16, 337–373, https://doi.org/10.5194/essd-16-337-2024, 2024

What Guidance Should be Provided to Models?

This change in input data assumptions would change model results, perhaps substantially.

Is it too late for models to re-calibrate before CMIP7?

What type of data should be provided to global models. While the Guevara et al. (2024) data is available by individual power plant, this is likely too granular for most global models.

Note also that:

- Emission height will vary across time
  - Higher in the recent past in some regions (before air pollution emission controls, when larger and taller stacks were used)
  - Lower into the more distant past when facilities where smaller.
- Industrial sector emissions will have an even wider range of heights than the electric power sector
  - Ranging from substantial emissions at the surface (construction, agriculture, etc.)
  - To much higher emissions from very large facilities (large smelters, oil processing facilities)
  - The fraction of emissions emitted above the surface layer will vary by emission species.

Longer-Term Questions

Should emission height distributions ultimately be provided:

- For large geographic regions? Or only a global average?
- Differentiated by emission species?
- Differentiated over time?

How much difference is meaningful?

As model resolution increases, should global models consider incorporating point source emissions data?

Include plume rise parameterizations?

CMIP Climate Forcings | WCRP

Emissions Harmonization: discussion

- Add questions using slido, with upvoting,

Three ways to join:

1) Scan QR code
2) Go to slido.com + Enter code: #2618796
3) Click on: https://app.sli.do/event/aEKsZcVCxwo1dWhpr1EkFP

Land use: historical and harmonization

CMIP Coupled Model Intercomparison Project
Climate Forcings

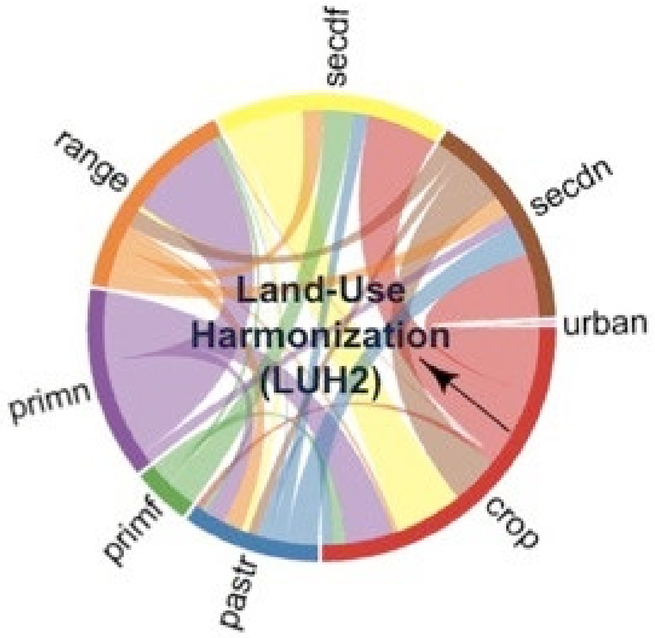
Pathway to regular and sustained delivery of climate forcing datasets workshop: 28-31 October 2024, ECMWF Reading

Session 2: Land-Use Harmonization

Louise Chini

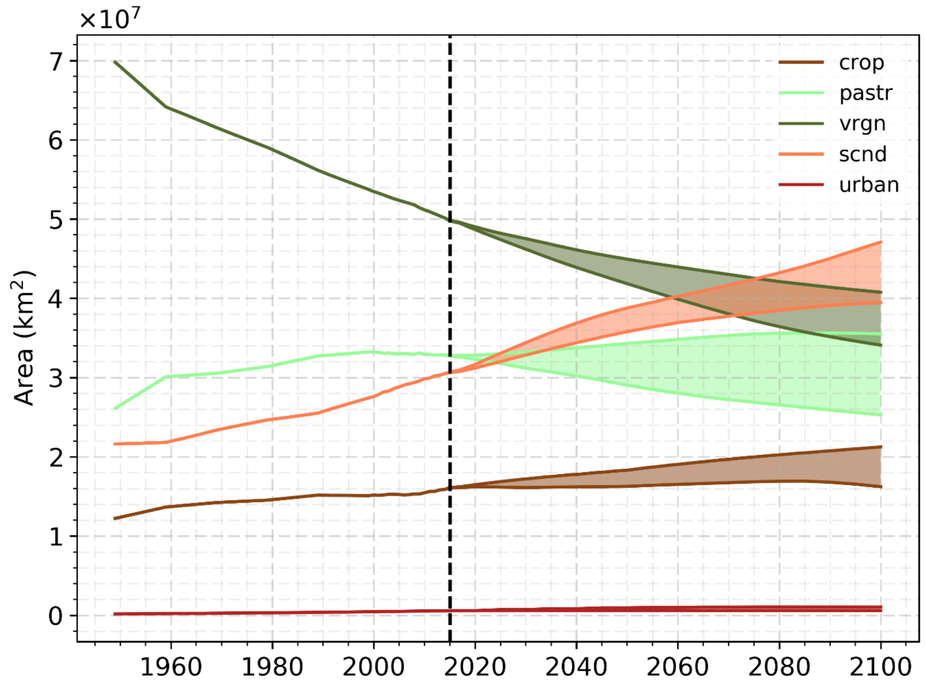
Overview

- Background on previous Land-Use Harmonization activities
- Plans for Land-Use Harmonization for CMIP7
- Next steps



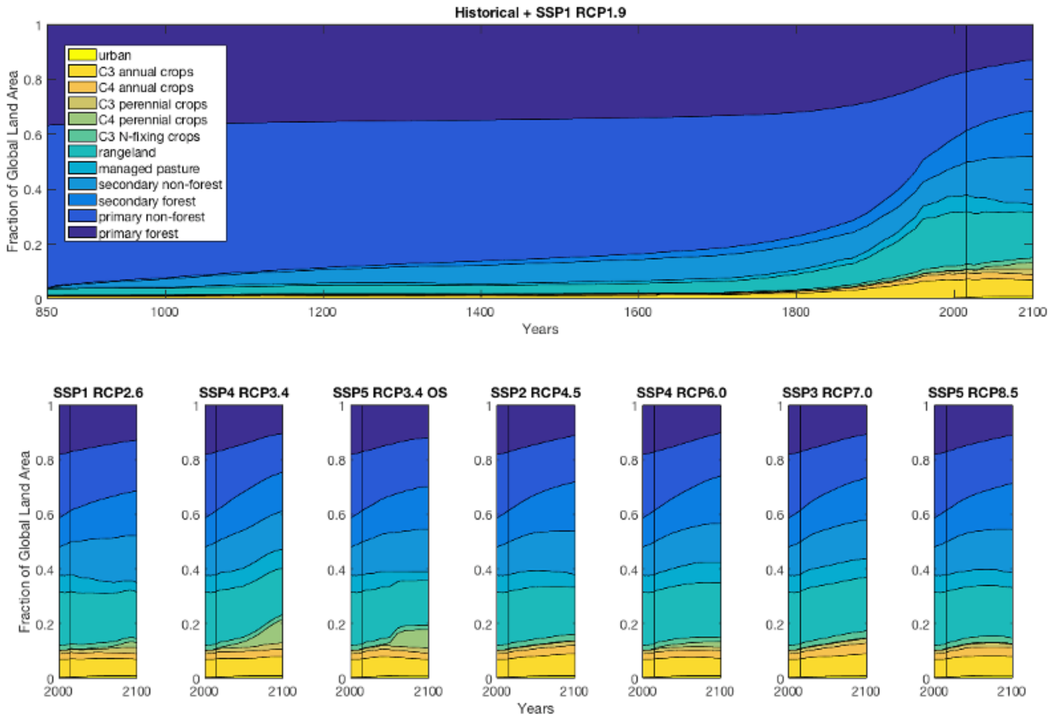
CMIP5: Land-Use Harmonization 1 (LUH1)

- Historical land-use data 1500-2005
- Four future scenarios 2005-2100
- 5 land-use states and associated transitions (including wood harvest, shifting cultivation, secondary age/area/k
- Annual, fractional, 0.5 degree spatial reso
- Used successfully in ESMs



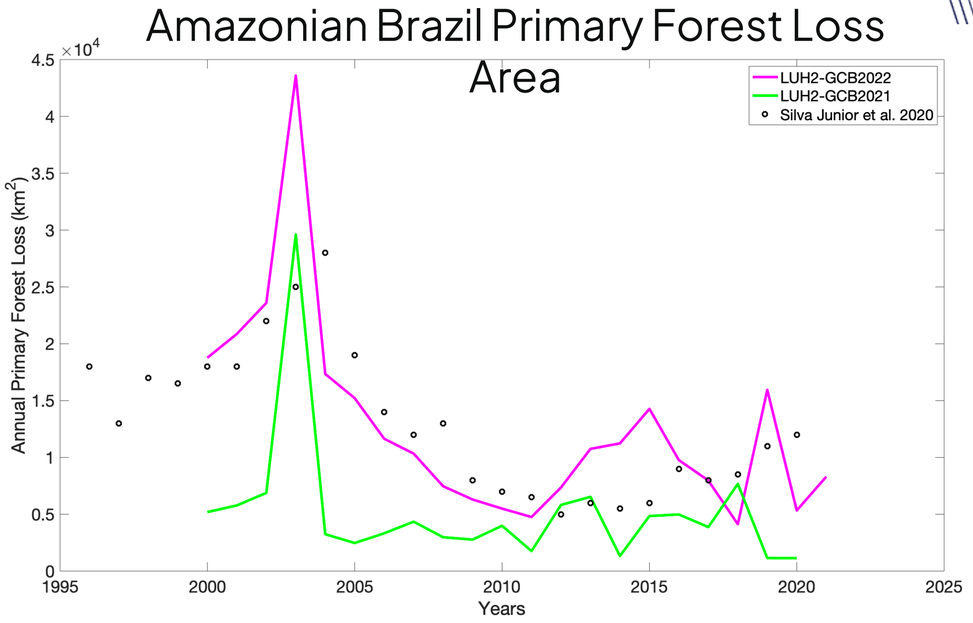
CMIP6: Land-Use Harmonization 2 (LUH2)

- Historical land-use data 850-2015
- 8 future scenarios 2015-2100
- 12 land-use states and associated transitions (including wood harvest, shifting cultivation, secondary age/area/biomass, crop sub-types, grazing sub-types, etc)
- Land-use management variables (irrigation, fertilizer, flooding, bioenergy crops, etc)
- Annual, fractional, 0.25 degree spatial resolution



Post-CMIP6 updates to LUH2

- Alternative historical reconstructions (high and low)
- Historical data updated annually for Global Carbon Budget and TRENDY models, including new data inputs for regions of importance (Brazil, Indonesia, China)
- New future scenarios produced for LAMACLIMA and ISIMIP3b (almost 50 new scenarios for IMAGE and REMIND-MAGPIE)



LUH Methodology

- Engage with Integrated Assessment Model and Scenarios community to achieve consensus on land-use variable definitions, formats, and initial conditions in harmonization year (very collaborative process)
- Pre-process IAM data into a common data format for input to LUH
- Preserve changes in IAM data as much as possible – aggregate to 2 degree resolution first, then downscale to 0.25 degrees after harmonizing
- Provide spatial patterns for regional/national data
- Compute secondary land age, area, and biomass, land-use transitions (including shifting cultivation), etc
- Check outputs of this process against previous datasets and diagnostics

Recent Land-Use Harmonization Discussions

- In preparation for land-use harmonization, there have been several discussions happening
  - ScenarioMIP Proposal an in particular the task team on CDR and IAM-ESM interactions
  - Forcings Task Team Harmonization Working Group
  - Integrated Assessment Modeling community and RESCUE team
- Consensus is that we will use LUH methodology again for CMIP7
  - It is a known format/process that is likely to be successful given the short timeframe
  - Both IAMs and ESMs are familiar with LUH
  - Hopefully we can also leverage knowledge from RESCUE and other teams working on this and develop common protocols for dataset delivery

Timeline

- October 2024 to January 2025:
  - Finalize the historical land-use forcing, which will provide the initial condition for the harmonization
  - This will set the data format, resolution, variables, etc
- October 2024 to January 2025: simultaneously prepare for harmonization
  - Create a land-use harmonization working group including contact persons at each IAM
  - Develop a template for land-use data to be passed from IAMs to LUH
- January 2025 to May 2025:
  - Development of new land-use harmonization algorithms
  - Testing IAM data
- June 2025:
  - Receive final scenarios
  - Land-Use Harmonization completed

Potential Challenges

- Consistency between IAM data outputs
- Consistency between LUH historical and IAM scenarios in harmonization year
- Time

Solutions

- Keep algorithms and data formats the same as CMIP6
- Work closely with IAMs for consistency and to share pre-processing workload

Land-Use Harmonization: discussion

- Add questions using slido, with upvoting,

Three ways to join:

1) Scan QR code
2) Go to slido.com + Enter code: #2618796
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Thank You

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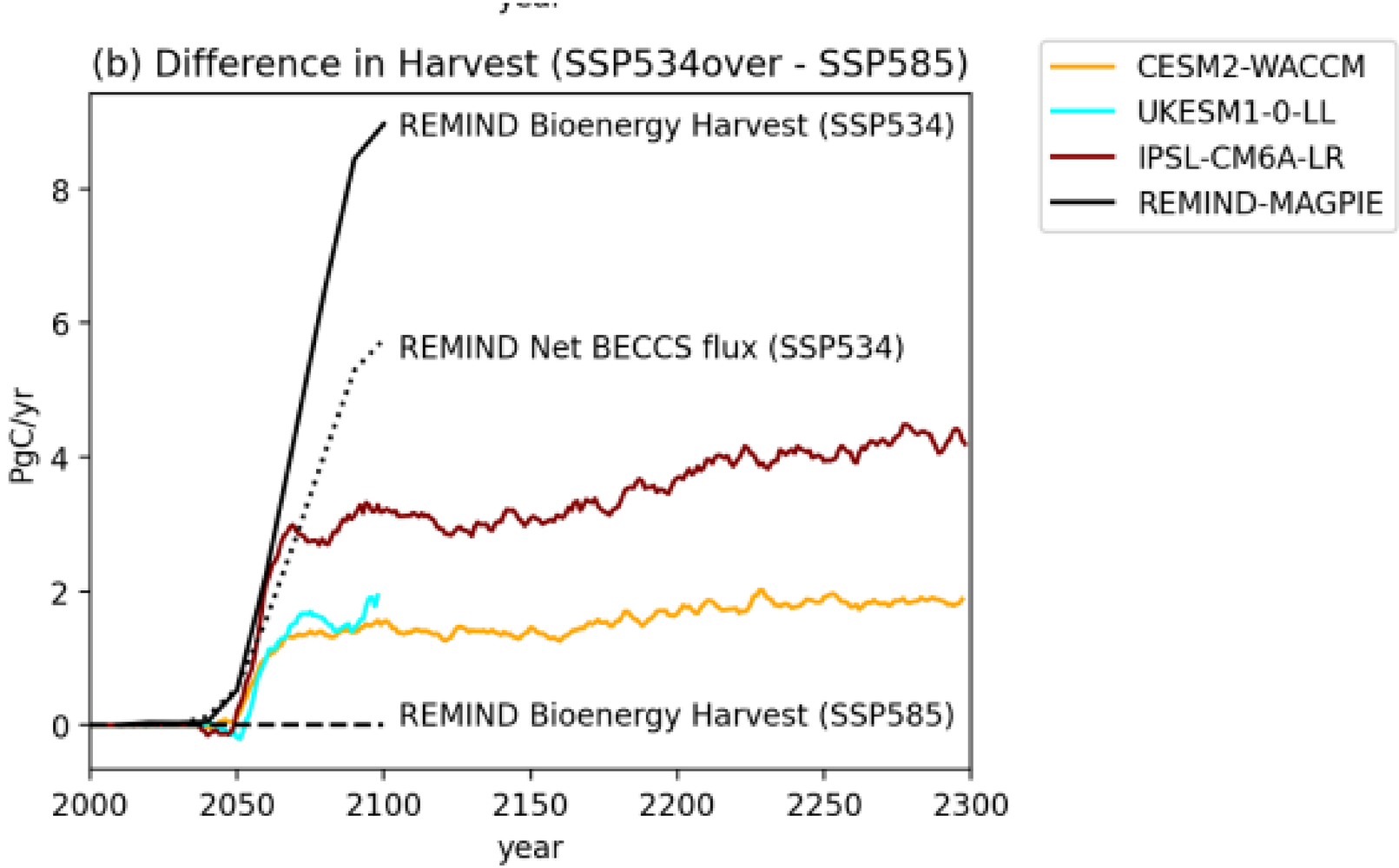
Carbon Dioxide Removal in CMIP7 scenarios

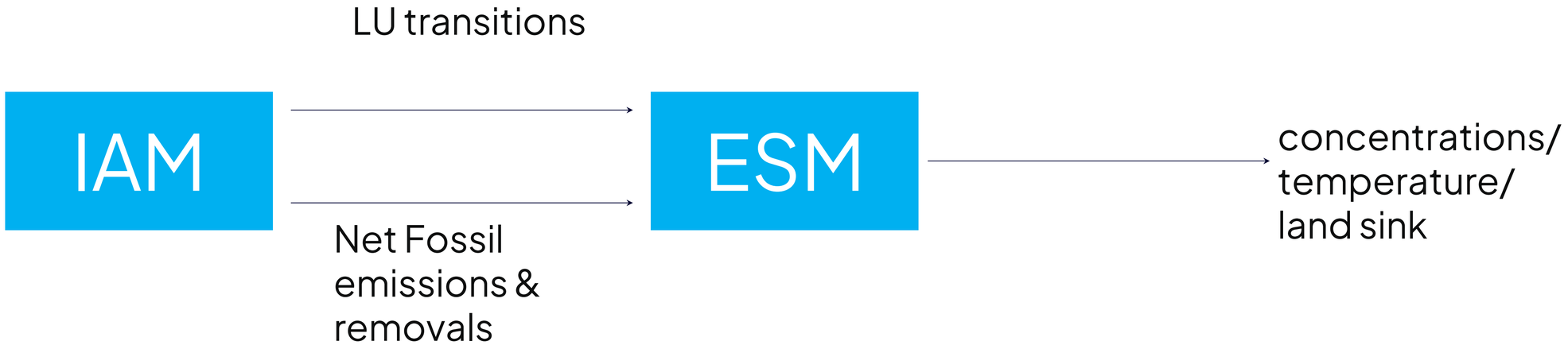
BECCS in ESMs: survey responses

Represented in ScenarioMIP CMIP7	Represented in some models	Planned representation	Not yet planned
· Afforestation/ reforestation	· Dedicated energy crops	· Dedicated LU transitions · DACCS · Sequestration pool	· Non-BECCS ecosystem CDR · BECCS-specific forests



There are potentially large differences between internally computed harvest rates in IAMs and those achievable in ESMs.

ScenarioMIP



- Crop yield internally calculated
- w. tech increases & capture losses
- Capture reported as -ve emissions

- Bioenergy crops & forests
- Currently harvested and go into product pool (decay time ~1 year for crop, 10-100 year for forest)

double counting?

Logically, BECCS crops should not exist in the ESM at all if their lifecycle emissions are already computed in the IAM and passed as a flux

options for addressing double counting

1 - remove BECCS crops from the land use dataset - represent area as bare ground, without natural vegetation.
2 - emissions flux adjustment to remove IAM estimate of counterfactual BECCS related land-use emissions

3 - post-hoc correction (requires sufficient diagnostics)

3 - explicit representation (BECCSMIP/RESCUE)

Diagnostics needed for accounting

existing

General

- Complete breakdown of nbp/fgco2_ant/fgco2_nat
- crop productivities (fHarvesttoProduct - Harvested Biomass That Goes into Product Pool (wood/food) kg m-2 s-1)
- crop losses (fHarvesttoAtmos) - harvested Biomass that goes straight to the atmosphere

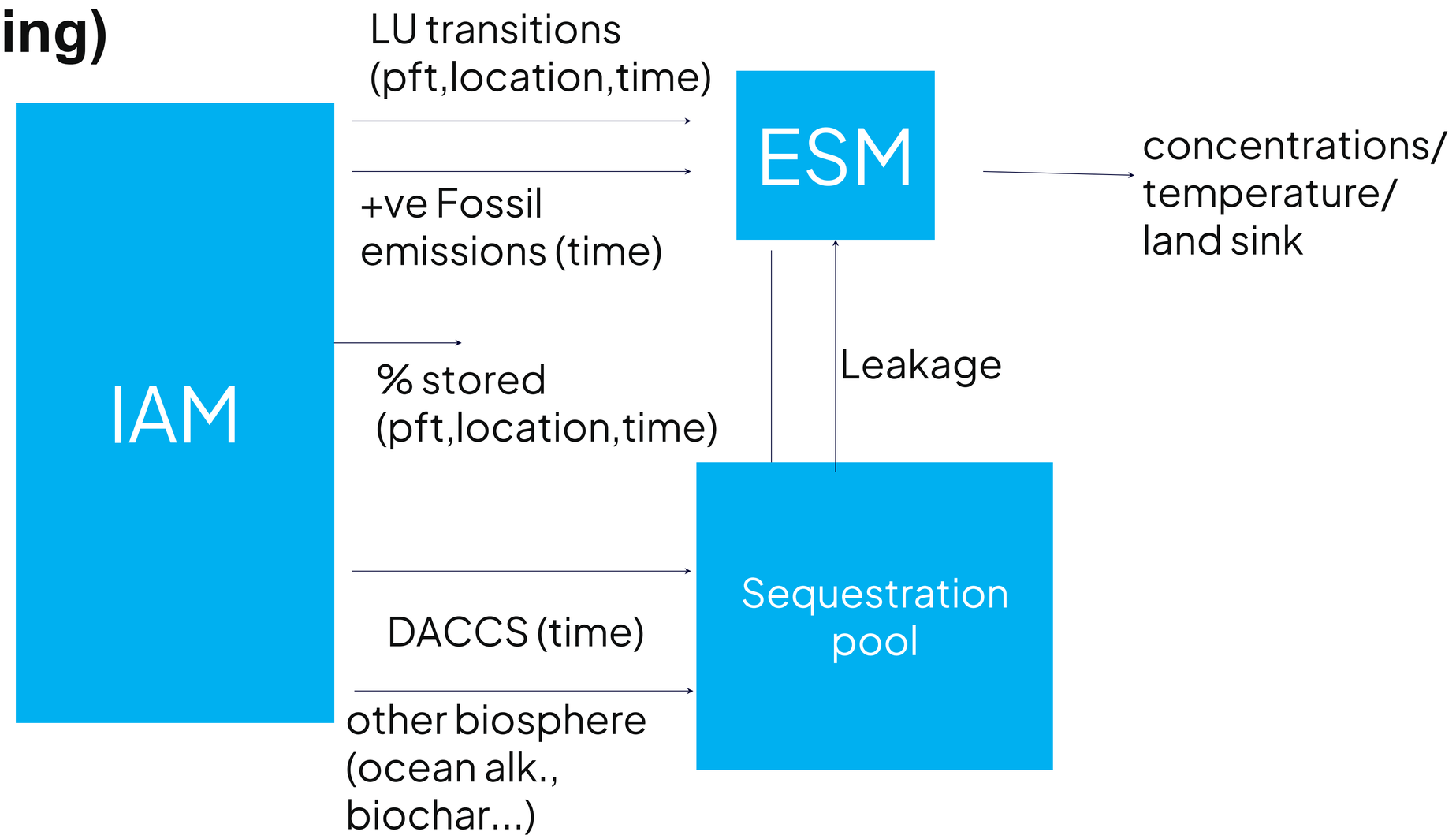
Needed for post-hoc correction (from ESM)

- fProductDecomp - decomposition rate of the product (or sequestration) pool **[question - already in NBP?]**

Needed for post-hoc correction (from IAM)

- Fraction of crops used for BECCS

Emissions data for BECCS (process resolving)



options for “BECCS-MIP” in CMIP7

how? and when?

Expand RESCUE to a wider MIP

Use RESCUE protocol adapted to ScenarioMIP pathways

Resolved BECCS using ScenarioMIP pathways (or a subset)

Fast track timeline (end of 2026?)

Post-AR7 cutoff?

What would a process-resolving BECCS forcing dataset contain?

existing

General
- LU transitions & crop specifications

minimal

BECCS-specific instructions
- gridded fraction of harvest allocated for BECCS
- efficiency (including loss/transport) of capture
- yield efficiency?

Sequestration pool
- sequestration pool parameters (loss rate, regionality?

extensive

Ecosystem CDR
- other activities (biochar, ocean alk)

non-ecosystem CDR
- non-biospheric capture total

Yield increases

- IAMs generally assume yield increases over time (e.g. in MagPIE, yield-increasing technological change can be acquired at cost)
- If desired yield factor is passed to LSMs, how should it be handled?
- Can crop pfts be dynamically adjusted without sacrificing consistency ?

- What additional outputs are required (process-resolving)?

existing

General

- Complete breakdown of nbp/fgco2_ant/fgco2_nat
- crop productivities (fHarvesttoProduct - Harvested Biomass That Goes into Product Pool (wood/food) kg m-2 s-1)
- crop losses (fHarvesttoAtmos)

minimal

- fProductDecomp - decomposition rate of the product (or sequestration) pool
- Flux to sequestration pool (fHarvesttoStorage)

extensive

- Storage Loss rate (fStorageDecomp)
- Efficiency/losses of sequestration

Discussion Points

Double Counting

Do we need a modified protocol to prevent double counting of carbon in emissions-driven simulations with CDR (without process-resolved BECCS)?

If so - so, do we modify the net fluxes or the land use transitions?

If not, what additional outputs do we need to track the size of the problem?

Towards BECCS process-representation in ScenarioMIP

Should forcing datasets with fractional BECCS allocation, efficiency and storage losses be prepared as along with wider scenarioMIP forcing inputs?

should BECCS be defined by pft or simply act on the total product pool?

Should forcing datasets prescribe the type of crop used for BECCS activity?

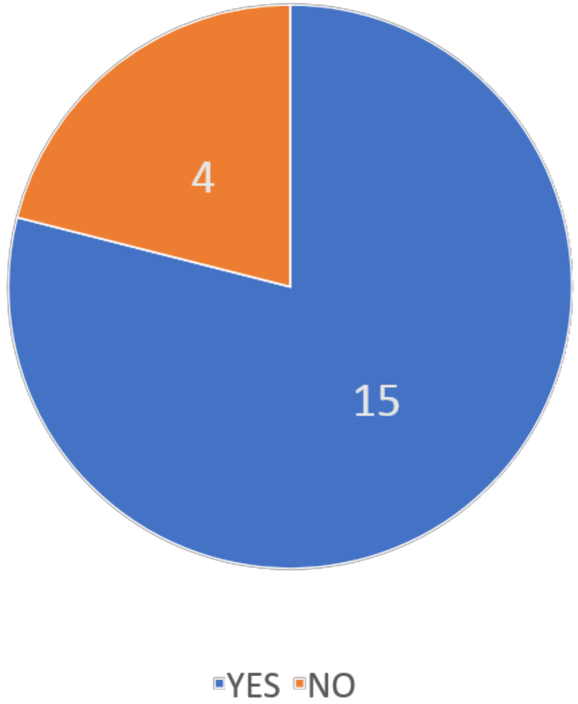
How should yield increases be prescribed and implemented in ESMs?

What additional outputs are needed to fully track the carbon budget of prognostic BECCS?

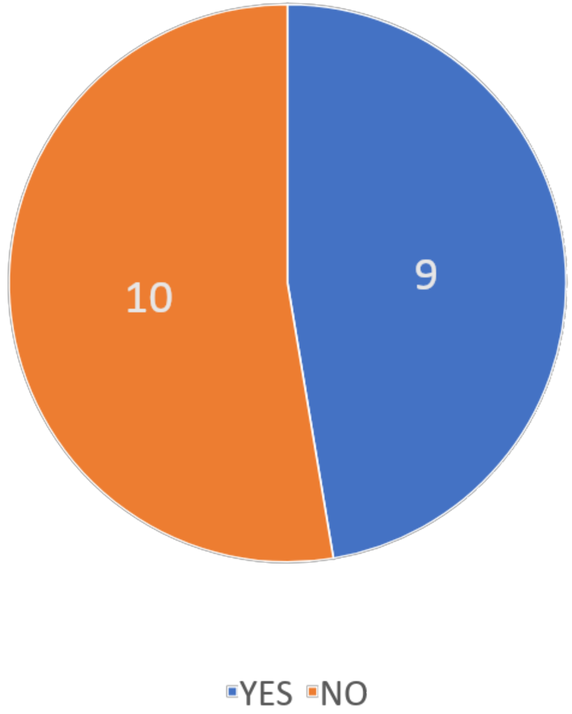
Thank You

BECCS in ESMs: survey responses

Does your model represent land use/land management?

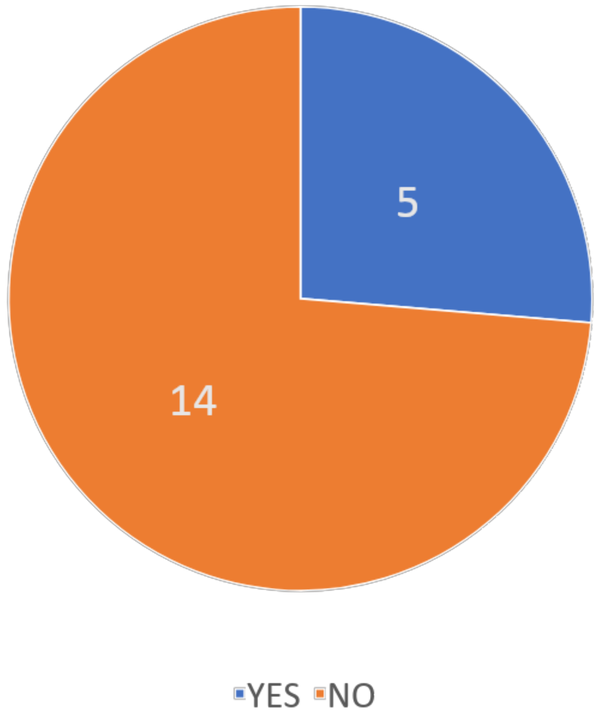


Does your model represent anthropogenic carbon pools (specific pools with various turnover times)?



Most models represent land management, 50% have anthro carbon pools

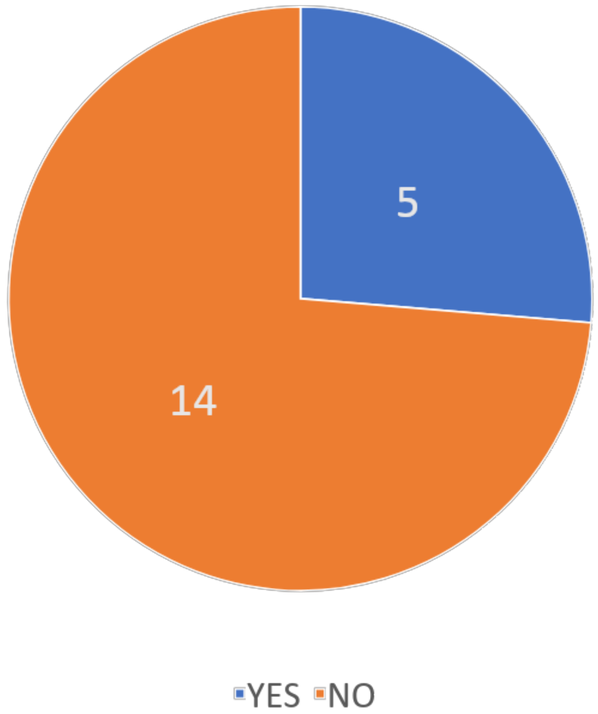
Does your model represent bioenergy plant functional types (PFT)?



Most models *don't* yet have dedicated energy crops.

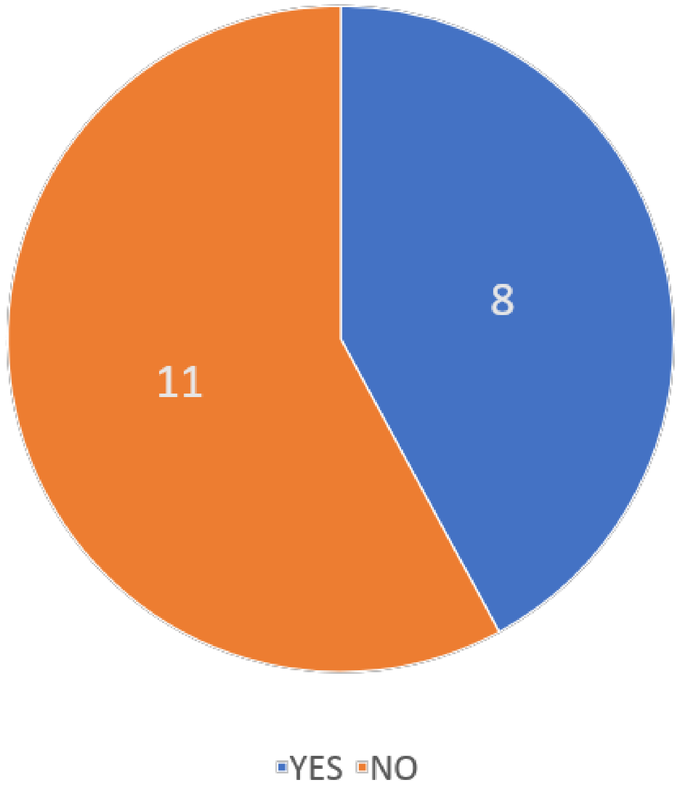
Of the 5, only 2 will represent harvest carbon losses

Does your model represent bioenergy plant functional types (PFT)?



Centre/group	Represent PFTs?	If yes, which bioenergy PFTs does your model include	If other, provide detail
AS-RCEC	Yes	C4 perennial grasses, plantation forests	
CMCC	Yes	C4 perennial grasses, plantation forests	
E3SM-Project	Yes	C4 perennial grasses	
MRI	Yes	C4 perennial grasses	
NOAA-GFDL	Yes	C4 perennial grasses, plantation forests	Planting and harvesting dates, crop species (herbaceous and trees), transport and destination to processing facilities where efficiency can be calculated.

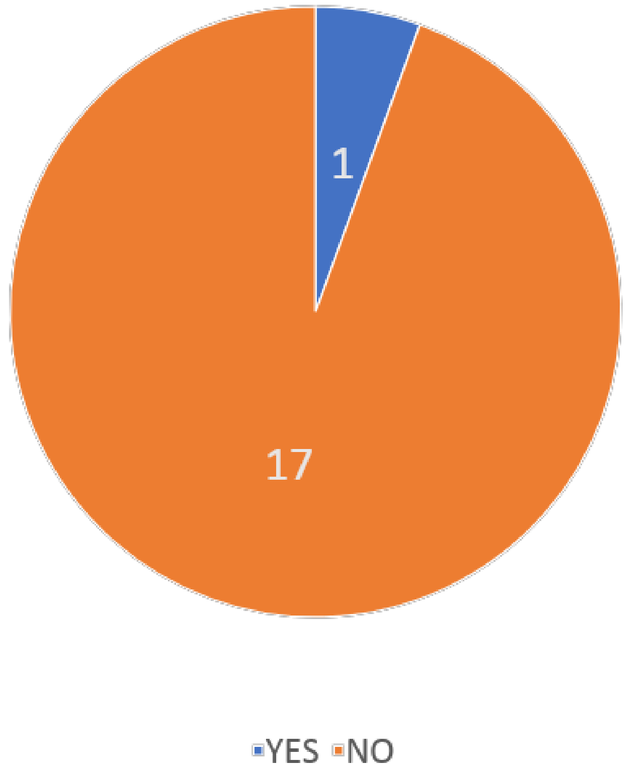
Is your, or will your, ESM be able to implement technical crop yield improvements?



40% of models plan to implement yield improvements

If including forest plantations as a bioenergy feedstock, are these handled separately from forest plantations used for A/Reforestation and/or forestry/logging?

Almost all models have no dedicated bioenergy forest.



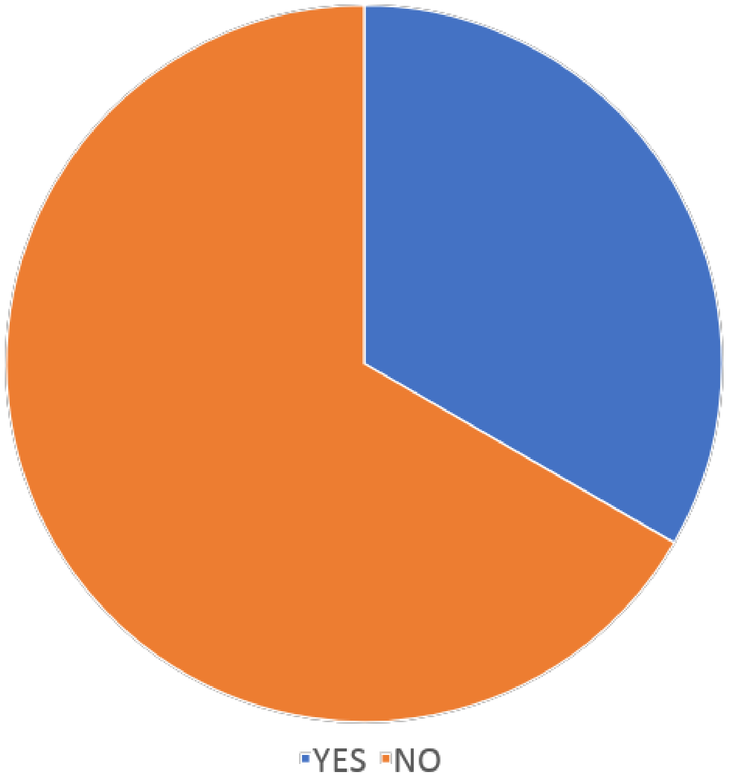
Could your model incorporate land-use forcing that provides spatially explicit information to distinguish states/transitions of crops used for BECCS and those of crops used for energy purposes without storage (i.e. biofuels)?

Centre/group	Yes/No	Explanation for response
CMCC	Yes	Our model has specific CFTs for BECCS and biofuels.
E3SM-Project	Yes	Land use transition maps provide information on states/transition of Miscanthus and switchgrass.
MRI	Yes	Our model would like to use the land-use forcing that provides the explicit information about crops.
NOAA-GFDL	Yes	We could add crop types as long as their specifications were provided in terms of physiological/ecological characteristics, planting and harvesting characteristics, fertilizer and irrigation needs if any.
NUIST	Yes	Will try to do it
AS-RCEC	No	We are not sure about this, but we will follow the land model in CESM3.
BCC	No	Under development
IPSL	No	It is not part of the primary scientific interests of IPSL but ongoing discussions on how to implement, in particular for scenarios with high CDR
MIROC	No	We assume that we would have to distinguish crops for food supply and those for bio-fuel. If that would not be the case, the answer would be yes.
MOHC	No	It is not yet clear how we will deal with this
NASA-GISS	No	Our ESM currently has irrigation, which enhances photosynthetic uptake, but it has not simulated enhanced carbon density, yet (but could). Currently does not have fertilization or a crop harvest scheme, it could be implemented if support was obtained, Our model would not be spatially explicit and would most likely implement the biofuels as fractions of a crop type. Note that we aren't really clear how this would impact the climate (beyond the net fluxes) so question why this should be included in the GCMs as opposed to the IAMs.

Only 5 models plan to handle BECCS-specific land use transitions

The other centres responded that their models did not represent BECCS or did not provide an answer.

Can you currently, or are you planning to, implement an explicit carbon removal pool representing geological carbon storage in your model?

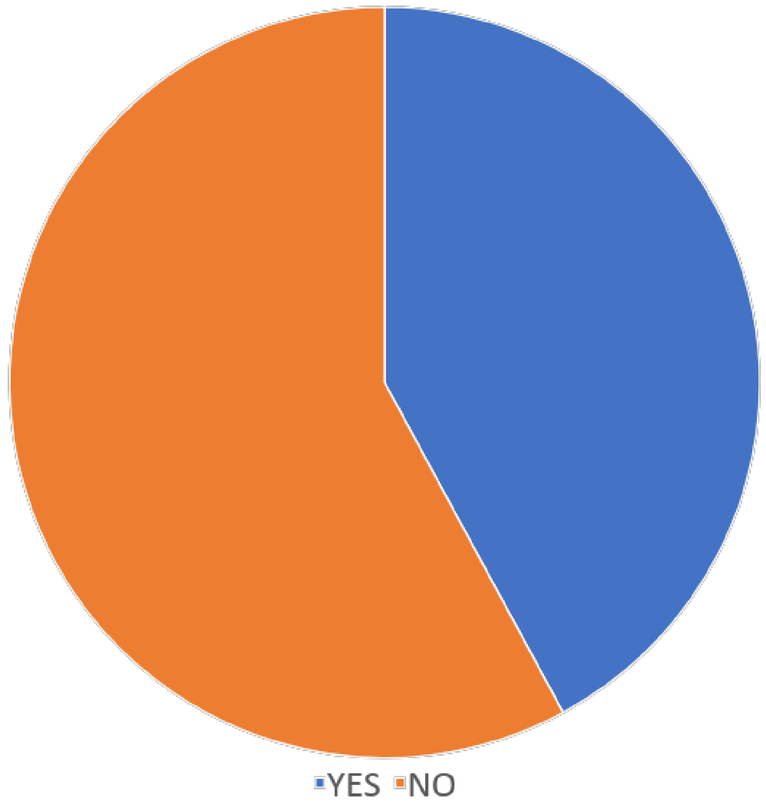


about 1/3 of models plan to implement a carbon sequestration pool.

most won't distinguish between types of CDR

4/6 will have it present in fast-track version

If the ESM-internal calculations/estimations of emissions / removals from BECCS is not included in ScenarioMIP, would you still be interested to investigate this within a separate MIP in the context of CMIP7?



40% of centers would be interested in a dedicated BECCS MIP

Which additional information from IAMs and/or the land-use forcing data would you need to represent BECCS in a meaningful way within your model?

Centre/group	Fraction of harvested biomass feedstock carbon ending in removal pool	Fertiliser and/or irrigation for bioenergy crops	Separation of emission (removal) forcing on type of BECCS	Leakage factor from removal pool	Other
CCCma					Do not have BECCS directly implemented, so cannot answer at this time. Might know more in future.
CMCC					
CNRM-CERFACS					
E3SM-Project					
INM					
IPSL					
MIROC					
NASA-GISS					Full partitioning of flux to atmosphere, to storage, and residue remaining on the ground
NIMS-KMA					
NOAA-GFDL					
NUIST					

Models have differing ideal requirements for BECCS

ScenarioMIP

JOINT GLOBAL CHANGE RESEARCH INSTITUTE

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ScenarioMIP: Current status and next steps

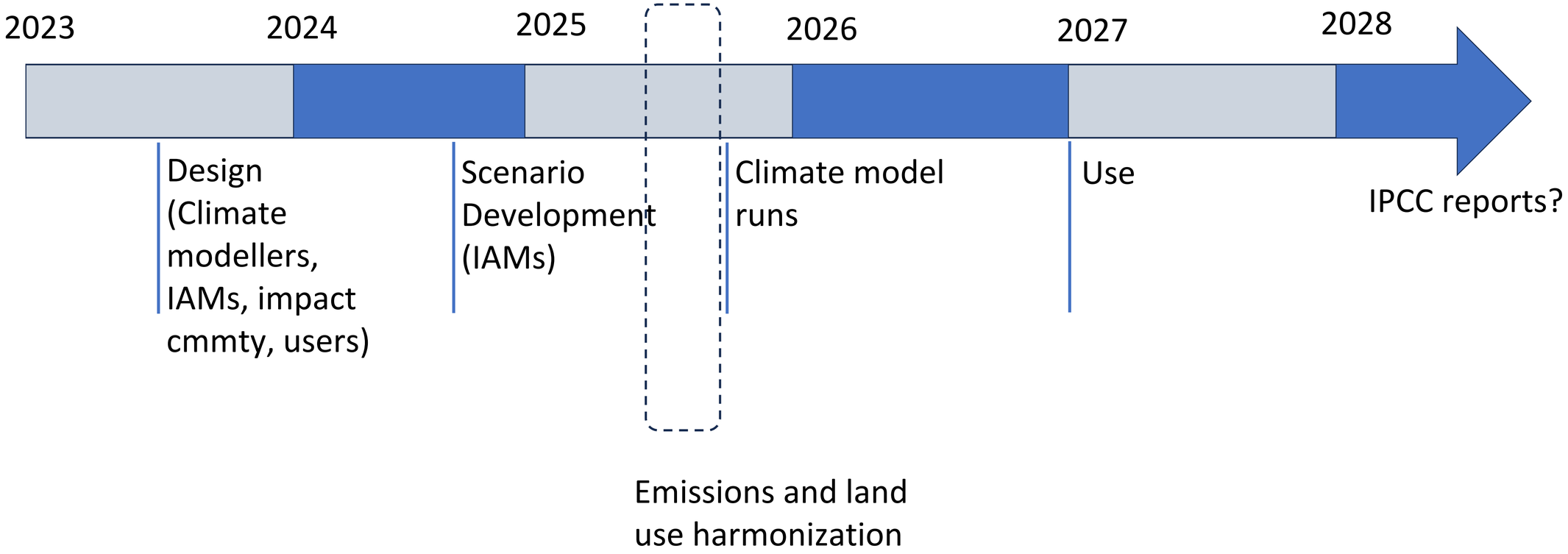
October 28, 2024

Brian O'Neill (PNNL), Claudia Tebaldi (PNNL), Detlef van Vuuren (PBL)

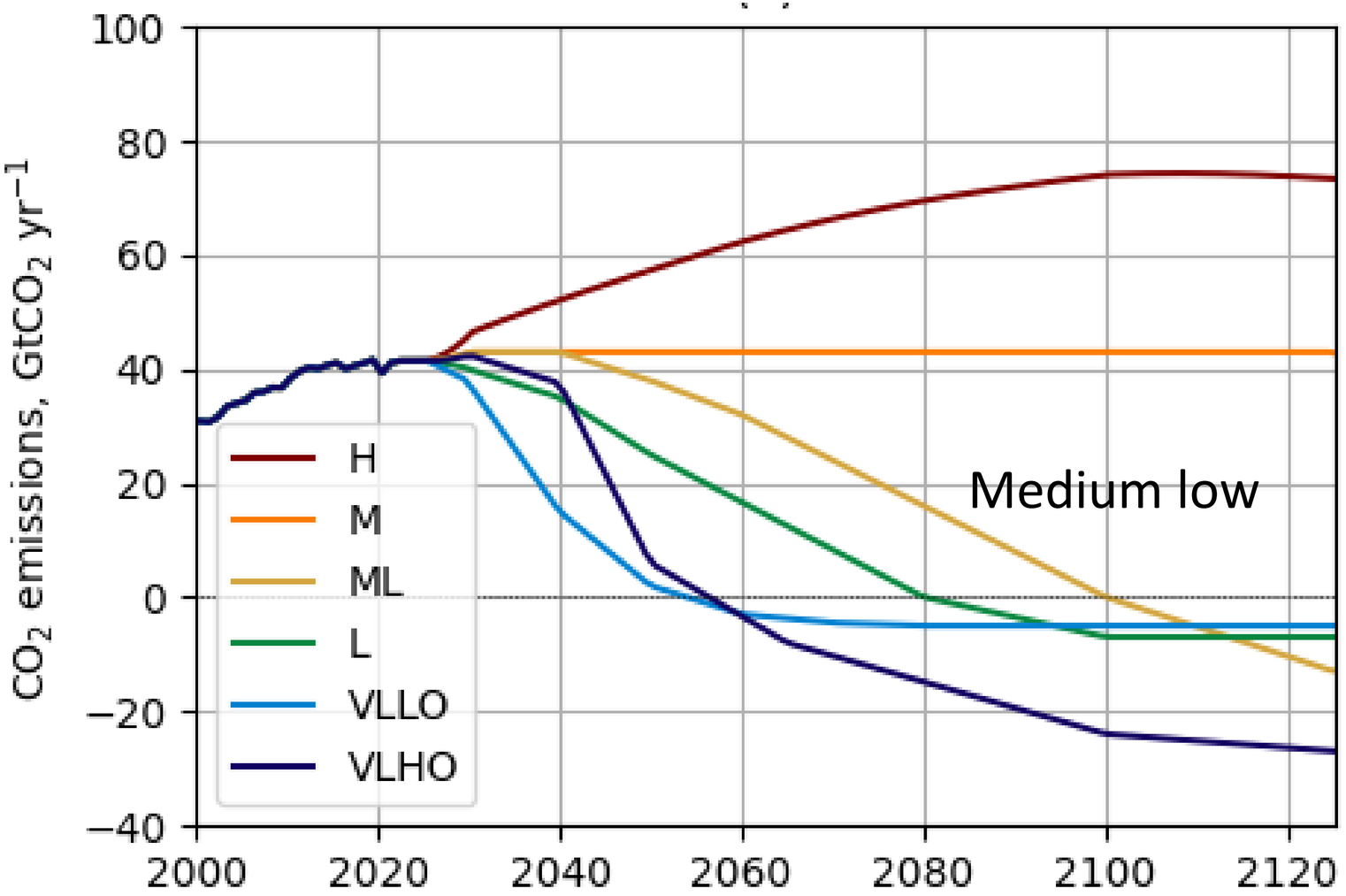
ScenarioMIP process to date

June ’23	Reading (UK) workshop and report
Sept ’23	Public webinar and review period for the report
Fall ’23	Expansion of SSC, creation of Advisory Group
Fall ’23	Creation of task forces Low scenarios High/middle scenario Extensions CDR in ESMs/IAMs
Jan ’24	First draft proposal by SSC
Feb ’24	Review by Advisory Group (and revisions)
April ’24	Public review (and revisions)
Oct ’24	Finalize draft
Nov ’24	Submission to GMD

Longer-term process



Illustrative CO2 emissions



High

Medium

Medium low

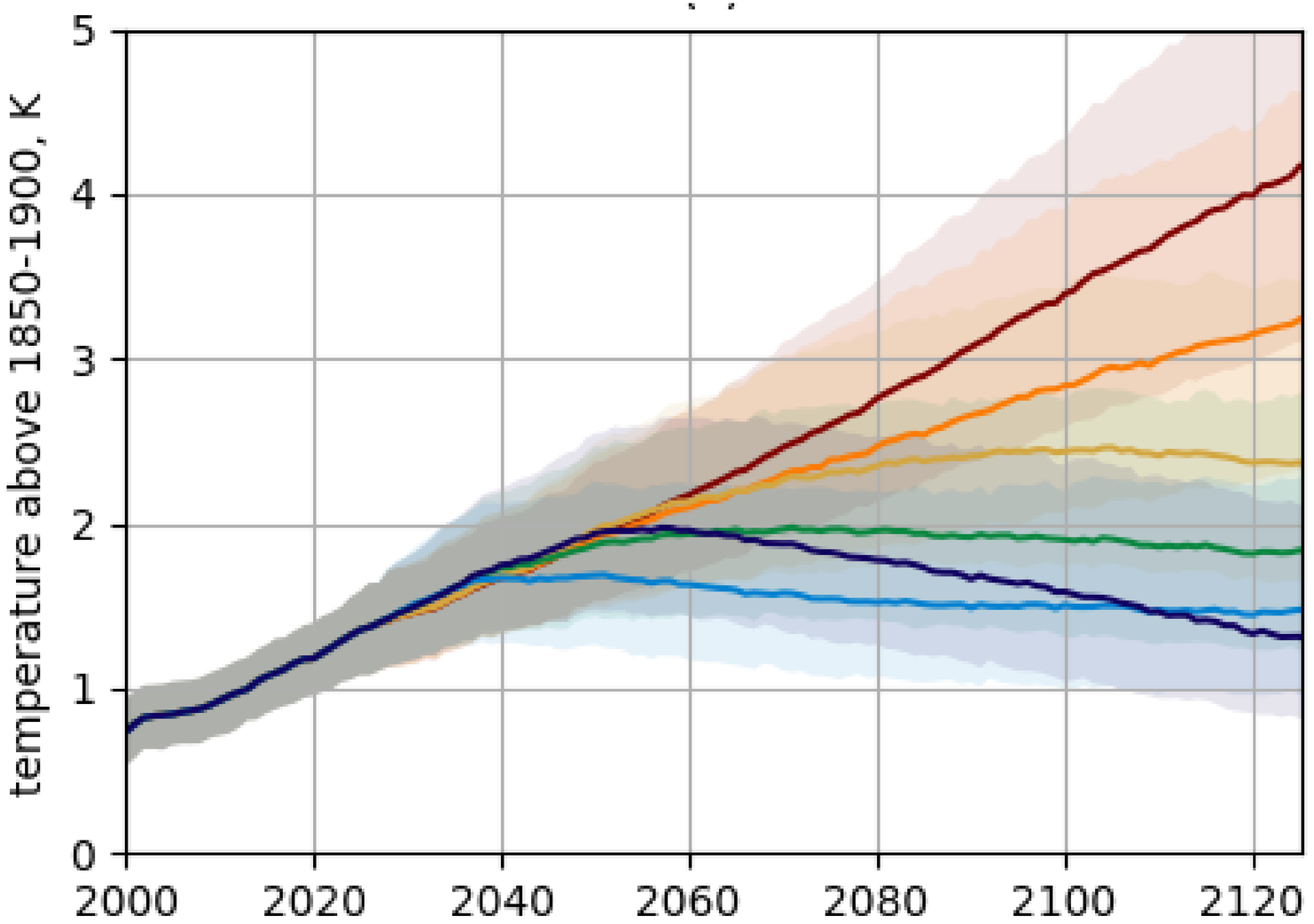
Low

Very low with limited overshoot

Very low after high overshoot

Courtesy Ben Sanderson

Illustrate global mean temperature change



High

Medium

Medium low

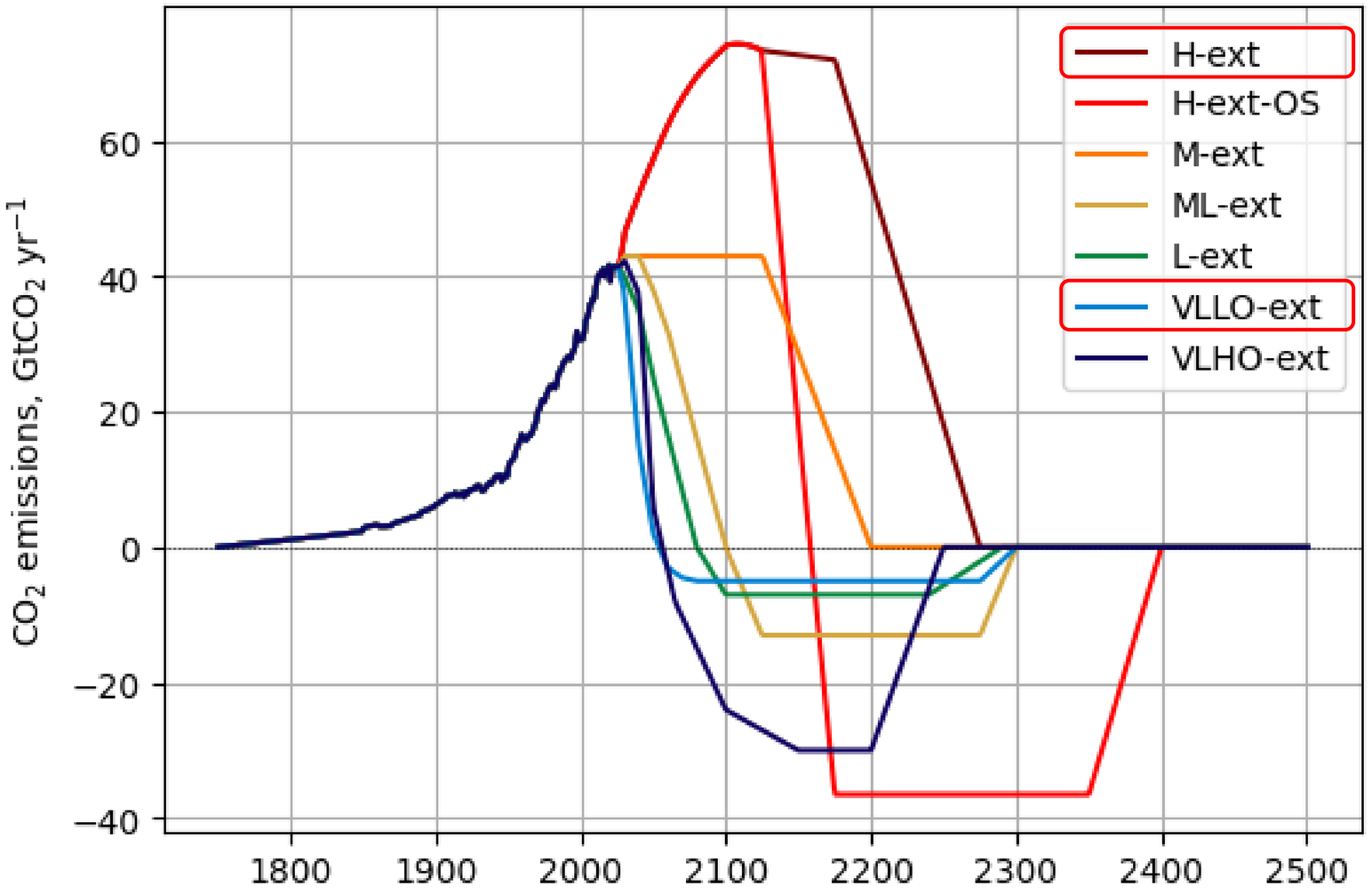
Low

Very low with limited overshoot

Very low after high overshoot

Courtesy Ben Sanderson

Long-term extensions



High priority (still under discussion)

Courtesy Ben Sanderson

Historical and near-term emissions

-2023	historical (CMIP)?
2024-25	hybrid historical/extrapolated?
-2025	common to all IAMs
2030	within common plausible range

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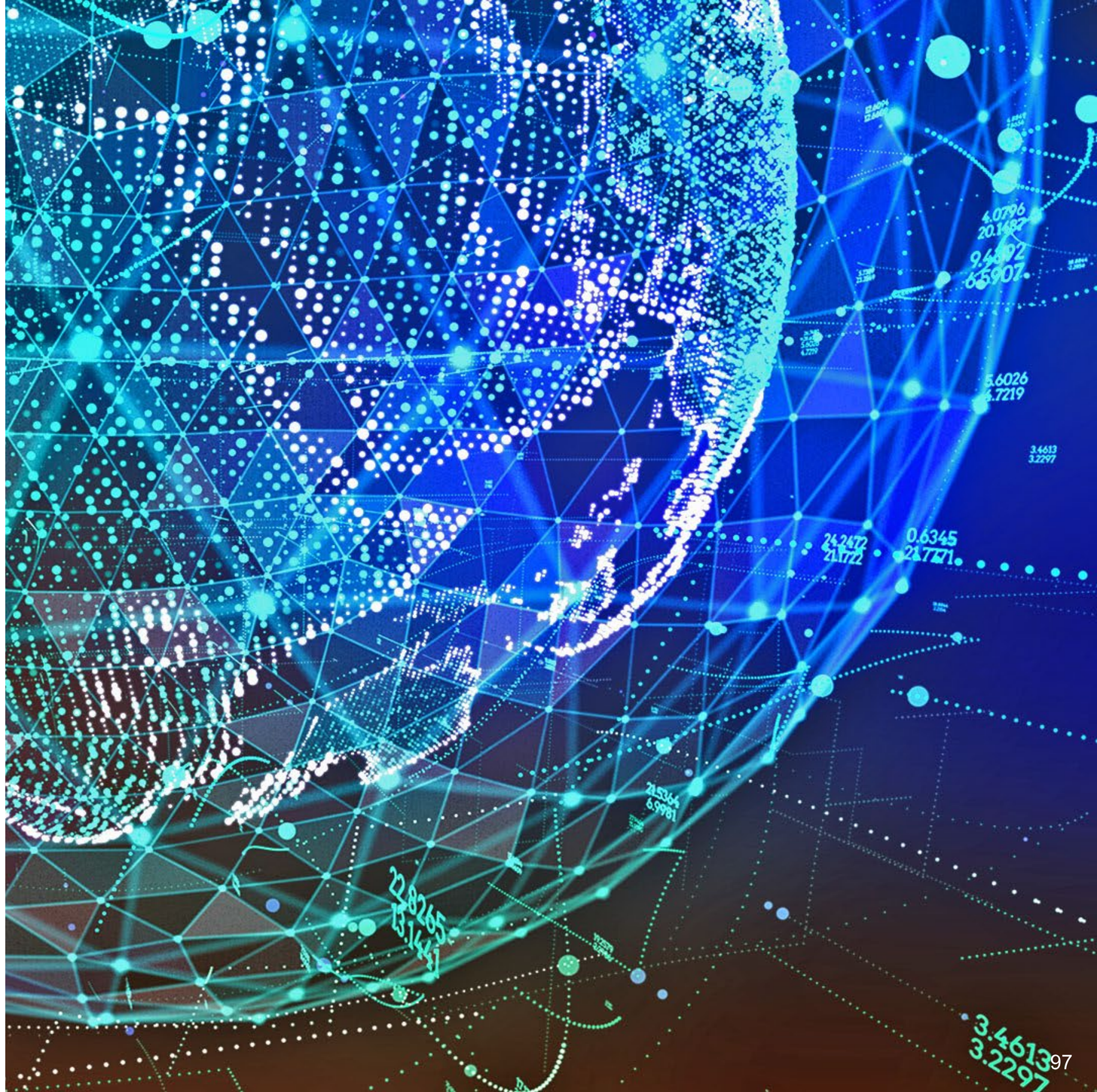
Thank you



General discussion

General discussion

- Add questions using slido, with upvoting,

Three ways to join:

1) Scan QR code
2) Go to slido.com + Enter code: #2618796
3) Click on: https://app.sli.do/event/aEKsZcVCxwo1dWhpr1EkFP

Thank You