

Core Model Proposal #410:

Updates to Socioeconomic and
Macroeconomic Data, Processing
Structure, and Visualization

June 2026

Xin Zhao
Pralit L. Patel
James A. Edmonds
Stephanie T. Morris
Allen A. Fawcett



U.S. DEPARTMENT
of **ENERGY**

Prepared for the U.S. Department of Energy
under Contract DE-AC05-76RL01830

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor Battelle Memorial Institute, nor any of their employees, makes **any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights.** Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof, or Battelle Memorial Institute. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

PACIFIC NORTHWEST NATIONAL LABORATORY
operated by
BATTELLE
for the
UNITED STATES DEPARTMENT OF ENERGY
under Contract DE-AC05-76RL01830

Printed in the United States of America

Available to DOE and DOE contractors from
the Office of Scientific and Technical Information,
P.O. Box 62, Oak Ridge, TN 37831-0062

www.osti.gov
ph: (865) 576-8401
fox: (865) 576-5728
email: reports@osti.gov

Available to the public from the National Technical Information Service
5301 Shawnee Rd., Alexandria, VA 22312
ph: (800) 553-NTIS (6847)
or (703) 605-6000
email: info@ntis.gov
Online ordering: <http://www.ntis.gov>

Core Model Proposal #410:

Updates to Socioeconomic and Macroeconomic Data, Processing
Structure, and Visualization

June 2026

Xin Zhao
Pralit L. Patel
James A. Edmonds
Stephanie T. Morris
Allen A. Fawcett

Prepared for
the U.S. Department of Energy
under Contract DE-AC05-76RL01830

Pacific Northwest National Laboratory
Richland, Washington 99354

Core Model Proposal #410: Updates to Socioeconomic and Macroeconomic Data, Processing Structure, and Visualization

Product: Global Change Analysis Model (GCAM)

Institution: Joint Global Change Research Institute (JGCRI)

Authors: Xin Zhao, Pralit Patel, Jae Edmonds, Stephanie Morris, & Allen Fawcett

Reviewers: Kate Calvin, Christoph Bertram, & Maridee Weber

Date committed: 9/29/2025

IR document number: PNNL-38412

Related sectors: Economy

Type of development: Data

Purpose: This Core Model Proposal (CMP) comprehensively restructures and updates the macroeconomic and socioeconomic modules in gcamdata. It includes visualizations of key data inputs, accounting identities, and data flows in the context of GCAM-Macro-KLEM. Major improvements include: (1) updating the Penn World Table (PWT) to version 10 and incorporating a new source, the Global Macro Database (GMD); (2) updating the SSP socioeconomics database from version 3.0.1 to 3.2; (3) introducing SSP-specific differentiation of employment and labor force data; (4) improving data integration between national accounts (from PWT, GMD, and GTAP) and GDP/population data from external sources; and (5) general data cleaning and structural refinements. We document the data sources and key assumptions used throughout the processing. These updates establish the foundation for the forthcoming KLEAM version of GCAM-macro.

Contents

1.	Introduction	1
2.	Overview of key changes in <i>gcamdata</i>	1
	Table 1 Key data and code changes made in <i>gcamdata</i>	3
	Table 2 Updated data flows in the socioeconomics modules in <i>gcamdata</i>	4
	Fig. 1 Schematic of updated data flows in socioeconomics modules in <i>gcamdata</i>	5
3.	GCAM-Macro (KLEM) accounting identities, data inputs, and visualization.....	1
	Fig. 2 GCAM-Macro-KLEM input-output framework and accounting identities.....	2
	Table 3 GCAM input data in socioeconomics modules (XMLs).	3
	Fig. 3 Reference Population by SSP and GCAM Region, 1975 – 2100.....	4
	Fig. 4 Reference GDP by SSP and GCAM Region, 1975 – 2100	5
	Fig. 5 Reference Employment-to-Population Ratio by SSP and GCAM Region, 1975 – 2100.....	6
	Fig. 6 Calibrated TFP in the Materials Sector by GCAM Region for the CORE GCAM scenario, 1975 – 2100.....	7
	Fig. 7 MER-to-PPP conversion factors in the base year (2021).	8
	Fig. 8 Historical Capital Stock in the Material Sector by GCAM region, 1971 – 2021	9
	Fig. 9 Historical Economy-Wide Depreciation Rates, 1971 – 2021.....	10
	Fig. 10 Historical Labor Compensation by GCAM Region, 1971 – 2021.....	11
	Fig. 11 Historical Capital Compensation by GCAM Region, 1971 – 2021.....	12
	Fig. 12 Historical Investment in the Energy Sectors by GCAM Region, 1971 – 2021	13
	Fig. 13 Historical Saving Rates by GCAM Region, 1971 – 2021.	14
	Fig. 14 Historical Capital Net Exports by GCAM Region, 1971 – 2021	15
	Fig. 15 Income Elasticities by GCAM Sector, Region, and SSP.....	16
4.	GCAM validation runs	17
	Fig. 16 GCAM validation scenarios.....	17
4.1.	Population and employment	18
4.2.	GDP	20
4.3.	Per capita GDP and total factor productivity (TFP)	21
	Fig. 17 World per capital GDP impacts due to RCP2p6 policies (open vs. fixed) across SPA.....	22
4.4.	Other national account variables	24
	Fig. 18 National account variables in Ref, global.....	24
4.5.	Radiative Forcing, Temperature, and Carbon Prices.....	26
4.6.	Emissions.....	28
5.	Summary	32
	References.....	33

1. Introduction

Socioeconomic drivers such as population and GDP play a central role in shaping future global economic and multisectoral dynamics in GCAM. In partial equilibrium models with dynamic trajectories, including GCAM, future changes in population and GDP are typically treated as exogenous and are often based on projections from the Shared Socioeconomic Pathways (SSP) database (<https://data.ece.iiasa.ac.at/ssp>). Since GCAM version 7.0, a macroeconomic module (the KLEM version) has been incorporated into the model, as detailed in Core Model Proposal (CMP)-332 (Patel et al., 2023). Specifically, a “Materials” sector was introduced to represent the rest of the economy (including household and government activity), enabling GCAM to endogenously calculate GDP. This endogenous GDP, in turn, feeds back into sectoral models through income elasticities.

To maintain consistency with externally specified SSP trajectories in the reference scenario, the total factor productivity (TFP) parameters in the Materials sector’s constant elasticity of substitution (CES) production function are calibrated to reconcile the resulting GDP with the SSP projections. When the model structure or input data are updated, the TFP must be recalibrated. For example, in the recent SSP database update documented in CMP-399 (Zhao et al., 2024), considerable adjustments were required in the recalibrated TFP values.

More recently, GCAM v8.0 and CMP-404 (Patel et al., 2025) updated GCAM’s base year from 2015 to 2021. While the TFP values were recalibrated, the underlying data required for GCAM-Macro were not fully updated; in some cases, they were simply extrapolated (e.g., PWT v9 data extended from 2017 to 2021). In addition, several outstanding bug fixes remained unresolved. These issues underscored the need for a comprehensive review of data flows within the socioeconomic and macroeconomic modules, which had become outdated and poorly organized.

This CMP, building on previous developments (CMPs 332, 399, & 404), presents a comprehensive restructuring and update of data processing within the macroeconomic and socioeconomic components of *gcamdata*, implemented in a traceable and transparent manner. We take this opportunity to visualize key data inputs into GCAM-Macro and to more clearly document the datasets, assumptions, and accounting identities underpinning the KLEM framework. These improvements aim to enhance user understanding of GCAM-Macro and its outputs, thereby facilitating broader adoption and application. They also lay the foundation for the forthcoming KLEAM version of GCAM-Macro.

2. Overview of key changes in *gcamdata*

The key data and code changes implemented in GCAM and *gcamdata* are summarized in **Table 1**. Previously, the socioeconomic modules and their associated data processing were not well organized or consistently maintained. In this CMP, we have fully restructured the socioeconomic modules to improve the traceability and transparency of data flows. The revised data processing flows are summarized in **Table 2**. In total, 19 socioeconomic modules were revised, including 3 XML-exporting modules (further

highlighted in **Table 3**). A schematic of the main data flows across these modules, along with key processing notes, is provided in **Figure 1**.

Key updates include:

- **SSP Database Updated to v3.2 from v3.0.1:** Incorporates previously omitted regions and corrects known bugs not addressed in BYU 2021.
- **Transition from PWT v9 to v10** (Feenstra et al., 2015): Moves from data ending in 2017 to 2019; significant structural changes required a comprehensive reassessment of data usage.
- **Integration of the Global Macro Database (GMD)** (Müller et al., 2025): Added for nominal GDP decomposition and exchange rates. Complements FAOSTAT, which remains the main GDP source for consistency. Note that the main GDP from FAOSTAT was also converted to 2021 USD using regional GDP deflators now (not USA deflators)
- **Modular Reorganization of Data Processing:** New dedicated modules introduced for SSP data, GTAP, national accounts, and population to improve structure and maintainability.
- **Improved Data Integration:** Enhanced consistency and traceability between national accounts (PWT, GMD, GTAP) and external GDP/population data (FAOSTAT, SSP).
- **Introduction of SSP-Specific Labor/Employment Data:** Employment and labor force data are now differentiated by SSP, improving consistency with future socioeconomic assumptions. Additionally, the definition of the working-age population is improved in the mapping file.
- **Refined Savings-Income Relationship:** Simplified construction of savings behavior; cleaned up processing by relying on historical saving rates and parameter inputs. Future exploration is needed to improve these parameters.
- **Consistent Population Handling:** Population is now processed similarly to GDP, with a unified dataset (*L101.Pop_thous_Scen_R_Y*) covering both historical and future years (like *L102.gdp_mil90usd_Scen_R_Y*).
- **Legacy Data/Processing Removed:** Obsolete GCAM3 GDP and population inputs are fully eliminated.
- **New Income Elasticity Module:** *module_socio_IncomeElasticity_xml* consolidates income elasticity assumptions, primarily for industrial sectors. Documentation and expansion to other sectors are ongoing.

Table 1 Key data and code changes made in gcamdata

Data file/R chunk	Changes made
socioeconomics	Remove GCAM3 related files. And remove unused elasticity files.
socioeconomics/GTAP	Include a sectoral mapping (GCAM_GTAP_sector_mapping_AgLU.csv) along with some naming updates.
socioeconomics/NationalAccounts	Include the new Global Macro Database dataset (GMD_2025_03.csv). Update related mapping files
socioeconomics/PWT	Remove PWT folder and move PWT v10 to the NationalAccounts folder.
socioeconomics/SSP	Update SSP database from v3.0.1 to v3.2. Improve work age population and labor force mapping.
ModelInterface_headers.txt generate_package_data.R	Header updates: the labor force share has been moved out of the NationalAccount header to enable SSP-specific differentiation.
constants.R	Update socioeconomics related constants. E.g., socioeconomics.SSP_DB_BASEYEAR <- 2025 (updated from 2020)
zaglu_L100.GTAP_downscale_ctry.R	Move GTAP related data processing to socioeconomic modules. This module can be removed later (when the old land rental profit calculation is dropped)
zenergy_L143.HDDCDD.R zenergy_L144.building_det_flsp.R zenergy_L223.electricity.R zenergy_L232.other_industry.R zenergy_L2321.cement.R zwater_L173.EFW_manufacturing.R	Remove “GCAM3” related dependencies and update the data use accordingly.
zenergy_L232.other_industry.R zenergy_L2321.cement.R	Improve income elasticity data flows.
zsocio_L100.GTAP.R zsocio_L100.SSP_database.R zsocio_L100.NationalAccounts.R	New modules to process source data
zsocio_L100.Population_hist.R	Renamed from zsocio_L100.Population_downscale_ctry
zsocio_L101.Population.R zsocio_L102.GDP.R	Improved structure and processing to stitch historical and future data.
zsocio_L201.Pop_GDP_scenarios.R zsocio_L281.macro_account_tracking.R	Improve data flows.
zsocio_L103.NationalAccounts.R zsocio_L203.NationalAccounts.R	Restructured based on zsocio_L180.GDP_macro.R and zsocio_L280.GDP_macro.R which were removed.
zsocio_xml_socioeconomics_IncomeElasticity.R zsocio_xml_socioeconomics_macro.R zsocio_xml_socioeconomics_SSP.R	Updated macro XML generating modules. Labor force shares are added to SSP scenarios now.
zsocio_xml_socioeconomics_IncomeElasticity.R configuration_ref.xml (all relevant configs)	A new module has been added to consolidate all income elasticity inputs into a single set of XML files (e.g., socioeconomics_incelas_SSP1.xml). The corresponding configuration files have also been updated accordingly.
zenergy_xml_aluminum_SSP.R zenergy_xml_cement_SSP.R zenergy_xml_chemical_SSP.R zenergy_xml_iron_steel_SSP.R zenergy_xml_Off_road_SSP.R zenergy_xml_other_industry_SSP.R zenergy_xml_paper_SSP.R zsocio_xml_bld_agg.R zsocio_L242.Bld_Inc_Elas_scenarios.R zsocio_L252.Trn_Inc_Elas_scenarios.R	Modules removed. These modules previously generated income elasticities by SSP—for example, aluminum_incelas_ssp1.xml—have been removed. These functionalities are now consolidated and processed through a new module under the socioeconomics system: zsocio_xml_socioeconomics_IncomeElasticity.R.

Table 2 Updated data flows in the socioeconomics modules in *gcamdata*

ID	Socioeconomics module	Module output
1	module_socio_L100.GDP_hist	L100.gdp_mil90usd_ctry_Yh
2	module_socio_L100.Population_hist	L100.Pop_thous_ctry_Yh
3	module_socio_L100.GTAP	L100.GTAP_capital_stock
4	module_socio_L100.SSP_database	L100.LaborForce_mil_SSP_ctry_Yfut_raw
		L100.Pop_thous_SSP_ctry_Yfut_raw
		L100.GDP_bilusd_SSP_ctry_Yfut_raw
5	module_socio_L100.NationalAccounts	L100.National_Accounts_GDP-Decomp_C_I_X_M_shares_R_Yh
		L100.National_Accounts_Metrics_R_Yh
		L100.National_Accounts_Employment_Share_POP_R_Yh
		L100.National_Accounts_Depreciation_Rate_R_Yh
		L100.National_Accounts_En_capital_inv_share_R_Yh
6	module_socio_L101.Population	L101.Pop_thous_R_Yh
		L100.Pop_thous_SSP_ctry_Yfut
		L101.Pop_thous_SSP_R_Yfut
		L101.Pop_thous_Scen_R_Y
7	module_socio_L102.GDP	L102.gdp_mil90usd_Scen_R_Y
		L102.pcgdp_thous90USD_Scen_R_Y
		L102.pcgdp_thous90USD_ctry_Yh
		L102.PPP_MER_R
8	module_socio_L103.NationalAccounts	L103.National_Accounts_mil90usd_R_Yh
		L103.LaborForceShare_Scen_R_Y
9	module_socio_L201.Pop_GDP_scenarios	L201.GDP_Scen
		L201.Pop_Scen
		L201.TotalFactorProductivity_Scen
		L201.LaborForceShare_Scen
		L201.PPPConvert
10	module_socio_L203.NationalAccounts	L203.NationalAccounts
		L203.SavingsRateParams
		L203.GDP_macro_function
		L203.FactorProductivity
11	module_socio_L281.macro_account_tracking	L281.BasePriceSectorMapping
		L281.GlobalTechAccountOutputUseBasePrice_fd
		L281.TrialValueResource
		L281.TechAccountOutput_entrade
		L281.TechAccountInput_entrade
		L281.TechAccountInput_NG_entrade
		L281.GlobalTechAccountInput_entrade
12	module_socio_L2323.iron_steel_Inc_Elas_scenarios	L2323.IncomeElasticity_iron_steel_Scen
13	module_socio_L2324.Off_road_Inc_Elas_scenarios	L2324.IncomeElasticity_Off_road_Scen
14	module_socio_L2325.chemical_Inc_Elas_scenarios	L2325.IncomeElasticity_chemical_Scen
15	module_socio_L2326.aluminum_Inc_Elas_scenarios	L2326.IncomeElasticity_aluminum_Scen
16	module_socio_L2327.paper_Inc_Elas_scenarios	L2327.IncomeElasticity_paper_Scen
17	module_socioeconomics_macro_xml	socioeconomics_macro.xml
18	module_socio_SSP_xml	socioeconomics_CORE.xml socioeconomics_SSPx.xml
19	module_socio_IncomeElasticity_xml	socioeconomics_incelas_ssp.xml

This visualization illustrates the data flow within the **gcamdata** system for the **GCAM-Macro** (socioeconomic) modules.

This visualization illustrates the data flow within the **gcamdata** system for the **GCAM-Macro** (socioeconomic) modules.

- ### 3. More specific improvements

- a. Separate modules were included in the SSP database, GTAP, and nation accounts (PIWT & GMD) now
b. Population will be processed in a way similar to GDR so **L101.Pop, thou.S, Scen_R_Y** which includes both hist and future is generated in module_socio_L101.Population, like **L102.gdp_mil90usd_Scen_R_Y**
c. GCAM3 related pop and gdp data are completely removed
d. *Scen_R_Y* related *income_elasticity* in *gcam3.us* was deleted and the function is only a parameter and hist and only parameters are stored, saving rates are needed
e. new module (module_socio_IncomeElasticity.xml) to collect the processing of income elasticities, currently mainly for industrial sectors. More documentation and explorations are needed for all sectors.

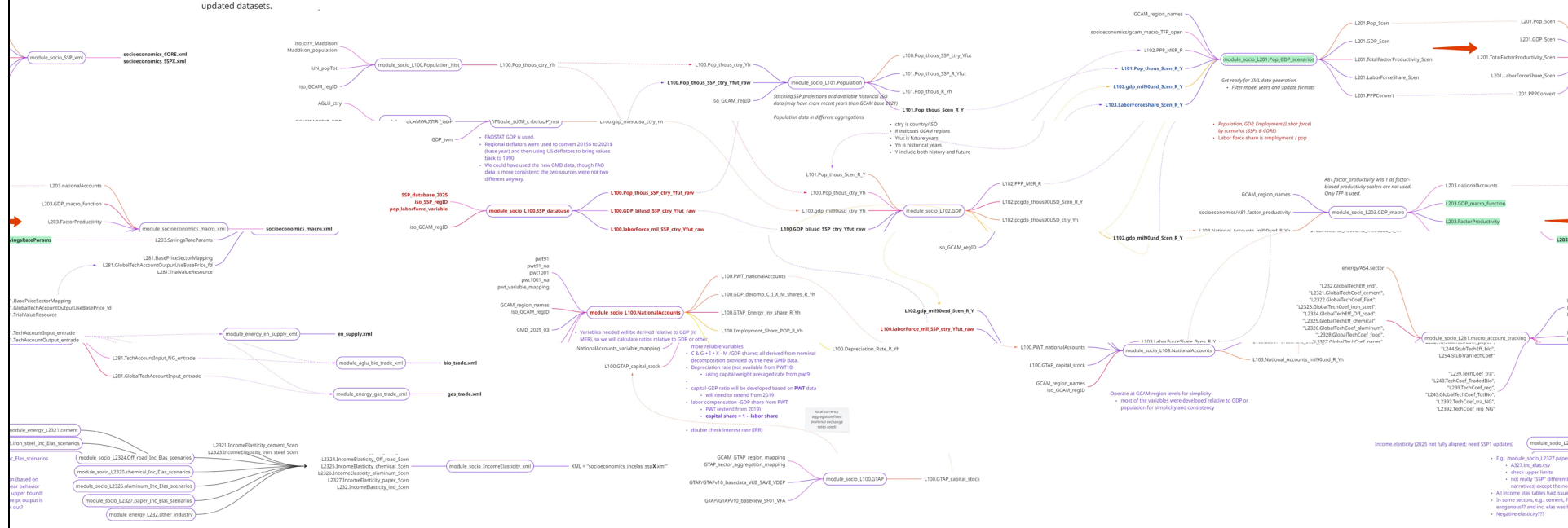


Fig. 1 Schematic of updated data flows in socioeconomics modules in gcamdata (a high-resolution PDF version provided on Confluence)

3. GCAM-Macro (KLEM) accounting identities, data inputs, and visualization

A summary of GCAM-Macro accounting identities in an input-output view is presented in **Fig. 2**, while the detailed structure of GCAM-Macro-KLEM has been documented in CMP-332 (Patel et al., 2023). This CMP enhances the overall data processing and quality for GCAM-Macro, establishing a stronger foundation for the forthcoming KLEAM development (which integrates agriculture into the KLEM framework). However, the calculation of energy capital investment, energy service aggregation, and their linkages to the macro module (as well as parameter uses) will be reviewed and documented in future work as part of the KLEAM integration.

Table 3 provides a more detailed summary of the socioeconomic data—specifically the three XML files—exported from gcamdata and used in GCAM. These represent the primary inputs for constructing the input-output framework of GCAM-Macro, as illustrated in **Fig. 2** (or alternatively, a Social Accounting Matrix). Additional variables are either derived from GCAM sectoral outputs or constructed based on available information. **Figs. 3–15** visualize these input data (see the “Fig/data source” column in **Table 3**). Detailed notes are added to figure captions. GCAM-Macro then extends these historical indicators into future periods using an internally consistent framework.

Note that in the figures, where relevant, Mexico is highlighted in regional panels as a reference, as it lies near the median among the 32 GCAM regions for key metrics such as population and per capita income. To aid region comparison, consistent gray y-axis ranges (based on the underlying data) are also included in regional panels, since axis scales may differ across panels and regions.

	En	Ma	HHD GOV	Trade	Sum
L		labor			labor-reward
K		capital-stock			capital-reward
En				energy-net-export	
Ma			C+G+I	material-net-export	gross-output
Sum		gross-output	C+G+I	NX	

GDP decomposition by income:

GDP = labor-compensation + capital-compensation

GDP decomposition by expenditure:

GDP = C + G + I + NX

- gross-output (Ma supply) = Nested CES production function (L, K, En; TFP; elasticities)
- gross-output (Ma demand) = C + G + I + material-net-export
- GDP = gross-output + energy-net-export

Materials production function

Nested constant elasticity of substitution (En, (L, K))

- En is an energy service index, linked to GCAM energy service inputs in final demand
- En is endogenous, aggregating energy services using initial prices as weights

Clearing capital/investment market

energy-investment + material-investment = savings + capital-net-export

- energy-investment: derived based on GCAM energy sectoral information
- capital-net-export: initially calibrated to -NX but being phased out to zero regionally (trade balance)
- savings = function(lagged savings-rate, per-capita GDP growth rate) x GDP
- material-investment = depreciation-rate x capital stock (beginning) + capital stock increase

Clearing labor market

Labor supply (employment linked to population) = Labor demand (material production input)

- all labor is currently placed in the Materials sector.

Fig. 2 GCAM-Macro-KLEM input-output framework and accounting identities

Table 3 GCAM input data in socioeconomics modules (XMLs). There are three socioeconomics XMLs needed in the configuration of GCAM.

XMLs	Variable/data	Periods	Fig/data source	Notes
socioeconomics_CORE.xml socioeconomics_SSP1.xml ... socioeconomics_SSP5.xml	Demographics: population	1975-2100	Fig. 3; UN & SSP Database	Labor force is indeed "employed". TFP is the only difference between CORE and SSP2 in this XML.
	National Account: GDP	1975-2100	Fig. 4; FAOSTAT & SSP Database	
	National Account: labor-force-share	1975-2100	Fig. 5; UN & SSP Database	
	National Account: total-factor-productivity	2025-2100	Fig. 6; UN & SSP Database	
	gdp-ppp-conversion	2021	Fig. 7; UN & SSP Database	
socioeconomics_macro.xml	National Account: capital-stock	1975-2021	Fig. 8; PWT, FAOSTAT & GTAP	labor-wages (labor compensation/rewards) and capital-value (capital compensation/rewards) are for the Materials sector. Economy-wide depreciation rates are used in the Materials sector.
	National Account: depreciation-rate	1975-2100	Fig. 9; PWT	
	National Account: labor-wages	1975-2021	Fig. 10; PWT & FAOSTAT	
	National Account: capital-value	1975-2021	Fig. 11; PWT, FAOSTAT & GTAP	
	National Account: energy-investment	1975-2021	Fig. 12; GMD, FAOSTAT, GTAP	
	National Account: savings-rate	1975-2021	Fig. 13; GMD & FAOSTAT	
	National Account: capital-net-export	1975-2021	Fig. 14; GMD & FAOSTAT	
	Saving-rate-param			
	gdp-macro-function			
socioeconomics_incelas_ssp1.xml ... socioeconomics_incelas_ssp5.xml	energy-final-demand: income-elasticity	2025-2100	Fig.15; various sectoral assumptions	

Reference Population by SSP and GCAM Region, 1975–2100

- Black lines represent regional values; the blue line highlights Mexico (SSP2)
- Historical population data is sourced from the UN database
- Future population (from 2025 onward) is projected using growth rates from the SSP database
- Population levels in 2025 are aligned across SSPs: 8.2 billion globally
- In GCAM-Macro, population is exogenous and labor force (employment) is linked to population

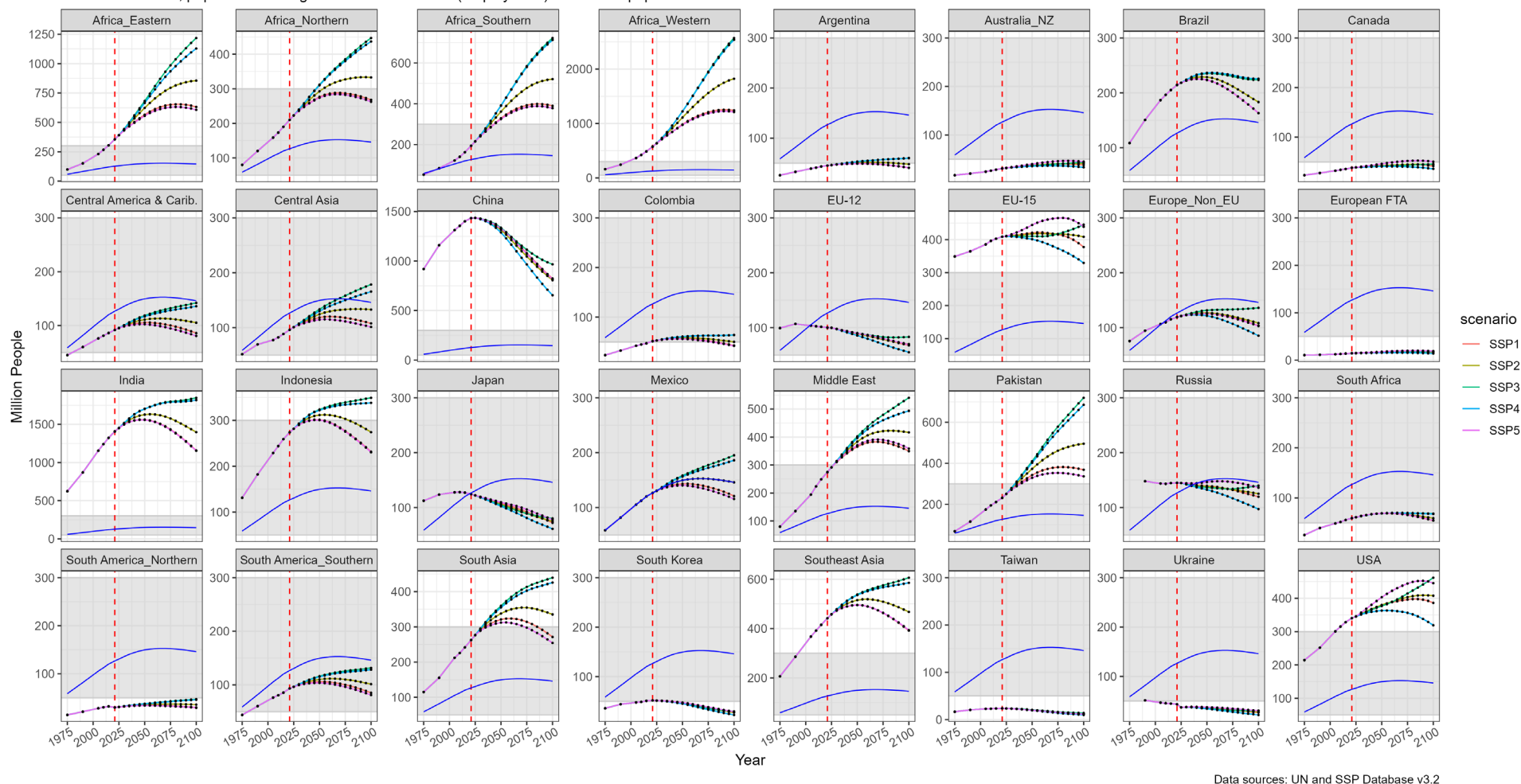
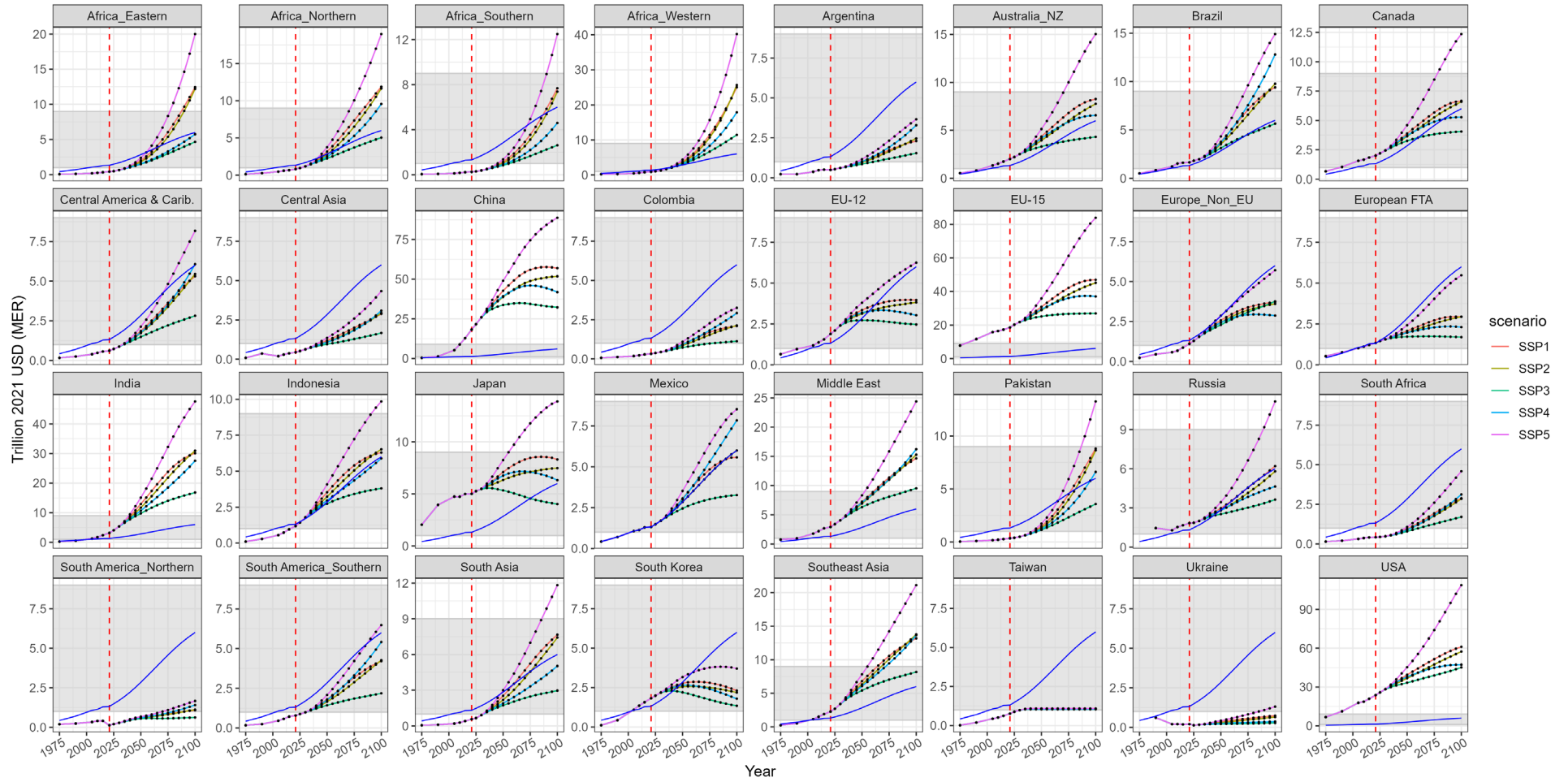


Fig. 3 Reference Population by SSP and GCAM Region, 1975 – 2100

Reference GDP by SSP and GCAM Region, 1975–2100

- Black lines represent regional values; the blue line highlights Mexico (SSP2)
- Historical GDP is sourced from FAOSTAT in MER and converted to 2021 dollars using region-specific deflators
- Future GDP values (from 2025 onward) are projected using growth rates from the SSP database
- GDP levels in 2025 are harmonized across all SSPs
- In GCAM-Macro (open GDP mode), GDP is endogenous, but these reference trajectories were essential for TFP calibration



Data sources: FAOSTAT (gcamfaostat) and SSP Database v3.2

Fig. 4 Reference GDP by SSP and GCAM Region, 1975 – 2100

Reference Employment-to-Population Ratio by SSP and GCAM Region, 1975–2100

- Black lines represent regional values; the blue line highlights Mexico (SSP2)
- Conceptual flow: Population → Working-Age Population → Labor Force (incl. unemployed) → Employed
- Working-age population shares by SSP are sourced from the SSP Database and determine future trends
- Historical employment data is from PWT; the employment-to-working-age-population ratio is extended into the future
- This implies constant labor force participation and employment rates beyond 2021
- In GCAM-Macro, the labor market clears with total labor demand constrained by available employment

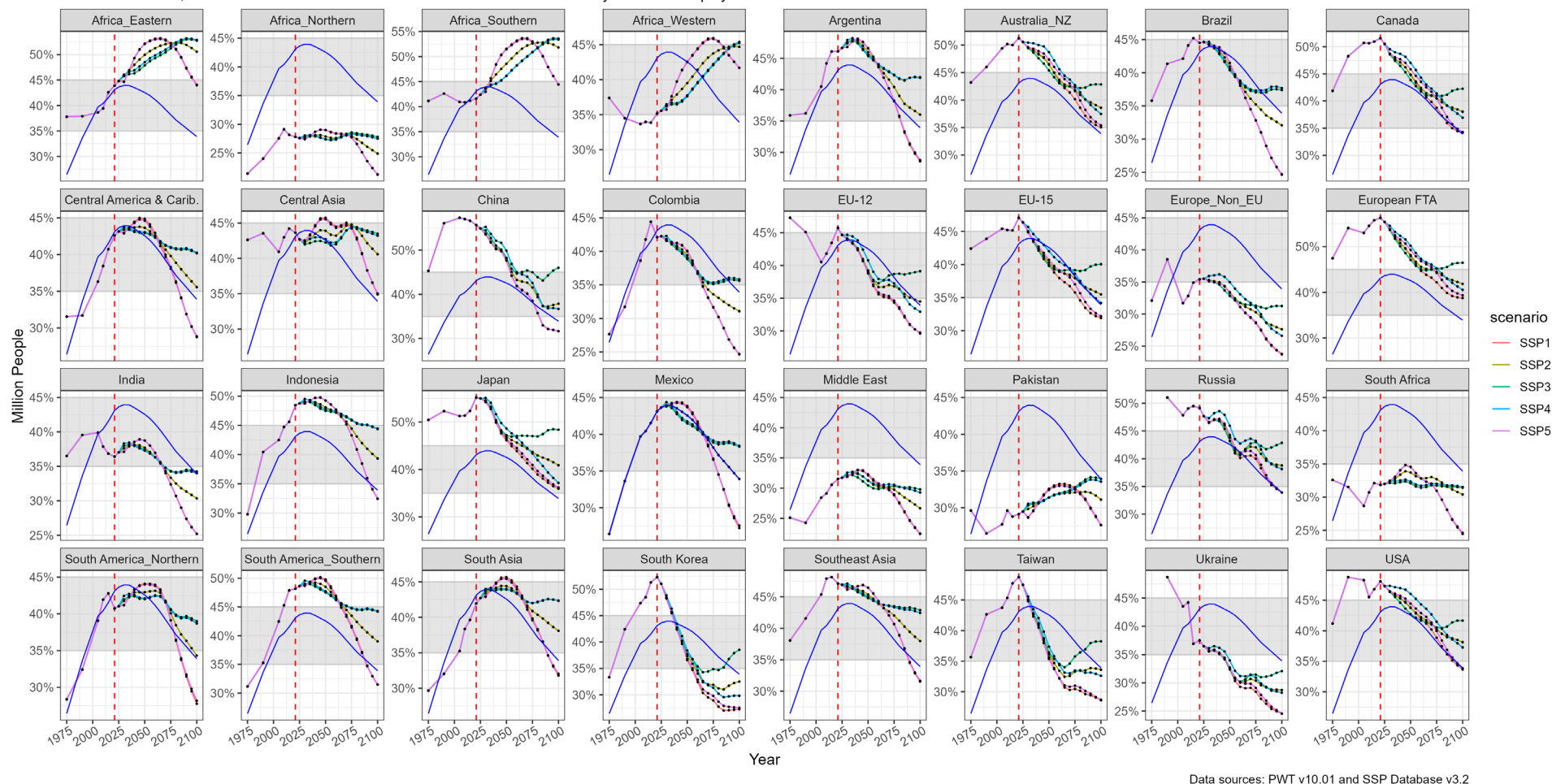
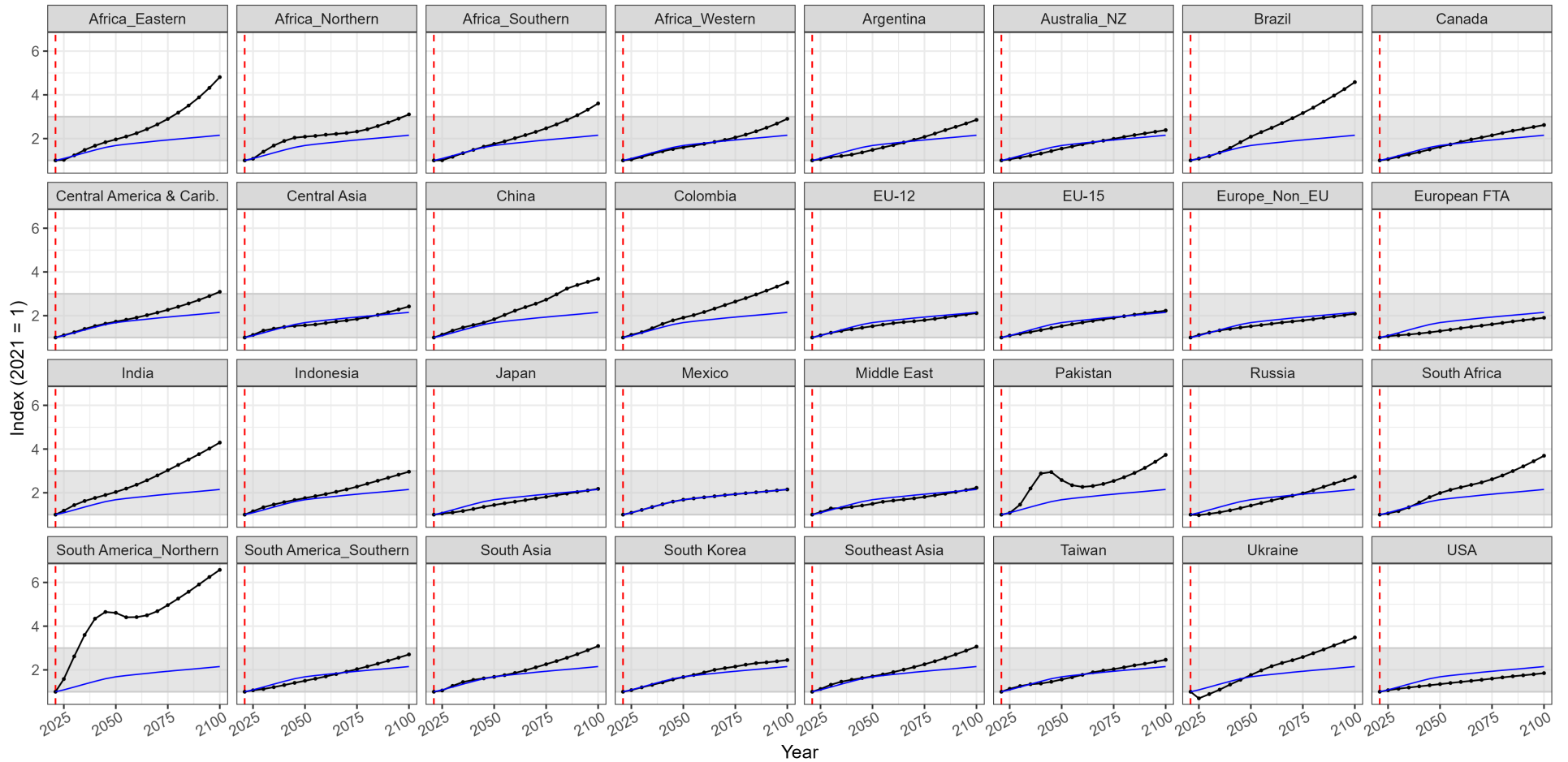


Fig. 5 Reference Employment-to-Population Ratio by SSP and GCAM Region, 1975 – 2100. A few regions currently have a large gender gap in employment, such as Northern Africa, the Middle East, and Pakistan. Future projections do not (yet) account for changes in this gender gap.

Calibrated TFP in the Material Sector by GCAM Region (GCAM Core), 2021–2100

- Based on the GCAM Core SSP2 scenario; these calibrated TFP values enable GCAM-Macro to reproduce SSP2 GDP trajectories
- Black lines represent regional values; the blue line highlights Mexico
- TFP values are applied to the CES production function for the Material sector in GCAM-Macro

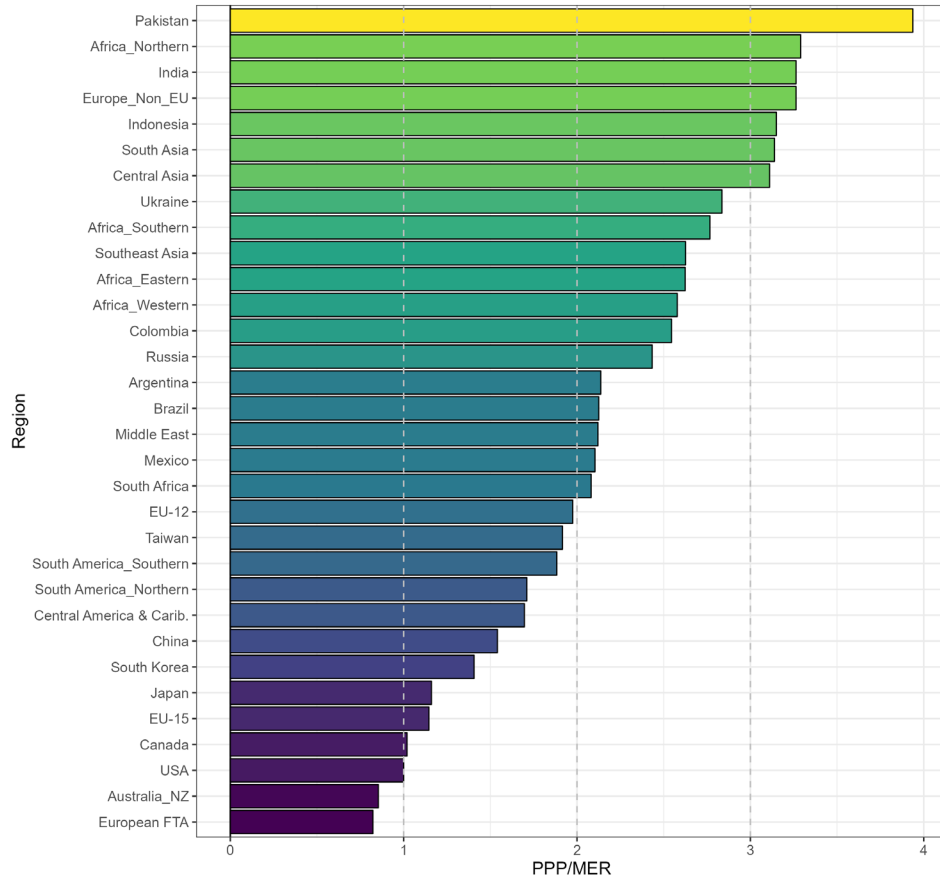


Data source: GCAM v8.3 (CMP-411)

Fig. 6 Calibrated TFP in the Materials Sector by GCAM Region for the CORE GCAM scenario, 1975 – 2100

MER-to-PPP Conversion Factors by GCAM Region in 2021

- MER = Market Exchange Rate (used as the main unit in modeling to maintain balance)
- PPP = Purchasing Power Parity
- Conversion factors were derived using MER GDP (FAOSTAT) and PPP GDP (SSP database)
- The USA is exactly 1; higher values indicate lower relative cost of living
- These values are held constant in future periods
- Currently PPP values are used only in the food demand model and for reporting purposes

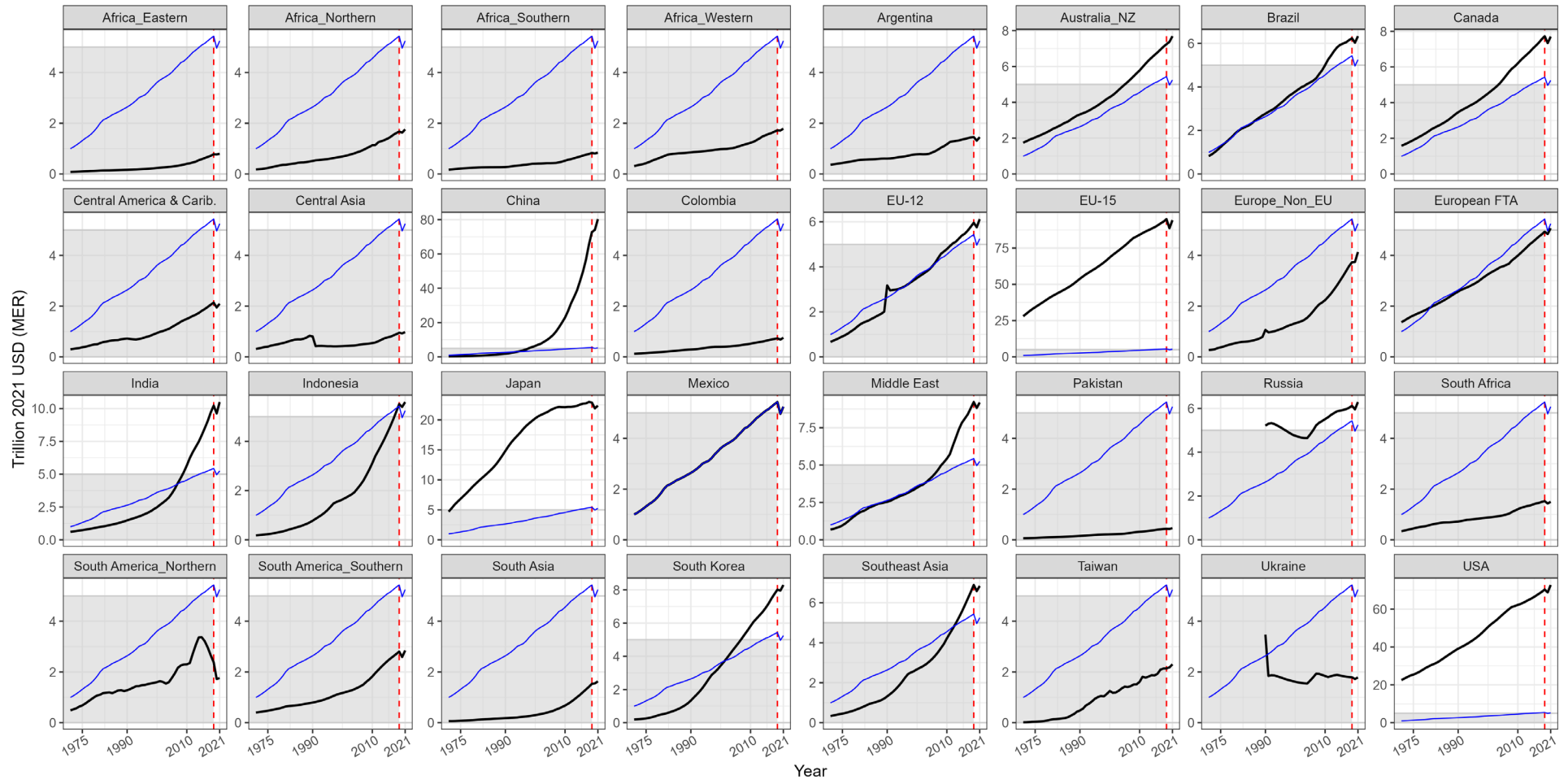


Data sources: FAOSTAT and SSP Database v3.2

Fig. 7 MER-to-PPP conversion factors in the base year (2021). The MER-to-PPP conversion factors are derived from two data sources: MER GDP (from FAOSTAT/UN) and PPP GDP (from the SSP database). After harmonizing dollar years to the GCAM base year (2021), a small discrepancy remains for the USA, where MER and PPP are not exactly equal. This issue also appeared in previous versions (e.g., ~0.95 in the current Master/GCAM 8.3). Note that only GDP growth rates from the SSP database are used to extend historical observations, so it has not been necessary to reconcile the SSP database exactly with historical observations. However, we expect the PPP-to-MER conversion factor to be 1 for the USA. The value was ~0.98 with the updates in this CMP and we rescaled regional values to ensure USA is 1.

Historical Capital Stock in the Material Sector by GCAM Region, 1971–2021

- Black lines represent regional values; blue line highlights Mexico
- Estimated world total: \$382 trillion in 2021 (based on market exchange rates, MER); median: ~\$5 trillion
- Step 1: Derived capital-to-GDP ratios using PWT data in national prices (rma / rgdpna), available through 2019 (red dotted) and extended to 2021
- Step 2: Applied capital-to-GDP ratios to FAOSTAT GDP data in MER
- Step 3: Partitioned total capital stock using sectoral shares from GTAP v10 (2014) for the Material sector
- The derived capital stock values are more comparable to GTAP estimates, as both are expressed in MER
- In GCAM-Macro, capital enters the Material production function directly and investment is derived based on depreciation

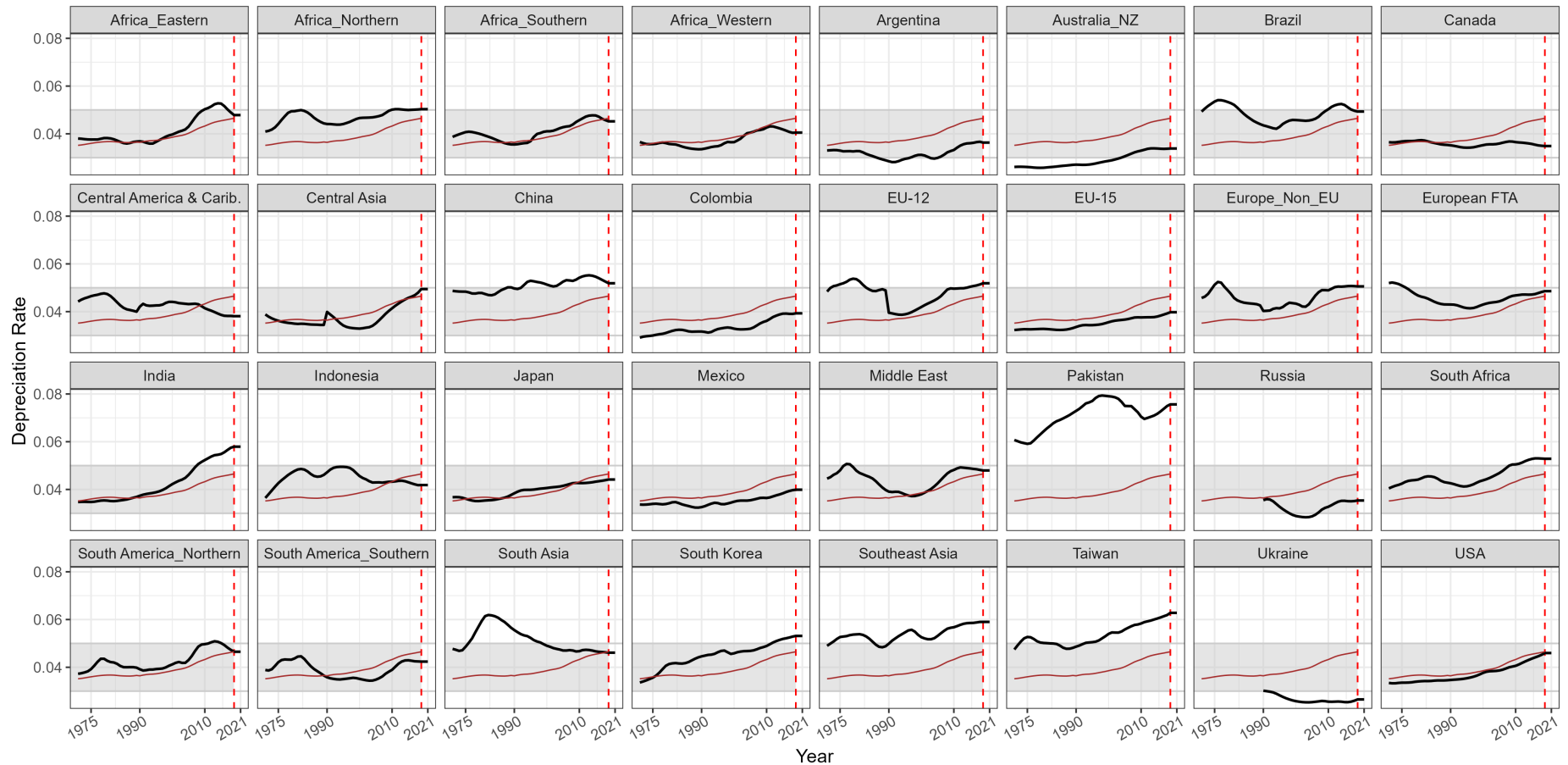


Data sources: PWT v10.01, FAOSTAT, & GTAP
Note: capital stock includes capital used in production activities (consumer durables are not included)

Fig. 8 Historical Capital Stock in the Material Sector by GCAM region, 1971 – 2021

Historical Economy-Wide Depreciation Rates by GCAM Region, 1971–2021

- Aggregated to 32 GCAM regions using capital stock as weights: black (regional) vs. dark red (world) lines
- Data available through 2019 (red dotted), with values extended to 2021
- Economy-wide rates applied to the Material sector (with constant future values)

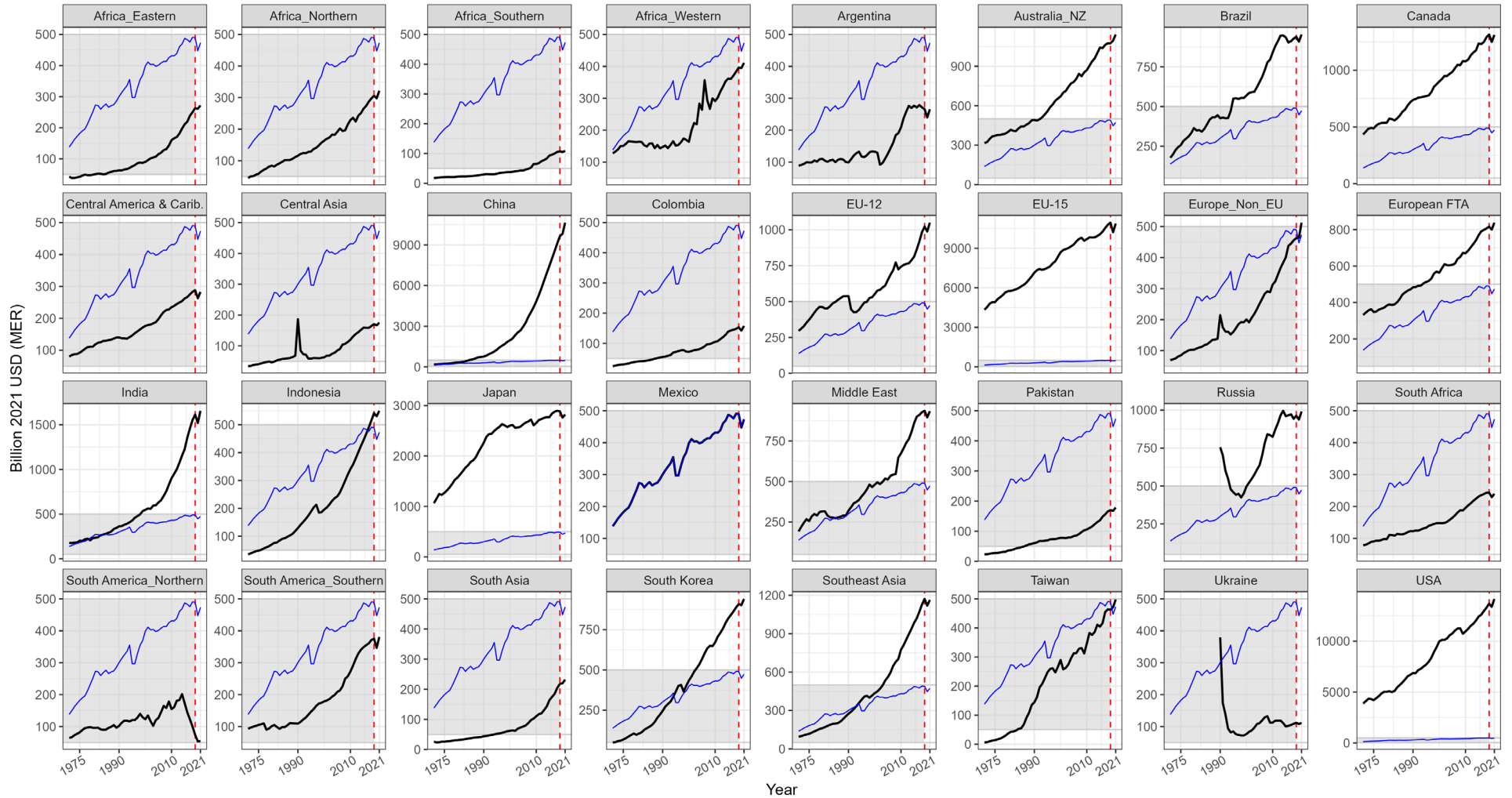


Data source: depreciation rate (delta) and capital stock (rma) from PWT v10.01; annual data in 1971 - 2019

Fig. 9 Historical Economy-Wide Depreciation Rates, 1971 – 2021. Depreciation rates represent the average decline of capital stock (e.g., due to wear and tear). Country-level estimates from PWT were aggregated to GCAM regions using capital-stock-weighted averages. In GCAM’s energy and material production modeling, depreciation of capital in detailed energy sectors is not explicitly tracked, as the focus is on new investment (cleared with savings). However, for the Material sector, deriving new investment requires knowledge of capital stock differences across periods and the associated depreciation. This is the context in which the GCAM regional depreciation rates shown here are applied.

Historical Labor Compensation by GCAM Region, 1971–2021

- Black lines represent regional values; blue line highlights Mexico
- Estimated world total: \$54.7 trillion (based on market exchange rates, MER); median: ~\$0.5 trillion
- Step 1: Get labor compensation shares relative to GDP (labsh) from PWT data, available through 2019 (red dotted) and extended to 2021
- Step 2: Applied labor compensation shares to FAOSTAT GDP data in MER
- In GCAM-Macro, physical labor (employment) enters the Material production function directly and wage rate can be calculated (labor compensation / employment)

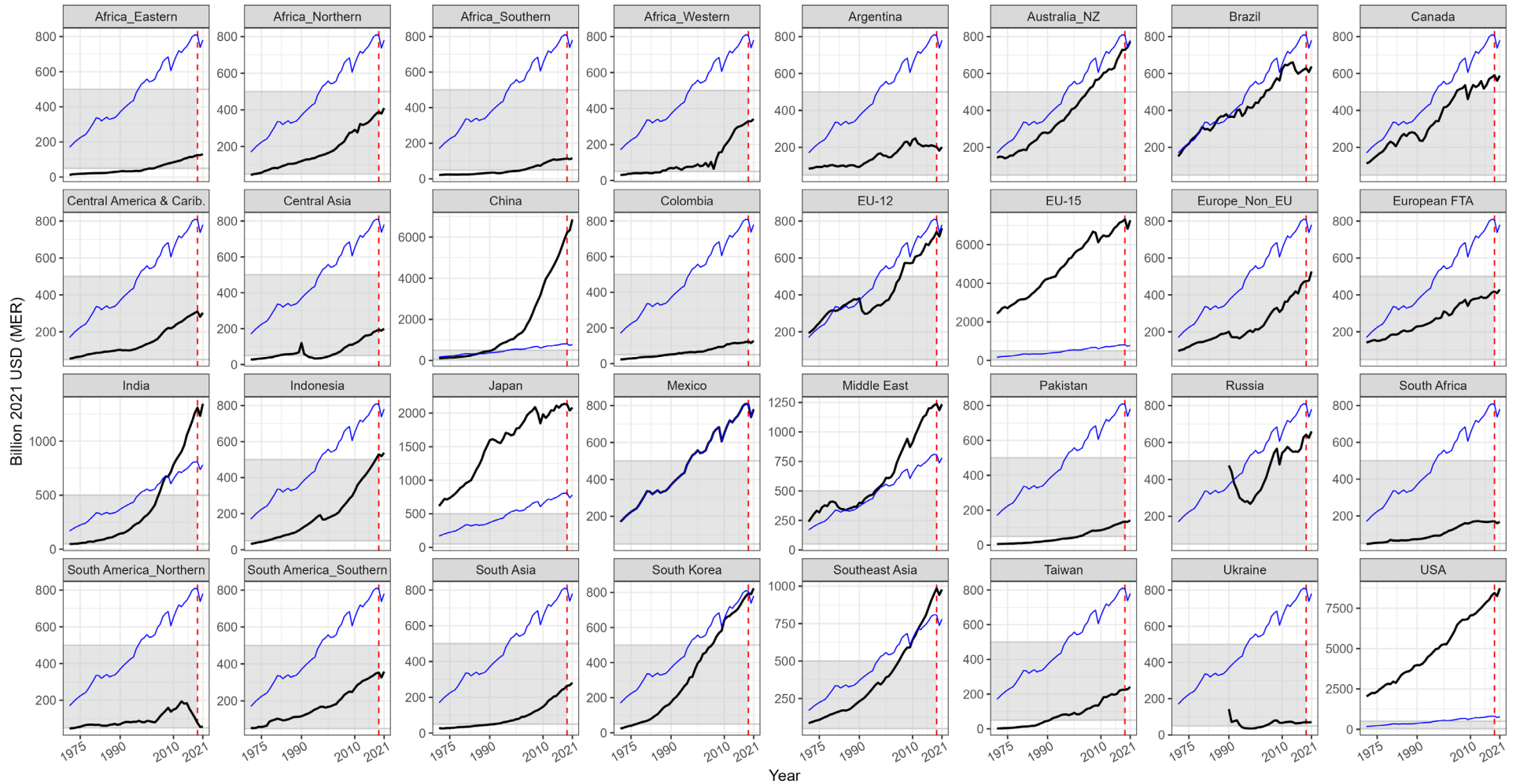


Data sources: PWT v10.01 & FAOSTAT

Fig. 10 Historical Labor Compensation by GCAM Region, 1971 – 2021

Historical Capital Compensation in the Material Sector by GCAM Region, 1971–2021

- Black lines represent regional values; blue line highlights Mexico
- Estimated global total: \$38.2 trillion (based on market exchange rates, MER); median regional value: ~\$0.5 trillion
- Step 1: Retrieved capital compensation shares relative to GDP as $(1 - \text{labsh})$ from PWT, available through 2019 (red dotted) and extended to 2021
- Step 2: Applied capital compensation shares to FAOSTAT GDP data in MER
- Step 3: Partitioned total capital compensation using sectoral shares from GTAP v10 (2014) for the Material sector
- In GCAM-Macro, capital stock enters directly into the Material sector production function; the capital rate of return (gross) is calculated as capital compensation divided by capital stock

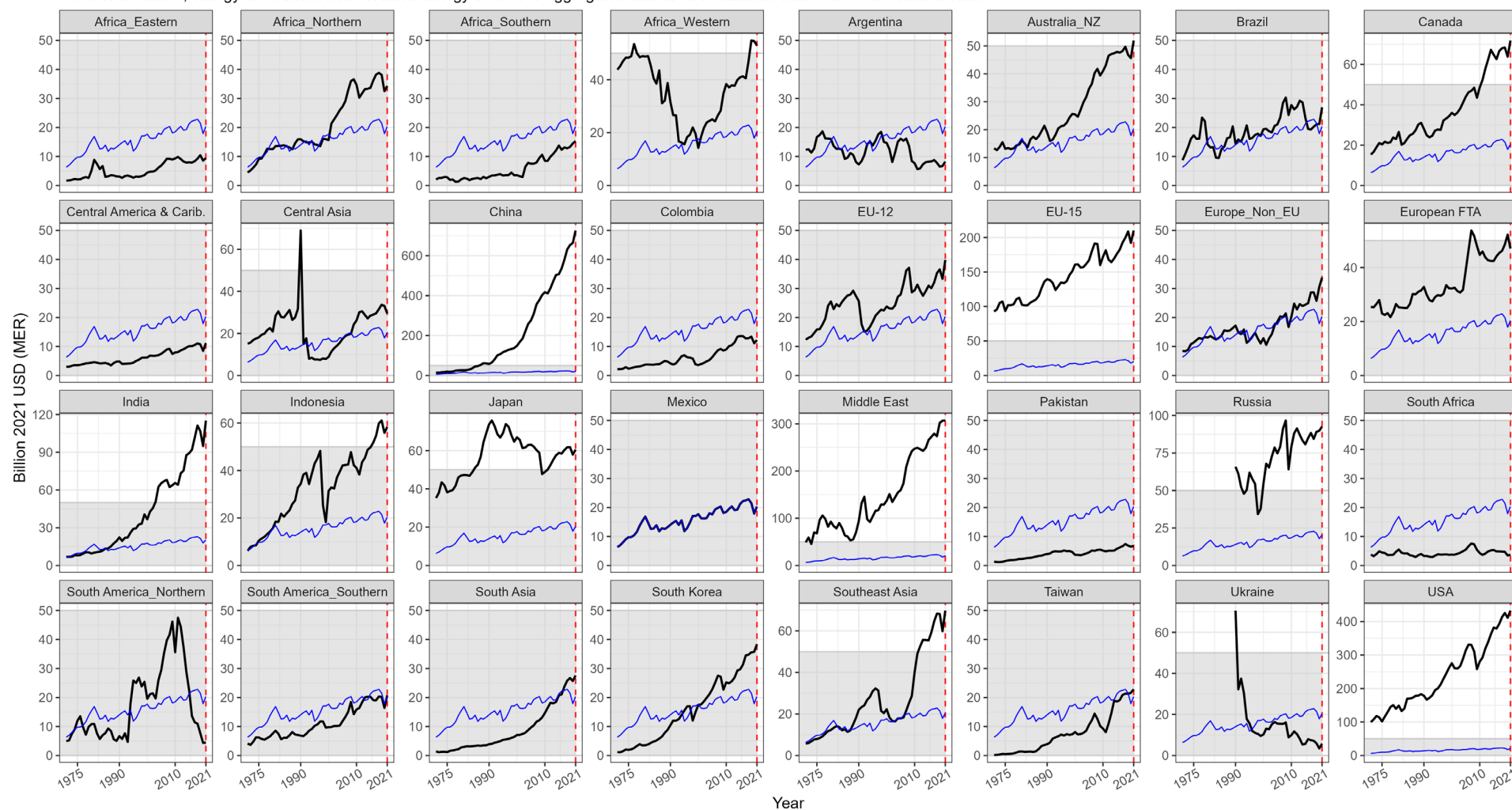


Data sources: PWT v10.01, FAOSTAT, & GTAP v10

Fig. 11 Historical Capital Compensation by GCAM Region, 1971 – 2021

Historical Investment in the Energy Sector by GCAM Region, 1971–2021

- Black lines represent regional values; the blue line highlights Mexico
- Step 1: Derived investment-to-GDP ratios (alongside other GDP decomposition elements) using GMD data, available through 2023
- Step 2: Applied these ratios to FAOSTAT GDP data (in MER) to estimate total investment
- Step 3: Allocated total investment to the Energy sector using sectoral shares from GTAP v10 (2014)
- In GCAM-Macro, energy investment from detailed energy sectors is aggregated and used to calibrate macro-level investment values

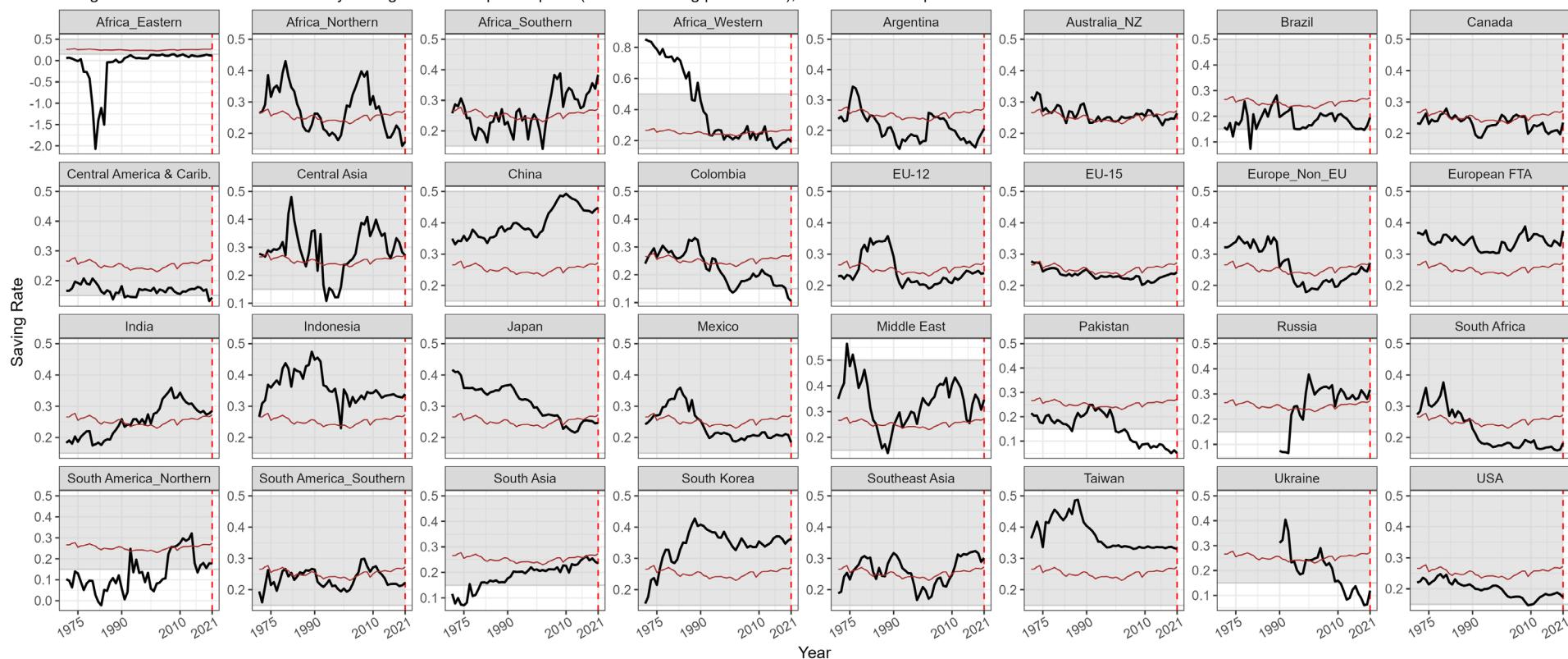


Data sources: GMD 2025, FAOSTAT, and GTAP v10

Fig. 12 Historical Investment in the Energy Sectors by GCAM Region, 1971 – 2021

Historical Saving Rates by GCAM Region, 1971–2021

- Saving rate = (Investment – Capital Net Export) / GDP
- Aggregated to 32 GCAM regions using GDP as weights: black (regional) vs. dark red (world) lines
- Future regional saving rates are modeled as a function of lagged saving (coefficient = 0.892), with adjustment based on per capita income growth (coefficient = 0.144)
- Regional investment is constrained by savings and net capital exports (which are being phased out), with a cleared capital market

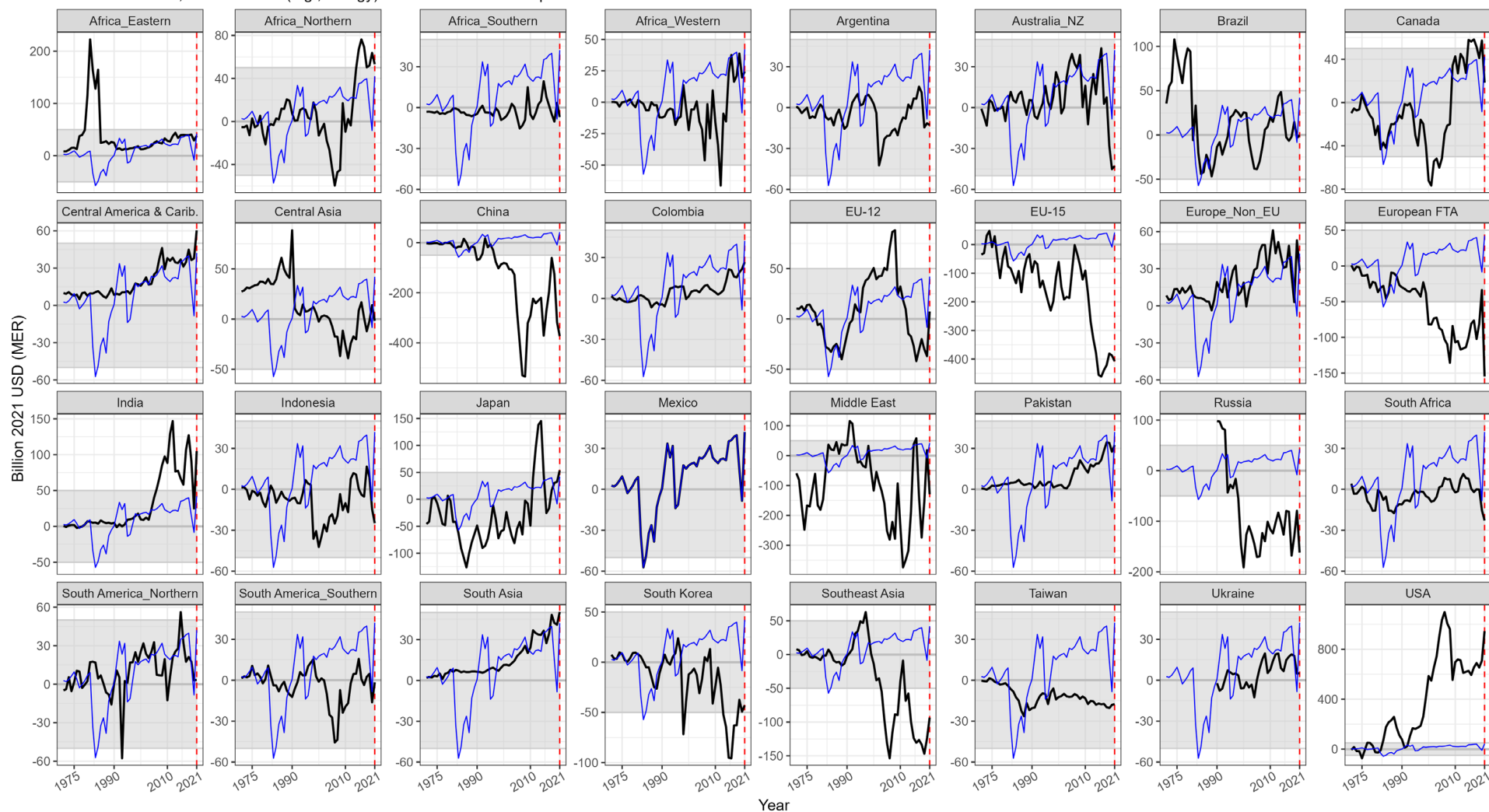


Data sources: GMD (investment and trade shares) and FAOSTAT (GDP)

Fig. 13 Historical Saving Rates by GCAM Region, 1971 – 2021. Saving rates are defined as $(\text{GDP} - \text{consumption}) / \text{GDP}$, which is equivalent to $(\text{investment} + \text{net exports}) / \text{GDP}$, where net exports are treated as negative capital net exports in our processing. Thus, Country-level saving rates were aggregated to GCAM regions using GDP as weights. For future projections, saving rate parameters follow the approach in previously GCAM version (v7 -v8.3), where a pooled regression model was estimated with panel data (GCAM regions $\times$ PWT data in 5-year steps). The parameters indicate lower saving rates with higher income growth. Those estimated parameters are used directly here for simplicity and consistency, though they carry uncertainty due to model specification and data coverage; future work may refine them with region-specific estimates.

Historical Capital Net Exports by GCAM Region, 1971–2021

- Black lines represent regional values; blue line highlights Mexico
- Capital net export = – net export; the global net total is zero by construction each year
- Trade values and ratios relative to GDP are sourced from the Global Macro Database (GMD); ratios are applied to FAOSTAT GDP to ensure consistency
- In GCAM-Macro, sectoral trade (e.g., energy) is tracked and used to partition total trade flows in the model

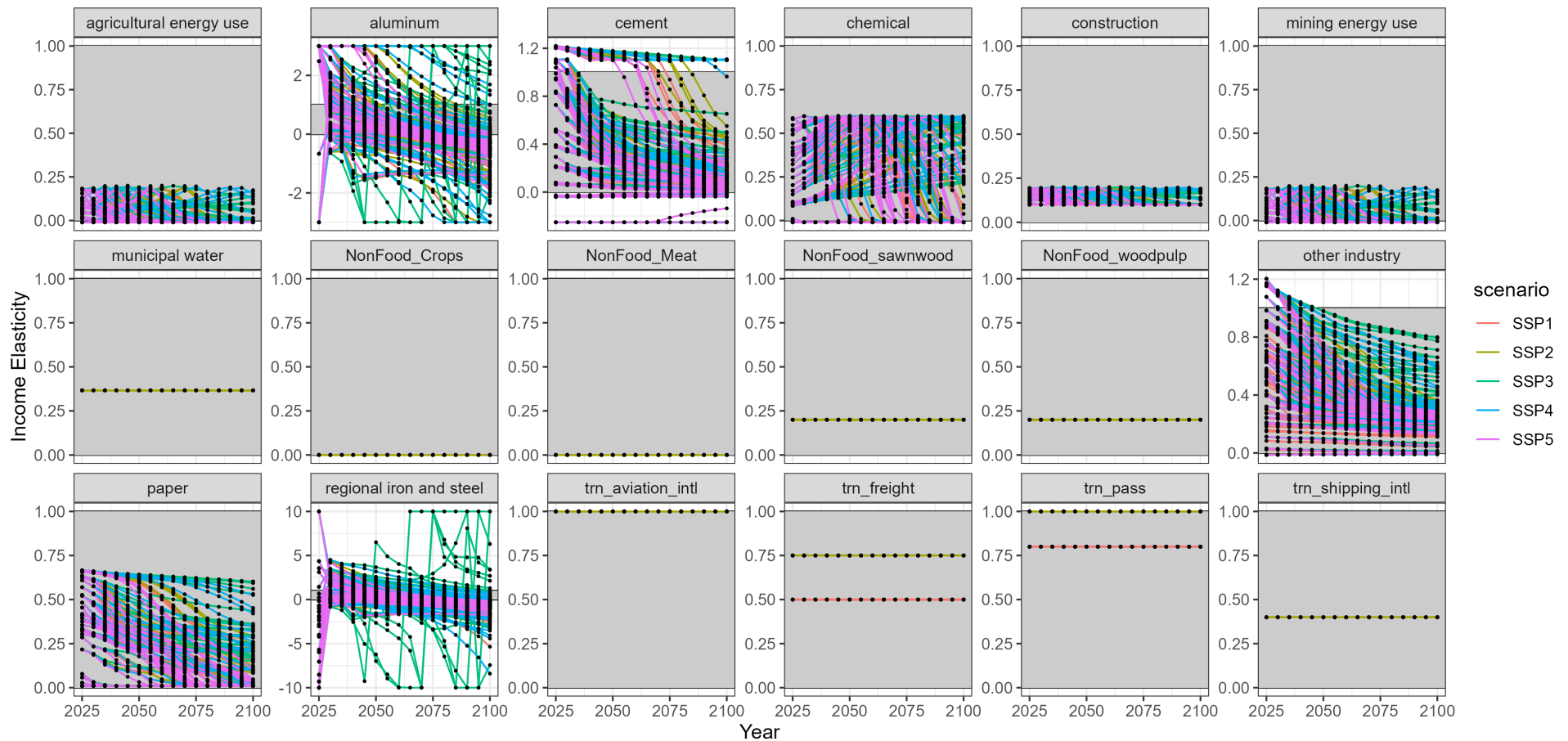


Data sources: GMD 2025, FAOSTAT

Fig. 14 Historical Capital Net Exports by GCAM Region, 1971 – 2021

Income Elasticities by Sector, GCAM Region, and SSP

- Income elasticity values for most sectors are now compiled in the `module\_socio\_IncomeElasticity\_xml` module
- A dedicated food demand model governs the response of food consumption to income changes
- Parameters for the building sector (and potentially other end-use sectors) are currently not included
- Constant elasticity values are applied to non-food agriculture, municipal water, and transport sectors; other sectors follow sector-specific assumptions
- In some cases (e.g., Iron & Steel), income elasticities were adjusted to better capture regional trends
- Further documentation and sensitivity analysis of elasticity parameters are needed
- Note: Although income levels were aligned across SSPs for 2025, some sectors still have differing parameters under SSP1 (will be fixed in KLEAM!)



Data sources: CMP-374 (Iron & Steel) and external assumptions

Fig. 15 Income Elasticities by GCAM Sector, Region, and SSP

4. GCAM validation runs

In accordance with the GCAM CMP convention, we present GCAM projection results, comparing the Updated branch with a recent Master branch (GCAM v8.3) for reference, RCP 2.6-fixed and RCP 2.6-open scenarios across shared socioeconomic pathways (GCAM core & SSP1-5 assumptions; excluding SSP2/3/4-RCP2p6). There are 24 SPA (shared policy assumption) and macroeconomic (fixed vs. open) scenarios in total (**Fig. 16**), as RCP 2.6 was not solved in SSP2-SSP4. The current master corresponds to GCAM v8.3. CI352 and CI365 are the pull request folders storing the validation runs.

		Core	SSP1	SSP2	SSP3	SSP4	SSP5
Master GCAM_v8.3 CI352	Ref.						
	2p6_fixedGDP						
	2p6_openGDP						
Updated CI365	Ref.						
	2p6_fixedGDP						
	2p6_openGDP						

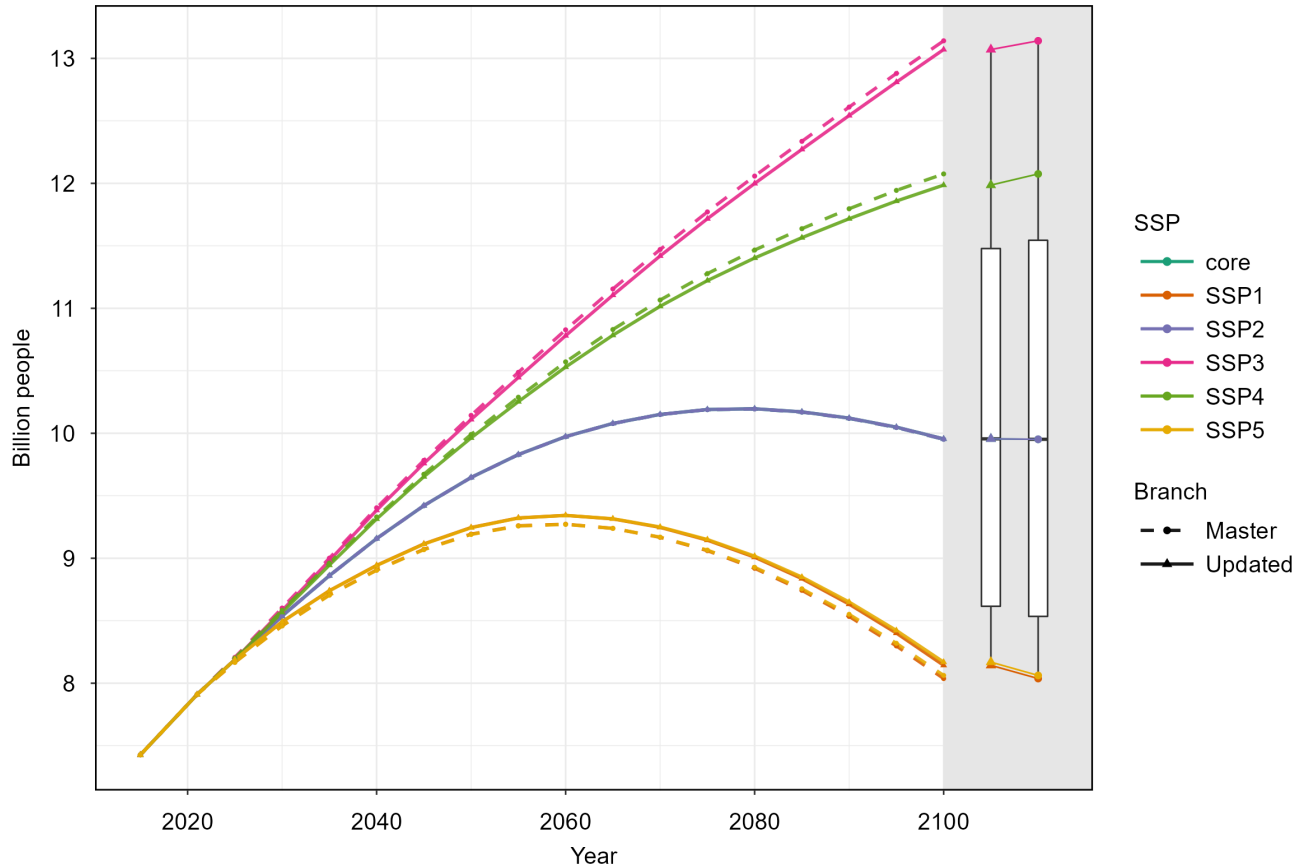
Fig. 16 GCAM validation scenarios

We update the key validation figures (in line with CMP-399), now highlighting revised results for national account variables—only key indicators are indexed here. Detailed sectoral results for energy, agriculture, and land use are not included in this document, as their impacts were relatively minor; they are available on internal Confluence pages. The figures are designed to be self-explanatory, with explanatory notes included in the captions where applicable.

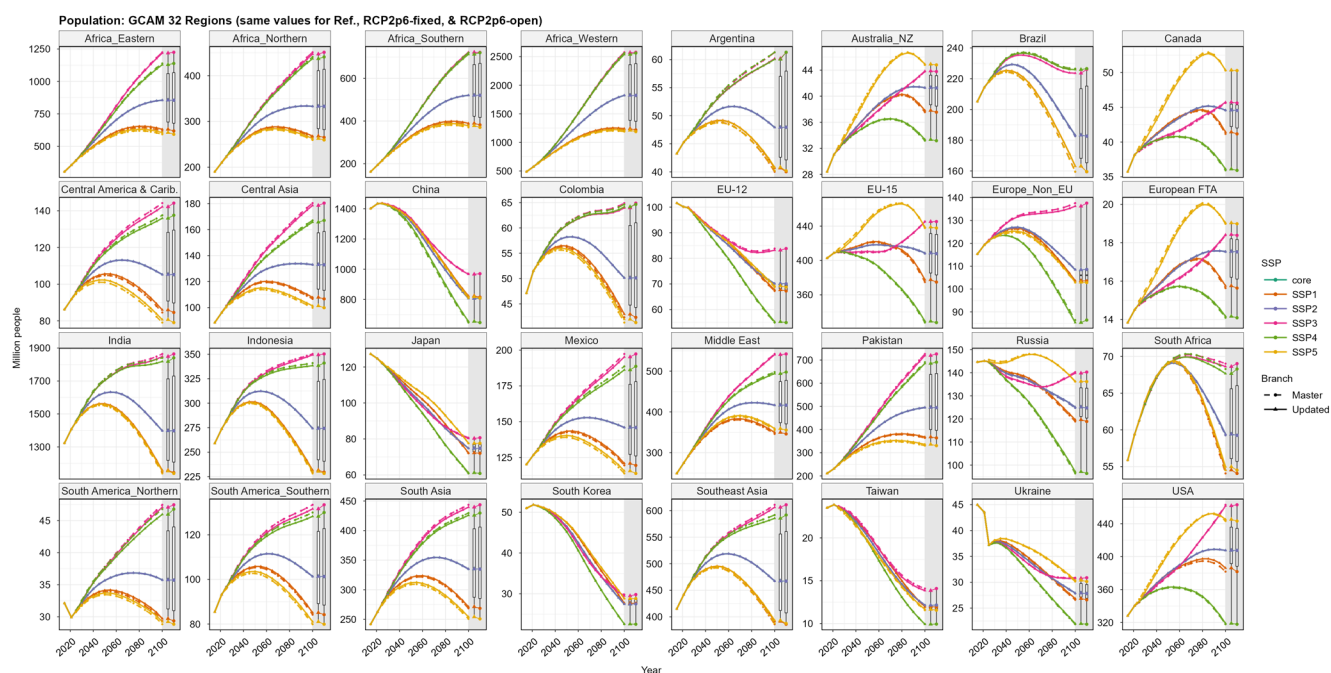
4.1. Population and employment

World Population (Identical for Reference, RCP2.6-Fixed, and RCP2.6-Open Scenarios)

1. Master vs. Updated (CMP-410): 2025 is now fully aligned in the Updated version; core = SSP2
2. World Population in Updated: 8.19 billion in 2025; ranges from 8.14 (SSP1) to 13.1 billion (SSP3) in 2100
3. Reference and both RCP2.6 scenarios (open/fixed) use identical population projections



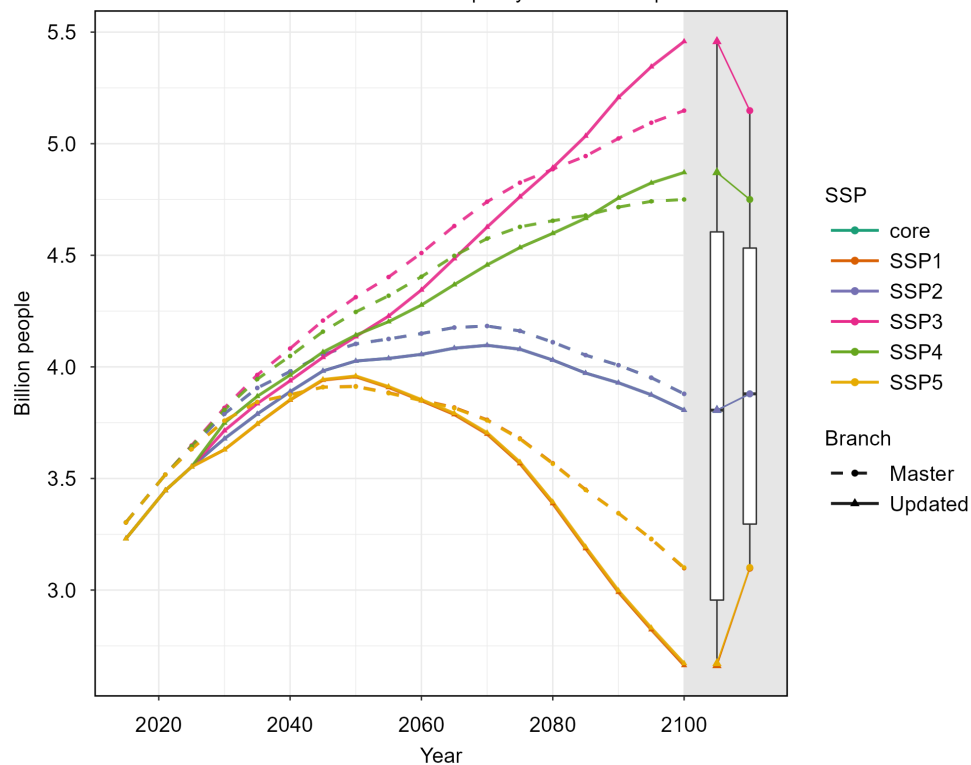
World population across SPA scenarios. The lines present population projections by 2100 by scenario (SSPs or GCAM core; GCAM-core is identical to SSP2 for population) across branches, Master (dotted lines) vs. Updated (solid lines). The boxplots show distributions of 2100 values across branches Master (left) vs. Updated (right), i.e., including the median values (line), the 1st and 3rd quartiles (boxes), and the 0-100 percentile ranges (whiskers) of the scenarios. Data of the boxplots are shown (points) and the lines connecting these points across branches show changes due to the updates. The same boxplot format (2100 scenario distribution, where applicable) is applied consistently across all validation figures.



Regional population projections across SPA scenarios.

World Labor Force (Employed)

1. Working-age population derivation has been improved
2. Labor force shares are now differentiated by SSP (previously SSP2 was applied to all)
3. Labor force influences TFP calibration and macroeconomic responses
4. Labor force remains the same across policy and GDP-response scenarios

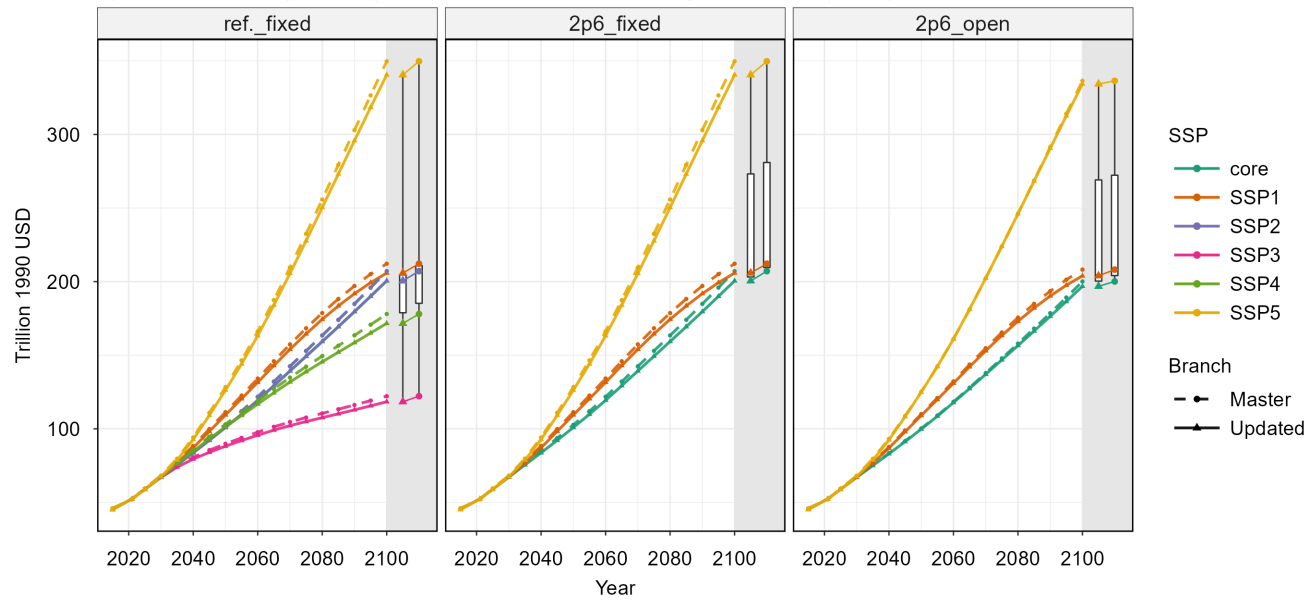


World labor force (employment) projections across SPA scenarios.

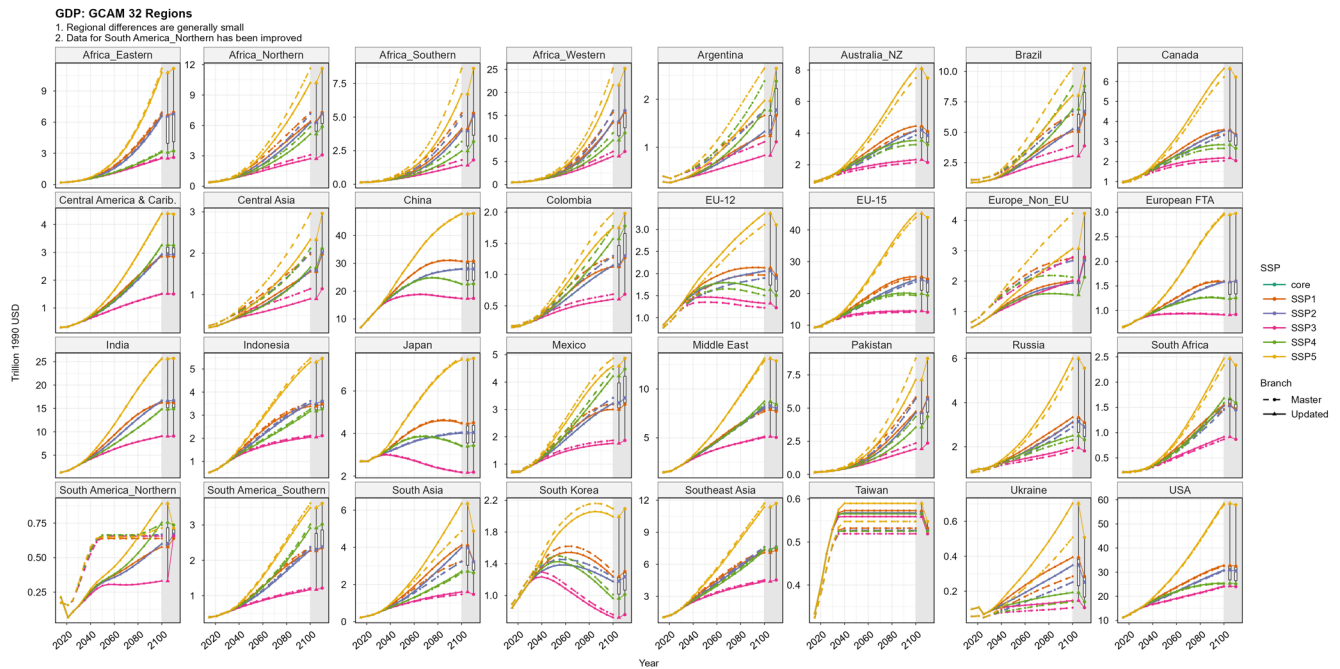
4.2. GDP

World GDP (Ref., RCP2p6-fixed, & RCP2p6-open)

Updates had relatively small impacts (due to SSP database and regional deflator updates)

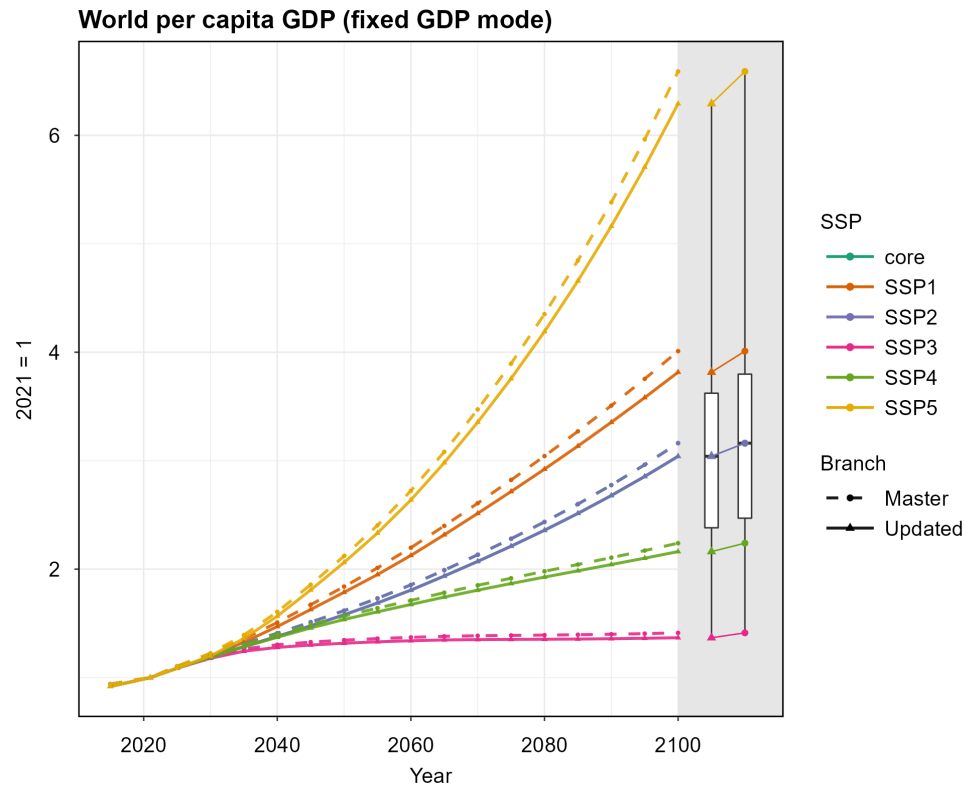


World GDP across SPA and GDP-response (fixed vs. open) scenarios

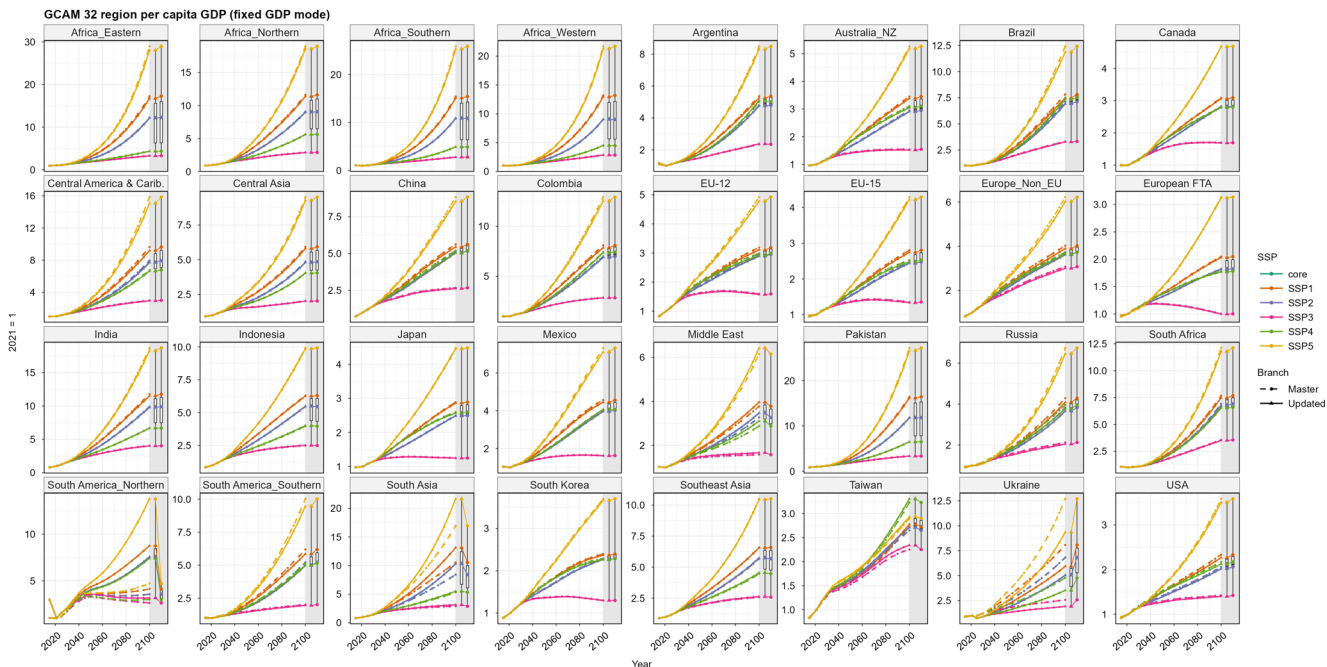


Regional GDP projections across SPA scenarios.

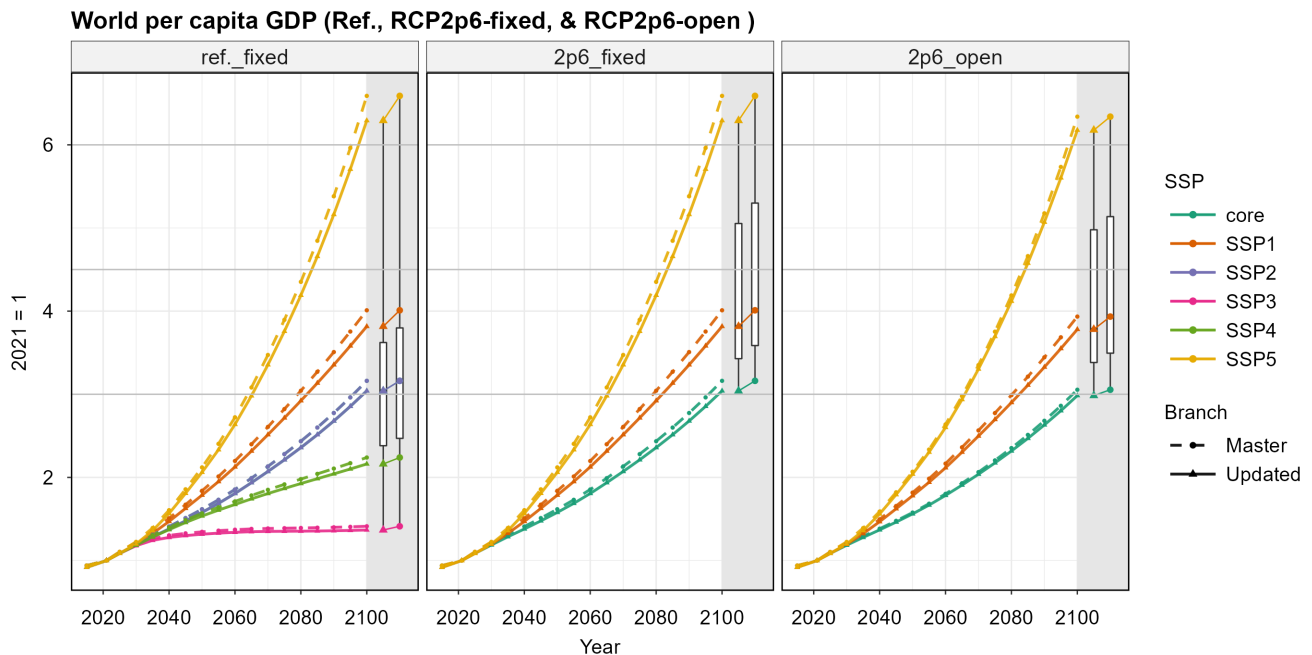
4.3. Per capita GDP and total factor productivity (TFP)



World per capita GDP across SPA (fixed-GDP mode) scenarios, relative to 2021



Regional per capita GDP across SPA (fixed-GDP mode) scenarios, relative to 2021



World per capita GDP across SPA and GDP-response (fixed vs. open) scenarios, relative to 2021

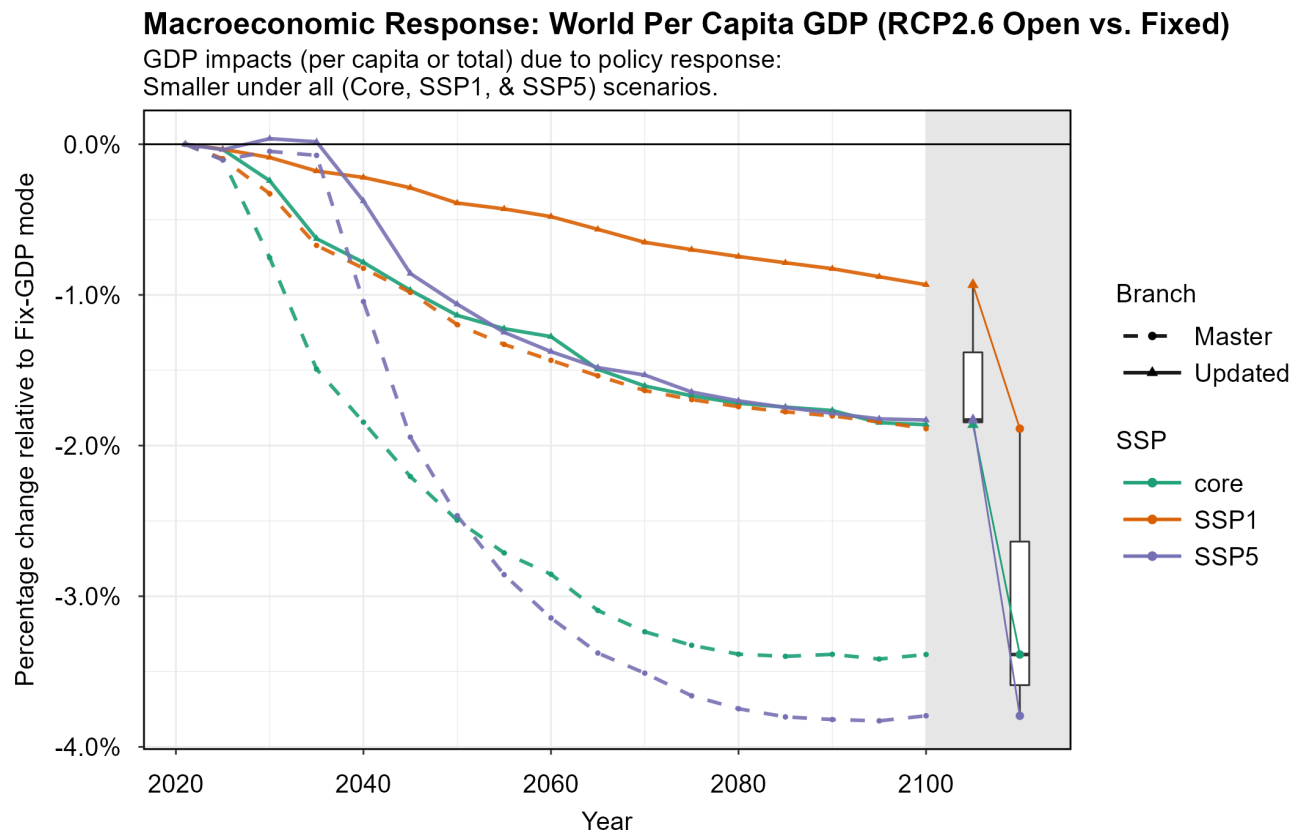
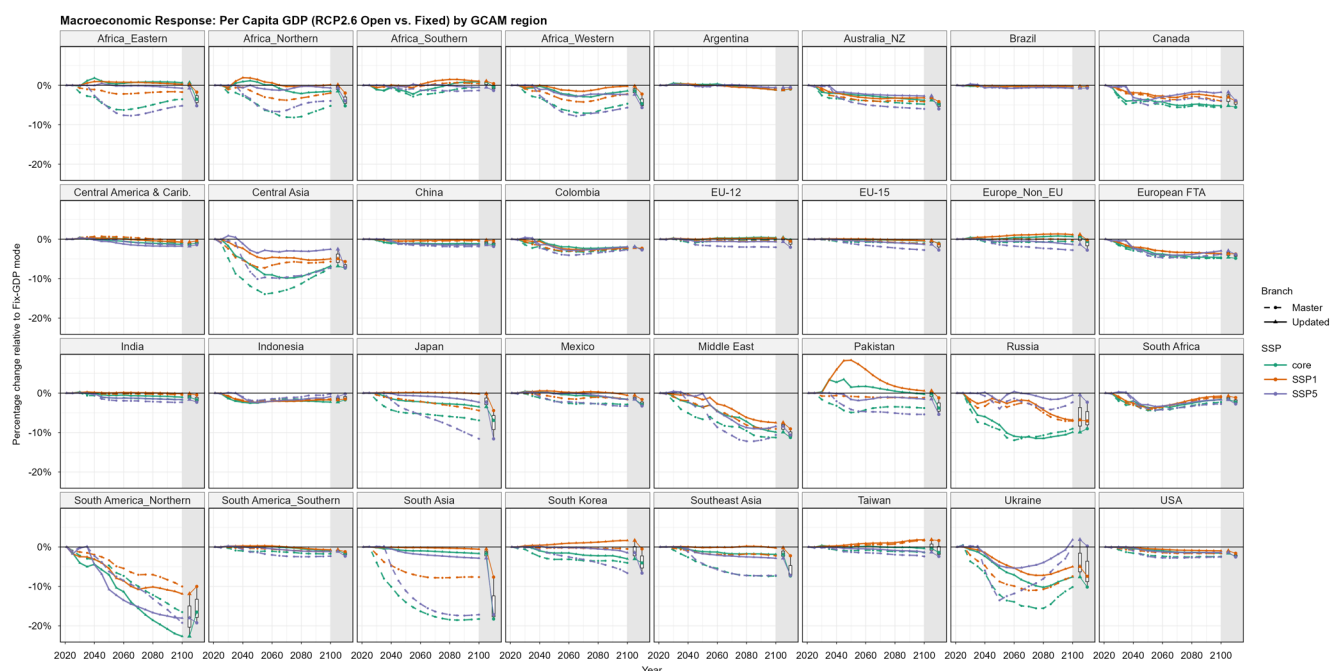
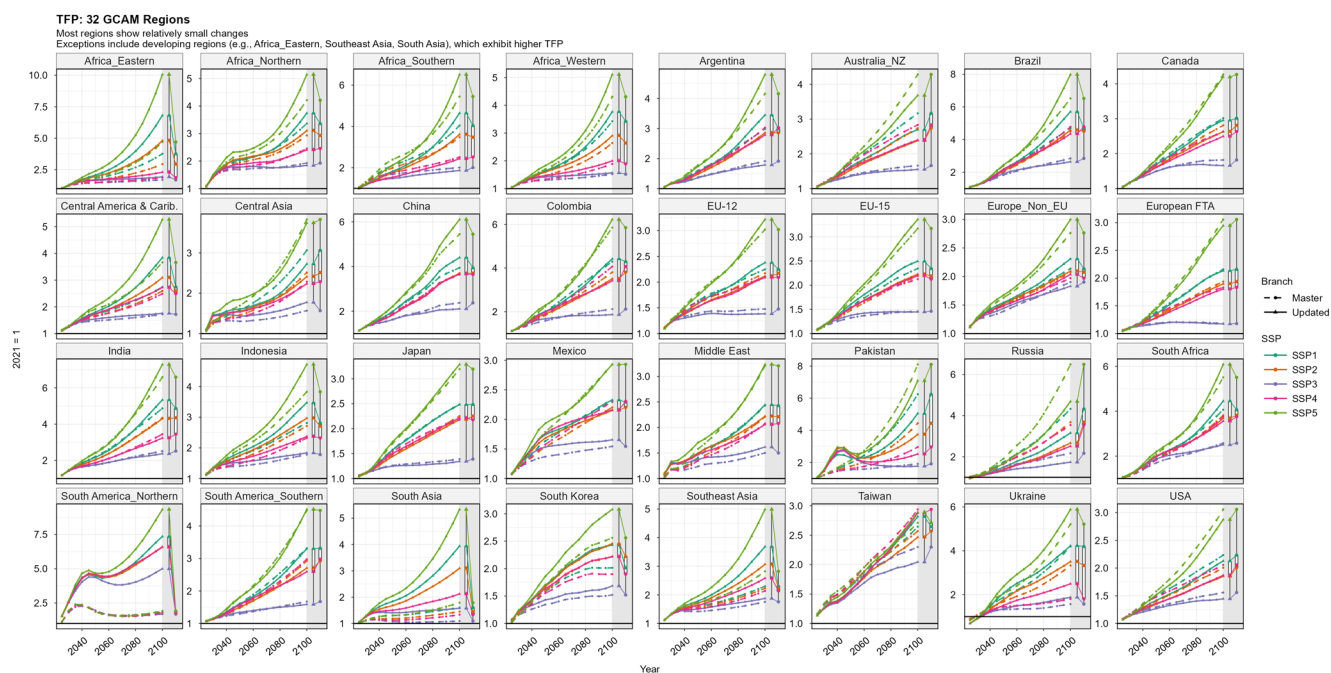


Fig. 17 World per capital GDP impacts due to RCP2p6 policies (open vs. fixed) across SPA



Regional per capital GDP impacts due to RCP2p6 policies (open vs. fixed) across SPA



Calibrated total factor productivity (TFP) by 32 GCAM regions

4.4. Other national account variables

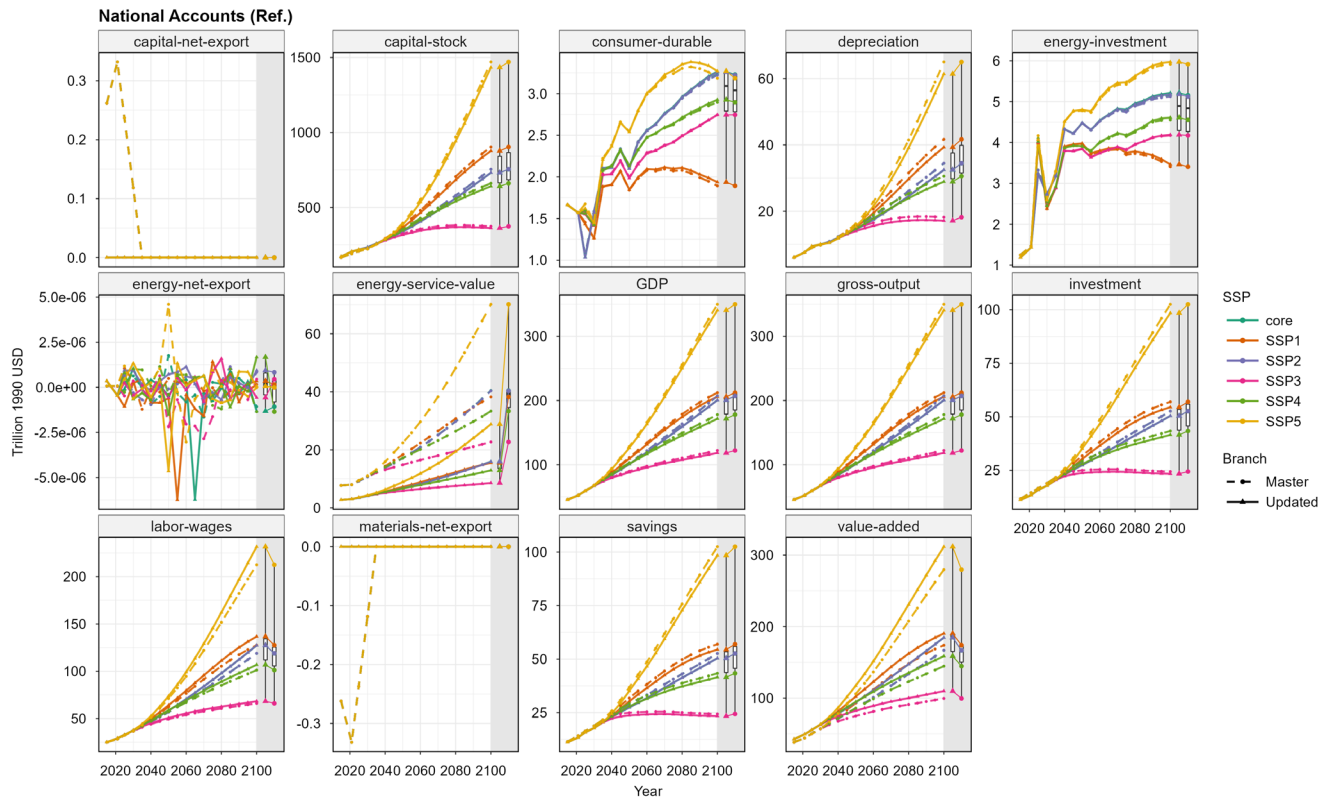
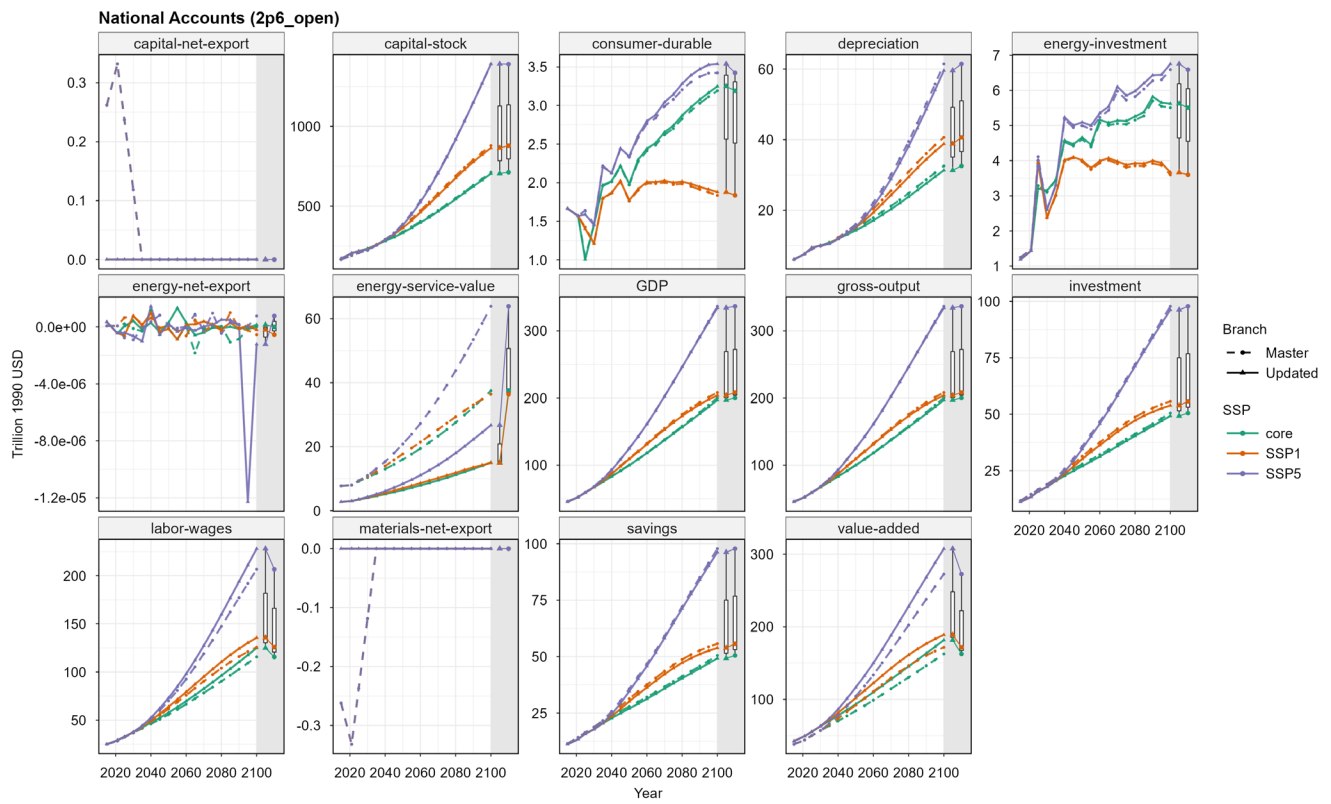


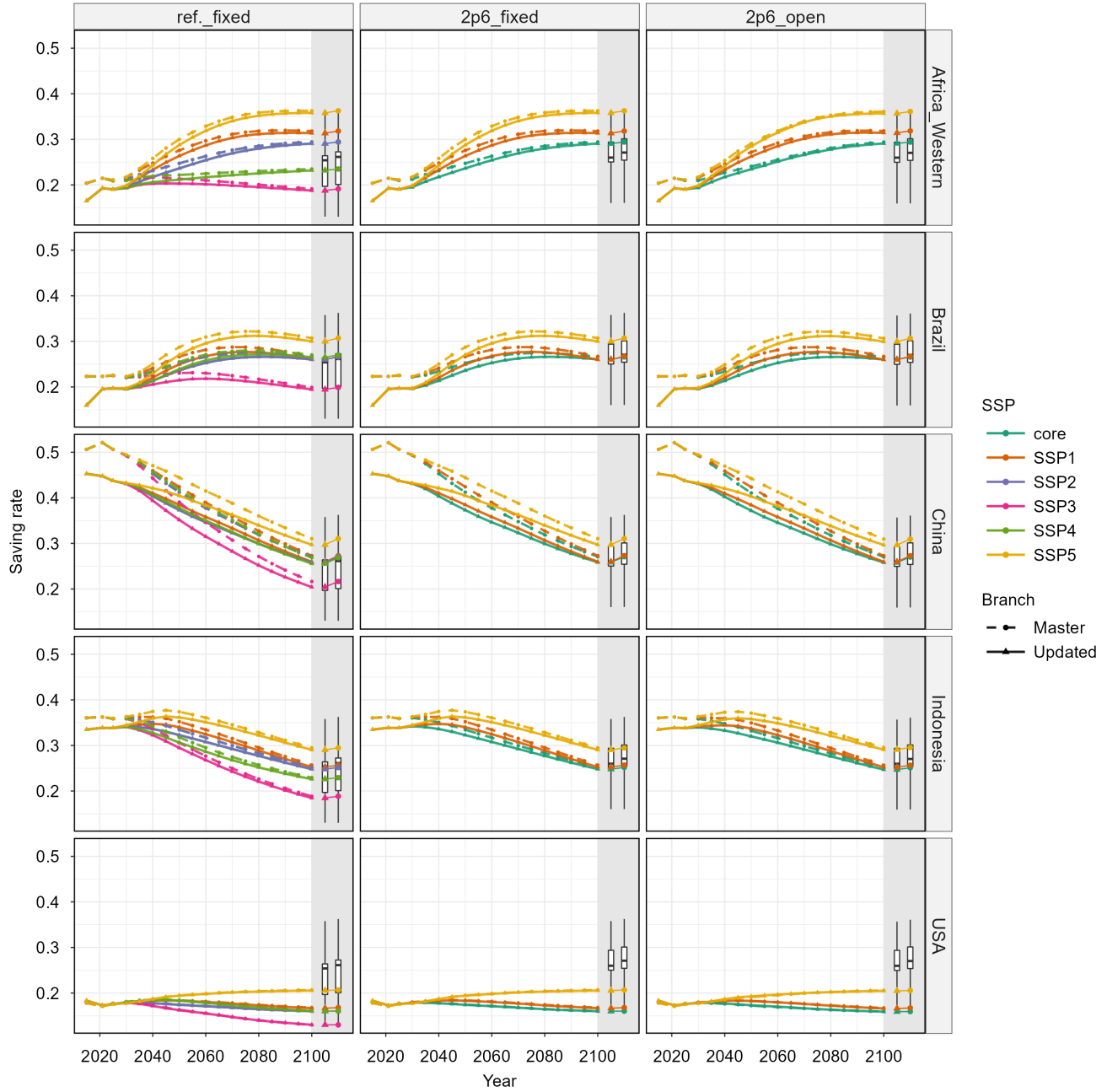
Fig. 18 National account variables in Ref, global.

- Energy service values show relatively larger changes due to updates in labor and capital compensation data.
- Trade imbalances were corrected so that global capital net exports and materials net exports sum to zero.
- Energy net exports are effectively zero, with minor variation due to rounding.
- The reported metrics—including capital stock, value added (labor + capital compensation), labor wages (labor compensation), gross output, and investment—refer to the Materials sector.



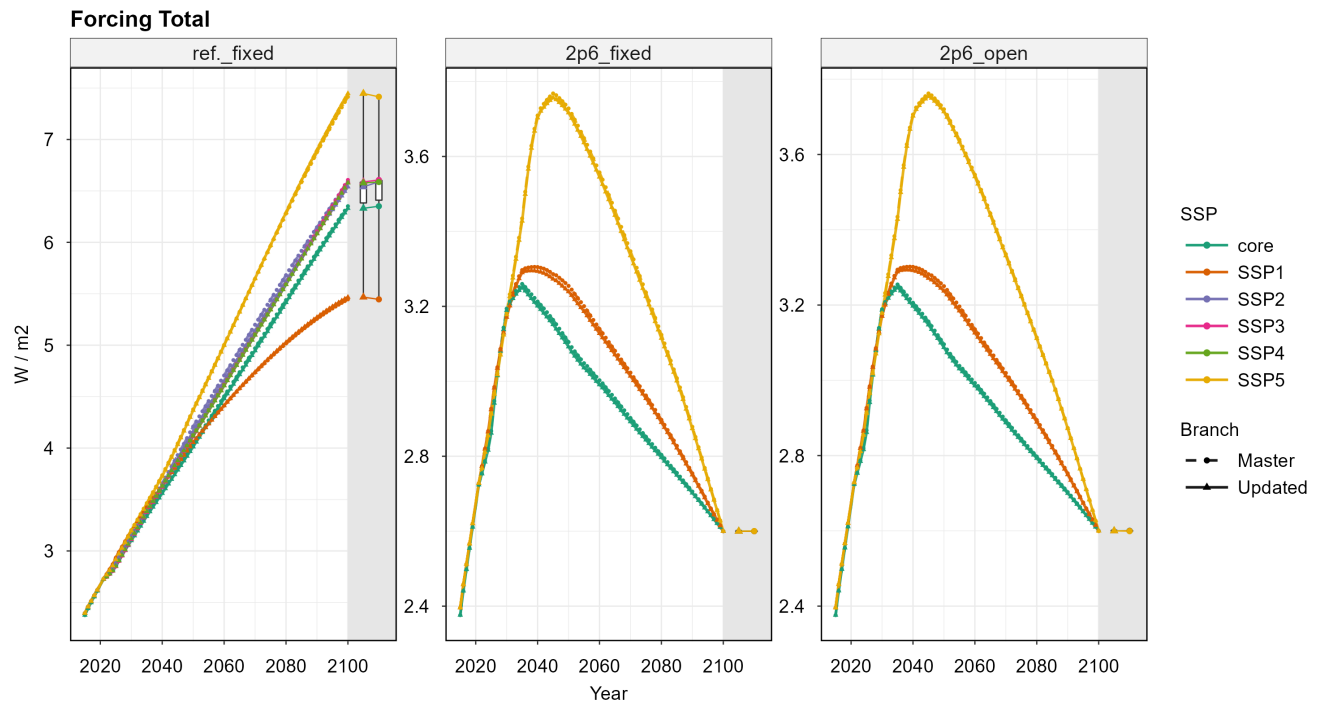
National account variables in rcp2p6 (open), global.

National account: saving rates in key regions

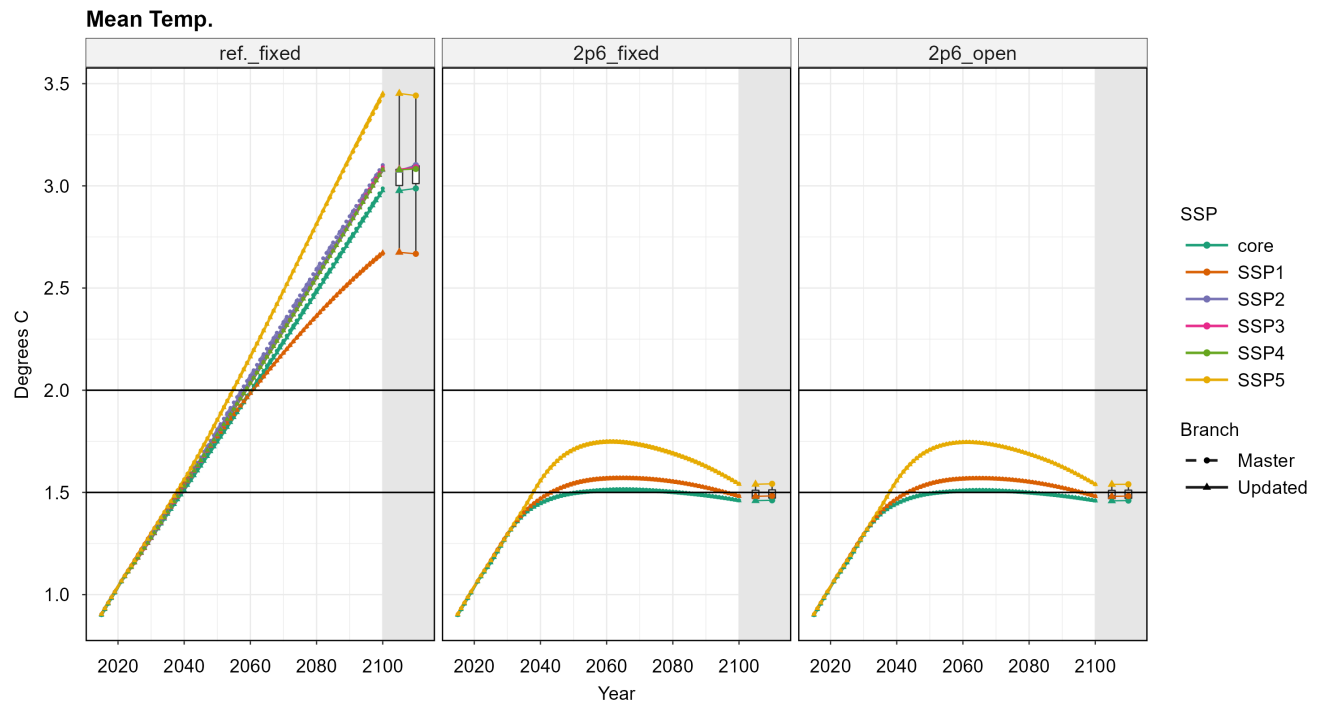


National account: Saving rates

4.5. Radiative Forcing, Temperature, and Carbon Prices



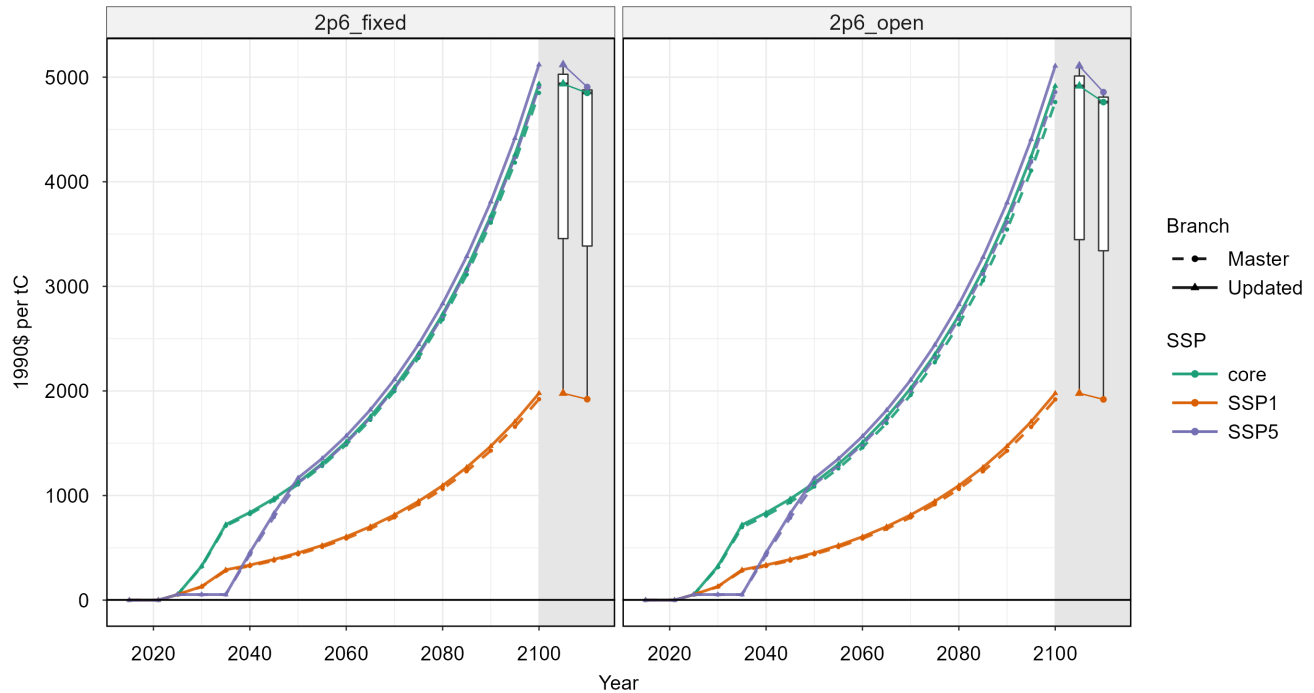
Total forcing across SPA and GDP-response (fixed vs. open) scenarios.



Global mean temperature change across SPA and GDP-response (fixed vs. open) scenarios.

Global Carbon Prices in RCP 2.6 scenarios

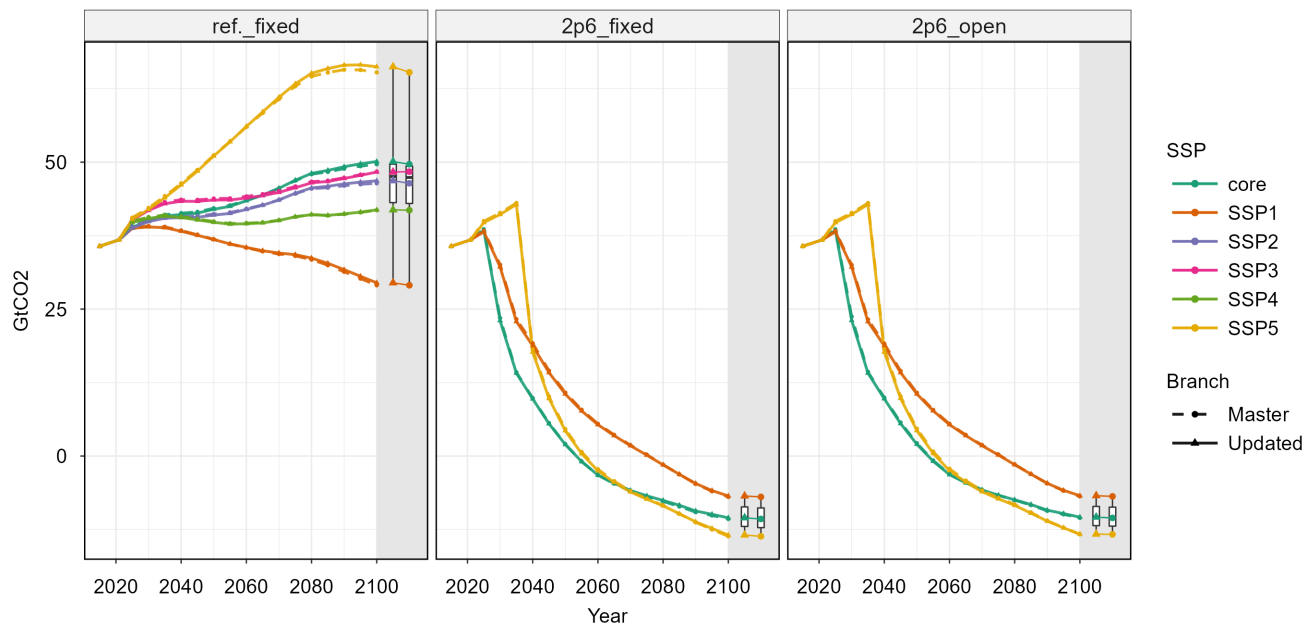
Relative small impacts on carbon prices



Global carbon prices across SPA and GDP-response (fixed vs. open) scenarios.

4.6. Emissions

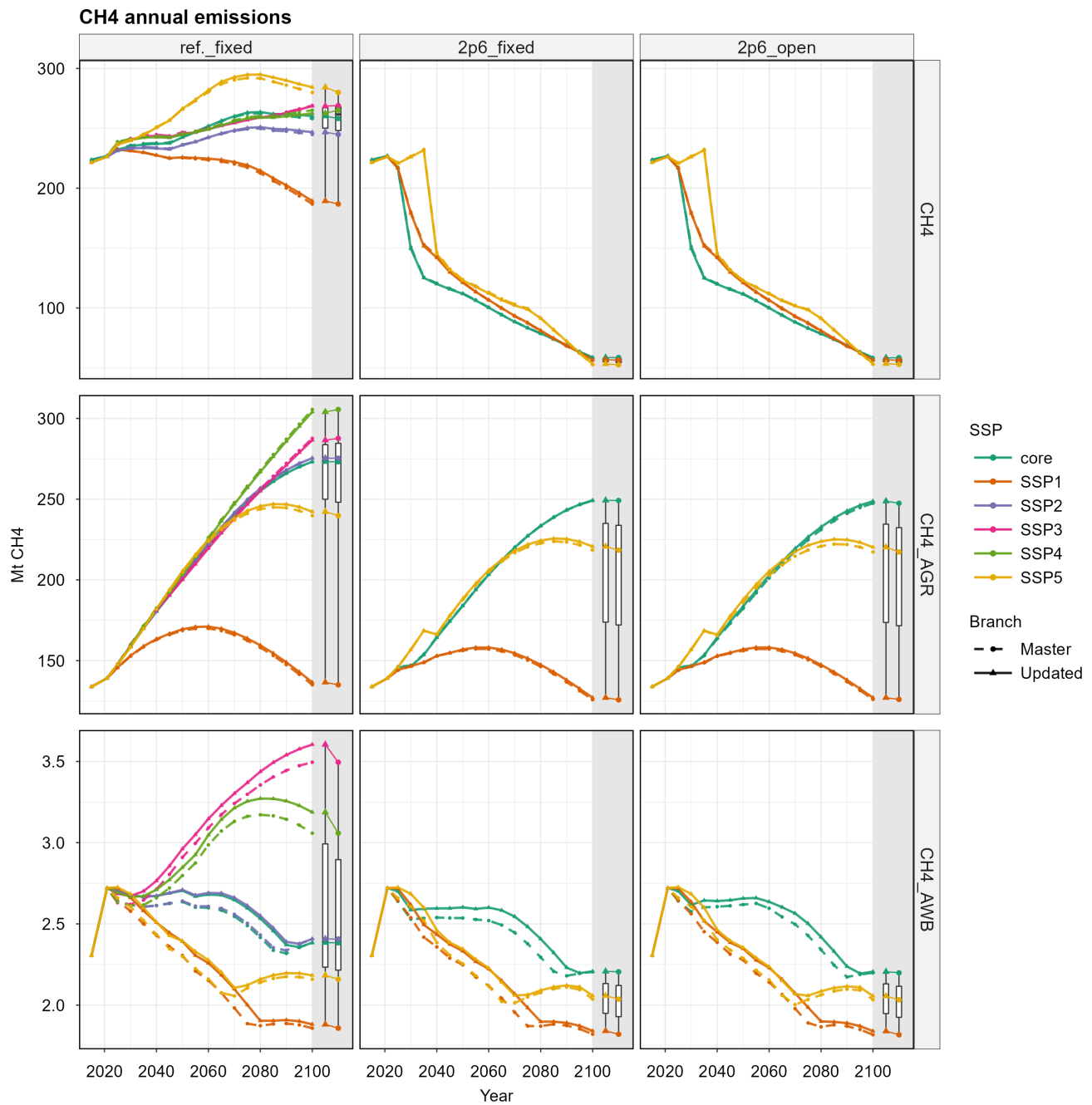
EIP annual CO2 emissions



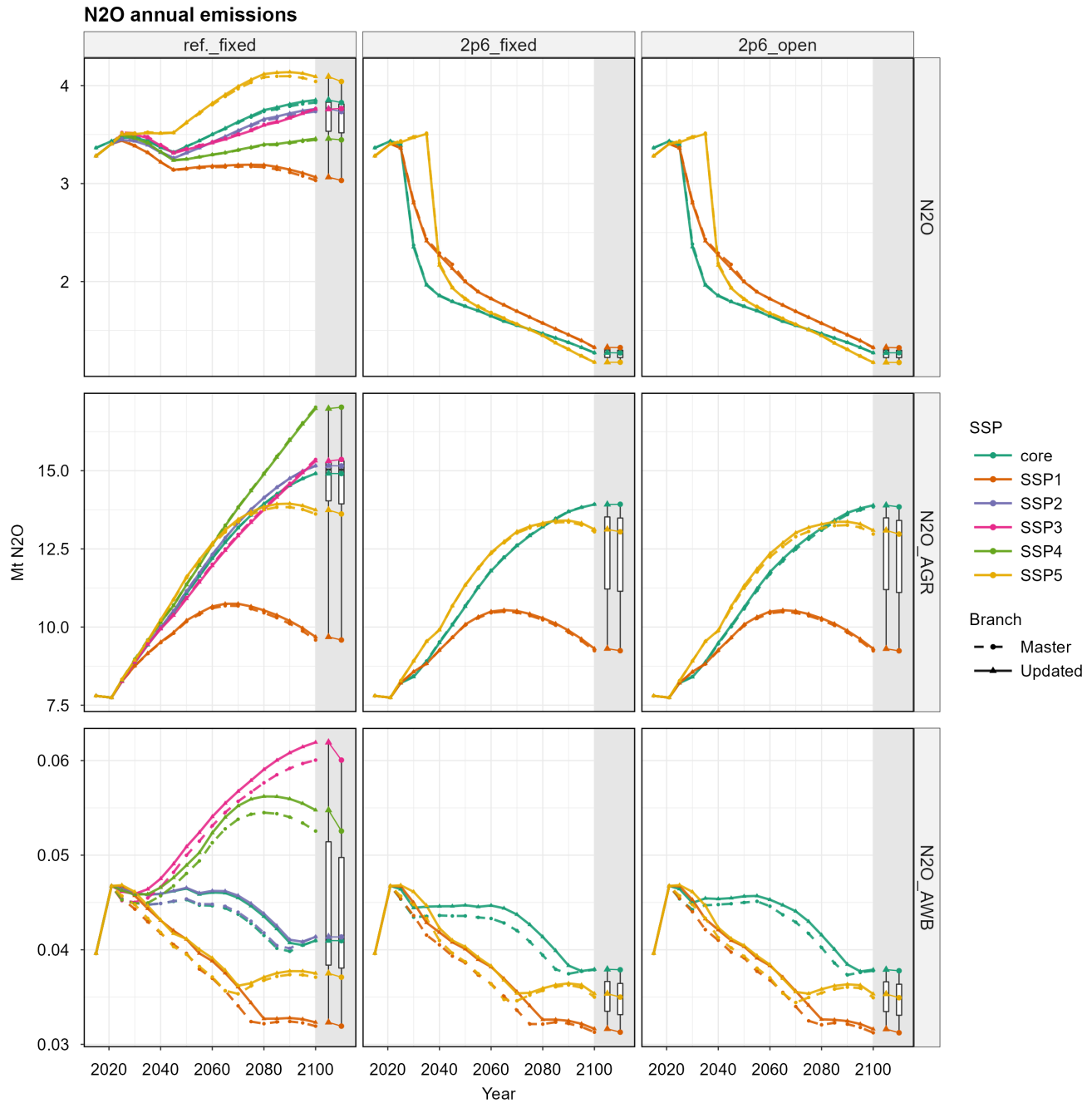
Global energy and industrial processes (EIP) carbon dioxide emissions across SPA and GDP-response (fixed vs. open) scenarios.



Global land use change carbon dioxide emissions across SPA and GDP-response (fixed vs. open) scenarios.



Global CH4 emissions across SPA and GDP-response (fixed vs. open) scenarios. Row panels indicate CH4 emissions by sector: non-Ag (CH4), agriculture (CH4_AGR), and agricultural waste burning (CH4_ABW).



Global N2O emissions across SPA and GDP-response (fixed vs. open) scenarios. Row panels indicate CH4 emissions by sector: non-Ag (CH4), agriculture (CH4_AGR), and agricultural waste burning (CH4_ABW).

Note: Only key figures are indexed. Other sectoral comparisons are not included in the released version of CMP, as the updates had only a minor impact.

5. Summary

This Core Model Proposal delivers a comprehensive restructuring of the macroeconomic and socioeconomic data processing system within GCAM, improving transparency, consistency, and traceability in the GCAM-Macro-KLEM framework. The updates integrate new and revised data sources, clean legacy structures, and enhance alignment across modules, laying a stronger foundation for future developments. While the overall impact of these updates on GCAM's sectoral projections is relatively modest, the changes have a relatively larger effect on macroeconomic outcomes. These shifts reflect improved calibration and internal consistency in the economic system.

Looking ahead, the forthcoming KLEAM version of GCAM-Macro will build on this structure to integrate agriculture into the macroeconomic framework using traceable and transparent data flows. Further efforts will focus on testing and refining key macroeconomic parameters, such as income elasticities and saving–investment parameters, across sectors and regions to improve overall model behavior. In addition, we will maintain a consistent set of key macroeconomic figures extending from historical observations to future projections. These developments will strengthen GCAM-Macro's capacity for broader socioeconomic and policy analyses.

References

- Feenstra, R.C., Inklaar, R., Timmer, M.P., 2015. The Next Generation of the Penn World Table. *American Economic Review* 105, 3150–3182. <https://doi.org/10.1257/aer.20130954>
- Foure, J., Aguiar, A., Bibas, R., Chateau, J., Fujimori, S., Lefevre, J., Leimbach, M., Rey-Los-Santos, L., Valin, H., 2020. Macroeconomic Drivers of Baseline Scenarios in Dynamic CGE models: Review and Guidelines Proposal. *Journal of Global Economic Analysis* 5, 28–62. <https://doi.org/10.21642/JGEA.050102AF>
- Müller, K., Xu, C., Lehib, M., Chen, Z., 2025. The Global Macro Database: A New International Macroeconomic Dataset. Working Paper Series. <https://doi.org/10.3386/w33714>
- Patel, P., Edmonds, J., Kim, S., Zhao, X., Sheng, D., Waldhoff, S., Lochner, E., 2023. Core Model Proposal# 332: GCAM Macro-Economic Module (KLEM Version) (No. PNNL-34479). Pacific Northwest National Laboratory, College Park, USA.
- Zhao, X., Patel, P., Di, S., Edmonds, J., Waldhoff, S., Fawcett, A., Bertram, C., O’neill, B., 2024. Core Model Proposal #399: Updating the SSP Database (v3.0) (Population, GDP, and Labor Force) and Labor Productivity (KLEM). <https://doi.org/10.13140/RG.2.2.26389.54243>

Pacific Northwest National Laboratory

902 Battelle Boulevard
P.O. Box 999
Richland, WA 99354

1-888-375-PNNL (7665)

www.pnnl.gov