PNNL-34349

Core Model Proposal #350:

Detailed Natural Gas Trade

June 2023

Brinda N. Yarlagadda
Matthew T. Binsted
Gokul C. Iyer

U.S. DEPARTMENT of ENERGY

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

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Pacific Northwest National Laboratory
Richland, Washington 99354

Core Model Proposal #350: Detailed Natural Gas Trade

Product: Global Change Analysis Model (GCAM)

Institution: Joint Global Change Research Institute (JGCRI)

Authors: Brinda Yarlagadda, Matthew Binsted, and Gokul Iyer

Reviewers: Marshall Wise and Pralit Patel

Date committed: 5/16/2023

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Related sector: energy

Type of development: data, queries

Purpose: This core model proposal adds detail to GCAM's natural gas trade model by separating gas trade between Liquefied Natural Gas (LNG) and six regional gas pipeline networks. This entails creating new trade markets for global LNG and the six regional pipeline networks, and modifying the regional natural gas sector in each region to reflect the competition between LNG and pipelines within imported natural gas, and between different pipeline networks. The nesting subsector capability (CMP #299 Infinite Subsector Nesting) was used to represent this additional level of competition on the consumption side.

Description of Changes

Model Structure

CMP #308 Regional Fossil Fossil Fuel Markets introduced an Armington trade model for fossil fuels in GCAM. This structure distinguishes between consumption of domestic and imported goods without any fixed bilateral trade patterns (i.e. imports are from a single global pool), and permits the tracking of gross trade of fossil fuel commodities.

This proposal extends this structure to add more detail for natural gas trade. Figures 1 and 2 provides an overview of the new structure. This change makes use of the nesting subsector capability (CMP#299 Infinite Subsector Nesting) on the consumption side (Figure 1). The first subsector level, dividing regional natural gas consumption between domestic and imported sources, is unchanged from the current structure. This proposal adds another level of subsector nesting to reflect the competition, within the import market, between LNG and pipelines. (To maintain consistent subsector / technology depth in the domestic natural gas nest, another subsector was added within domestic natural gas, but there is no competition at this level.) Imported LNG comes from traded LNG, which is exported from any GCAM region, thus LNG is traded globally (Figure 2). Imported pipeline gas comes only from the specific pipeline(s) that a region can import from. For example, in the case of the USA region, imported pipeline gas can come only from the North American pipeline ("imported N.Amer pipeline gas"). Only the USA, Canada, and Mexico can export to "traded N.Amer pipeline gas". In this way, pipeline gas is regionally traded via one of six regional pipeline networks. Thus, natural gas produced from any given region can be either produced for the domestic market, produced for LNG export, or produced for export via one of the six regional pipeline networks.

Each GCAM region will export to only one of the regional gas pipeline networks, but can potentially import from multiple networks. Figures 3-4 presents a map and Venn diagram of how the regional gas pipeline networks overlap. The North America (N.Amer) and Latin America (LA) pipeline networks are isolated; GCAM regions in these networks only export to / import from their network. There is some overlap between the four pipeline networks in the eastern hemisphere. Arrows on the map indicate which additional pipeline networks a region may import from, in addition to its own. Regions in the Venn diagram are located in the circles for the pipeline networks from which they import (up to 3). The boxes for each region are color coded to match the primary network that region is a part of (i.e., the one it exports to). For example, EU-12 exports to the EUR pipeline network and can import from the EUR, RUS, and Afr_MidE networks. The choice to have each region export from only one network is largely driven by convenience / simplicity; the pipeline networks a given region can import from is informed by bilateral trade data on country-level gas trade (see historical data processing below for more detail).

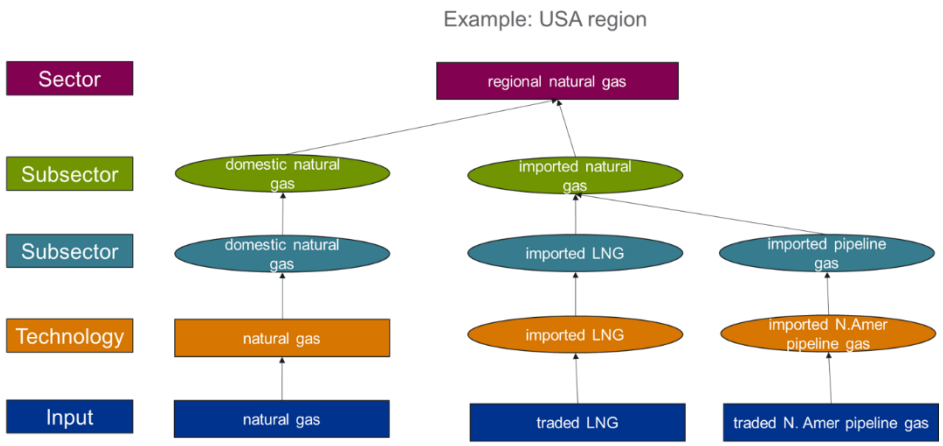


Figure 1. Regional natural gas market structure (consumption side).

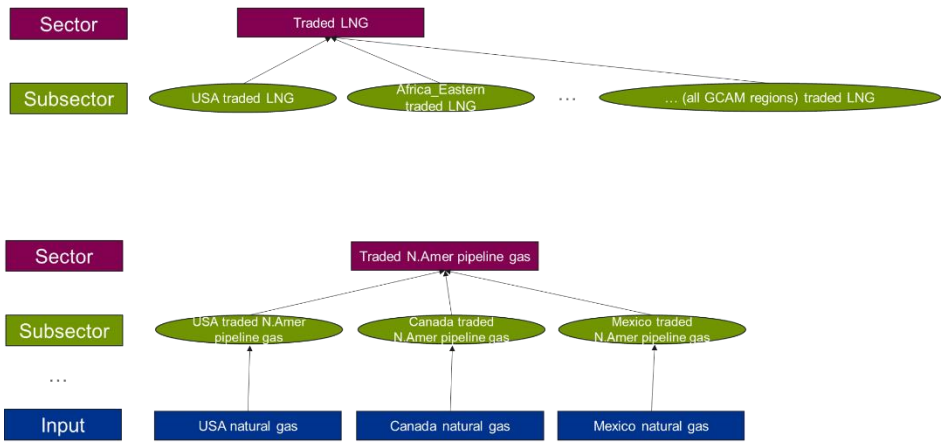
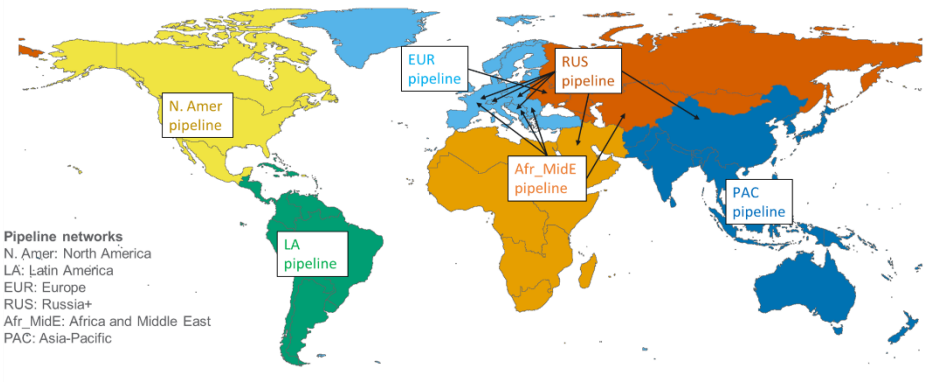
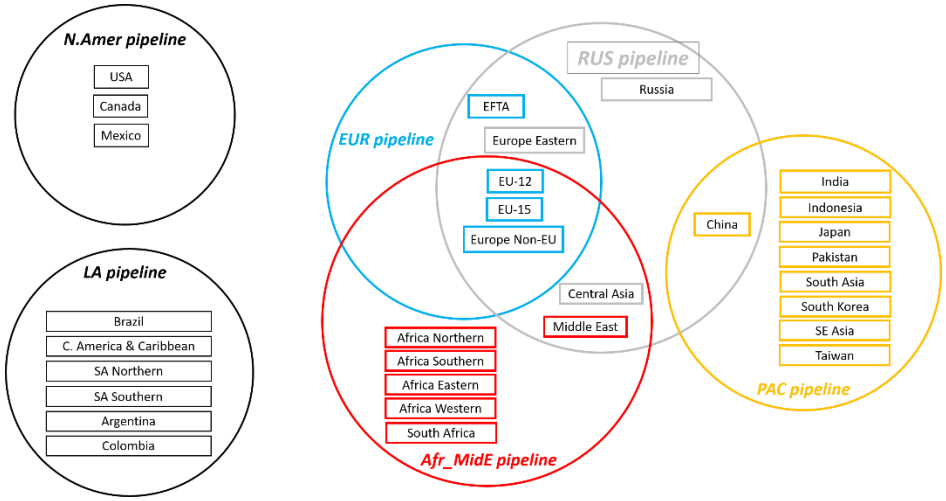


Figure 2. Traded natural gas market structure (exports).





Figures 3 (top) and 4 (bottom). Regional gas pipeline networks. Each GCAM region exports to only one of the regional gas pipeline networks, but can potentially import from multiple networks. Western hemisphere (N.Amer and LA) pipeline networks are isolated. Eastern hemisphere networks partially overlap. Arrows on the map indicate additional pipeline networks that specific regions may import from, in addition to its own. Regions are located in the circles for the pipeline networks from which they import (up to 3). The boxes for each region are color coded to match the primary network that region is a part of (i.e., the one it exports to).

Historical Data Processing

Historical natural gas trade data is calibrated to COMTRADE data for the 2015 base. The COMTRADE data set used contains volumetric data on bi-lateral trade of natural gas, via pipeline and LNG, for exporter/importer country pairs. COMTRADE data was already being utilized for fossil fuel trade, as described in CMP#308 Regional Fossil Fossil Fuel Markets CMP, but LNG and pipeline gas trade flows were previously added together to have aggregated traded natural gas, whereas here we keep them disaggregated. This data is aggregated to GCAM's 32 energy-economic regions, with intra-regional trade (i.e., trade between countries within a GCAM region) excluded.

Total gas trade is adjusted to maintain GCAM's global energy balances (calibrated based on the International Energy Agency (IEA)'s Energy Balances data set); in other words, gross COMTRADE flows are adjusted to realize net trade consistent with natural gas production and consumption (and implicit net trade) data from the IEA (IEA, 2019). Further adjustments are made to ensure that annual energy flows are balanced for (1) total natural gas imports and exports (across pipeline and LNG carriers) in each region; (2) pipeline exports and imports for each of the six regional pipeline network blocs shown in Figure 1; and (3) LNG imports and exports globally. Adjustments were made by including an additional "gas trade statistical differences" sector to balance out all regions trade imbalances in historical years; these "gas trade statistical differences" technologies are made inoperable (shareweight = 0) for all future years.

By assumption, all exports from a region go into its primary regional pipeline network bloc, but regions are allowed to import from multiple regional pipeline network blocs if such trade flows are present in the historical data. In the future, pipeline trade relationships are limited to those established historically – the model structure does not allow new pipeline export/import relationships to develop. All regions are allowed to trade natural gas via LNG in the future, as imported LNG and traded LNG shareweights converge to 1 by 2030.

Model Assumptions

regional natural gas sector

sector		nesting subsector					subsector				
sector name	sector logit exponent	subsector name	logit exponent	share weight (terminal)	interpolation to-year	interpolation rule	subsector name	logit exponent	share weight (terminal)	interpolation to-year	interpolation rule
regional natural gas	-3	domestic natural gas	-6	1	2300	s-curve	domestic natural gas	-6	1	2300	s-curve
		imported natural gas	-6	USA: 0.6 other regions: 1	2100	linear	imported LNG	-6	1	2030	linear
							imported pipeline gas	-6		2100	fixed

technologies within regional natural gas sector

sector	nesting subsector	subsector	technology	lifetime	half life	steepness	interpolation to-year	interpolation type	median shutdown point	profit shutdown steepness
regional natural gas	domestic natural gas	domestic natural gas	domestic natural gas	45	23	0.2	2100	fixed	-0.5	6
	imported natural gas	imported LNG	imported LNG	45	23	0.2	2100	fixed	-0.5	6
		imported pipeline gas	imported N.Amer pipeline gas imported LA pipeline gas imported EUR pipeline gas imported RUS pipeline gas imported Afr_MidE pipeline gas imported PAC pipeline gas	45	23	0.2	2100	fixed	-0.5	6

gas trade sectors

sector			subsector				
name	logit exponent	share weight (terminal)	name	logit exponent	share weight (terminal)	interpolation to-year	interpolation type
traded LNG	-6	1	traded LNG	-6	1	2030	linear
traded N.Amer pipeline gas traded LA pipeline gas traded EUR pipeline gas traded RUS pipeline gas traded Afr_MidE pipeline gas traded PAC pipeline gas	-6	1	traded N.Amer pipeline gas traded LA pipeline gas traded EUR pipeline gas traded RUS pipeline gas traded Afr_MidE pipeline gas traded PAC pipeline gas	-6	n/a	2100	fixed

traded technology

sector	subsector	technology	lifetime	half life	steepness	median shutdown point	profit shutdown steepness
traded LNG	traded LNG	traded LNG	45	23	0.2	-0.5	6
traded N.Amer pipeline gas traded LA pipeline gas traded EUR pipeline gas traded RUS pipeline gas traded Afr_MidE pipeline gas traded PAC pipeline gas	traded N.Amer pipeline gas traded LA pipeline gas traded EUR pipeline gas traded RUS pipeline gas traded Afr_MidE pipeline gas traded PAC pipeline gas	traded N.Amer pipeline gas traded LA pipeline gas traded EUR pipeline gas traded RUS pipeline gas traded Afr_MidE pipeline gas traded PAC pipeline gas	45	23	0.2	-0.5	6

trade costs (1975$/GJ)

sector	subsector	technology	cost component	1975	2015	2100	source
regional natural gas	imported LNG	imported LNG	regasification	0.09	0.09	0.09	email correspondence from Sauleh Siddiqui (American University)
	imported pipeline	imported N.Amer pipeline gas imported LA pipeline gas imported EUR pipeline gas imported RUS pipeline gas imported Afr_MidE pipeline gas imported PAC pipeline gas	trade *	0	0	0	N/A
traded LNG	traded LNG	traded LNG	liquefaction	0.27	0.27	0.27	email correspondence from Sauleh Siddiqui (American University)
		traded LNG	shipping	0.17	0.17	0.17	
traded N.Amer pipeline gas traded LA pipeline gas traded EUR pipeline gas traded RUS pipeline gas traded Afr_MidE pipeline gas traded PAC pipeline gas	traded N.Amer pipeline gas traded LA pipeline gas traded EUR pipeline gas traded RUS pipeline gas traded Afr_MidE pipeline gas traded PAC pipeline gas	traded N.Amer pipeline gas traded LA pipeline gas traded EUR pipeline gas traded RUS pipeline gas traded Afr_MidE pipeline gas traded PAC pipeline gas	pipeline	0.15	0.15	0.15	Derived from EIA data on new U.S. natural gas pipeline projects from 1996-2020 (EIA-NaturalGasPipelineProjects.xls, retrieved from https://www.eia.gov/naturalgas/data.cfm#pipelines on 10/27/2021). Data on pipeline cost, capacity, and length (in miles) are converted to $/GJ using an assumed 90% capacity factor, 13% fixed charge rate, and pipeline length equal to the 90th percentile in the data set (roughly 320 miles). (NOTE: All entries in the EIA data set are U.S. domestic pipelines; an upper-end pipeline length is used since GCAM costs represent international pipelines, which would tend to be longer.)

*** NOTE**: LNG trade costs are split between exporters and importers. Liquefaction and shipping are allocated to technologies within the traded LNG sector, which represents LNG exports from each region; regasification costs are allocated to the imported LNG technology within regional natural gas. Conversely, pipeline trade costs are assigned only to the exporter (in traded *R* pipeline gas sectors), largely for convenience.

gcamdata changes

Added

- inst/extdata/energy
  - A21.stubtech_interp_R.csv
  - A_ff_RegionalNestingSubsector_NG.csv
  - A_ff_RegionalSubsector_NG.csv

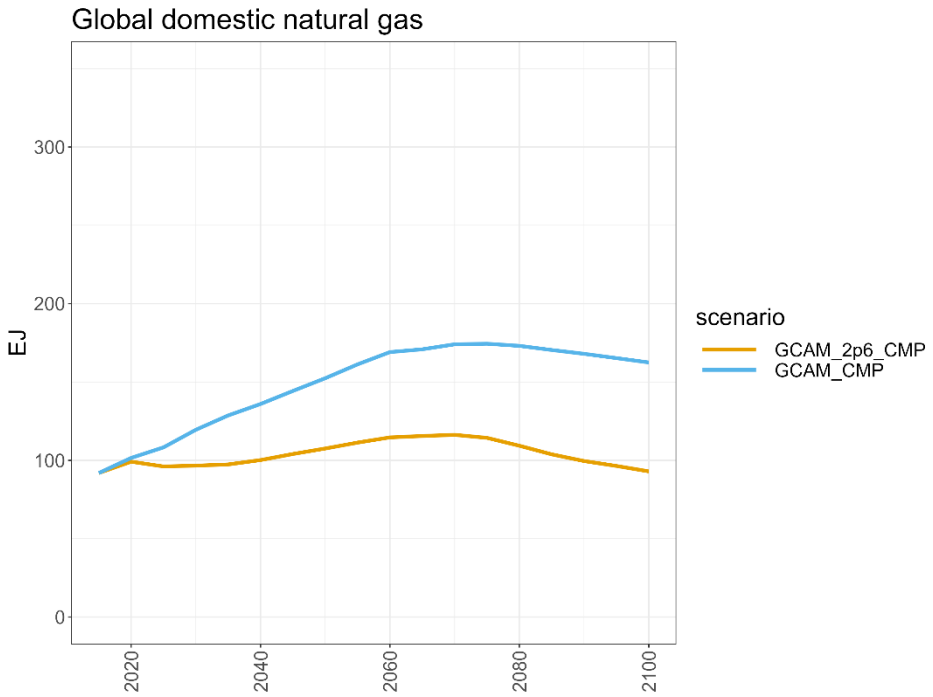
    - A_ff_RegionalTechnology_NG.csv
    - A_ff_RegionalTechnologyCost_NG.csv
    - A_ff_TradedSector_NG.csv
    - A_ff_TradedSubsector_NG.csv
    - A_ff_TradedTechnology_NG.csv
    - A_ff_TradedTechnologyCost_NG.csv
    - GCAM_region_pipeline_bloc.csv
- R
    - zchunk_batch_gas_trade_xml.R
    - zchunk_L2391.gas_trade_flows.R
    - zchunk_L2392.gas_trade.R
- xml
    - gas_trade.xml

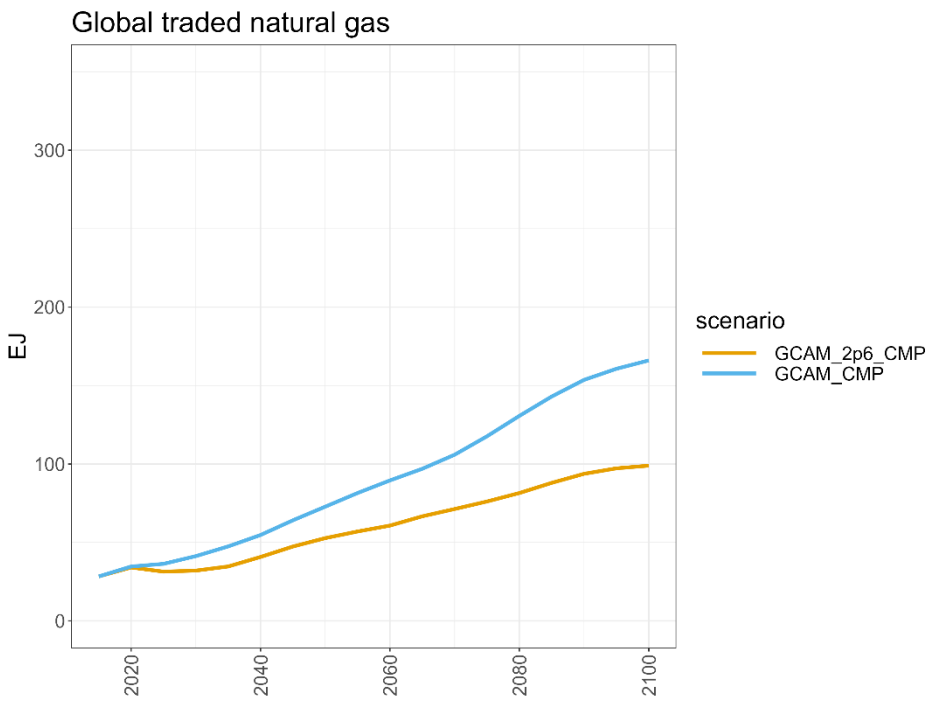
Modified

- inst/extdata/energy/mappings
    - comtrade_commodity_code.csv
- inst/extdata/energy
    - A_regions.csv
- inst/extdata/mi_headers
    - ModelInterface_headers.txt
- man
    - module_energy_LB1011.ff_GrossTrade.Rd
- R
    - zchunk_LB1011.fossilFuel_GrossTrade_EJ_R_C_Y.R

Validation

Global and regional natural gas trade projections:





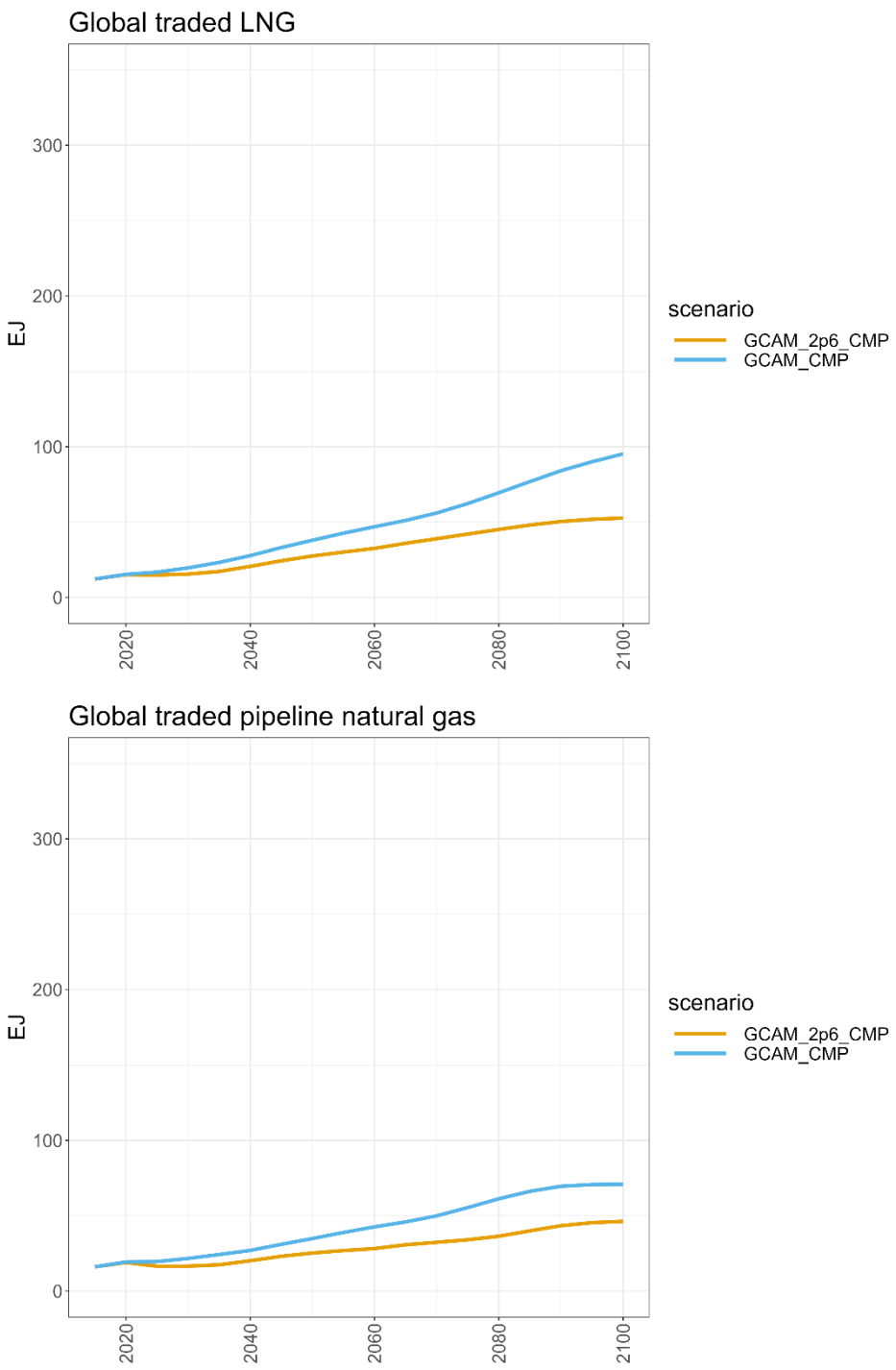
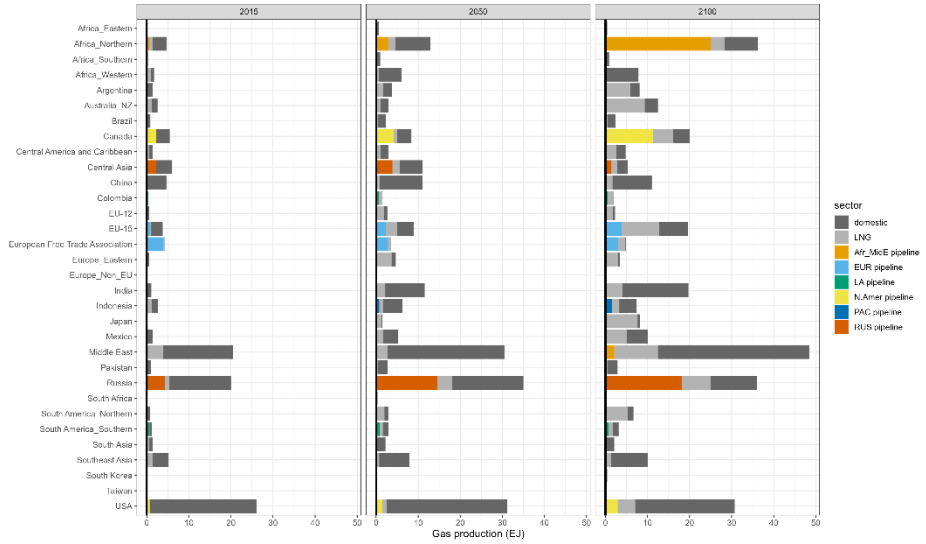
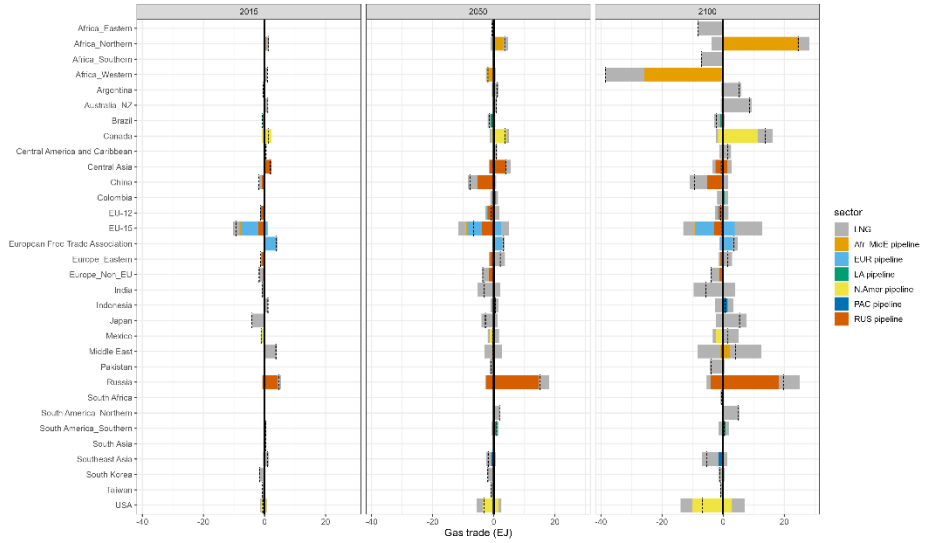


Figure 5. Global natural gas projections. a) total domestic natural gas (produced and consumed domestically - not traded); b) total traded natural gas; c) traded LNG; and d) traded pipeline natural gas through 2100.

In 2015, 92 EJ of natural gas was domestically produced and consumed, while 28 EJ of natural gas was traded, out of which 16 EJ was traded through pipelines and 12 EJ was traded as LNG.

Traded natural gas (both pipeline and LNG) grow significantly over the century. By 2050, under Reference ("GCAM_CMP"), both traded pipeline gas and traded LNG are projected to be around the same level globally (35 EJ and 38 EJ, respectively). By 2100, the quantity of traded LNG is larger than traded pipeline gas (95 EJ and 71 EJ, respectively). The faster growth of LNG over the century reflects its increased dominance due to improvements in LNG infrastructure technology, allowing LNG to be shipped more widespread around the world. Under GCAM_2p6_CMP, all natural gas flows are lower in magnitude than under GCAM_CMP, reflecting the shifting away from natural gas to other low-emission fuels.





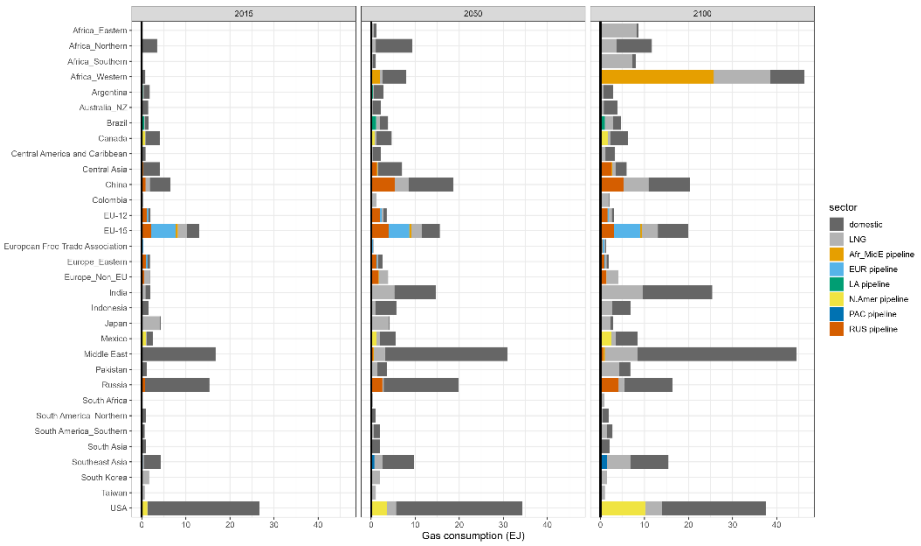
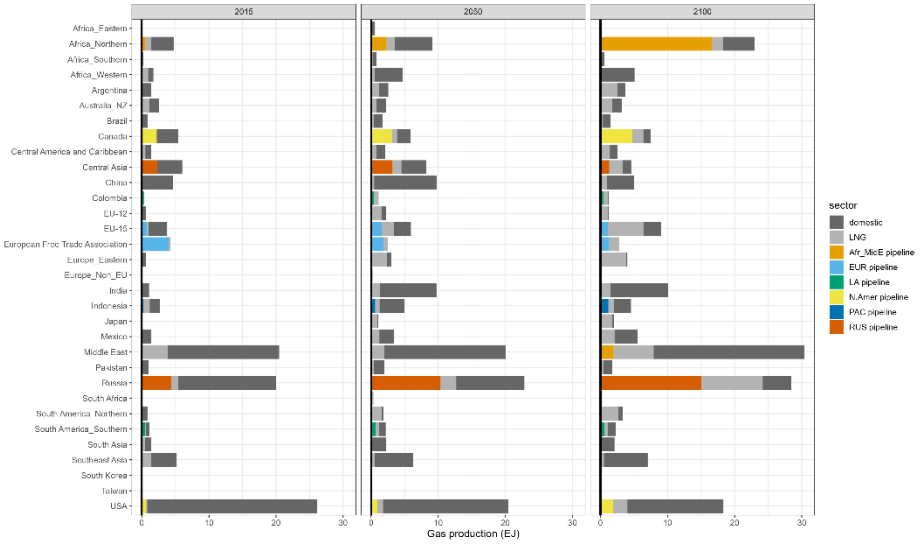


Figure 6. Regional natural gas projections (by GCAM region) in Reference ("GCAM_CMP") scenario. a, top) Natural gas production, b, middle) Natural gas trade. Gross exports are shown to the right of the y-axis, gross imports are shown to the left of the y-axis, and net trade is shown with a dashed line. c, bottom) Natural gas consumption.



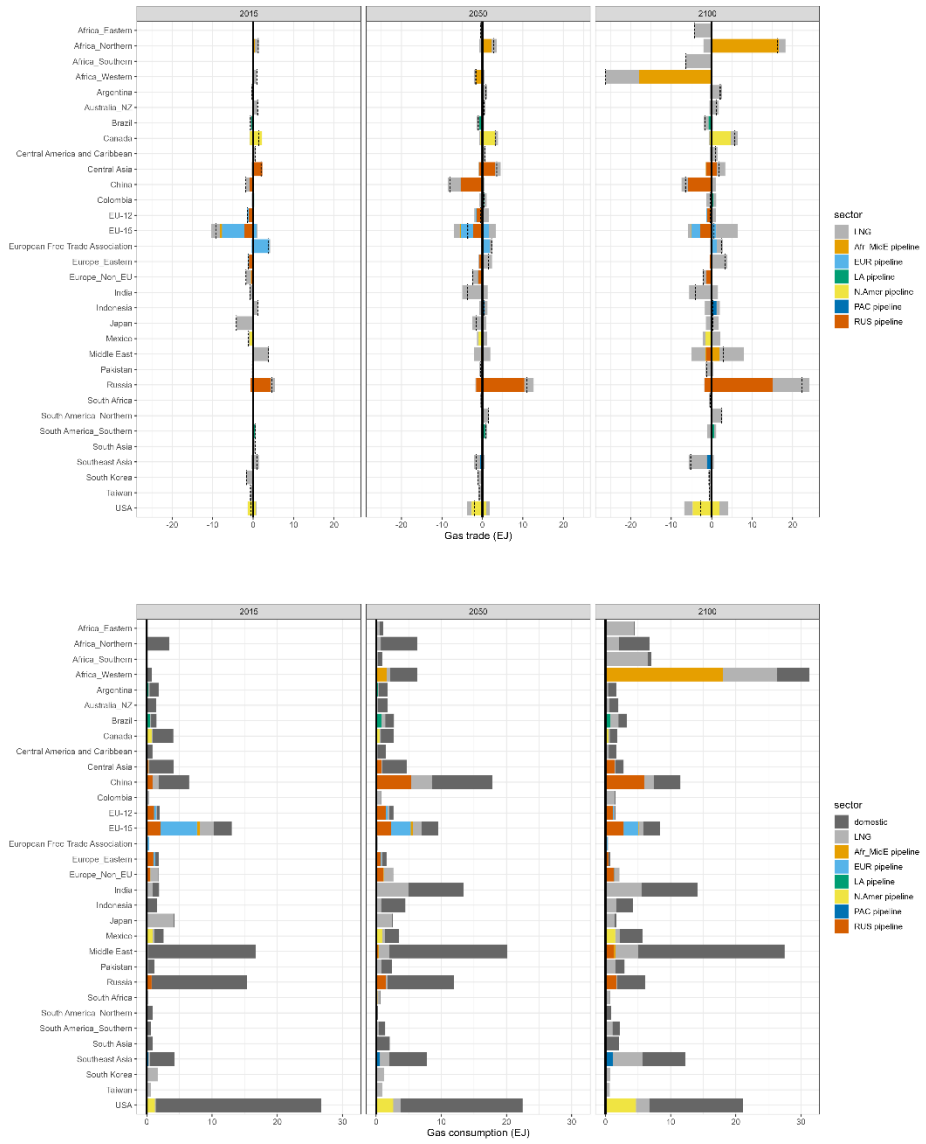
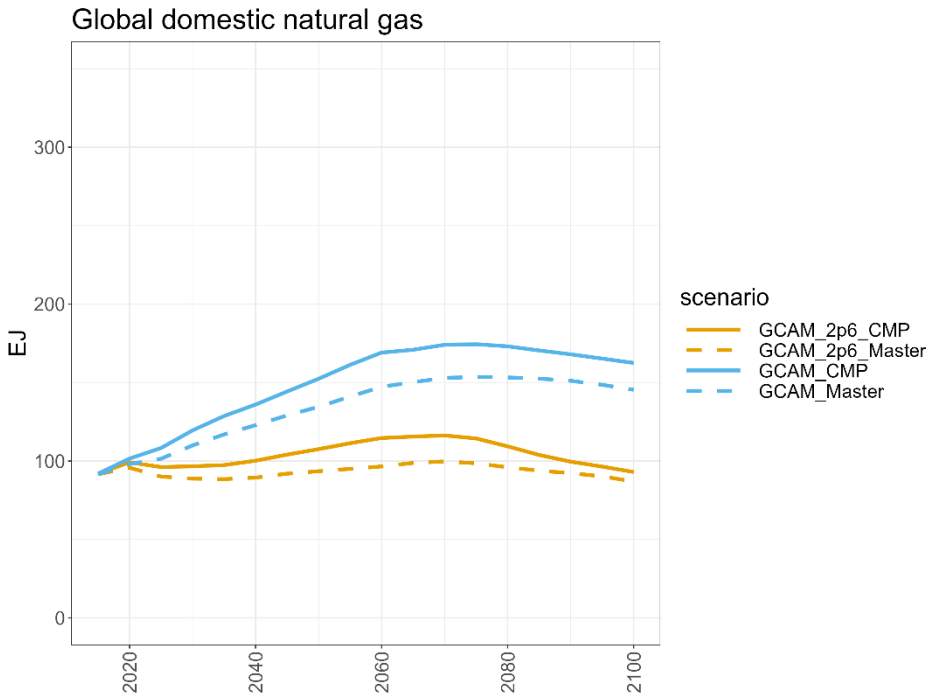


Figure 7. Regional natural gas projections (by GCAM region) in GCAM_2p6_CMP scenario. a, top) Natural gas production, b, middle) Natural gas trade. Gross exports are shown to the right of the y-axis, gross imports are shown to the left of the y-axis, and net trade is shown with a dashed line. c, bottom) Natural gas consumption.

In the Reference ("GCAM_CMP") scenario, the USA, Middle East, and Russia are the largest gas producers and remain so through 2050. By 2100, these three regions continue to remain dominant producers, with Africa_Northern becoming the second largest producer. Russia is a major pipeline gas exporter in 2015, and remains so under Reference conditions through the century. Russian pipeline gas is imported by many regions in Europe, and Central Asia and China. Canada and Africa_Northern also become major pipeline gas exporters by 2100, largely imported by the USA and Africa_Western, respectively. Several regions increase their LNG exports or imports over the century. Historically, the USA, Middle East, Russia and EU-15 were the largest NG consumers in 2015. China and India become major consumers in 2050, and

Africa_Western becomes a major consumer (largely of imported pipeline gas) by 2100. In the GCAM_2p6_CMP scenario, regional natural gas production, trade, and consumption trends remain similar as under Reference, but lower in magnitude.

Comparison of this CMP and Master:



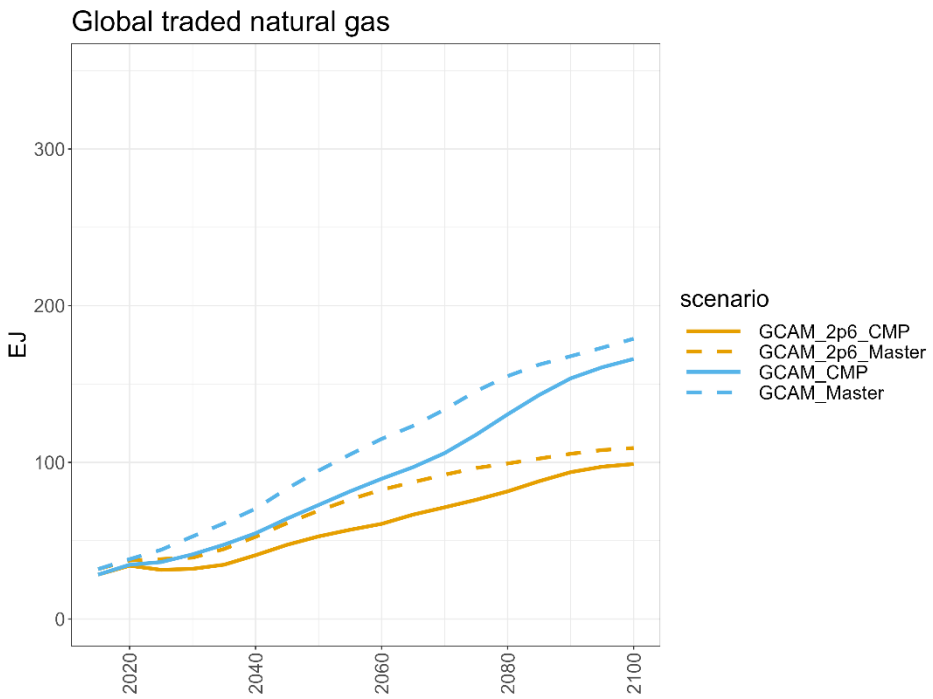
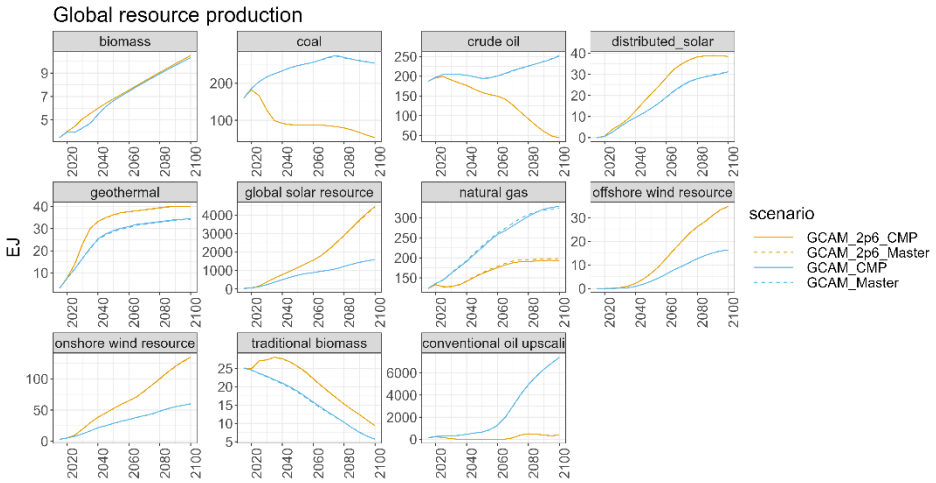
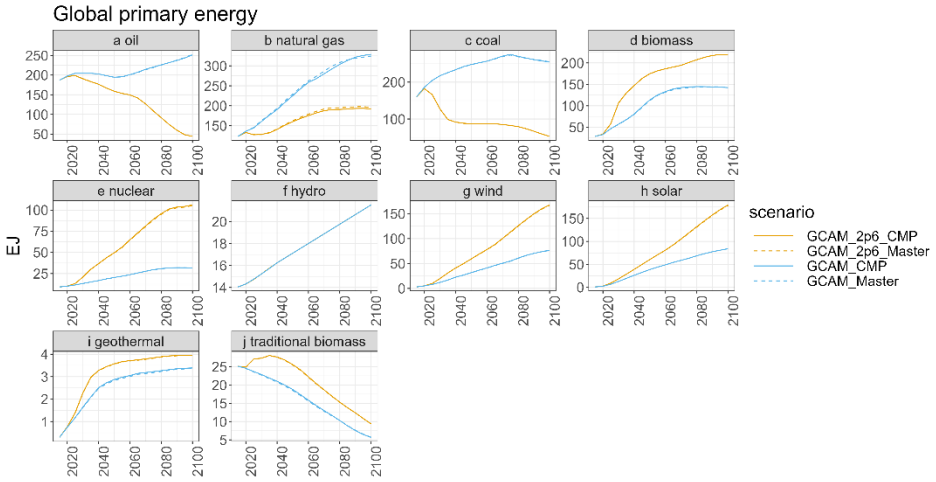


Figure 8. a) Global total domestic natural gas, b) Global total traded natural gas. This CMP results in more domestic gas and less traded gas over the century compared to the current master branch.





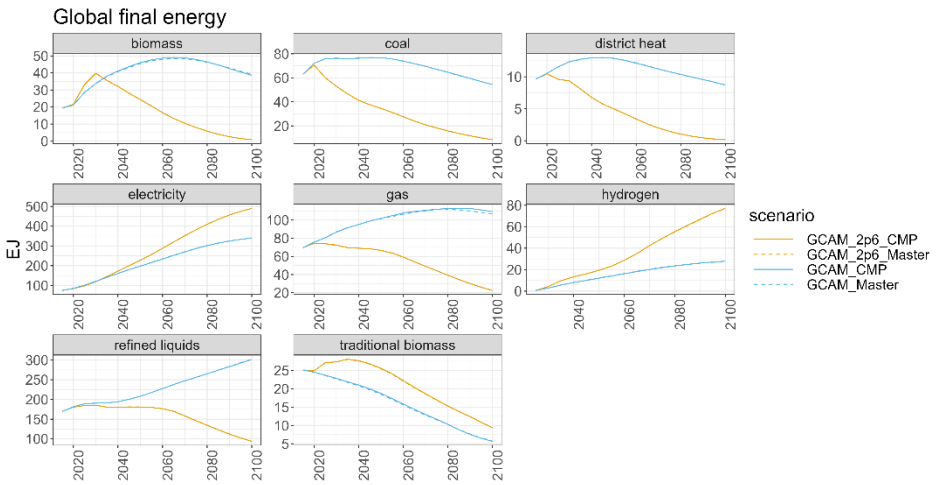


Figure 9. a) Global resource production; b) Global primary energy; c) Global final energy. This CMP does not significantly change the overall energy production and consumption across fuels.

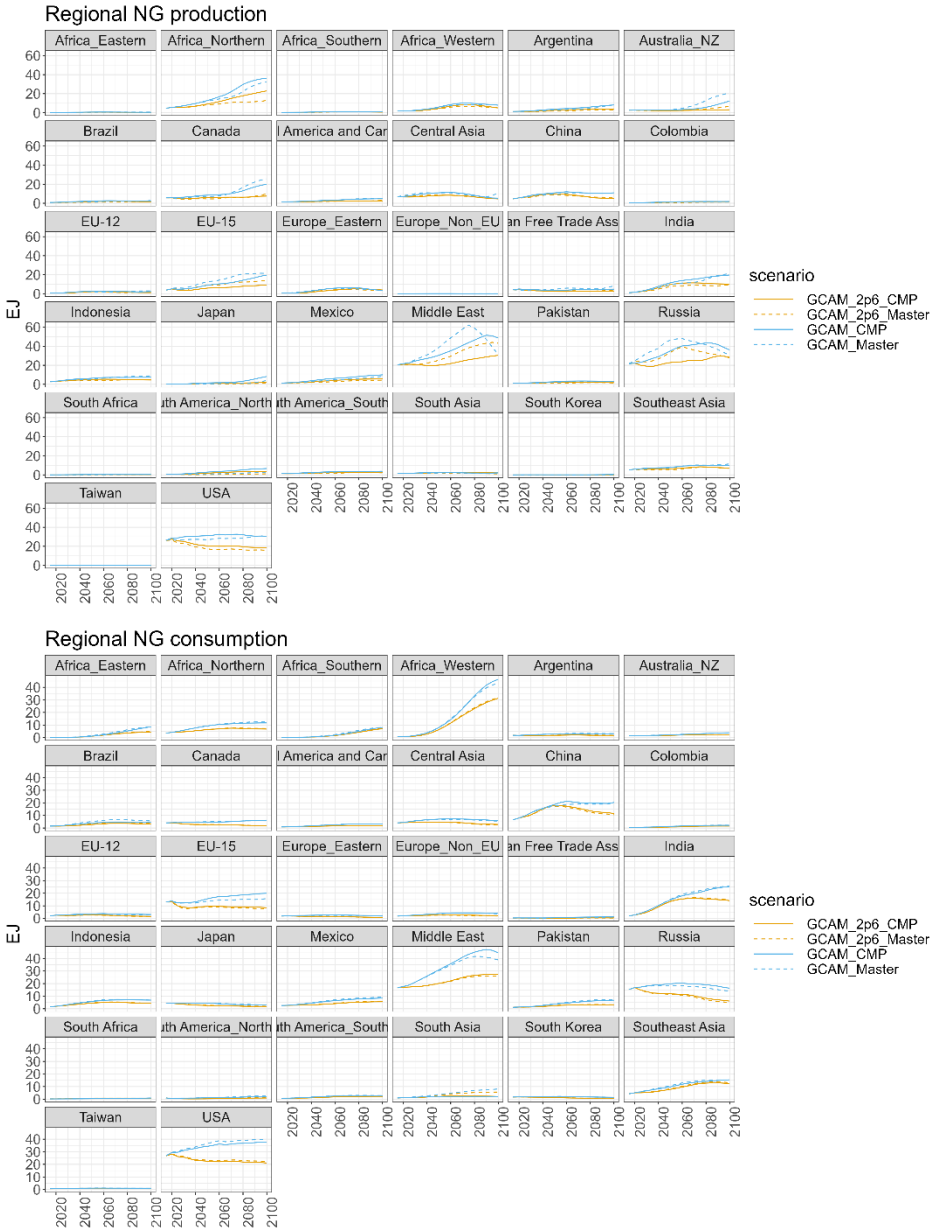
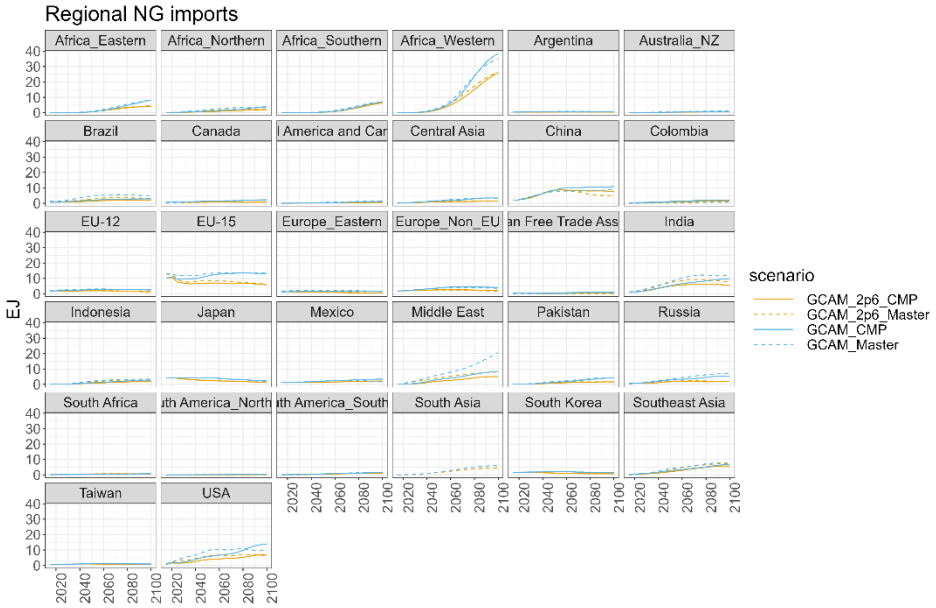
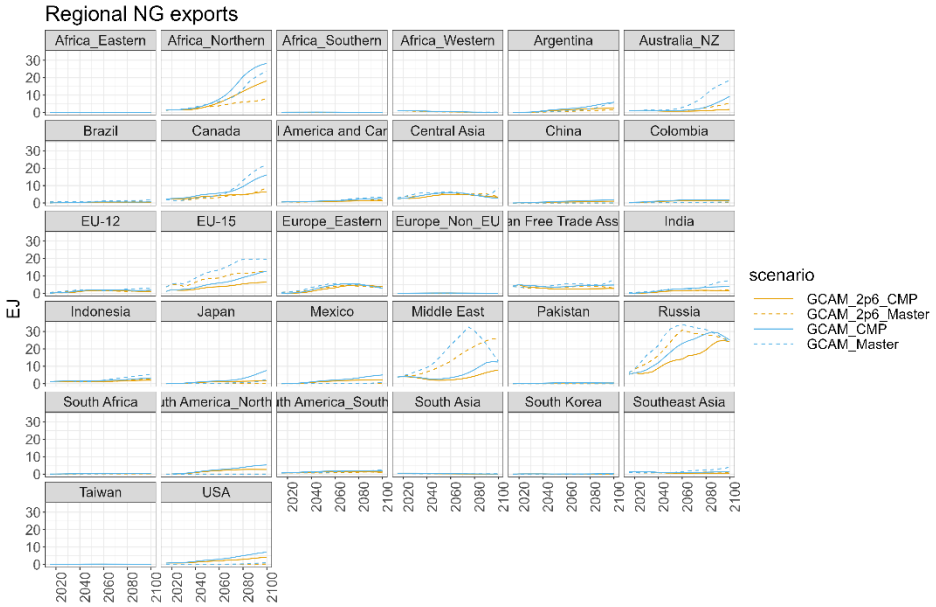


Figure 10. a) Regional natural gas production, b) Regional natural gas consumption. This CMP results in slightly more natural gas production in the USA, Africa_Northern, and India by end of century, as well as in the Middle East and Russia under the Reference scenario. There is less natural gas production in Africa_Western, Australia_NZ, Canada, EU-15, as well as Russia and Middle East under 2p6. This CMP results in slightly more natural gas consumption in EU-15, Middle East, Russia, and less natural gas consumption in the USA.


Regional NG imports
Africa_Eastern
Africa_Northern
Africa_Southern
Africa_Western
Argentina
Australia_NZ
Brazil
Canada
l America and Car
Central Asia
China
Colombia
EU-12
EU-15
Europe_Eastern
Europe_Non_EU
an Free Trade Ass
India
Indonesia
Japan
Mexico
Middle East
Pakistan
Russia
South Africa
ith America_North
ith America_South
South Asia
South Korea
Southeast Asia
Taiwan
USA
EJ
scenario
GCAM_2p6_CMP
GCAM_2p6_Master
GCAM_CMP
GCAM_Master


Regional NG exports
Africa_Eastern
Africa_Northern
Africa_Southern
Africa_Western
Argentina
Australia_NZ
Brazil
Canada
l America and Car
Central Asia
China
Colombia
EU-12
EU-15
Europe_Eastern
Europe_Non_EU
an Free Trade Ass
India
Indonesia
Japan
Mexico
Middle East
Pakistan
Russia
South Africa
ith America_North
ith America_South
South Asia
South Korea
Southeast Asia
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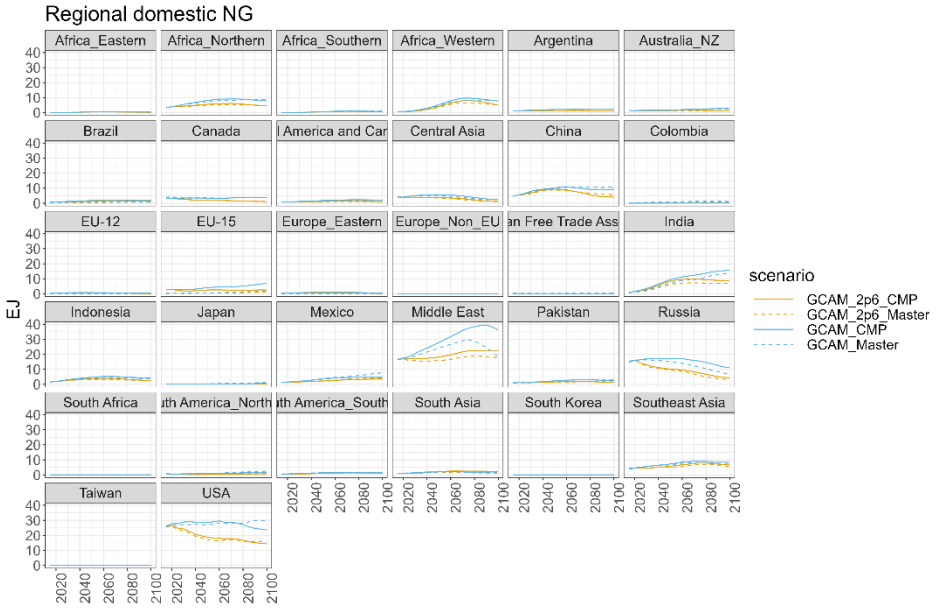

Figure 11. a) Regional natural gas imports, b) Regional natural gas exports, c) Regional domestic natural gas. This CMP results in more gas imports in Africa_Western and China, and less gas imports in EU-15, India, the Middle East, and Russia. In the USA, there are less imorts in the CMP than in Master for most the century, but more imports This CMP results in more gas exports from Africa_Northern and the USA, and less gas exports from Australia_NZ, Canada, EU-15, the Middle East, and Russia. Changes in domestic gas include more domestic gas consumption in the Middle East, Russia, EU-15, and India, and less domestic gas consumption in the US by the end of the century.

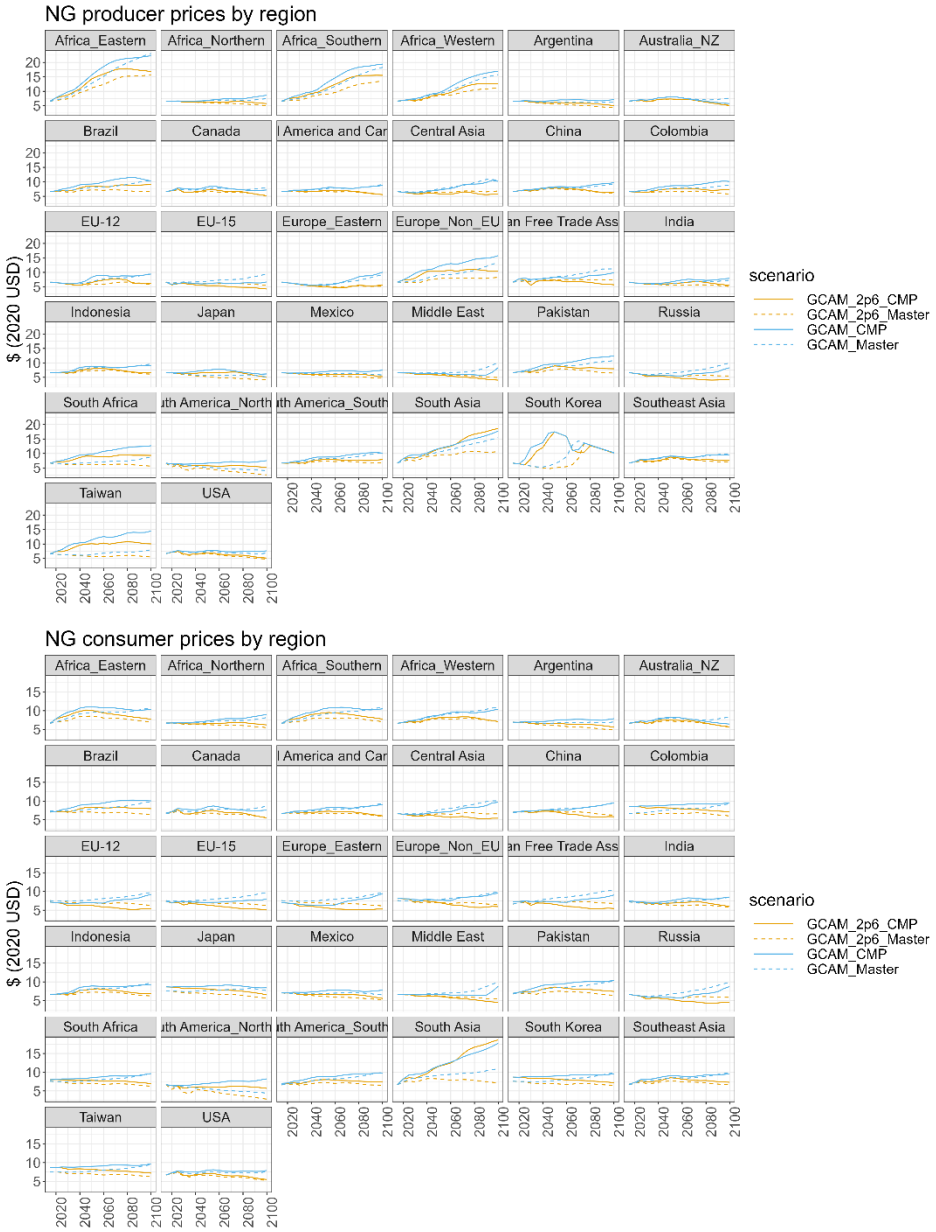

Figure 12. a) Natural gas producer prices by region, b) Natural gas consumer prices by region.

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