Core Model Proposal 414: Update to non-CO2 MAC curves: 2025

Product: Global Change Analysis Model (GCAM)

Institution: Joint Global Change Research Institute (JGCRI)

Authors: Paelina DeStephano, Gokul Iyer

Reviewers: Pralit Patel, Kate Calvin

Date committed: May 22, 2026

IR document number: PNNL-39438

Related sector: Emissions

Type of development: Data

Purpose: Updated input data

Background
Much of the work done to incorporate the EPA MAC into GCAM is documented in CMP 313. This CMP reflects the 2025 updates the EPA has made to the non-CO2 MACCs. These updates include the Oil and Gas NSPS, the AIM ACT regulations, and the CHIPS Act.

New options for mitigation have been included for enteric fermentation, including red algae, cattle masks, 3-NOP, and intensive grazing. New manure management options including renewable natural gas have also been added, which assume 50% of mixed digesters or covered lagoons are linked to an RNG system.

The DayCent model used for croplands has been expanded to include 20+ crops with a 5-degree grid resolution. Nitrogen use is assumed to be consistent with an SSP2 scenario. The use of the DayCent model reveals higher methane emissions from rice cultivation than the previous modeling approach.

In the oil and gas sector, new baseline emissions projections are used for the US, incorporating the 2024 NSPS/EG rulemaking. In other countries, high-efficiency mitigations options are available to reduce oil and gas emissions. Updated baseline emission projections for coal mining were also implemented

Updated baseline emission projections are also implemented for landfills and wastewater. New mitigation options in the waste sector include landfill RNG.

The MAC updates to industrial processes and product use include updated baseline emissions for ODS Substitutes, incorporating vintaging model estimates from SPD consistent with AIM Act analyses and the inclusion of the Kigali Amendment for signatories to the Montreal Protocol. For electronics, semiconductor mitigation options and costs were updated and projections now include the US growth consistent with the CHIPS Act analyses. Baseline projections, costs, and availability of mitigation options were also updated for electric power systems, consistent with an expanded grid due to increased electricity demand. For metal production, updated model results indicate lower baseline emissions and mitigation potential.

The new MAC data also includes updates to baseline emission projections for HCFC-22, Nitric Acid and Adipic Acid.

Description of Changes
New Data Sets
The data for this update can be found in gcam-core\input\gcamdata\inst\extdata\ emissions\EPA_2025, in gcamdata PREBUILT_DATA and in DOI: 10.5281/zenodo.20337889. Data includes updates to emission baselines, MACC results by sector, and relevant sectoral and regional mapping files. The updates to emission baselines and mac results are directly produced by the EPA and available for public download. Detailed plots of the changes to the MAC curves as a result of the new input data are at the end of this CMP in Appendix A.

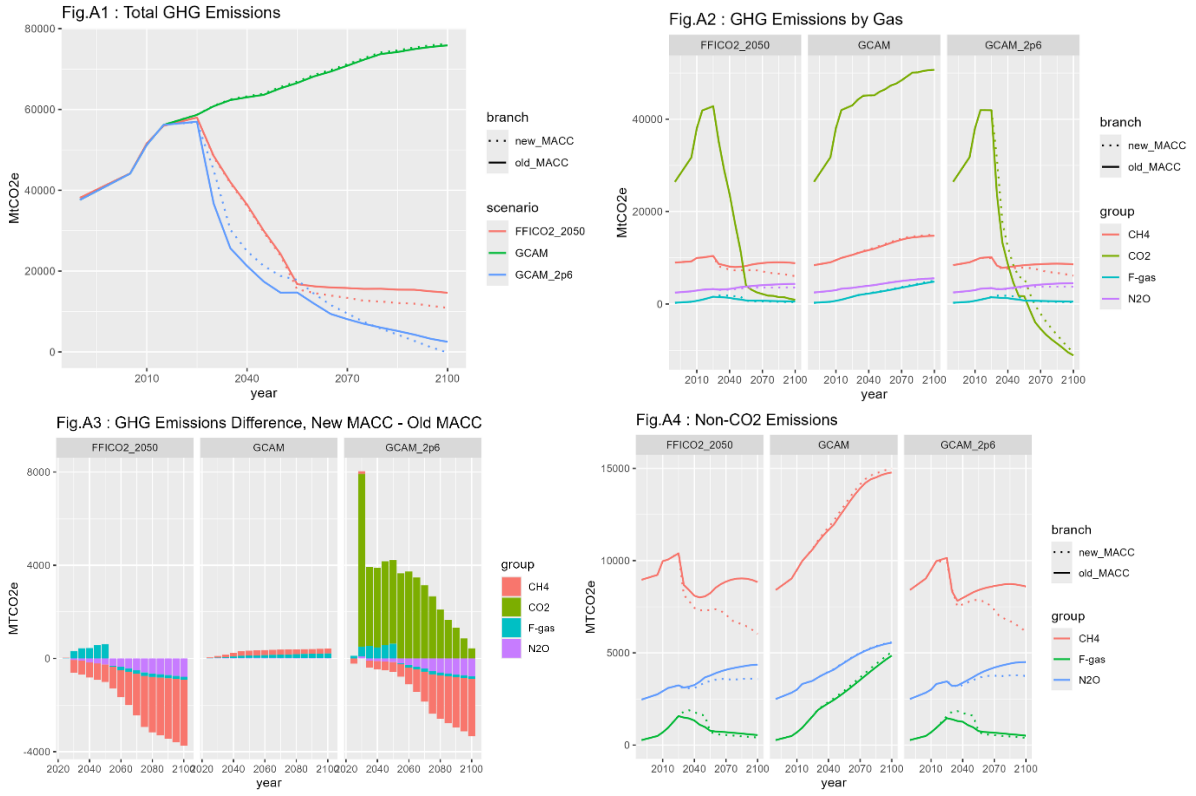
GCAM Data System
Most changes to the GCAM data system occur in zemissions_L152.MACC.R and are primarily associated with reading in new data files and updating dollar-year conversions as appropriate.

One change occurs in line 135 of zemissions_L252.MACC.R, which is to change the mac_reduction_adder function error_no_match default to FALSE.

Validation
This validation section first focuses on two standard validation runs - titled GCAM and GCAM_2p6, and a custom run, FFICO2_2050. The first is a default run, the second uses the 2p6 forcing target, and the FFICO2_2050 run is a global FFI CO2 constraint that reaches 0 by 2050. This added scenario allows insight into the response of non-CO2s when maintaining consistent CO2 declines.

Figure A.1 compares the global total GHG emissions in the current GCAM projections (old_MACC, solid line) and the proposed modification (new_MACC, dashed line) for two validation scenarios - GCAM (representing the default scenario), GCAM_2p6, and FFICO2_2050. Overall, the new MACCs do not lead to significant changes in the GCAM scenario. In the GCAM_2p6 scenario, there is an increase in GHG emissions in the near-term, but by 2080 the GHG emissions under the new MACC are lower. In the FFICO2 total GHG emissions decline in lockstep through 2050, with the new MACC achieving more reductions in the second half of the century.

Figures A.2 – A.4 show global GHG emissions by gas. The changes in the GCAM scenario are minimal. In the GCAM_2p6 scenario, the MACC updates lead to a relative decline in CH4 and N2O, a small near-term relative increase in F-gases and a relative increase in CO2, particularly in 2030. The differences under FFICO2_2050 are less dramatic given the constant levels of CO2 imposed by the constraint. The new MACC leads to more significant declines in all nonCO2s with the exception of a near term increase in F-gases.



Looking at the changes to CH4 in more depth in figure A.5, we see that the new MACCs lead to a notable decrease in agricultural methane under the GCAM_2p6 and FFICO2_2050 scenarios, with a small increase in CH4 from FFI in the GCAM and GCAM_2p6 scenarios. Figure A.6 shows that the decreases in CH4 emissions in the GCAM_2p6 and FFICO2_2050 scenarios occur in all sectors, but most prominently in beef and dairy. These declines in emissions are not attributable to a reduction in production as shown in the emission intensity results in figure A.7.

Fig.A5 : CH4 Emissions

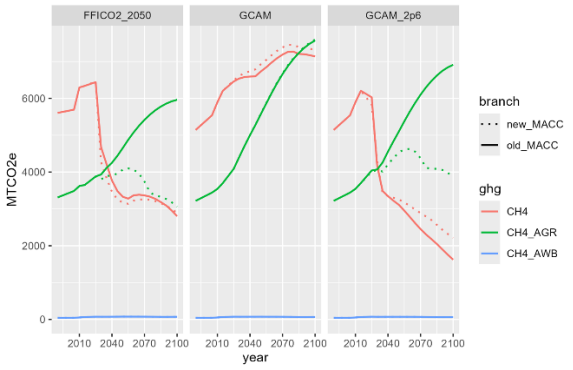


Fig.A6 : CH4_AGR Emissions

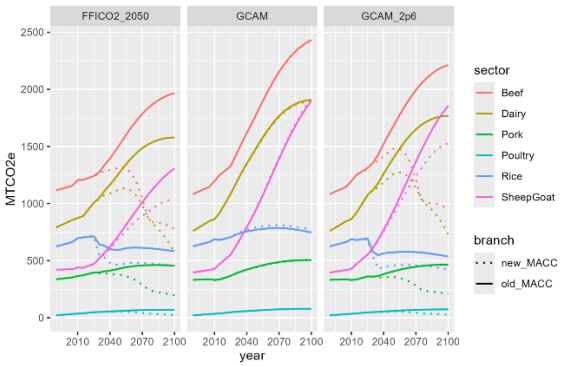
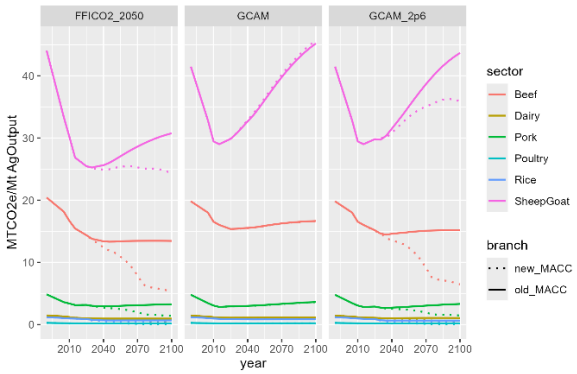


Fig.A7 : CH4_AGR Emissions Intensity



Turning to other CH4 emissions (i.e. not those coded as CH4_AGR or CH4_AWB), we see in figure A.8 that the new MACCs lead to increases in emissions in Urban Processes, Natural Gas, and Crude Oil in the GCAM scenario, and declines in Coal emissions as compared to the previous MACCs. Under the GCAM_2p6 scenario, in which the model favored mitigation reductions in CH4_AGR to meet forcing targets, we see a relative increase in CH4 emissions in Urban Processes, and Coal, with short term relative decreases in CH4 emissions from Oil and Natural Gas. In the FFICO2_2050 scenario, we see sustained declines in Oil and Natural gas emissions. For clarity, smaller emissions categories are shown in figure A.9.

Fig.A8 : CH4 Emissions by Sector

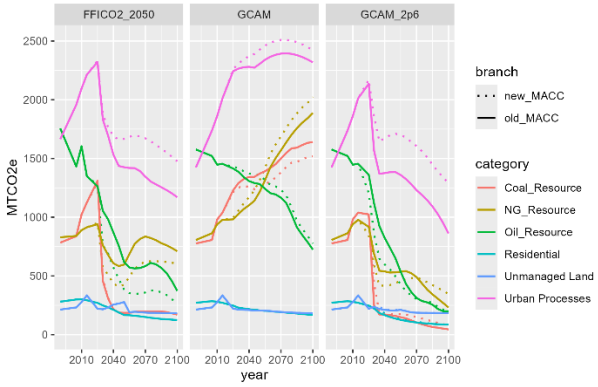
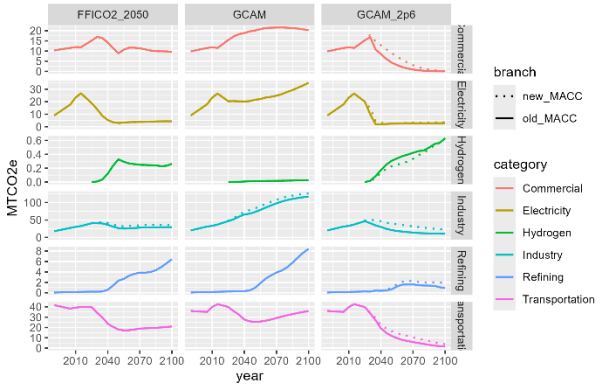


Fig.A9 : CH4 Emissions by Sector



Looking at N2O emissions in figure A.10, we see small changes in the GCAM scenario - lower N2O emissions in N2O_AGR and higher emissions in the FFI N2O category. Under GCAM_2p6 and FFICO2_2050, there is a similar but more pronounced trend, with high mitigation potential in N2O_AGR. Figure A.11 shows the changes in N2O_AGR emissions by sector and illuminates similar trends to what was observed in CH4 - strong reductions in Beef and Dairy, and smaller reductions in other sectors.

Fig.A10 : N2O Emissions

Fig.A11 : N2O_AGR Emissions

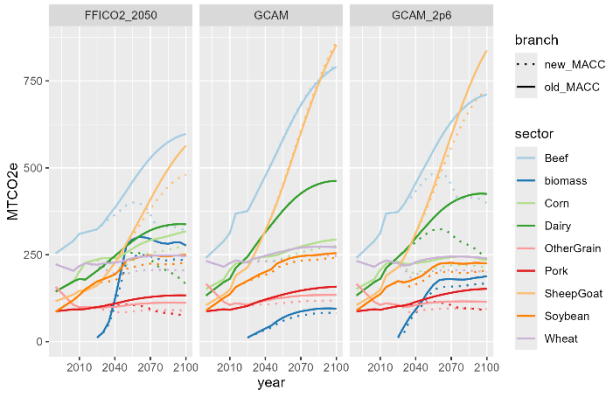


Fig.A12 : N2O Emissions by Sector

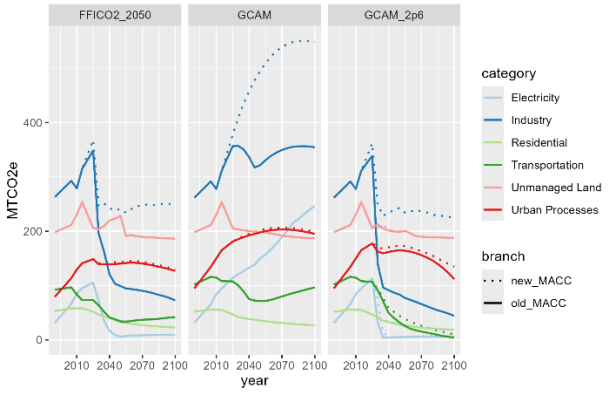
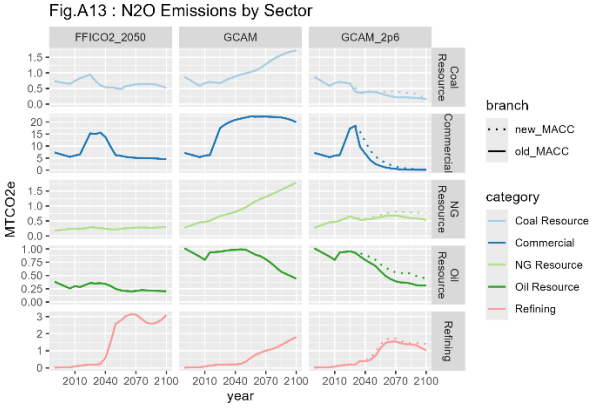
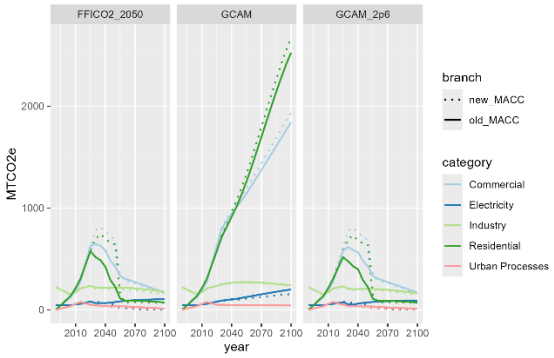


Fig.A13 : N2O Emissions by Sector



The N2O species (e.g. not N2O_AGR or N2O_AWB) sees much higher emissions under the new MACC for the industry sector in all scenarios, as seen in figure A.12. The other sectors, shown in figure A.13, show more modest changes. Figure A.14 shows F-gas emissions under the GCAM scenario MACC updates show slightly higher emissions in the Residential and Commercial sector, and lower emissions in the Electricity Sector. In the GCAM_2p6 and FFICO2_2050 scenario, Commercial and Residential emissions are a fair bit higher in the near term under the new MACC. This uptick in F-gases is driven by a near-term (2030-2050) increase in HFC125, HFC134a, and HFC143a within commercial and residential electric cooling.

Fig.A14 : F-gas Emissions by Sector



Turning our attention to CO2, we do not see any changes in CO2 in the default scenario or under the CO2 constraint (GCAM and FFICO2_2050 scenarios) as this update does not make changes to CO2 emissions. We do see changes to CO2 emissions under the GCAM_2p6 scenario. As we saw in figure A.2, lower emissions among non-CO2s leaves room for higher CO2 emissions to reach the 2p6 target. Figure A.15 shows a sectoral breakdown of CO2 emissions, and we see the largest increases in CO2 emissions under the new MACC occurring in industry and transportation. Figure A.16 shows the changes in CO2 sequestration, with more CO2 sequestration occurring in the electric sector towards the end of the century and somewhat lower sequestration occurring in H2 central production and iron and steel. Figure A.17 shows the resulting CO2 price to be lower under the new MACC.

Fig.A15 : CO2 Emissions by Sector

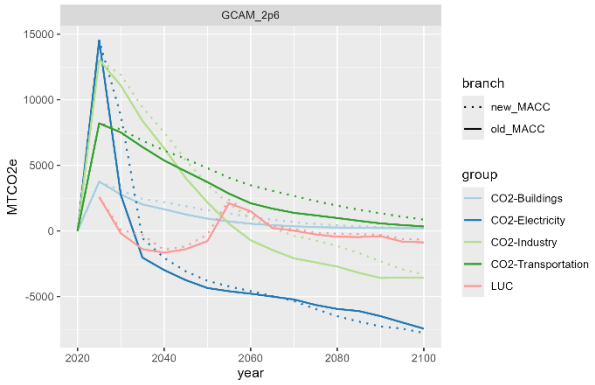


Fig.A16 : CO2 Sequestration

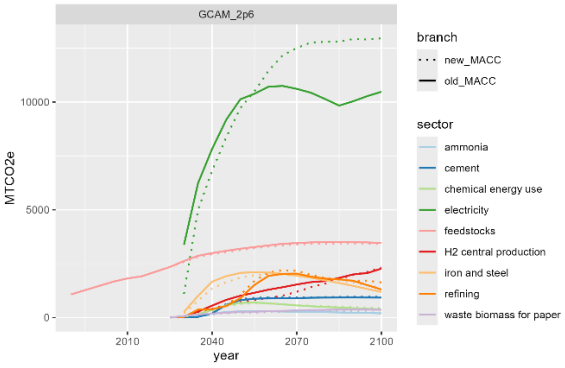
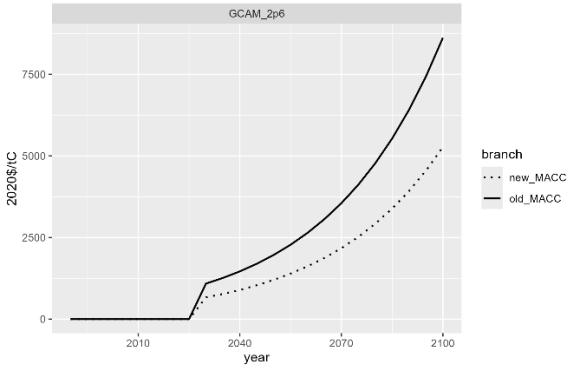


Fig.17 : CO2 Price



Turning to results for the climate system, we see in figure A.18 that the new MACC leads to near term increases in temperature in the 2p6 scenario and overall lower global temperature in the FFICO2_2050 scenario, trends replicated in the climate forcing results shown in figure A.19.

Fig.A18 : Global Mean Surface Temperature

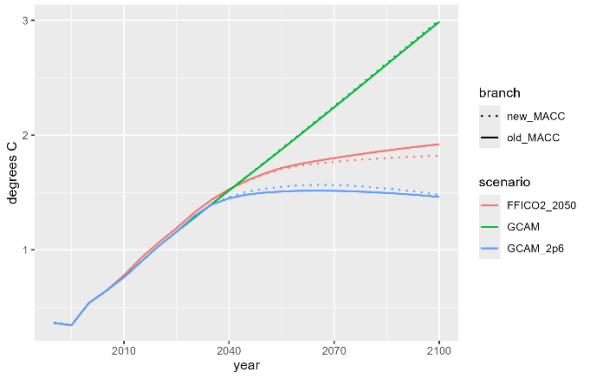
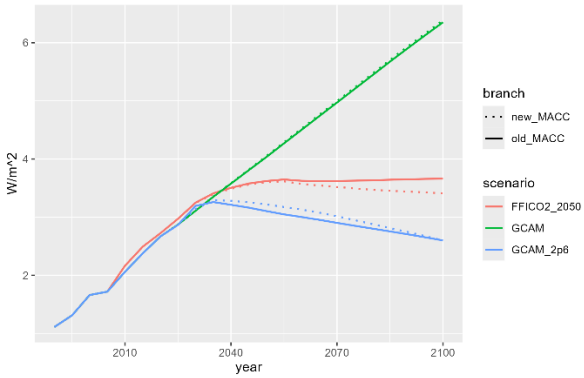


Fig.A19 : Climate Forcing



Appendix A: Changes to MAC Inputs

There are some changes to the MAC Control availability on a regional basis based on the underlying data provided by the EPA. There are no longer MAC controls for:

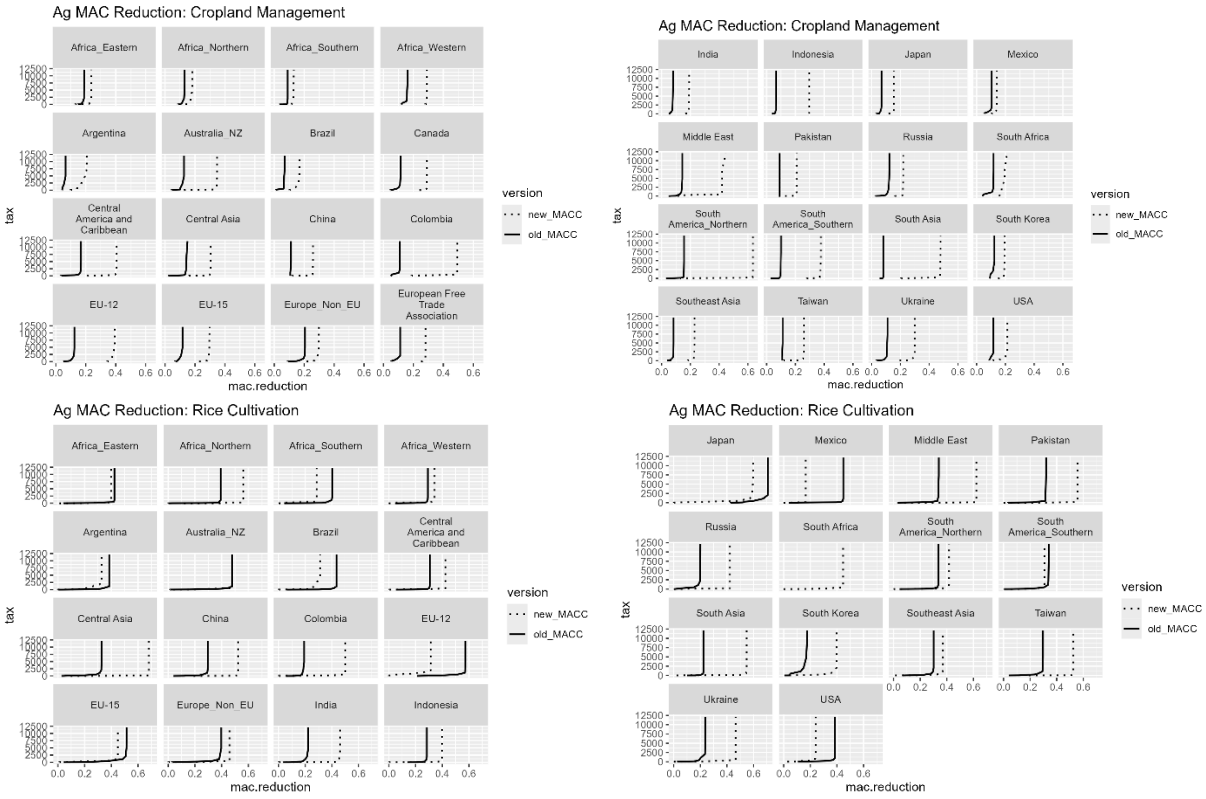
- Solvent Use in the USA, Autralia_NZ, Canada, EU-12, European Free Trade Association, Japan, Mexico, EU-15 and South Korea.
- HCFC-22 Production in China, EU-15, India, Mexico, South America_Northern, South Korea, Southeast Asia, Japan, Russia and Argentina
- Coal Mining Activities in Africa Eastern
- Landfilling of Solid Waste in South Africa
- Nitric and Adipic Acid Production in Africa Eastern
- Semiconductor Manufacturing in Africa Eastern
- Aluminum and Magnesium Production in Colombia
- Electric Power Systems in EU-15, EU-12 and Japan
- Foams in Australia_NZ, Canada, Mexico

There are now MAC Controls for:

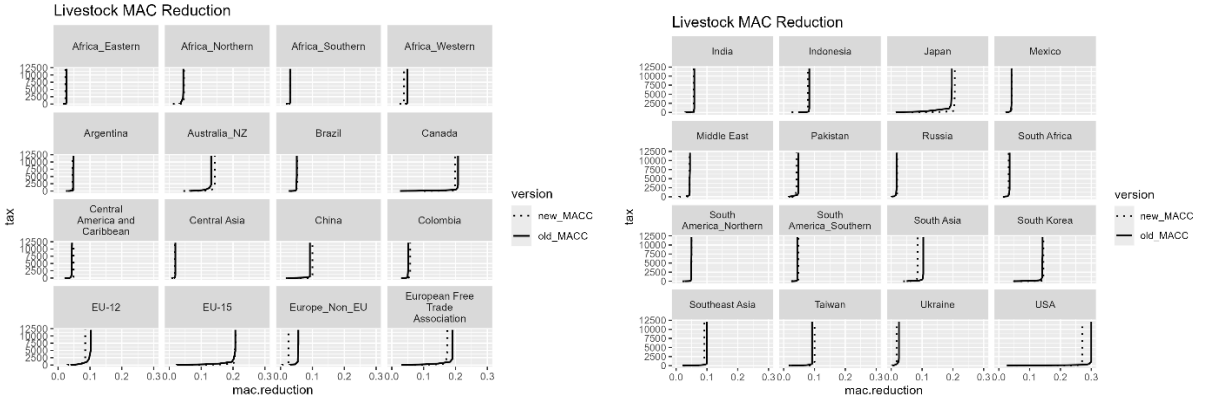
- Rice Cultivation in South Africa
- Fire Protection in India
- Foams in Africa Eastern, Africa Northern, Africa Southern, Africa Western, Central America and Caribbean, Central Asia, South America Northern, South Asia, Southeast Asia
- Nitric and Adipic Acid Production in Africa Southern, Africa Western, Pakistan, and South Asia

Consistent with previous MAC Curves, there are no MAC Controls for F-gases in Taiwan

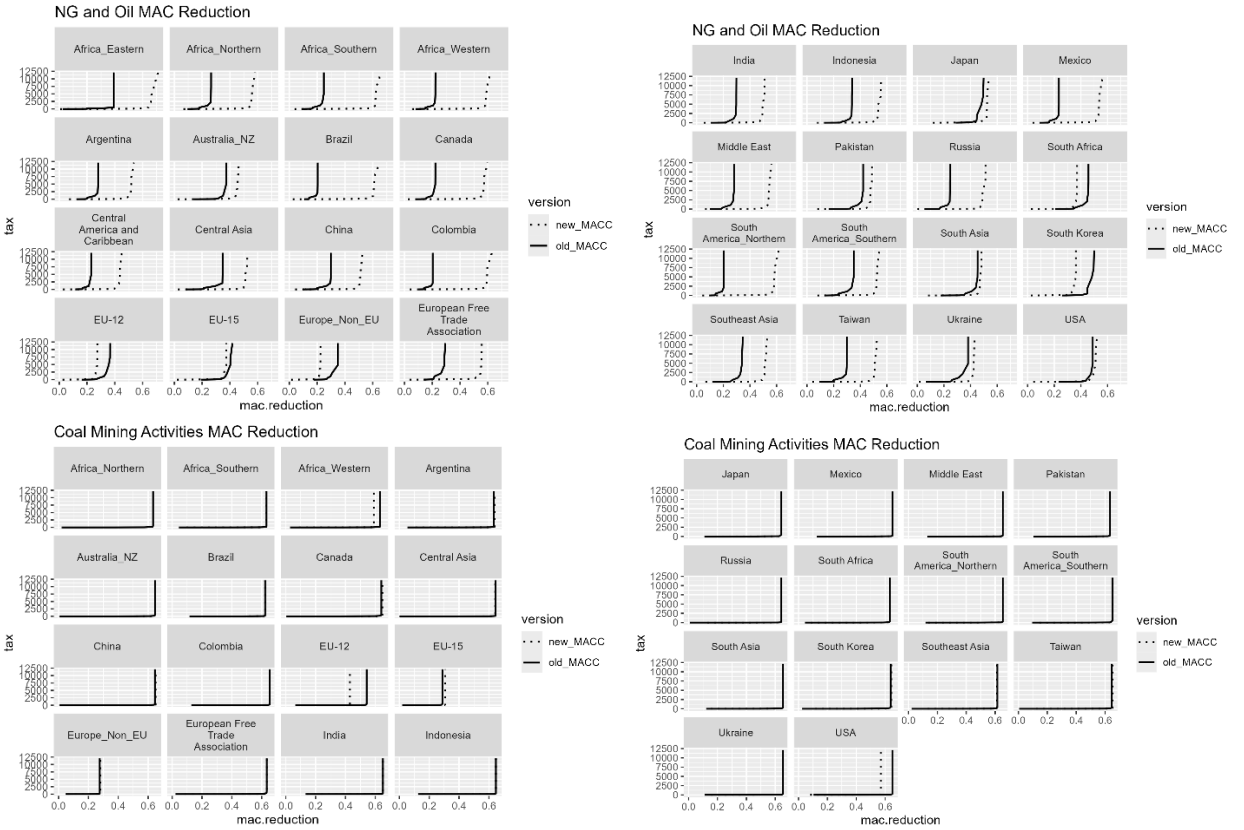
The MAC curves in L252.AgMAC represent MAC controls for "Cropland Management" and "Rice Cultivation" among all AgSupplySectors. The MAC curves vary by region and mac control, but are the same for all AgSupplySectors, and Non.CO2s (CH4_AGR and N2O_AGR in this instance). AgSupplySubsectors and AgProductionTechnologies are regionalized, and thus vary by region, for instance the MAC is the same for CornC4_AfrCstE_IRR_lo and CornC4_AfrCstE_RFD_hi - and all technologies within the African_Eastern region.



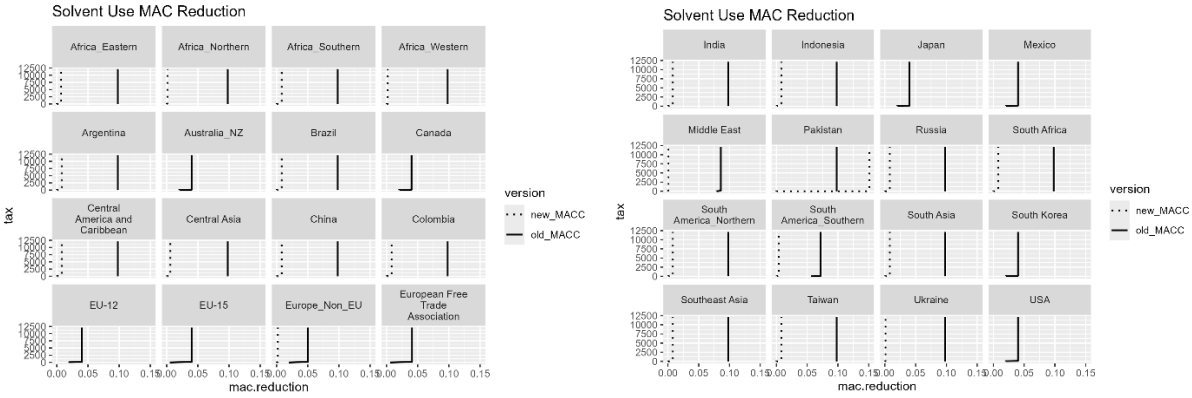
The MAC curves in L252.MAC_an represent MAC controls for "Livestock" among "Beef", "Dairy", "Pork", "Poultry" and "SheepGoat" supplysectors. The MAC curves vary by region, but are the same for all supplysectors, subsectors, stub.technologies, and Non.CO2s (CH4_AGR and N2O_AGR in this instance).

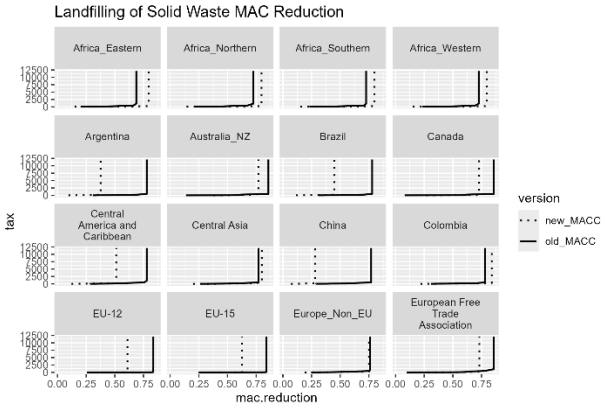


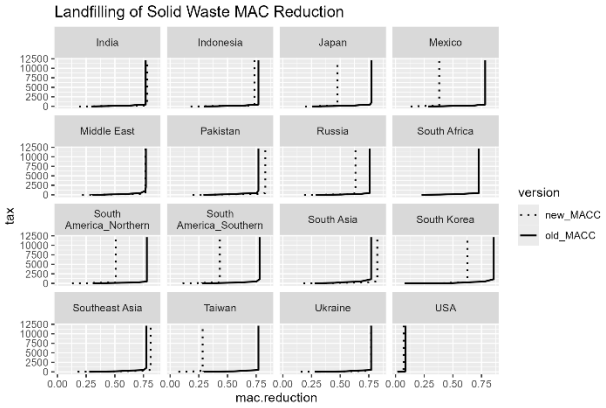
The MAC curves in L252.ResMAC_fos, represent MAC controls for "Natural Gas and Oil Systems" and "Coal Mining Activities". The MAC curves vary by region, but are the same for all resources, subresources, technologies, and Non.CO2s (just CH4 in this instance).

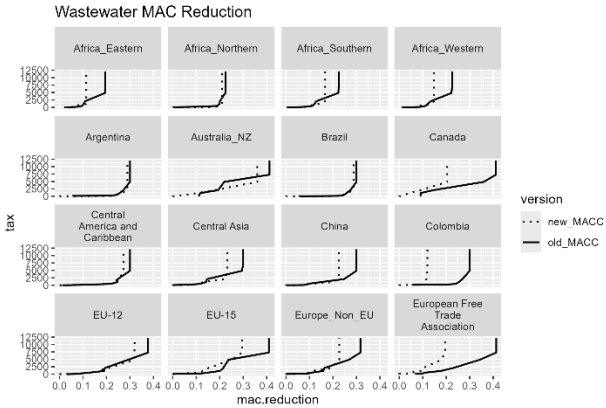


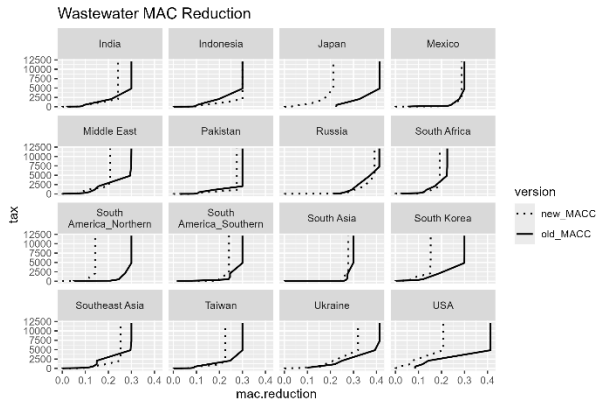
The MAC curves in L252.MAC_prc, represent MAC controls for "Solvent Use", "Landfilling of Solid Waste", "Wastewater", "Nitric and Adipic Acid Production" and "HCFC-22 Production". The MAC curves vary by region, but are the same for all supplysectors, subsectors, stub.technologies, and Non.CO2s (CH4 and N2O in this instance). MACs for F-gases associated with Solvent Use are shown in conjunction with L252.MAC_higwp.

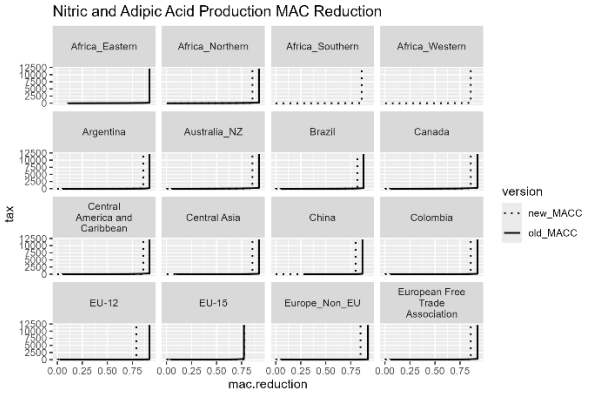


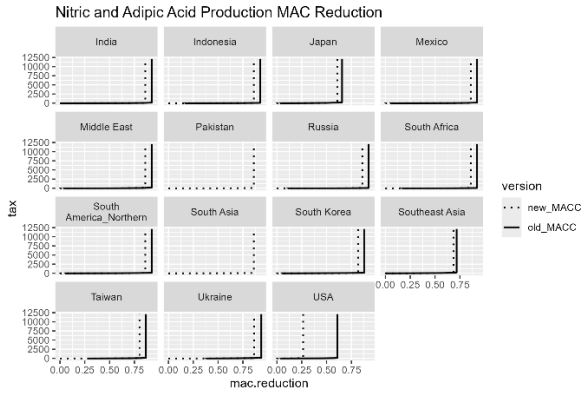

Landfilling of Solid Waste MAC Reduction
Africa_Eastern
Africa_Northern
Africa_Southern
Africa_Western
Argentina
Australia_NZ
Brazil
Canada
Central America and Caribbean
Central Asia
China
Colombia
EU-12
EU-15
Europe_Non_EU
European Free Trade Association
tax
mac.reduction
version
new_MACC
old_MACC

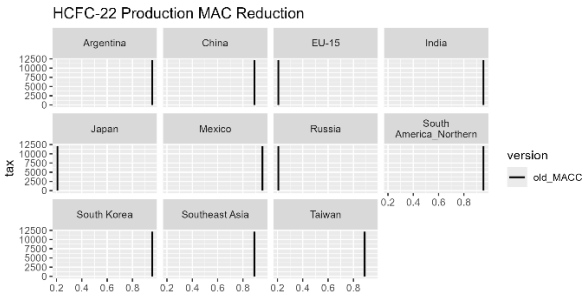

Landfilling of Solid Waste MAC Reduction
India
Indonesia
Japan
Mexico
Middle East
Pakistan
Russia
South Africa
South America_Northern
South America_Southern
South Asia
South Korea
Southeast Asia
Taiwan
Ukraine
USA
tax
mac.reduction
version
new_MACC
old_MACC


Wastewater MAC Reduction
Africa_Eastern
Africa_Northern
Africa_Southern
Africa_Western
Argentina
Australia_NZ
Brazil
Canada
Central America and Caribbean
Central Asia
China
Colombia
EU-12
EU-15
Europe_Non_EU
European Free Trade Association
tax
mac.reduction
version
new_MACC
old_MACC

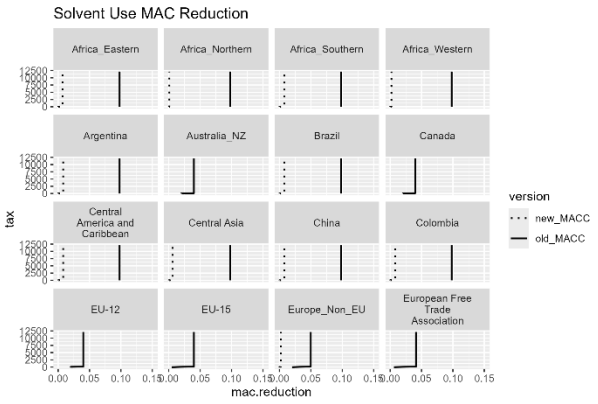

Wastewater MAC Reduction
India
Indonesia
Japan
Mexico
Middle East
Pakistan
Russia
South Africa
South America_Northern
South America_Southern
South Asia
South Korea
Southeast Asia
Taiwan
Ukraine
USA
tax
mac.reduction
version
new_MACC
old_MACC

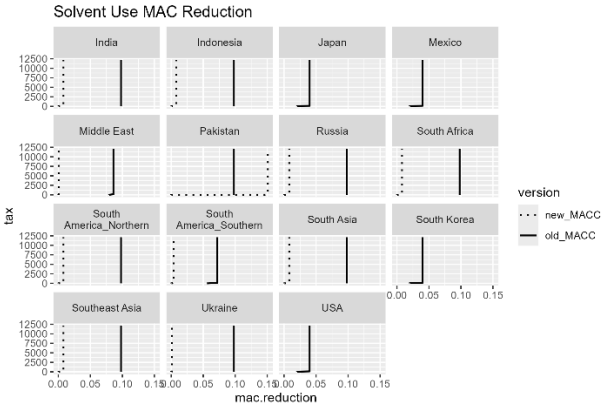

Nitric and Adipic Acid Production MAC Reduction
Africa_Eastern
Africa_Northern
Africa_Southern
Africa_Western
Argentina
Australia_NZ
Brazil
Canada
Central America and Caribbean
Central Asia
China
Colombia
EU-12
EU-15
Europe_Non_EU
European Free Trade Association
tax
mac.reduction
version
new_MACC
old_MACC

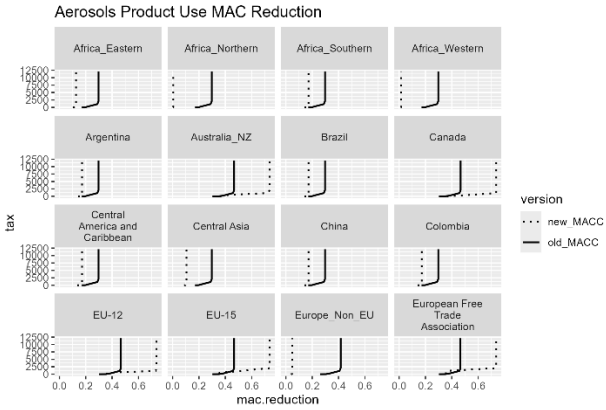

Nitric and Adipic Acid Production MAC Reduction
India
Indonesia
Japan
Mexico
Middle East
Pakistan
Russia
South Africa
South America_Northern
South Asia
South Korea
Southeast Asia
Taiwan
Ukraine
USA
tax
mac.reduction
version
new_MACC
old_MACC

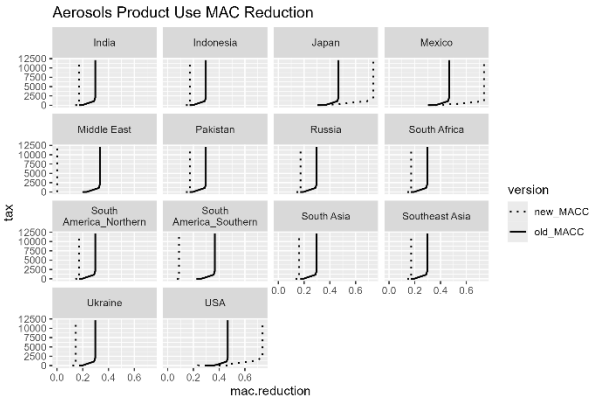

HCFC-22 Production MAC Reduction
Argentina
China
EU-15
India
Japan
Mexico
Russia
South America_Northern
South Korea
Southeast Asia
Taiwan
tax
mac.reduction
version
old_MACC

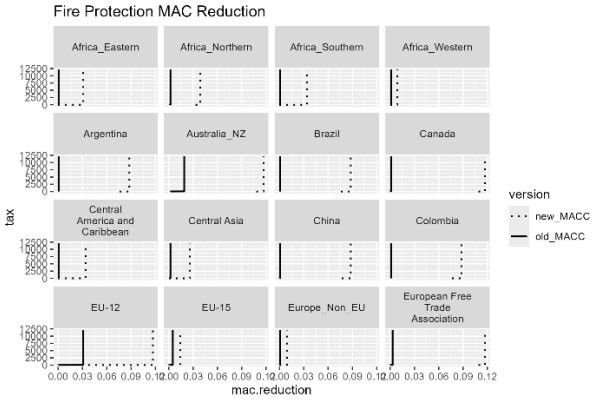
The MAC curves in L252.MAC_higwp, represent F-gas MAC controls for "Refrigeration and Air Conditioning", "Electric Power Systems", "Foams", "Solvent Use", "Aerosols Product Use", "Fire Protection", "Aluminum and Magnesium Production", and "Semiconductor Manufacturing".

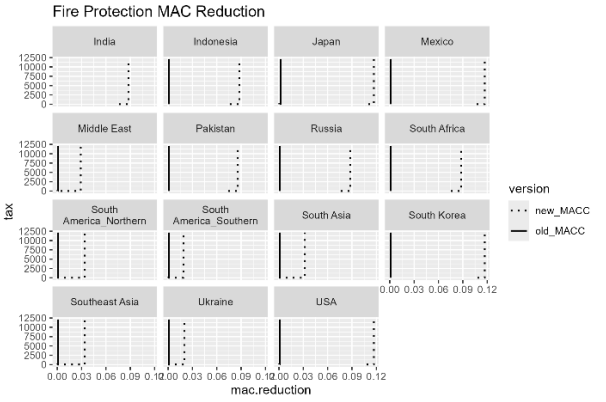

Solvent Use MAC Reduction
Africa_Eastern
Africa_Northern
Africa_Southern
Africa_Western
Argentina
Australia_NZ
Brazil
Canada
Central America and Caribbean
Central Asia
China
Colombia
EU-12
EU-15
Europe_Non_EU
European Free Trade Association
tax
mac.reduction
version
new_MACC
old_MACC

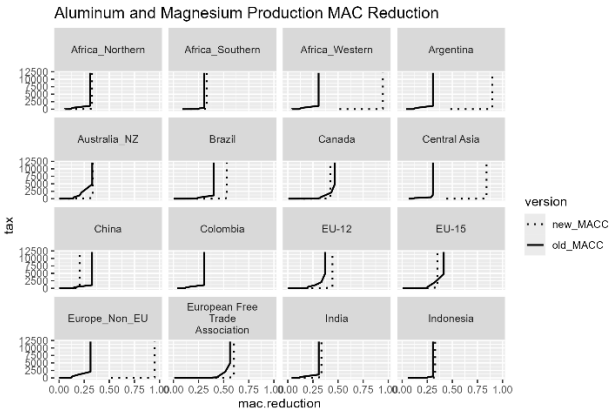

Solvent Use MAC Reduction
India
Indonesia
Japan
Mexico
Middle East
Pakistan
Russia
South Africa
South America_Northern
South America_Southern
South Asia
South Korea
Southeast Asia
Ukraine
USA
tax
mac.reduction
version
new_MACC
old_MACC

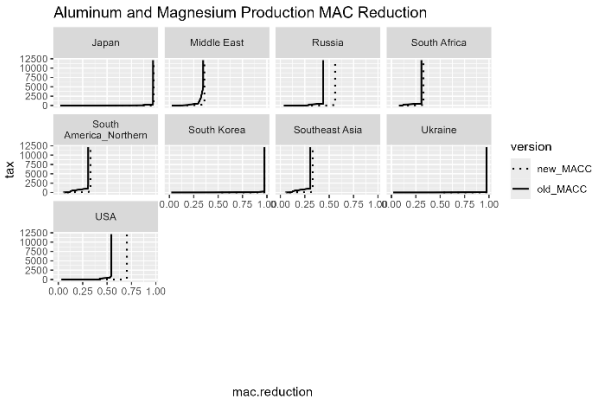

Aerosols Product Use MAC Reduction
Africa_Eastern
Africa_Northern
Africa_Southern
Africa_Western
Argentina
Australia_NZ
Brazil
Canada
Central America and Caribbean
Central Asia
China
Colombia
EU-12
EU-15
Europe_Non_EU
European Free Trade Association
tax
mac.reduction
version
new_MACC
old_MACC

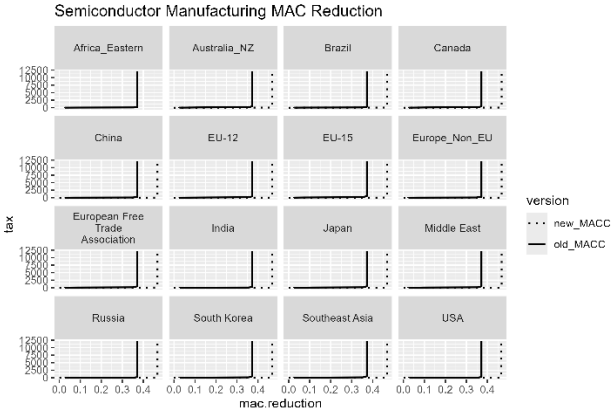

Aerosols Product Use MAC Reduction
India
Indonesia
Japan
Mexico
Middle East
Pakistan
Russia
South Africa
South America_Northern
South America_Southern
South Asia
Southeast Asia
Ukraine
USA
tax
mac.reduction
version
new_MACC
old_MACC


Fire Protection MAC Reduction
Africa_Eastern
Africa_Northern
Africa_Southern
Africa_Western
Argentina
Australia_NZ
Brazil
Canada
Central America and Caribbean
Central Asia
China
Colombia
EU-12
EU-15
Europe_Non_EU
European Free Trade Association
tax
mac.reduction
version
new_MACC
old_MACC


Fire Protection MAC Reduction
India
Indonesia
Japan
Mexico
Middle East
Pakistan
Russia
South Africa
South America_Northern
South America_Southern
South Asia
South Korea
Southeast Asia
Ukraine
USA
tax
mac.reduction
version
new_MACC
old_MACC


Aluminum and Magnesium Production MAC Reduction
Africa_Northern
Africa_Southern
Africa_Western
Argentina
Australia_NZ
Brazil
Canada
Central Asia
China
Colombia
EU-12
EU-15
Europe_Non_EU
European Free Trade Association
India
Indonesia
tax
mac.reduction
version
new_MACC
old_MACC


Aluminum and Magnesium Production MAC Reduction
Japan
Middle East
Russia
South Africa
South America_Northern
South Korea
Southeast Asia
Ukraine
USA
tax
mac.reduction
version
new_MACC
old_MACC


Semiconductor Manufacturing MAC Reduction
Africa_Eastern
Australia_NZ
Brazil
Canada
China
EU-12
EU-15
Europe_Non_EU
European Free Trade Association
India
Japan
Middle East
Russia
South Korea
Southeast Asia
USA
tax
mac.reduction
version
new_MACC
old_MACC