GHG emissions in MFMOD

Beginning with the October 2021 edition of the Macro Poverty Outlook, the MFMod modeling system has been extended to include projections for GHG emissions. This note briefly describes the new GHG module of MFMod and therefore supplements Burns et al (2019), which documents the MFMod system.

Description of the GHG module

Underlying data for emissions are taken from the World Resources Institute's CAIT database (http://cait.wri.org/docs/CAIT2.0_CountryGHG_Methods.pdf) and cover all MFMod countries (except West Bank and Gaza and Kosovo) up until 2018. Additional energy intensity of GDP data were sourced from the IEA database (https://www.oecd-ilibrary.org/energy/data/iea-co2-emissions-from-fuel-combustion-statistics/indicators-for-co2-emissions_data-00433-en). These data were also used in cases where other data were unavailable (see Table 1 below for a coverage list).

Emissions are classified and decomposed following the 2006 IPCC guidelines (https://www.ipcc-nggip.iges.or.jp/public/2006gl) which classify emissions across 5 main categories/sources.

1. **Energy**
    a. **Fuel combustion activities**: this includes electricity/heat, manufacturing/construction, transportation, and other fuel combustion.
    b. **Fugitive emissions**: this includes flaring, leakages, venting from mining and refining activities.
2. **Industrial processes**: this includes emissions from industrial processes and product use, excluding those related to energy combustion (category 1a), extraction, processing and transport of fuels (category 1b). This notably covers cement production, as well as the chemical and metal industry.
3. **Agriculture**: this includes emissions from livestock, manure management, agricultural soils, rice cultivation and crop burning. This category does not include CO2 emissions from fossil fuels associated with agricultural activities (category 1a).
4. **Land-use and change in forestry**: this includes emissions and removals from forest land, cropland, grassland, wetlands, settlements, and other land.
5. **Waste**: this includes emissions from landfills, wastewater management, human sewage.

Additional detail on each category can be found at http://cait.wri.org/docs/CAIT2.0_CountryGHG_Methods.pdf.

CAIT data used account for emissions of all greenhouse gases comprising CO2, CH4, F-gas and NO2 emissions. Emissions are measured in kilotons of carbon dioxide equivalent (ktCO2e). **Emissions linked to international bunkers are excluded from totals in accordance with IPCC guidelines as they cannot be attributed to a country specifically.** As a result the sum of country emissions will underestimate global emissions by the amount of emissions from these international bunkers.

Depending on data availability for a given country, the new GHG variables appear in the models as identities, exogenous variables, or behavioral equations as per the following table.

Table 1: Emissions module variables and structure		
	IEA-covered countries	**Non-covered countries**
Total	Identity (= 1 + ... + 5)	Identity (=1 + … + 5)
Energy	Identity (= a + b)	Identity (= a + b)
Fuel combustion activities	Identity: Intensity decomposition	Endogenous: Linked to GDP
Fugitive emissions (flaring, leakages, venting)	Endogenous: Linked to 1a*	Endogenous: Linked to 1a*
Industrial processes	Endogenous: Linked to industrial activity	Endogenous: Linked to industrial activity
Agriculture	Endogenous: Linked to agricultural activity	Endogenous: Linked to agricultural activity
Land-use and change in forestry	Exogenous	Exogenous
Waste	Endogenous: Linked to GDP	Linked to GDP
* except for oil exporting countries, where fugitive emissions are modelled as a function of oil production.		

A more technical description of the underlying relationships between emissions and the macroeconomic forecast is presented in the appendix.

Emissions Forecasts

As CAIT data ends in 2018, data beyond this point are model estimate and or projections. Data for the period 2018-20 are derived assuming that emissions from energy, fuel combustion activities and waste grow in line with real GDP. GHG emissions from agriculture and industry are extended by growing them in line with the value added of the associated sector. Fugitive emissions are extended in line with oil production for oil exporting countries. Countries without a significant oil exporting industry have their fugitive emissions extend in line with energy, fuel combustion activities. Finally, Land-use and change in forestry is assumed to remain constant from 2018 to 2020.

Forecasts for 2020 through 2023 are model-assisted judgment forecasts. Model projections derive from the econometric equations discussed in the appendix. The system allows country economists to deviate from these model suggestions (which reflect past behavior of the economy). Model suggestions are evaluated by country economists and maybe revised reflecting the analyst's knowledge of recent data, trends and or policy.

For all type of emissions except Land-use and change in forestry (Category 4), model suggestions link emissions to economic activity and would be expected to grow roughly in line with activity over the forecast horizon. Although change in technology can lead to a disconnect between activity and emissions, this effect is unlikely to be felt strongly over the MPO forecast horizon. Note that estimated equations account for gradual technological progress.

For land-use and change in forestry, absent external information to the country, country economists are advised to hold related emissions constant at their last historical value. This recommendation stems from the fact that reliable estimates for those emissions are difficult to produce. As such, CAIT data for this category tend to present a very low volatility with a stair-like profile.

Figure 1 illustrates the full emissions module as it appears in the model front end, inclusive of model suggestions and user judgement (add factors in the sheets below).

Figure 1: Emissions module display in the isumlate interface

Linked to GDP

Variable	Mode	Disp	2015	2016	2017	2018	2019	2020	2021	2022	2023
Unless otherwise indicated, all vars kt											
GHG intensities											
Total GHG emissions div by GDP	i	l	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Energy, fuel combustion activities div by GDP	i	l	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Energy, fugitive, div by Energy, fuel combustion	i	l	17.1	17.6	16.7	16.0	16.0	16.2	15.7	15.4	14.9
Industrial processes div by industry VA	i	l	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Agriculture div by agriculture VA	i	l	0.6	0.6	0.7	0.8	0.9	0.8	0.8	0.8	0.9
Waste div by GDP	i	l	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total GHG emissions (ktCO2e)	i	g	-0.1	4.0	-2.3	0.8	5.1	-7.6	5.3	4.5	4.8
GHG emissions from											
Energy, fuel combustion activities (ktCO2e)	i	g	-2.6	-3.6	4.9	4.2	7.6	-9.0	6.5	5.2	6.0
GHG intensity of energy (ktCO2e / ktoe)	x	g	-6.4	0.4	-0.4	7.6	0.0	-1.7	4.6	4.3	4.0
Model Suggestion	i	g	-6.4	0.4	-0.4	7.6	0.0	-1.7	1.8	-1.8	-3.7
Add-Factor	e	add	-4.7	-3.0	-4.2	4.1	0.8	-1.4	2.8	6.1	7.7
Energy intensity of GDP (ktoe / mn LCU)	x	g	0.9	-4.2	-2.1	-8.0	0.0	0.0	-4.0	-3.7	-3.3
Model Suggestion	i	g	0.9	-4.2	-2.1	-8.0	0.0	0.0	-15.2	-22.7	-30.1
Add-Factor	e	add	26.2	23.9	27.3	19.2	28.5	22.6	11.2	16.4	18.1
Energy, fugitive (ktCO2e)	x	g	2.3	-0.5	-0.5	-0.5	7.6	-7.6	3.3	2.8	2.6
Model Suggestion	i	g	2.3	-0.5	-0.5	-0.5	7.6	-7.6	1.2	0.9	1.6
Add-Factor	e	add	4.3	3.2	-0.1	-0.6	5.1	-1.6	2.1	1.9	1.0
Industrial processes (ktCO2e)	x	g	-0.3	-20.3	-3.9	-4.1	7.1	-2.8	7.0	6.6	6.2
Model Suggestion	i	g	-0.3	-20.3	-3.9	-4.1	7.1	-2.8	22.4	18.6	15.9
Add-Factor	e	add	6.5	-13.0	-15.8	-21.8	-19.7	-22.8	-15.4	-12.0	-9.7
Agriculture (ktCO2e)	x	g	7.1	30.8	-19.5	-6.9	-2.6	-4.0	3.7	3.8	3.6
Model Suggestion	i	g	7.1	30.8	-19.5	-6.9	-2.6	-4.0	-9.9	-10.7	-11.8
Add-Factor	e	add	-2.2	28.7	-2.4	3.5	8.5	9.2	13.6	14.5	15.4
Land-use change and Forestry (ktCO2e)	x	g	0.0	-146.1	0.0	6.0	0.0	0.0	0.0	0.0	0.0
Waste (ktCO2e)	x	g	-0.2	-0.1	-0.1	-0.1	0.1	-7.4	1.5	1.0	-0.3
Model Suggestion	i	g	-0.2	-0.1	-0.1	-0.1	0.1	-7.4	-3.4	-4.3	-4.5
Add-Factor	e	add	1.9	3.9	1.6	2.5	1.8	1.2	4.9	5.3	4.2
Real GDP, mn LCU (memo)	i	g	3.2	0.2	7.5	5.2	7.6	-7.4	6.1	4.8	5.4
GHG emissions from (% of Total GHG emissions)											
Energy, fuel combustion activities	i	l	58.0	53.8	57.7	59.7	61.1	60.2	60.9	61.3	62.0
Energy, fugitive	i	l	9.9	9.5	9.7	9.5	9.8	9.8	9.6	9.4	9.2
Industrial processes	i	l	5.5	4.2	4.1	3.9	4.0	4.2	4.3	4.3	4.4
Agriculture	i	l	19.4	24.4	20.1	18.6	17.2	17.9	17.6	17.5	17.3
Land-use change and Forestry	i	l	-0.9	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Waste	i	l	8.1	7.8	8.0	7.9	7.5	7.6	7.3	7.0	6.7

IEA-covered country list: AGO, ALB, ARE, ARG, ARM, AUS, AUT, AZE, BEL, BEN, BGD, BGR, BHR, BIH, BLR, BOL, BRA, BRN, BWA, CAN, CHE, CHL, CHN, CIV, CMR, COD, COG, COL, CRI, CYP, CZE, DEU, DNK, DOM, DZA, ECU, EGY, ERI, ESP, EST, ETH, FIN, FRA, GAB, GBR, GEO, GHA, GNQ, GRC, GTM, GUY, HKG, HND, HRV, HTI, HUN, IDN, IND, IRL, IRN, IRQ, ISL, ISR, ITA, JAM, JOR, JPN, KAZ, KEN, KGZ, KHM, KOR, KWT, LAO, LBN, LBY, LKA, LTU, LUX, LVA, MAR, MDA, MDG, MEX, MKD, MLI, MLT, MMR, MNE, MNG, MOZ, MUS, MYS, NAM, NER, NGA, NIC, NLD, NOR, NPL, NZL, OMN, PAK, PAN, PER, PHL, POL, PRT, PRY, PSE, QAT, ROU, RUS, SAU, SDN, SEN, SGP, SLV, SRB, SSD, SUR, SVK, SVN, SWE, SYR, TGO, THA, TJK, TTO, TUN, TUR, TZA, UGA, UKR, URY, USA, UZB, VNM, XKX, YEM, ZAF, ZMB, ZWE

Appendix: technical description of underlying modelling assumptions and equations

For emissions marked as linked to GDP in the table above, the following ECM functional form is estimated to account for the relationship between activity and emissions:

$$\Delta log(EM_t^X) = \alpha - \beta(log(EM_{t-1}^X) - \log(GDP_{t-1})) + \gamma * trend + \delta * \Delta log(GDP_t)$$

Where EM^X are em EM^X issions for category X. This X functional form links emissions to activity while also accounting for a changing technological trend to account for the evolving greenhouse gases intensity of activity.

Linked to a sector

For emissions linked to a specific sector (agriculture or industry) in the table above, a similar functional form is used, targeted on the given sector:

$$\Delta log(EM_t^X) = \alpha - \beta(log(EM_{t-1}^X) - \log(VA_{t-1}^X)) + \gamma * trend + \delta * \Delta log(VA_t^X)$$

Where VA^X is val VA^X ue added for sector X associ X ated to the given emission category.

Fugitive emissions

For non-oil exporting countries, fugitive emissions are assumed to depend on the level of emissions from fuel combustion activities. The estimated functional form is as follows:

$$\Delta log(EM_t^{FUG}) = \alpha - \beta\left(log\left(EM_{t-1}^{FUG}\right) - \log\left(EM_{t-1}^{COMB}\right)\right) + \gamma * trend + \delta * \Delta log(EM_t^{COMB})$$

Where EM^{FUG} are fu EM^{FUG} gitive emissions and EM^{COMB} are em EM^{COMB} issions from fuel combustion activities.

For oil exporting countries, fugitive emissions are linked to production of oil in the following simplified manner:

$$\Delta log(EM_t^{FUG}) = \Delta log(Q_t^{OIL})$$

Where Q_t^{OIL} is the Q_t^{OIL} level of production of oil.

Intensity decomposition

For countries for which IEA data are available on the energy intensity of GDP, greenhouse gases emissions are decomposed as follows along the simplified Kaya identity:

$$EM_t^{ENER} = \underbrace{\left(\frac{EM_t^{ENER}}{EnergyUse_t}\right)}_{\text{GHG intensity of energy}} * \underbrace{\left(\frac{EnergyUse_t}{GDP_t}\right)}_{\text{energy intensity of GDP}} * GDP_t = INT_t^{GHG} * INT_t^E * GDP_t$$

Where INT_t^{GHG} is the INT_t^{GHG} GHG intensity of energy and INT_t^E is the INT_t^E energy intensity of GDP.

GHG intensity of energy is then modelled as a function of the relative price of oil and of a country-specific technological trend.

$$\Delta log(INT_t^{GHG}) = \alpha - \beta\left(log(INT_{t-1}^{GHG}) + \omega * \log\left(\frac{P_{t-1}^{OIL} * FX_{t-1}}{P_{t-1}^{C}}\right)\right) + \gamma * trend - \delta * \Delta log\left(\frac{P_t^{OIL} * FX_t}{P_t^{C}}\right)$$

Energy intensity of GDP is estimated as a function of the decomposition of GDP across the agricultural, industrial and services sectors consistent with different energy intensity to activity in each sector. The functional form also accounts for a country-specific technological trend.

$$\Delta Int_t^E = \alpha - \beta * \left(Int_{t-1}^E - \omega_1 sh_{t-1}^{AGR} - \omega_2 sh_{t-1}^{IND}\right) + \delta_1 * \Delta sh_t^{AGR} + \delta_2 * \Delta sh_t^{IND} + \gamma * trend$$

Where sh^k is the sh^k share of sector k in GDP k with $sh^{AGR} + sh^{IND} + sh^{SRV} = 1$. $sh^{AGR} + sh^{IND} + sh^{SRV} = 1$