Background Note on Non-CO2 Forcings

October 26, 2023

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I. Overview

The treatment of land emissions and non-CO2 greenhouse gases is changed in the current DICE model. In earlier treatments, land emissions and non-CO2 GHGs were exogenous. In the current treatment, land emissions are endogenous and included with industrial CO2, while non-CO2 GHG emissions are divided into abatable and non-abatable. The abatable non CO2 greenhouse gases are included as a CO2 equivalent. Because the stock-flow-forcings relationship for non-CO2 emissions is simplified, there are small discrepancies in the results relative to complete earth-systems models.

II. Emissions data and projections

Land CO2 emissions were excluded from abatable emissions in earlier versions. Additionally, a major problem with the earlier treatment was that it assumed that land emissions decline sharply over time. If we look at IPCC estimates, we see a 0.7% per year increase in land per year over last forty years. This changes the outlook considerably for non-industrial CO2. In the new simulations, the baseline land emissions are changed to minus 2% per year.

	1750–2019 Cumulative (PgC)	1850-2019 Cumulative (PgC)	1980–1989 Mean Annual Growth Rate (PgC yr^{-1})	1990–1999 Mean Annual Growth Rate (PgC yr^{-1})	2000–2009 Mean Annual Growth Rate (PgC yr^{-1})	2010–2019 Mean Annual Growth Rate (PgC yr^{-1})
Emissions						
Fossil fuel combustion and cement production	445 ± 20	445 ± 20	5.4 ± 0.3	6.3 ± 0.3	7.7 ± 0.4	9.4 ± 0.5
Net land use change	240 ± 70	210 ± 60	1.3 ± 0.7	1.4 ± 0.7	1.4 ± 0.7	1.6 ± 0.7
Total emissions	685 ± 75	655 ± 65	6.7 ± 0.8	7.7 ± 0.8	9.1 ± 0.8	10.9 ± 0.9
Partition						
Atmospheric increase	285 ± 5	265 ± 5	3.4 ± 0.02	3.2 ± 0.02	4.1 ± 0.02	5.1 ± 0.02
Ocean sink[c]	170 ± 20	160 ± 20	1.7 ± 0.4	2.0 ± 0.5	2.1 ± 0.5	2.5 ± 0.6
Terrestrial sink	230 ± 60	210 ± 55	2.0 ± 0.7	2.6 ± 0.7	2.9 ± 0.8	3.4 ± 0.9
Budget imbalance	0	20	–0.4	–0.1	0	–0.1

Table Note-NC-1. IPCC AR6 Calculations on Emissions (Table 5.1), with label as follows:

Global anthropogenic CO_2 budget accumulated since the industrial revolution (onset in 1750) and averaged over the 1980s, 1990s, 2000s, and 2010s. By convention, a negative ocean or land to atmosphere CO_2 flux is equivalent to a gain of carbon by these reservoirs. The table does not include natural exchanges (e.g. rivers, weathering) between reservoirs. Uncertainties represent the 68% confidence interval (Friedlingstein et al., 2020).

Next, if we look at historical emissions of CO2 and CO2-2, we see that CO2-e has grown a little more slowly than fossil CO2 over period 1970 – 2018 (0.2% per year more slowly).

	Average annual growth rate		
Period	CO2-e	CO2	Difference
1970-2021	1.5%	1.7%	-0.19%
2000-2021	1.6%	1.8%	-0.20%
Source: non-c02vco2 history-010323.xls			

Table Note-NC-2. Historical growth CO2 and CO2-e emissions.

Item	2020	2025	2050	2100
Base/NC industrial emissions (GtCO2/yr)	39.55	43.38	61.12	78.54
Base/NC land emissions (GtCO2/yr)	5.90	5.31	3.14	1.09
Abateable nonCO2 emissions GHG (GtCO2e/yr)	9.24	9.56	11.14	14.30
Total, CO2-e abateable emissions (GtCO2e/yr)	**54.69**	**58.24**	**75.39**	**93.93**
Base/NC CO2 forcings (W/m2)	2.43	2.69	4.04	6.62
Abateable other forcings (w/m2)	1.16	1.10	1.04	1.28
Exogenous forcings (w/m2)	(0.20)	(0.16)	0.04	0.44
Total abateable forcings (w/m2)	**3.39**	**3.63**	**5.12**	**8.34**

Base/NC = with zero emissions control

Source: non-co2GHG-MAC-up010323.xls

Table Note-NC-3. Projections CO2 and CO2-e emissions.

Item	Growth, 2020-2100
Base/NC industrial emissions (GtCO2/yr)	0.86%
Base/NC land emissions (GtCO2/yr)	-2.09%
Abateable nonCO2 emissions GHG (GtCO2e/yr)	0.55%
Total, CO2-e abateable emissions (GtCO2e/yr)	0.68%
Base/NC CO2 forcings (W/m2)	1.26%
Abateable other forcings (w/m2)	0.12%
Exogenous forcings (w/m2)	na
Total abateable forcings (w/m2)	1.13%

Base/NC = with zero emissions control

Source: non-co2GHG-MAC-up010323.xls

Table Note-NC-4. Projections of growth of CO2 and CO2-e emissions.

III. Abatement costs

The abatement cost function is drawn from Harmsen 2019. The maximum reduction at the CO2 backstop of $480 is 57% in 2050; and about 69% in 2100. The curve is more convex that for CO2. However, this may be because it is constructed using engineering approaches. We assume that the mitigation cost function is the same and that the abatable part is 65% of non-CO2-GHG.

The following shows the marginal cost function for CO2 and non-CO2 GHGs from DICE and Harmsen. Note that the price/marginal cost curve for non-CO2 GHG's is much more convex than for CO2.

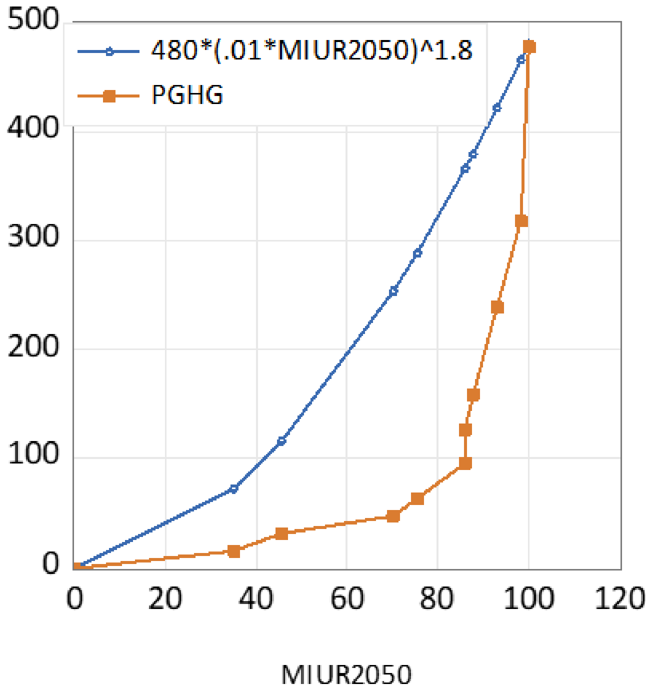

Figure Note-NC-1. Projections of growth of CO2 and CO2-e emissions.

[Source; Lab Notes for DICE.]

The following is the regression of the marginal cost on the emissions control rate for the Harmsen data, showing the higher convexity.

Dependent Variable: LOG(PGHG)
Method: Least Squares
Date: 12/20/21 Time: 14:00
Sample: 2 11
Included observations: 10

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-7.442956	1.881006	-3.956901	0.0042
LOG(MIUR2050)	2.800396	0.435560	6.429421	0.0002

R-squared	0.837851	Mean dependent var	4.615397
Adjusted R-squared	0.817583	S.D. dependent var	1.065225
S.E. of regression	0.454961	Akaike info criterion	1.439648
Sum squared resid	1.655918	Schwarz criterion	1.500165
Log likelihood	-5.198238	Hannan-Quinn criter.	1.373261
F-statistic	41.33745	Durbin-Watson stat	0.581986
Prob(F-statistic)	0.000203		

Table Note-NC-5. Projections of growth of CO2 and CO2-e emissions.

[Source; Lab Notes for DICE.]

IV. Forcings and carbon price error

The issue with the non-CO2 gases is that they cannot easily be translated from forcings into CO2e and the reverse. I had originally thought that we could multiple CO2 by a forcings ratio to get CO2e. However, this is inaccurate. The reason is that dF/dCO2 differs with the level of concentrations. A little experimentation also shows that it is not obvious how to put in a correction factor. The calculation of dF/dCO2 is not the natural = constant/M(t) (from logarithmic derivative).

Additionally, the treatment leads to error in calculation of the carbon price and SCC. Some experimentation showed that this was because of the addition of GHGs other than industrial CO2. See the following table:

Ratio SCC/cprice							
Year	2020	2025	2030	2035	2040	2045	2050
NO NON-CO2 GHG	1.19	0.89	0.91	0.92	0.93	0.94	0.95
ALL GHG	1.33	1.03	1.04	1.05	1.06	1.06	1.05
ONLY IND CO2	1.16	1.00	1.00	1.00	1.00	1.00	1.00
NO NON-CO2 GHG	19.4%	-10.9%	-9.2%	-7.8%	-6.6%	-5.6%	-4.9%
ALL GHG	33.2%	3.3%	4.5%	5.2%	5.6%	5.6%	5.4%
ONLY IND CO2	16.3%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Table Note-NC-6. Error in carbon price due to non-CO2 GHGs.

[Source; Lab Notes for DICE.]

V. GAMS model for non-CO2 GHGs

The following is the GAMS code for non-CO2 GHGs, "Nonco2-b-4-3-1.gms". Note that this is an "Include" subroutine.

```
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* nonco2 Parameters
Parameters
      CO2E_GHGabateB(t)       Abateable non-CO2 GHG emissions base
      CO2E_GHGabateact(t)      Abateable non-CO2 GHG emissions base (actual)
      F_Misc(t)              Non-abateable forcings (GHG and other)
      emissrat(t)            Ratio of CO2e to industrial emissions
      sigmatot(t)            Emissions output ratio for CO2e
      FORC_CO2(t)              CO2 Forcings
;
** Parameters for non-industrial emission
** Assumes abateable share of non-CO2 GHG is 65%
Parameters
      eland0        Carbon emissions from land 2015 (GtCO2 per year)  / 5.9    /
      deland        Decline rate of land emissions (per period)      / .1     /
      F_Misc2020     Non-abatable forcings 2020                   /  -0.054    /
      F_Misc2100     Non-abatable forcings 2100                    / .265/
      F_GHGabate2020 Forcings of abatable nonCO2 GHG               / 0.518 /
      F_GHGabate2100 Forcings of abatable nonCO2 GHG               / 0.957 /
      ECO2eGHGB2020  Emis of abatable nonCO2 GHG GtCO2e  2020          /  9.96/
      ECO2eGHGB2100  Emis of abatable nonCO2 GHG GtCO2e  2100          /  15.5 /
      emissrat2020   Ratio of CO2e to industrial CO2 2020             / 1.40 /
      emissrat2100   Ratio of CO2e to industrial CO2 2020             / 1.21 /
      Fcoef1        Coefficient of nonco2 abateable emissions          /0.00955/
      Fcoef2        Coefficient of nonco2 abateable emissions          /.861/
      ;
** Parameters emissions and non-CO2
      eland(t) = eland0*(1-deland)**(t.val-1); eland(t) = eland0*(1-deland)**(t.val-1);
      CO2E_GHGabateB(t)=ECO2eGHGB2020+((ECO2eGHGB2100-ECO2eGHGB2020)/16)*(t.val-1)$(t.val le
16)+((ECO2eGHGB2100-ECO2eGHGB2020))$(t.val ge 17);
      F_Misc(t)=F_Misc2020 +((F_Misc2100-F_Misc2020)/16)*(t.val-1)$(t.val le 16)+((F_Misc2100-
F_Misc2020))$(t.val ge 17);
      emissrat(t) = emissrat2020 +((emissrat2100-emissrat2020)/16)*(t.val-1)$(t.val le 16)+((emissrat2100-
emissrat2020))$(t.val ge 17);
      sigmatot(t) = sigma(t)*emissrat(t);
      cost1tot(t) = pbacktime(T)*sigmatot(T)/expcost2/1000;
VARIABLES
      ECO2(t)        Total CO2 emissions (GtCO2 per year)
      ECO2E(t)       Total CO2e emissions including abateable nonCO2 GHG (GtCO2 per year)
      EIND(t)        Industrial CO2 emissions (GtCO2 per yr)
      F_GHGabate      Forcings abateable nonCO2 GHG
;
Equations
      ECO2eq(t)        CO2 Emissions equation
      ECO2Eeq(t)       CO2E Emissions equation
      EINDeq(t)       Industrial CO2 equation
      F_GHGabateEQ(t);
```