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Climate change metrics: bridging IPCC AR6 updates and dynamic life cycle assessments

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S1 – Table S1. Evolution of radiative efficiency (RE), perturbation lifetime (τ), GWP and GTP at 100 years between the First IPCC Assessment Report (FAR) (Shine et al., 1990), SAR (Houghton et al., 1995), TAR (Ramaswamy et al., 2001), AR4 (Forster et al., 2007), AR5 (Myhre et al., 2013) and AR6 (Forster et al., 2021).

		FAR	SAR	TAR	AR4	AR5	AR6
CO_2	RE ($W\ m^{-2}\ ppb^{-1}$).10^{-5}	1.78[a]	1.75[a]	1.548	1.4	1.37	1.33
CH_4	RE ($W\ m^{-2}\ ppb^{-1}$).10^{-5}	37[a]	37[a]	37	34	36.3	38.9 (57[b])
	τ (year)	10	12	12	12	12.4	11.8
	GWP_{100}	21	21	23	25	28 – 30	27 – 29.8
	GTP_{100}	-	-	-	4 – 7[c]	4 – 6	4.7 – 7.5
N_2O	RE ($W\ m^{-2}\ ppb^{-1}$).10^{-5}	308[a]	307[a]	310	303	300	320 (280[b])
	τ (year)	150	120	114	114	121	109
	GWP_{100}	290	310	296	298	265	273
	GTP_{100}	-	-	-	270[c]	234	233

[a] Calculated after equations from (Shine et al., 1990, Table 2.2) and concentration indicated in the corresponding IPCC report.
[b] With chemical effects included. AR6 indicates this radiative efficiency value in its main report.
[c] Values from (Shine et al., 2005) cited in AR4.

S2 – Analytical solutions of AGWP and AGTP metrics for valid CO_2, CH_4 and N_2O.

$$AGWP_{CO2}(H) = A_{CO2}\left\{\alpha_0 H + \sum_j^3 \alpha_j\tau_j\left(1 - e^{-\frac{H}{\tau_j}}\right)\right\} \tag{S1.1}$$

$$AGTP_{CO2}(TH) = A_{CO2}\sum_{j=1}^{2}\left\{\alpha_0 c_j\left(1 - \exp(\tfrac{-TH}{d_j})\right) + \sum_{i=1}^{3}\frac{\alpha_i\tau_i c_j}{\tau_i - d_j}\left(\exp(\tfrac{-H}{\tau_i}) - \exp(\tfrac{-TH}{d_j})\right)\right\} \tag{S1.2}$$

For non-CO_2 gas i :

$$AGWP_i = A_i\tau_i(1 - e^{-\frac{H}{\tau_i}}) \tag{S1.3}$$

$$AGTP_i(TH) = A_i\sum_{j=1}^{2}\frac{\tau c_j}{\tau_i - d_j}\left(\exp(\tfrac{-TH}{\tau_i}) - \exp(\tfrac{-TH}{d_j})\right) \tag{S1.4}$$

S3 – Table S2. Extra climate parameters values used for the computation of climate metrics

Variable	Definition	Unit	Value	Uncertainty	Uncertainty distribution type	Source
$AGWP_{CH4}$						
RE_{CH4}	Radiative efficiency in CH_4 mixing ratio without indirect effects	$W.m^{-2}.ppb^{-1}$	3.89×10^{-4}	0.96×10^{-4}	Normal 1.645σ	(Forster et al., 2021)
$\tau_{atm, CH4}$	Total atmospheric lifetime	Years	9.1	0.9	Normal 1σ	(Szopa et al., 2021)
f_{CH4}	Feedback factor	Unitless	1.30	0.07	Normal 1σ	(Thornhill et al., 2021)
f1	Tropospheric ozone indirect effect scaling	Unitless	0.36	0.18	Normal 1.645σ	(Forster et al., 2021)
f2	Stratospheric water vapour indirect effect scaling	Unitless	0.103	0.103	Normal 1.645σ	(Forster et al., 2021)
$AGWP_{N2O}$						
RE_{N2O}	Radiative efficiency in N_20 mixing ratio without indirect effects	$W.m^{-2}.ppb^{-1}$	3.19×10^{-3}	1.25×10^{-3}	Normal 1.645σ	(Forster et al., 2021)
$\tau_{atm, N2O}$	Mean atmospheric lifetime	Years	116	9	Normal 1.645σ	(Canadell et al., 2021)
f_{N20}	Feedback factor	Years	0.94	0.01	Normal 1.645σ	(Prather et al., 2015)
-	Methane lifetime effect in ppb(CH_4) per ppb(N_2O)	-	-1.7	1.7	Normal 1.645σ	(Forster et al., 2021)
RE_{N20}^{O3}	Upper stratospheric ozone depletion	$W.m^{-2}.ppb^{-1}$	5.5×10^{-4}	0.4×10^{-4}	Normal 1.645σ	(Forster et al., 2021)
AGTP						
λ	Net feedback parameter	$W.m^{-2}.K^{-1}$	1.16	0.40	Normal 1σ	(Forster et al., 2021)
$\Delta F_{2\times co2}$	Effective radiative forcing of CO_2 doubling	$W.m^{-2}$	3.93	0.47	Normal 1σ	(Forster et al., 2021)
CCf						
γ	IRF_{CCf} intensity term	$kgCO_2\ yr^{-1}\ °C^{-1}$	11.06×10^{12}	-	-	(Gasser et al., 2017)
β_{1-3}	Coefficient for fraction of IRF_{CCf} associated with a nominal timescale	Unitless	β_1=0.6368 ; β_2=0.3322 ; β_3=0.0310	-	-	(Gasser et al., 2017)
κ_{1-3}	IRF_{CCf} nominal timescale	Years	κ_1=2.376 ; κ_2=30.14 ; κ_3=490.1	-	-	(Gasser et al., 2017)

S4 – Analytical resolution of the convolution between IRF_{CH4} and $AGxx_{CO2}$ describing to methane oxidation

$$IRF_{CH4} * AGWP_{CO2}(H) = Y\frac{M_{CO2}}{M_{CH4}}\frac{1}{\tau_{\mathrm{CH4}}^{\mathrm{OH}}}\int_0^H e^{-\frac{t}{\tau_{CH4}^{OH}}}\int_0^{H-t} A_{CO2}IRF_{CO2}(x)\,dxdt \tag{S3.1}$$
$$= Y\frac{M_{CO2}}{M_{CH4}}\frac{1}{\tau_{\mathrm{CH4}}^{\mathrm{OH}}}A_{CO2}\Bigg[\alpha_0\tau_{CH4}^{OH}\left(H+\tau_{CH4}^{OH}\left(e^{-\frac{H}{\tau_{CH4}^{OH}}}-1\right)\right)$$
$$-\sum_i\left\{\frac{\alpha_i{\tau_i}^2\tau_{CH4}^{OH}}{\tau_i-\tau_{CH4}^{OH}}\left(e^{-\frac{H}{\tau_i}}-e^{-\frac{H}{\tau_{CH4}^{OH}}}\right)+\alpha_i\tau_i\tau_{CH4}^{OH}\left(1-e^{-\frac{H}{\tau_{CH4}}}\right)\right\}\Bigg]$$

$$IRF_{CH4} * AGTP_{CO2}(H) = Y\frac{M_{CO2}}{M_{CH4}}\frac{1}{\tau_{\mathrm{CH4}}^{\mathrm{OH}}}\int_0^H e^{-\frac{t}{\tau_{CH4}}}\int_0^{H-t} A_{CO2}IRF_{CO2}(x)IRF_T(t-x)\,dxdt \tag{S3.2}$$
$$= Y\frac{M_{CO2}}{M_{CH4}}\frac{1}{\tau_{\mathrm{CH4}}^{\mathrm{OH}}}A_{CO2}\times ECS$$
$$\times\sum_{j=1}^{2}\left\{\frac{\alpha_0c_j\tau_{\mathrm{CH4}}^{\mathrm{OH}}d_j}{\tau_{\mathrm{CH4}}^{\mathrm{OH}}-d_j}\left(e^{-\frac{H}{\tau_{\mathrm{CH4}}^{\mathrm{OH}}}}-e^{-\frac{H}{d_j}}\right)+\alpha_0c_j\tau_{\mathrm{CH4}}^{\mathrm{OH}}\left(1-e^{-\frac{H}{\tau_{\mathrm{CH4}}^{\mathrm{OH}}}}\right)\right.$$
$$\left.+\sum_{i=1}^{3}\frac{\alpha_i{\tau_i}^2c_j\tau_{\mathrm{CH4}}^{\mathrm{OH}}}{(d_j-\tau_i)(\tau_i-\tau_{CH4}^{OH})}\left(e^{-\frac{H}{\tau_i}}-e^{-\frac{H}{\tau_{\mathrm{CH4}}^{\mathrm{OH}}}}\right)+\frac{\alpha_i\tau_ic_jd_j\tau_{\mathrm{CH4}}^{\mathrm{OH}}}{(d_j-\tau_i)(\tau_{CH4}^{OH}-d_j)}\left(e^{-\frac{H}{\tau_{\mathrm{CH4}}^{\mathrm{OH}}}}-e^{-\frac{H}{d_j}}\right)\right\}$$

S5 – Table S3. Fitting parameters of model responses in CO_2 (*IRF_{CO2}*) for a 100 GtC emission pulse added to a constant background of 389 ppm from (Joos et al., 2013, Supplementary Information, Table S1) considered to compute uncertainty range

model	*nryears*	a_0	a_1	a_2	a_3	τ_1	τ_2	τ_3
~~NCAR CSM1.4~~	~~289~~	~~2.935E-07~~	~~3.665E-01~~	~~3.542E-01~~	~~2.793E-01~~	~~1.691E+03~~	~~2.836E+01~~	~~5.316E+00~~
~~HadGEM2-ES~~	~~101~~	~~4.340E-01~~	~~1.973E-01~~	~~1.889E-01~~	~~1.798E-01~~	~~2.307E+01~~	~~2.307E+01~~	~~3.922E+00~~
~~MPI-ESM~~	~~101~~	~~1.252E-07~~	~~5.864E-01~~	~~1.826E-01~~	~~2.310E-01~~	~~1.781E+02~~	~~9.039E+00~~	~~8.989E+00~~
Bern3D-LPJ	1000	6.345E-10	5.150E-01	2.631E-01	2.219E-01	1.955E+03	4.583E+01	3.872E+00
Bern3D-LPJ (ensemble)	585	2.796E-01	2.382E-01	2.382E-01	2.440E-01	2.762E+02	3.845E+01	4.928E+00
Bern2.5D-LPJ	1000	2.362E-01	9.866E-02	3.850E-01	2.801E-01	2.321E+02	5.850E+01	2.587E+00
CLIMBER2-LPJ	1000	2.318E-01	2.756E-01	4.900E-01	2.576E-03	2.726E+02	6.692E+00	6.692E+00
DCESS	1000	2.159E-01	2.912E-01	2.410E-01	2.518E-01	3.799E+02	3.631E+01	3.398E+00
GENIE (ensemble)	1000	2.145E-01	2.490E-01	1.924E-01	3.441E-01	2.701E+02	3.932E+01	4.305E+00
LOVECLIM	1000	8.539E-08	3.606E-01	4.503E-01	1.891E-01	1.596E+03	2.171E+01	2.281E+00
MESMO	1000	2.848E-01	2.938E-01	2.382E-01	1.831E-01	4.543E+02	2.500E+01	2.014E+00
UVic2.9	1000	3.186E-01	1.748E-01	1.921E-01	3.145E-01	3.046E+02	2.656E+01	3.800E+00
ACC2	985	1.779E-01	1.654E-01	3.796E-01	2.772E-01	3.862E+02	3.689E+01	3.723E+00
Bern-SAR	1000	1.994E-01	1.762E-01	3.452E-01	2.792E-01	3.331E+02	3.969E+01	4.110E+00
MAGICC6 (ensemble)	604	2.051E-01	2.533E-01	3.318E-01	2.098E-01	5.961E+02	2.197E+01	2.995E+00
TOTEM2	984	7.177E-06	2.032E-01	6.995E-01	9.738E-02	8.577E+04	1.118E+02	1.583E-02
multi-model mean	1000	2.173E-01	2.240E-01	2.824E-01	2.763E-01	3.944E+02	3.654E+01	4.304E+00

In this study, all models that compute IRF CO_2 at least up to 500 years (long-term time horizon in climate metrics) have their fit extended up to 1000 years for the uncertainty range. In other words, fits from NCAR CSM1.4, HadGEM2-ES and MPI-ESM are not considered here.

S6 – IRF_T to match MAGICC's behaviour used in AR6

Please see the Jupyter Notebook (Nicholls et al., [code]) that was used for AR6. At "Out [33]" is the table containing ensemble member draws of IRF_T parameters (columns d1, d2, q1, q2).

All draws are explicitly available in our developed dynamic climate change assessment tool on the following path : Code/modules/Database.py from line 239 to line 838.

S7 – Table S4. Cradle-to-grave dynamic life cycle inventory of 1m² of insulating material – either Polystyrene or Straw bale – that ensure a thermal resistance of 7 $m^2.K.W^{-1}$ during 50 years.

Polystyrene			
Year	CO_2	CH_4	N_2O
1	2,45E+01	2,59E-01	1,55E-04
50	2,79E-01	2,30E-02	5,07E-06

Straw bale							
Year	CO_2	CH_4	N_2O	**Year**	CO_2	**Year**	CO_2
0	-5.15E+01	2.45E-03	1.84E-03	**91**	7.25E-02	**131**	5.26E-02
1	9.11E-01	2.45E-03	3.6E-05	**92**	7.19E-02	**132**	5.22E-02
50	2.77E-01	9.72E-04	1.49E-05	**93**	7.14E-02	**133**	5.18E-02
51	3.58E+01	3.40E-01	6.3E-02	**94**	7.08E-02	**134**	5.13E-02
52	2.79E+00	5.51E-03		**95**	7.02E-02	**135**	5.09E-02
53	8.61E-01	1.62E-03		**96**	6.97E-02	**136**	5.05E-02
54	9.50E-02			**97**	6.91E-02	**137**	5.01E-02
55	9.65E-02			**98**	6.86E-02	**138**	4.97E-02
56	9.59E-02			**99**	6.80E-02	**139**	4.93E-02
57	9.53E-02			**100**	6.75E-02	**140**	4.89E-02
58	9.45E-02			**101**	6.69E-02	**141**	4.85E-02
59	9.38E-02			**102**	6.64E-02	**142**	4.81E-02
60	9.30E-02			**103**	6.59E-02	**143**	4.78E-02
61	9.23E-02			**104**	6.53E-02	**144**	4.74E-02
62	9.15E-02			**105**	6.48E-02	**145**	4.70E-02
63	9.08E-02			**106**	6.43E-02	**146**	4.66E-02
64	9.01E-02			**107**	6.38E-02	**147**	4.62E-02
65	8.94E-02			**108**	6.33E-02	**148**	4.59E-02
66	8.86E-02			**109**	6.28E-02	**149**	4.55E-02
67	8.79E-02			**110**	6.23E-02	**150**	4.51E-02
68	8.72E-02			**111**	6.18E-02		
69	8.65E-02			**112**	6.13E-02		
70	8.58E-02			**113**	6.08E-02		
71	8.52E-02			**114**	6.03E-02		
72	8.45E-02			**115**	5.98E-02		
73	8.38E-02			**116**	5.93E-02		
74	8.31E-02			**117**	5.88E-02		
75	8.25E-02			**118**	5.84E-02		
76	8.18E-02			**119**	5.79E-02		
77	8.11E-02			**120**	5.74E-02		
78	8.05E-02			**121**	5.70E-02		
79	7.99E-02			**122**	5.65E-02		
80	7.92E-02			**123**	5.61E-02		
81	7.86E-02			**124**	5.56E-02		
82	7.80E-02			**125**	5.52E-02		
83	7.73E-02			**126**	5.47E-02		
84	7.67E-02			**127**	5.43E-02		
85	7.61E-02			**128**	5.39E-02		
86	7.55E-02			**129**	5.34E-02		
87	7.49E-02			**130**	5.30E-02		
88	7.43E-02						
89	7.37E-02						
90	7.31E-02						

S8 – Table S5. Mean values of several climate metrics applied on the two studied thermal insulating products that are behind Fig. 5.

	Polystyrene (fossil-based)	Straw bale (bio-based)
GWP_{20}	48.9	42.1
GWP_{100}	33.7	23.8
GWP_{500}	27.8	7.44
GTP_{50}	28.8	19.0
GTP_{100}	27.1	13.2
ΔF_{20} (10^{-12} W yr m^{-2})	0.88	-0.91
ΔF_{100} (10^{-12} W yr m^{-2})	2.90	-0.79
ΔF_{500} (10^{-12} W yr m^{-2})	8.8	0.99
$\Delta T_{negative}$ (10^{-15} °C)	–	-28.7
ΔT_{peak} (10^{-15} °C)	27.8 (14 years)	27.5 (66 years)
$\Delta T_{long\text{-}term}$ (10^{-15} °C)	9.4	-0.10

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