

Supplementary for

emIAM v1.0: an emulator for Integrated Assessment Models using marginal abatement cost curves

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Table S1. Equation forms and boundary of parameters for fitting MAC curves

	AIM	GEM	MESSAGE	IMAGE	COFFEE	TIAM	REMIND	WITCH	POLES	GET
Equation 1	$f(x)=a*x^b+c*x^d$									
a	[0,+inf)	[0,+inf)	[0,+inf)	[0,+inf)	[0,+inf)	[0,+inf)	[0,+inf)	[0,+inf)	[0,+inf)	[0,+inf)
b	[0.01,100]	[0.01,100]	[0.01,100]	[0.01,100]	[0.01,100]	[0.01,100]	[0.01,100]	[0.01,100]	[0.01,100]	[0.01,100]
c	[0,+inf)	[0,+inf)	[0,+inf)	[0,+inf)	[0,+inf)	[0,+inf)	[0,+inf)	[0,+inf)	[0,+inf)	[0,+inf)
d	[0.01,100]	[0.01,100]	[0.01,100]	[0.01,100]	[0.01,100]	[0.01,100]	[0.01,100]	[0.01,100]	[0.01,100]	[0.01,100]
Equation 2	$f(x)=a*x+b*(exp(c*x)-1)$									
a	-	-	-	-	-	-	-	-	-	-
b	-	-	-	-	-	-	-	-	-	-
c	(-inf,50]	(-inf,50]	(-inf,50]	(-inf,50]	(-inf,50]	(-inf,50]	(-inf,50]	(-inf,50]	(-inf,50]	(-inf,50]
Equation 3	$f(x)=a*x+b*x^2+c*x^3+d*x^4$									
a	-	-	-	-	-	-	-	-	-	-
b	[0.01,100]	[0.01,100]	[0.01,100]	[0.01,100]	[0.01,100]	[0.01,100]	[0.01,100]	[0.01,100]	[0.01,100]	[0.01,100]
c	-	-	-	-	-	-	-	-	-	-
d	[0.01,100]	[0.01,100]	[0.01,100]	[0.01,100]	[0.01,100]	[0.01,100]	[0.01,100]	[0.01,100]	[0.01,100]	[0.01,100]
Equation 4	$f(x)=a*(b^(c*x)-1)$									
a	[0,+inf)	[0,+inf)	[0,+inf)	[0,+inf)	[0,+inf)	[0,+inf)	[0,+inf)	[0,+inf)	[0,+inf)	[0,+inf)
b	[0.001,+inf)	[0.001,+inf)	[0.001,+inf)	[0.001,+inf)	[0.001,+inf)	[0.001,+inf)	[0.001,+inf)	[0.001,+inf)	[0.001,+inf)	[0.001,+inf)
c	(-inf,100]	(-inf,100]	(-inf,100]	(-inf,100]	(-inf,100]	(-inf,100]	(-inf,100]	(-inf,100]	(-inf,100]	(-inf,100]

Table S2. Carbon price pathways of different initial levels with a 5% of growth rate

Scenarios	2010	2015	2020	2025	2030	2035	2040	2045	2050	2055	2060	2065	2070	2075	2080	2085	2090	2095	2100
T0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
T1	1	1.3	1.6	2.1	2.7	3.4	4.3	5.5	7.0	9.0	11.5	14.6	18.7	23.8	30.4	38.8	49.6	63.3	80.7
T2	2	2.6	3.3	4.2	5.3	6.8	8.6	11.0	14.1	18.0	22.9	29.3	37.4	47.7	60.9	77.7	99.1	126.5	161.5
T3	3	3.8	4.9	6.2	8.0	10.2	13.0	16.5	21.1	27.0	34.4	43.9	56.0	71.5	91.3	116.5	148.7	189.8	242.2
T5	5	6.4	8.1	10.4	13.3	16.9	21.6	27.6	35.2	44.9	57.3	73.2	93.4	119.2	152.1	194.2	247.8	316.3	403.7
T7	7	8.9	11.4	14.6	18.6	23.7	30.3	38.6	49.3	62.9	80.3	102.4	130.8	166.9	213.0	271.8	346.9	442.8	565.1
T10	10	12.8	16.3	20.8	26.5	33.9	43.2	55.2	70.4	89.9	114.7	146.4	186.8	238.4	304.3	388.3	495.6	632.5	807.3
T15	15	19.1	24.4	31.2	39.8	50.8	64.8	82.7	105.6	134.8	172.0	219.5	280.2	357.6	456.4	582.5	743.4	948.8	1211.0
T20	20	25.5	32.6	41.6	53.1	67.7	86.4	110.3	140.8	179.7	229.3	292.7	373.6	476.8	608.5	776.7	991.2	1265.1	1614.6
T25	25	31.9	40.7	52.0	66.3	84.7	108.0	137.9	176.0	224.6	286.7	365.9	467.0	596.0	760.7	970.8	1239.0	1581.4	2018.3
T30	30	38.3	48.9	62.4	79.6	101.6	129.7	165.5	211.2	269.6	344.0	439.1	560.4	715.2	912.8	1165.0	1486.8	1897.6	2421.9
T40	40	51.1	65.2	83.2	106.1	135.5	172.9	220.6	281.6	359.4	458.7	585.4	747.2	953.6	1217.1	1553.3	1982.5	2530.2	3229.2
T50	50	63.8	81.4	103.9	132.7	169.3	216.1	275.8	352.0	449.3	573.4	731.8	934.0	1192.0	1521.3	1941.6	2478.1	3162.7	4036.5
T60	60	76.6	97.7	124.7	159.2	203.2	259.3	331.0	422.4	539.1	688.0	878.1	1120.8	1430.4	1825.6	2330.0	2973.7	3795.3	4843.8
T70	70	89.3	114.0	145.5	185.7	237.0	302.5	386.1	492.8	629.0	802.7	1024.5	1307.5	1668.8	2129.8	2718.3	3469.3	4427.8	5651.1
T80	80	102.1	130.3	166.3	212.3	270.9	345.8	441.3	563.2	718.8	917.4	1170.9	1494.3	1907.2	2434.1	3106.6	3964.9	5060.3	6458.4
T90	90	114.9	146.6	187.1	238.8	304.8	389.0	496.4	633.6	808.7	1032.1	1317.2	1681.1	2145.6	2738.4	3494.9	4460.5	5692.9	7265.7
T100	100	127.6	162.9	207.9	265.3	338.6	432.2	551.6	704.0	898.5	1146.7	1463.6	1867.9	2384.0	3042.6	3883.3	4956.1	6325.4	8073.0
T110	110	140.4	179.2	228.7	291.9	372.5	475.4	606.8	774.4	988.4	1261.4	1609.9	2054.7	2622.4	3346.9	4271.6	5451.8	6958.0	8880.3
T120	120	153.2	195.5	249.5	318.4	406.4	518.6	661.9	844.8	1078.2	1376.1	1756.3	2241.5	2860.8	3651.2	4659.9	5947.4	7590.5	9687.6
T130	130	165.9	211.8	270.3	344.9	440.2	561.9	717.1	915.2	1168.1	1490.8	1902.6	2428.3	3099.2	3955.4	5048.2	6443.0	8223.1	10494.9
T140	140	178.7	228.0	291.0	371.5	474.1	605.1	772.2	985.6	1257.9	1605.4	2049.0	2615.1	3337.6	4259.7	5436.6	6938.6	8855.6	11302.3

Table S3. Parameter values in global MAC curves for energy-related CO₂, CH₄, and N₂O emissions derived from nine ENGAGE IAMs and GET. No data are available for energy-related CH₄, and N₂O emissions from GEM and TIAM.

Model	Variable	a	b	c	d	MaxABL	Max1st	Max2nd
AIM	CO ₂	192.98	1.25	16.51	18.28	112.7	6.4	1.0
AIM	CH ₄	94.24	0.91	822.81	18.27	94.3	6.2	1.7
AIM	N ₂ O	171.87	1.41	1249.37	12.65	87.2	5.7	1.1
COFFEE	CO ₂	40.32	1.15	40.48	5.63	146.4	5.9	0.9
COFFEE	CH ₄	455.91	5.77	14.38	0.35	87.9	4.9	3.1
COFFEE	N ₂ O	85.37	0.39	85.37	0.39	38.4	6.2	2.3
GEM	CO ₂	272.42	1.57	119.95	6.82	108.0	5.7	1.1
GEM	CH ₄							
GEM	N ₂ O							
IMAGE	CO ₂	309.98	1.23	83.50	24.63	107.6	6.0	1.1
IMAGE	CH ₄	879.73	11.96	283.45	1.18	91.8	4.8	1.0
IMAGE	N ₂ O	22900.43	14.02	126.54	0.27	78.1	5.3	1.3
MESSAGE	CO ₂	471.55	3.02	179.97	30.24	112.0	5.0	0.8
MESSAGE	CH ₄	103852.03	49.10	2332.36	7.75	93.7	5.5	1.4
MESSAGE	N ₂ O	38175.32	5.95	155.77	0.43	62.0	3.8	0.9
POLES	CO ₂	1785.75	16.24	2092.84	3.01	110.2	4.4	0.8
POLES	CH ₄	4016.39	7.61	4016.39	7.61	97.2	5.8	1.1
POLES	N ₂ O	630.22	1.71	14691.35	7.56	87.4	5.3	0.8
REMIND	CO ₂	316.94	1.82	591.39	21.77	103.5	6.1	0.7
REMIND	CH ₄	143.80	1.02	2139.05	14.81	97.4	5.3	1.3
REMIND	N ₂ O	5558.24	2.93	44.00	0.17	47.8	2.9	0.9
TIAM	CO ₂	183.59	11.93	394.27	1.39	116.2	4.6	0.8
TIAM	CH ₄							
TIAM	N ₂ O							
WITCH	CO ₂	421.02	1.40	971.12	7.56	100.0	3.8	1.1
WITCH	CH ₄	1528.23	36.27	153.56	3.52	98.2	5.8	3.4
WITCH	N ₂ O	97.19	0.73	437940.23	8.98	50.8	3.3	1.3

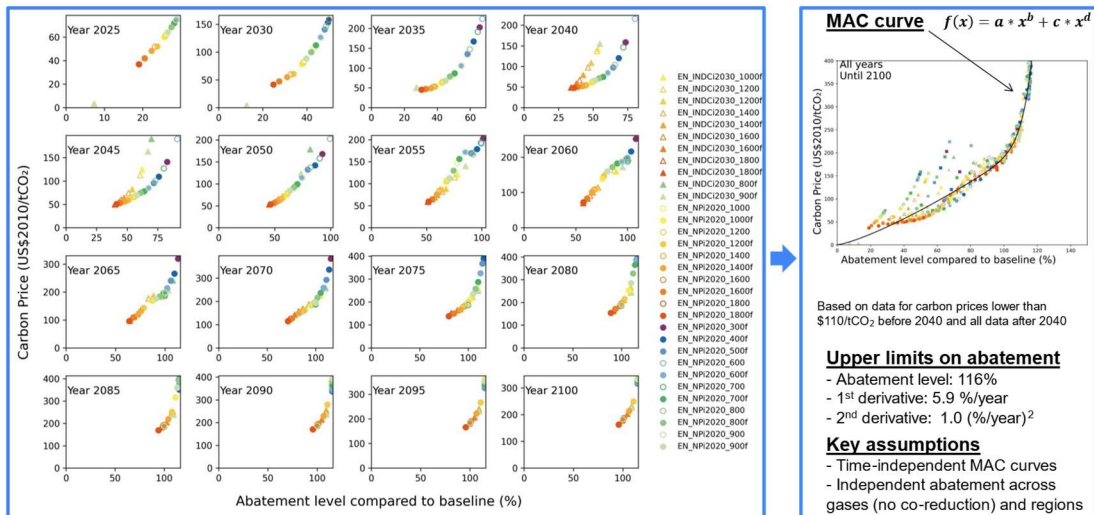


Figure S1. Overview of the methods to derive AIM MAC curves and limits on abatement. The description of the figure can be found in Figure 1 of the main text.

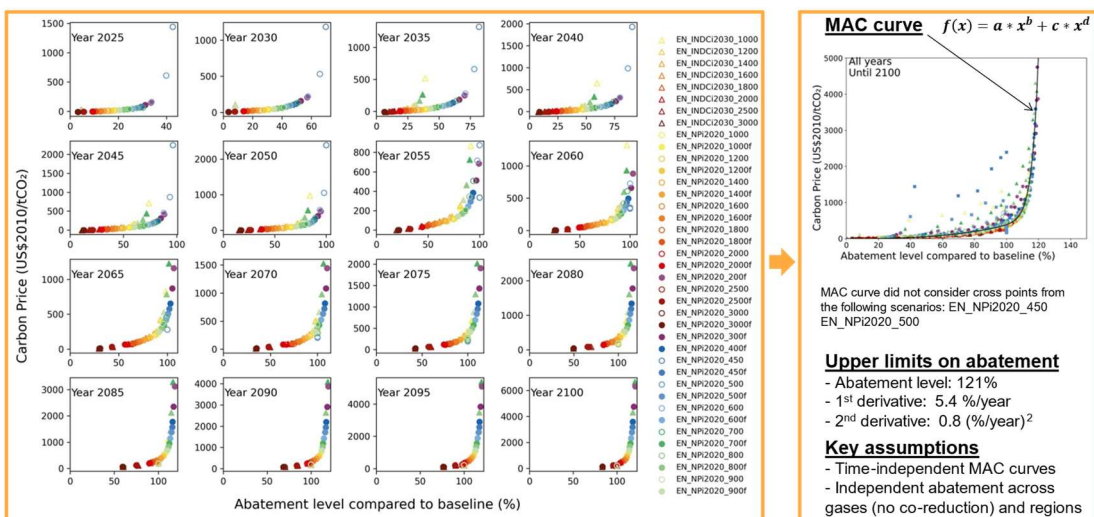


Figure S2. Overview of the methods to derive MESSAGE MAC curves and limits on abatement.

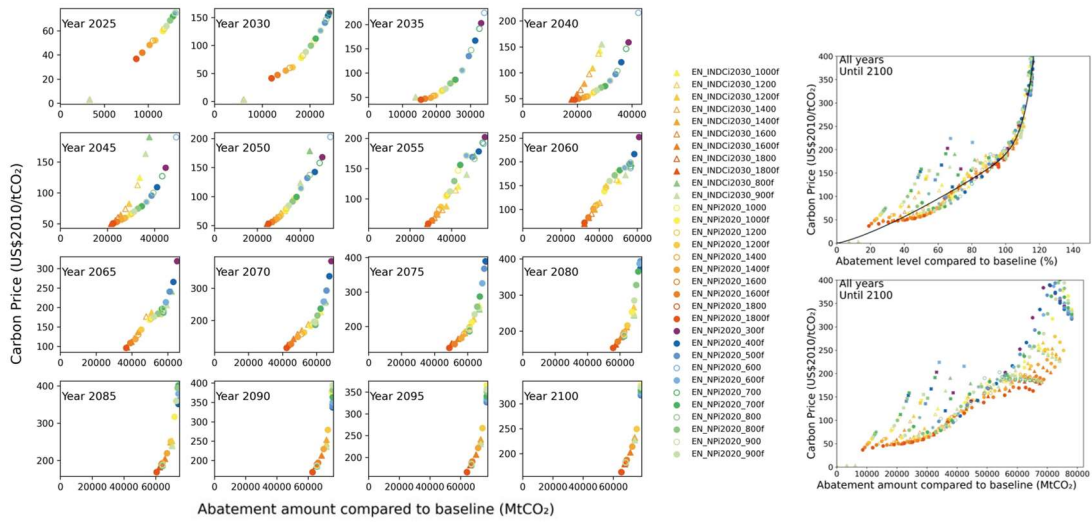


Figure S3. Overview of the methods to derive AIM MAC curves and limits on abatement. The results is in the absolute term.

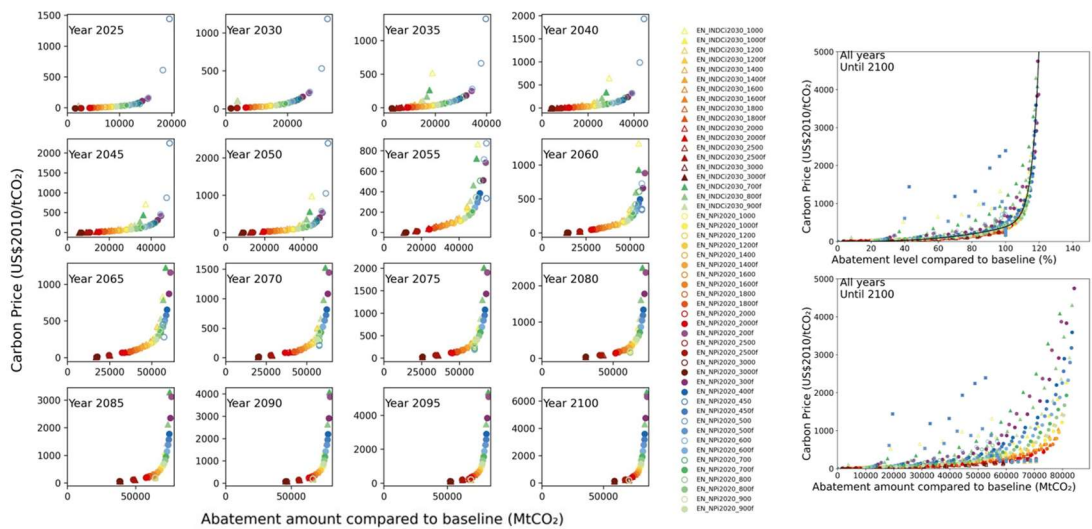


Figure S4. Overview of the methods to derive MESSAGE MAC curves and limits on abatement. The results is in the absolute term.

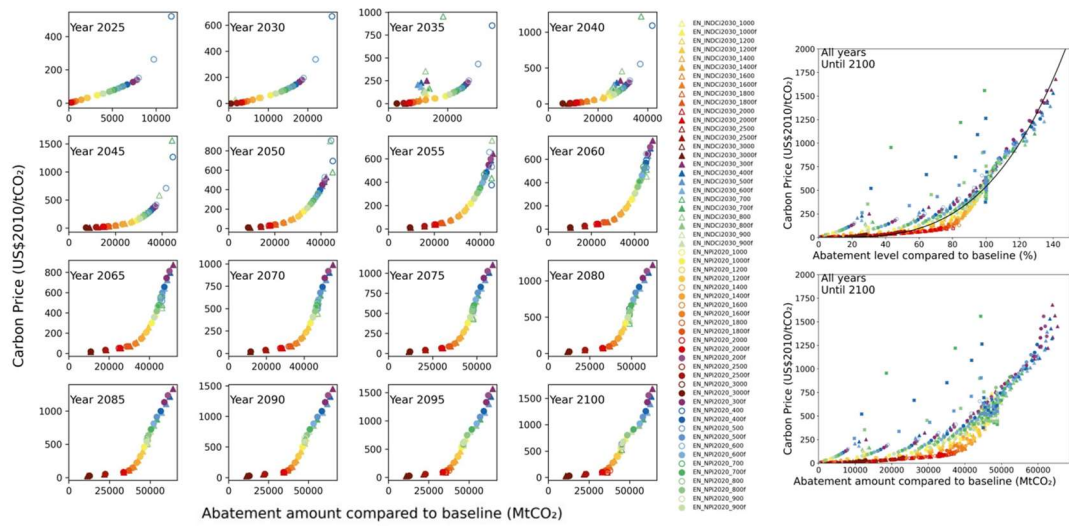


Figure S5. Overview of the methods to derive AIM MAC curves and limits on abatement. The results is in the absolute term.

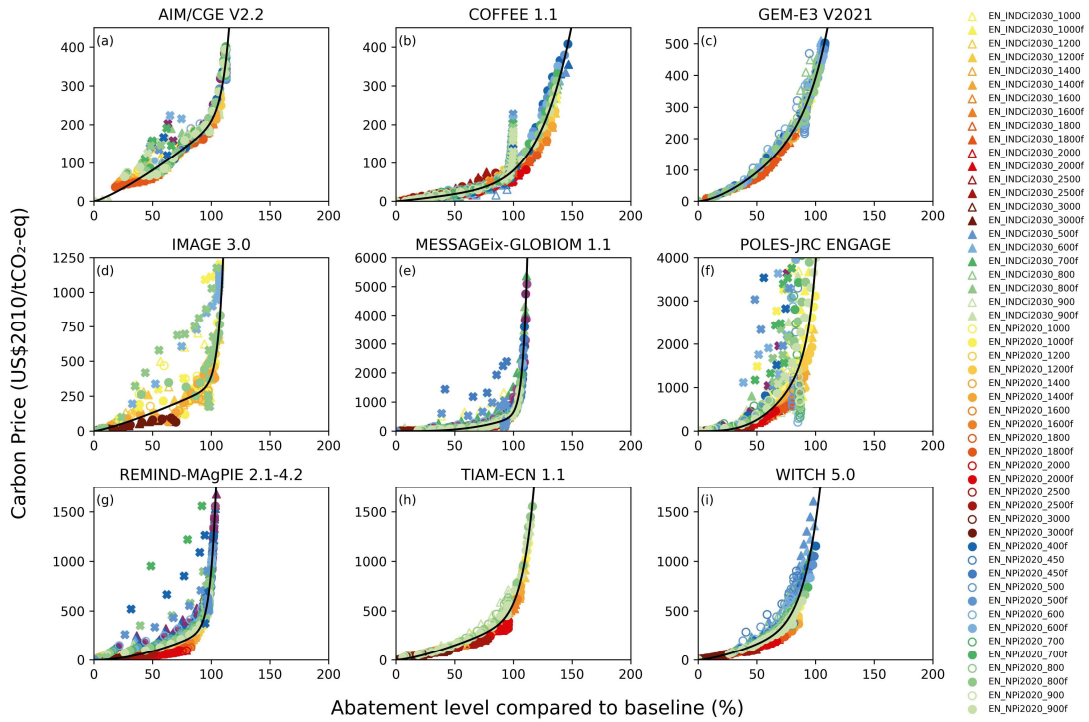


Figure S6. Global energy-related CO₂ MAC curve from nine ENGAGE IAMs. Each panel shows the results from each IAM from the ENGAGE Scenario Explorer. Points are the data obtained from the ENGAGE Scenario Explorer shown in colors and markers as designated in the legend. Black lines are the MAC curves. Open circles are the data that were not considered in the derivation of MAC curves.

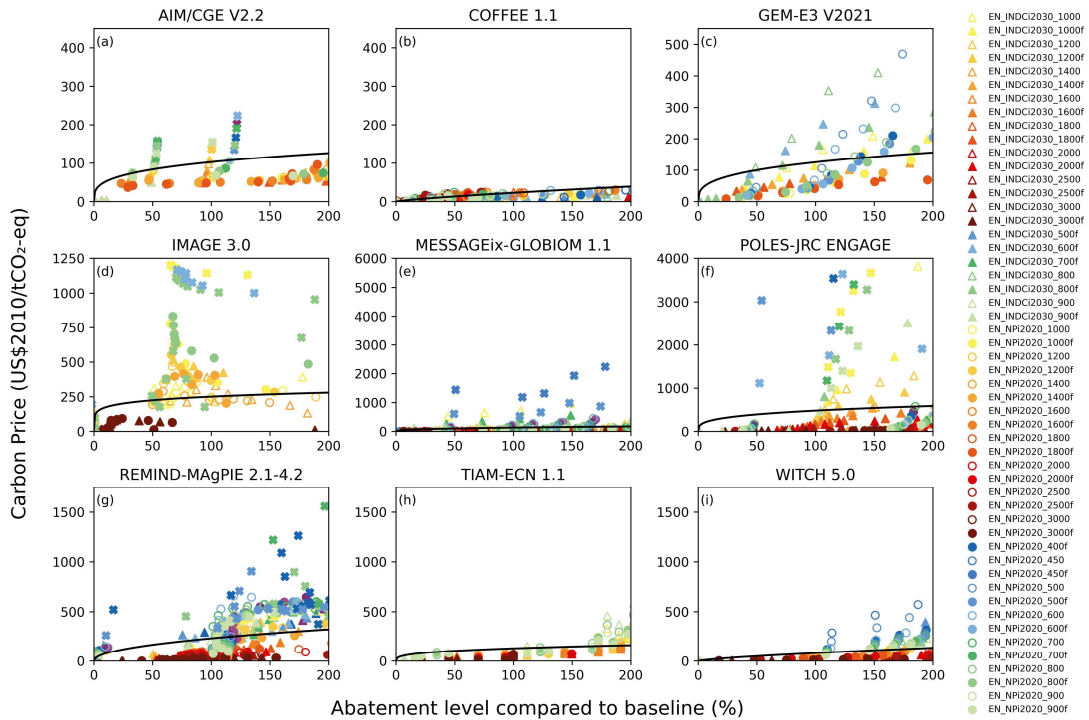


Figure S7. Global non-energy-related CO₂ MAC curve from nine ENGAGE IAMs

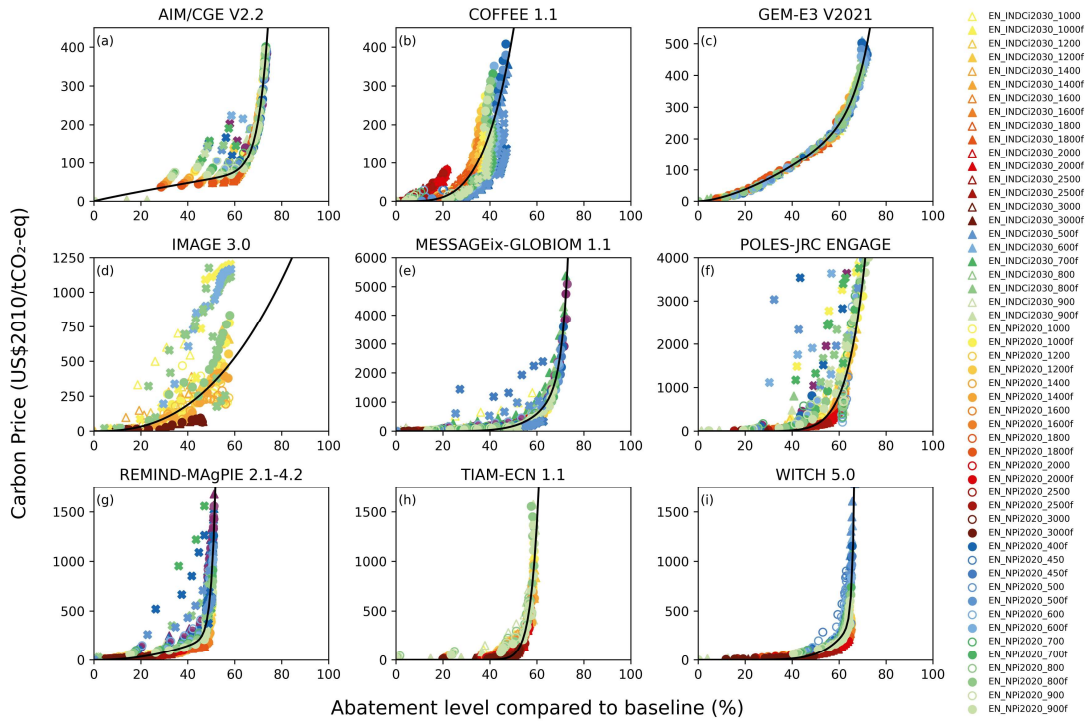


Figure S8. Global total anthropogenic CH₄ MAC curve from nine ENGAGE IAMs

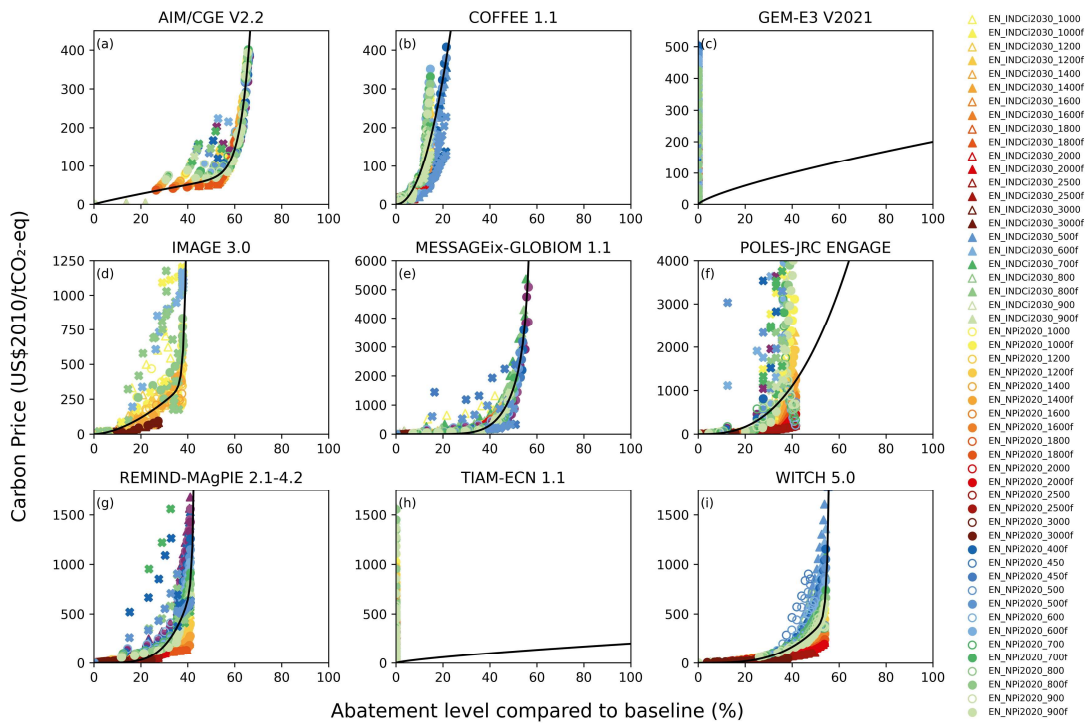


Figure S9. Global energy-related CH₄ MAC curve from nine ENGAGE IAMs

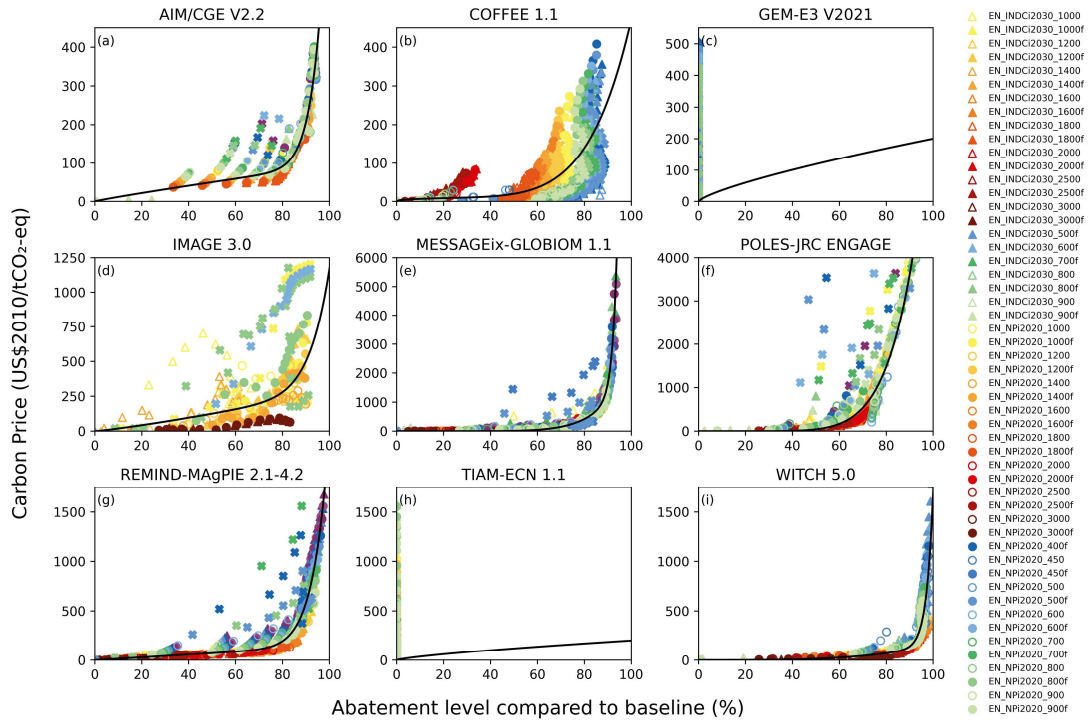


Figure S10. Global non-energy-related CH₄ MAC curve from nine ENGAGE IAMs

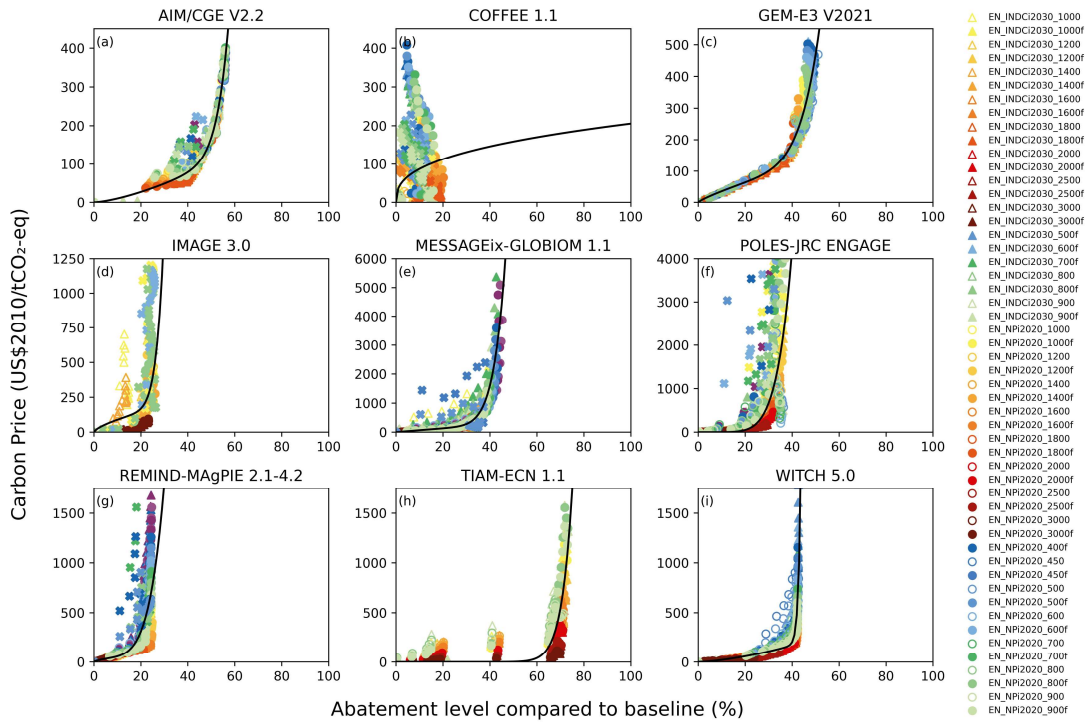


Figure S11. Global total anthropogenic N₂O MAC curve from nine ENGAGE IAMs

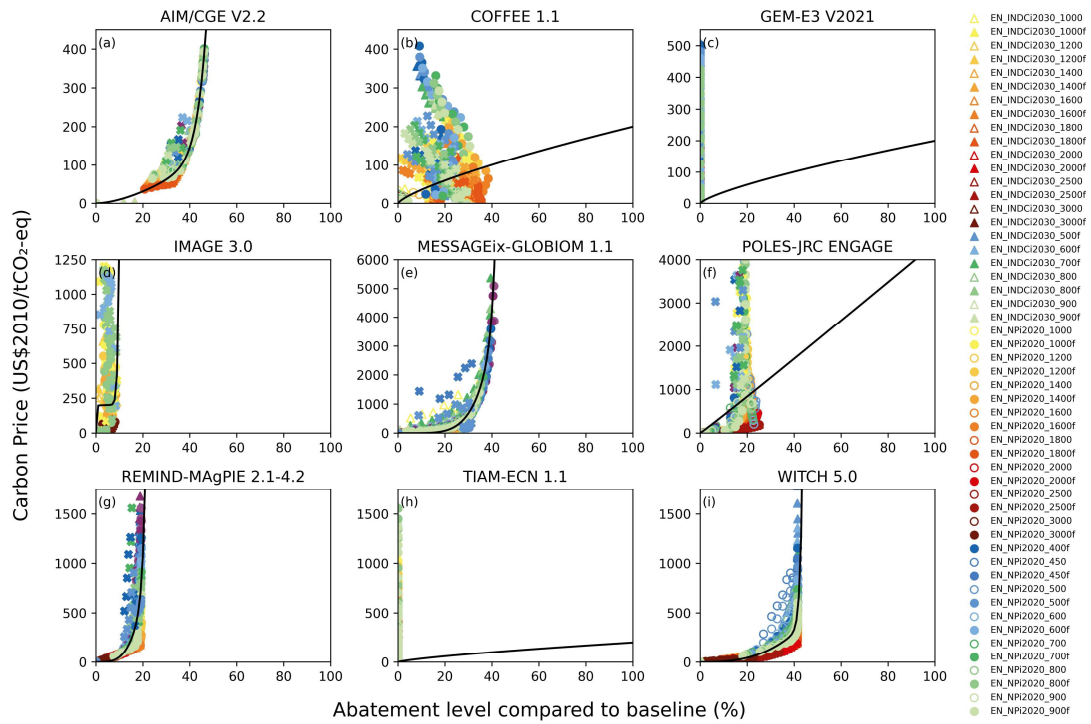


Figure S12. Global energy-related N₂O MAC curve from nine ENGAGE IAMs

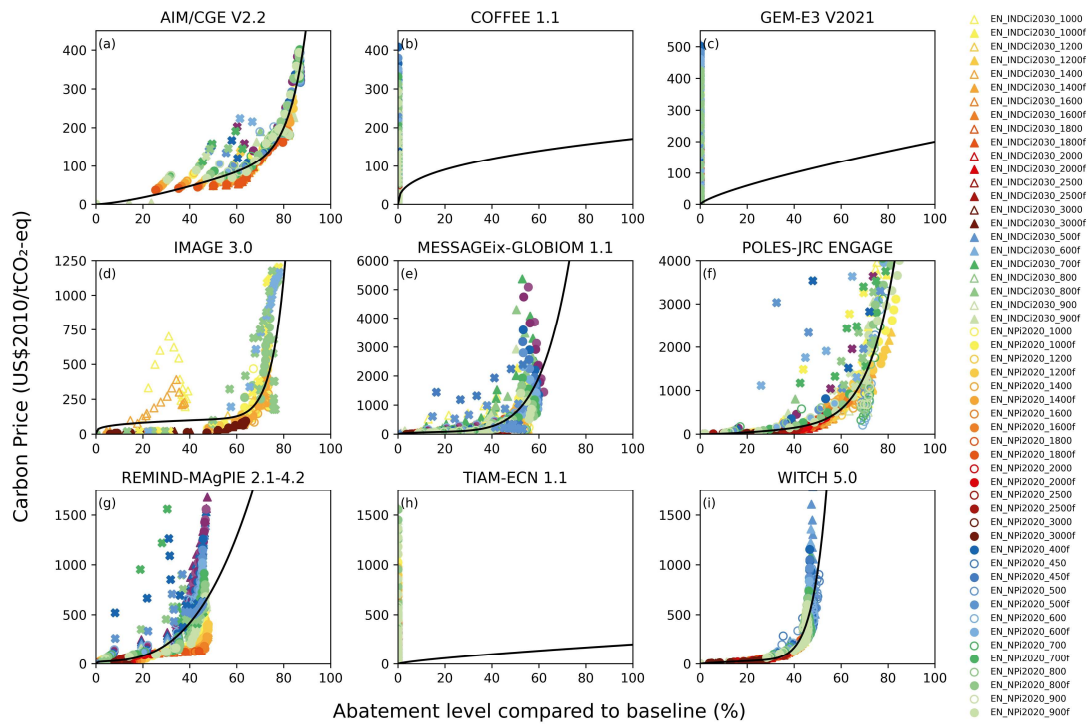


Figure S13. Global non-energy-related N₂O MAC curve from nine ENGAGE IAMs

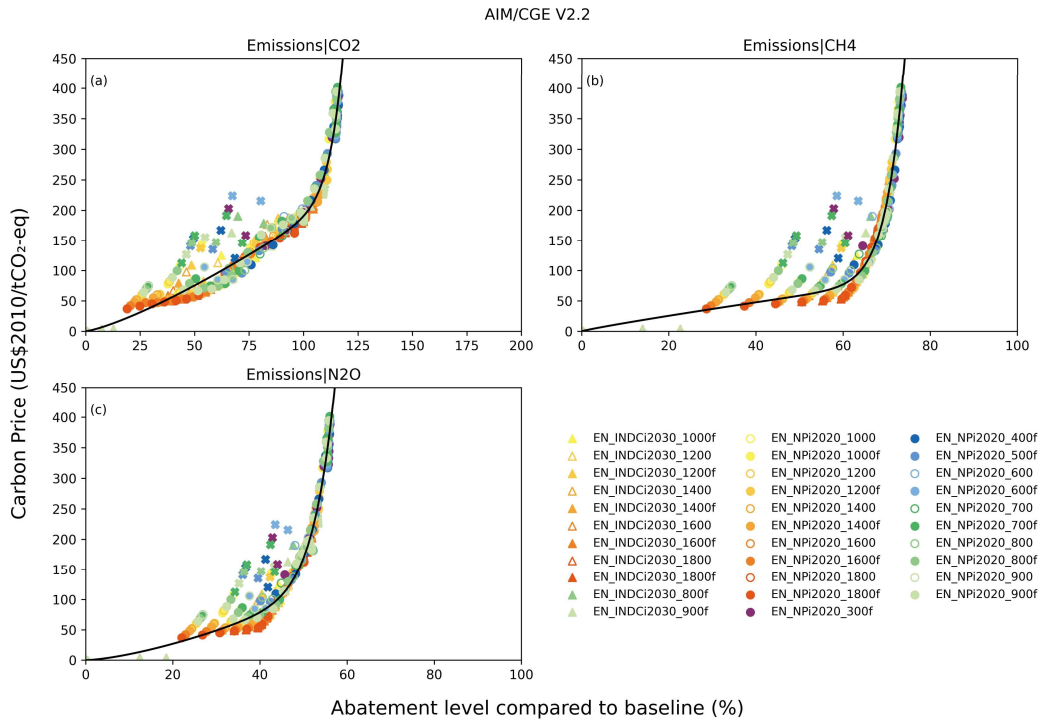


Figure S14. Global AIM MAC curve

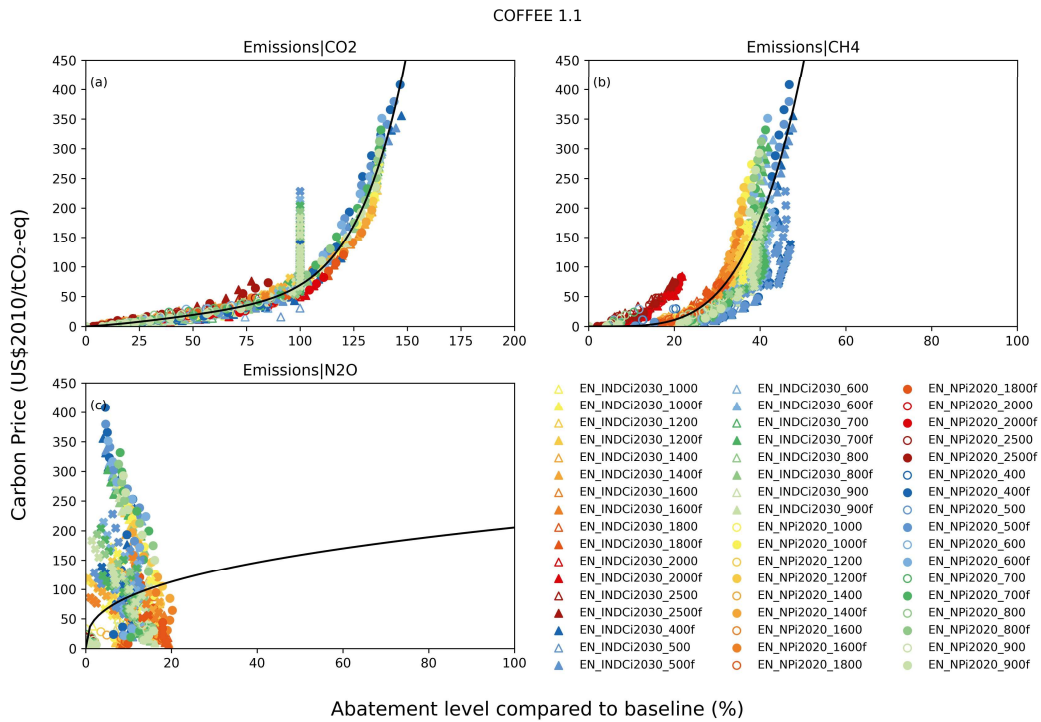


Figure S15. Global COFFEE MAC curve

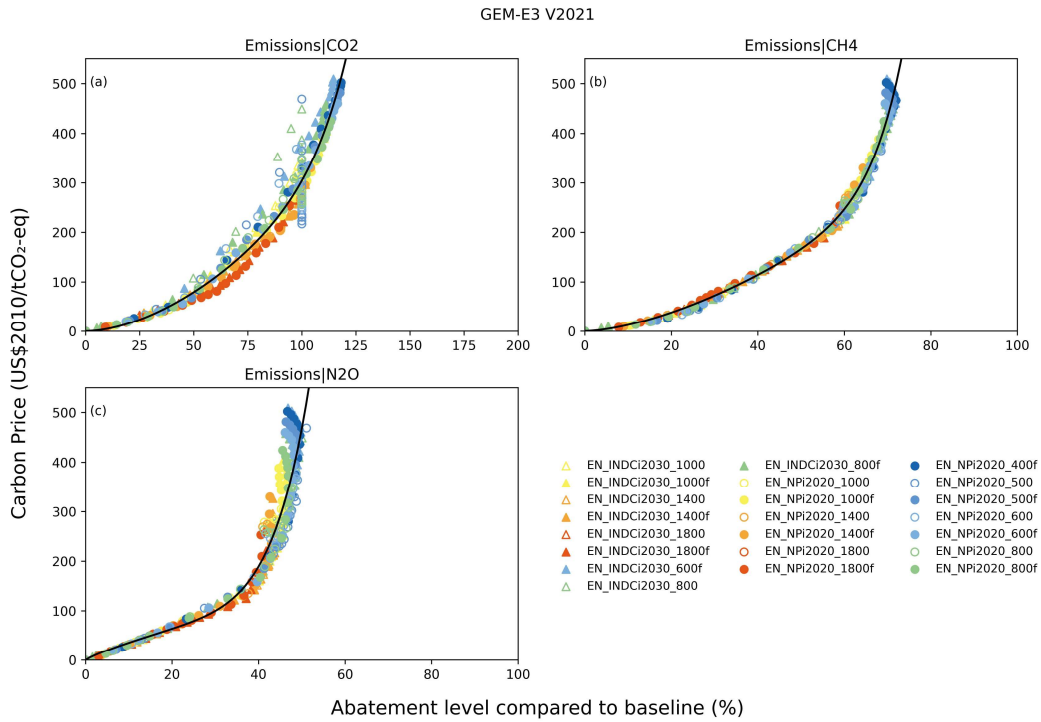


Figure S16. Global GEM MAC curve

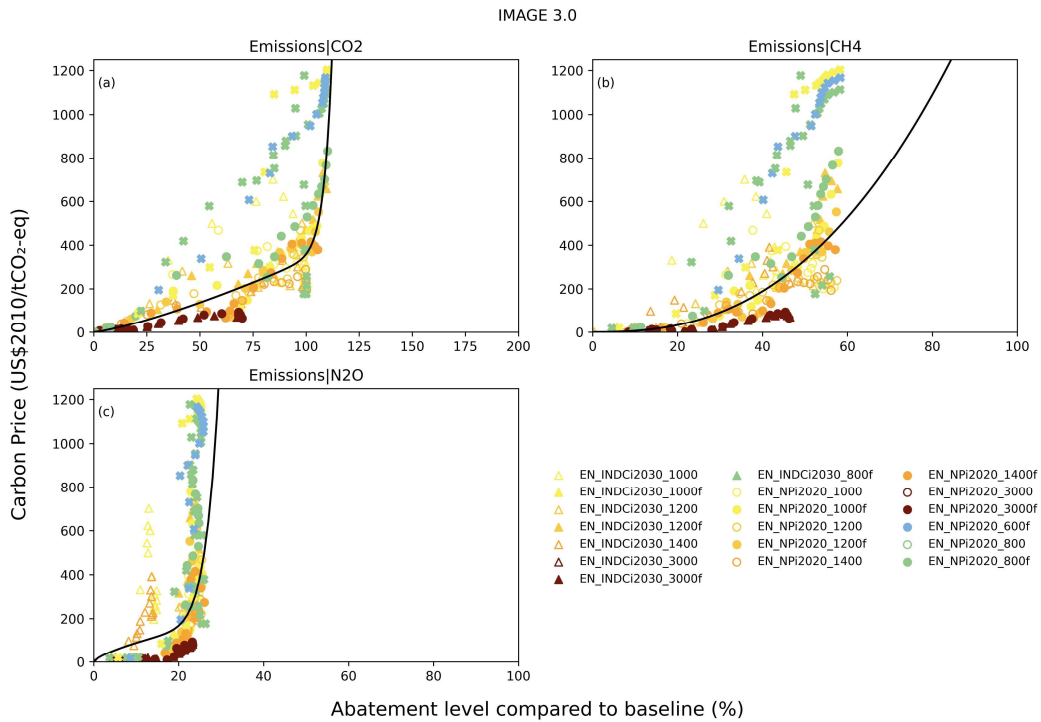


Figure S17. Global IMAGE MAC curve

MESSAGEix-GLOBIOM 1.1

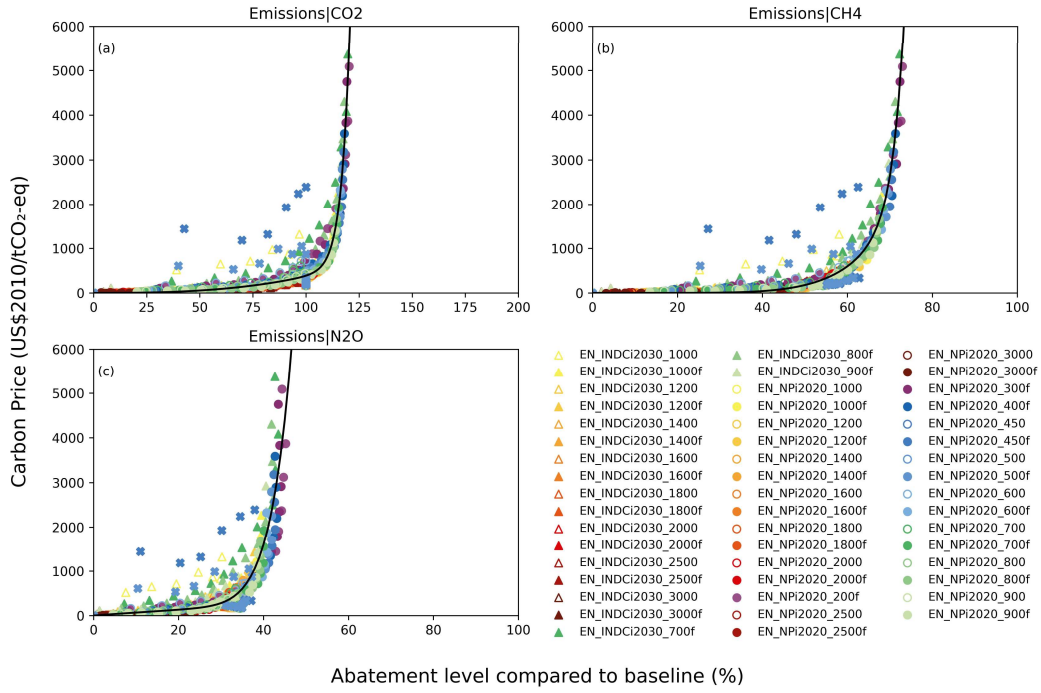


Figure S18. Global MESSAGE MAC curve

POLES-JRC ENGAGE

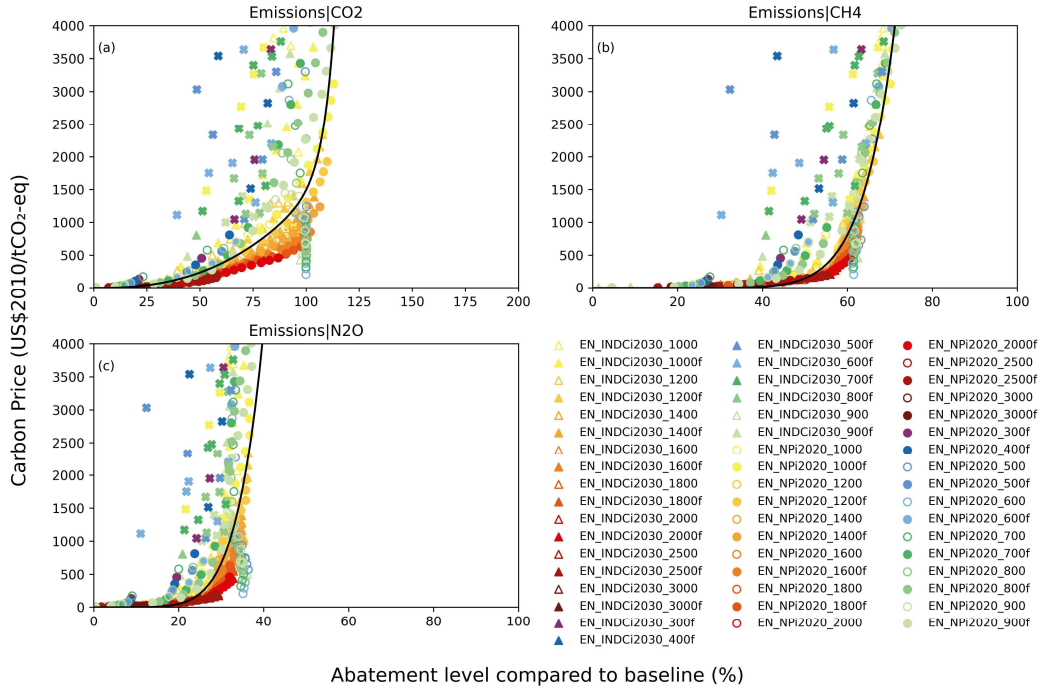


Figure S19. Global POLES MAC curve

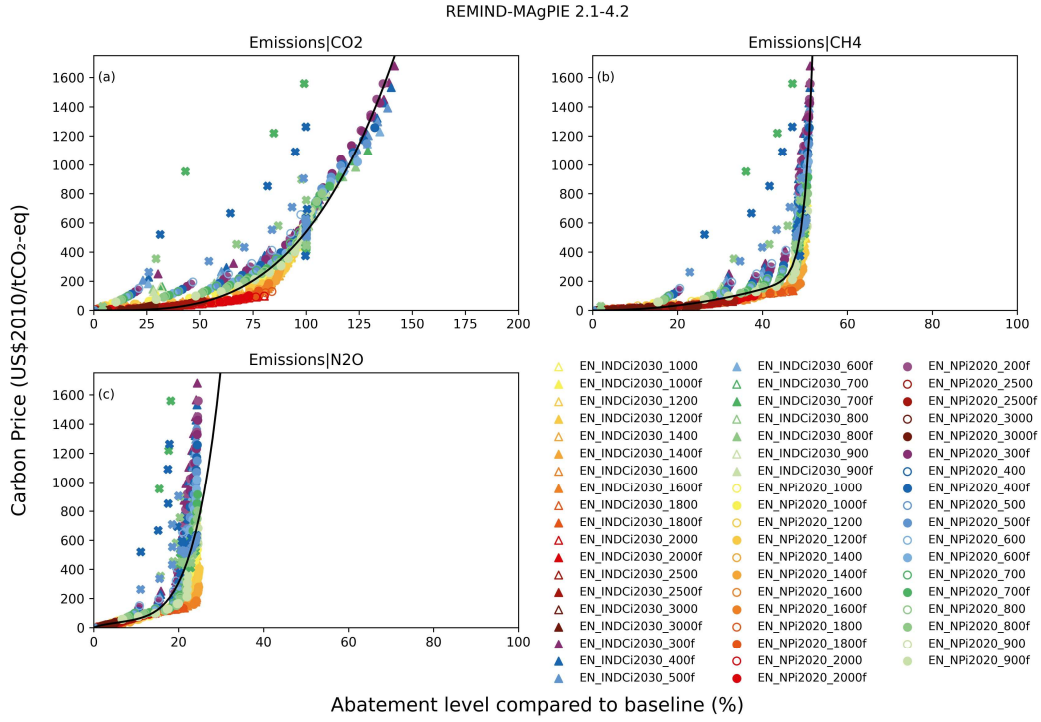


Figure S20. Global REMIND MAC curve

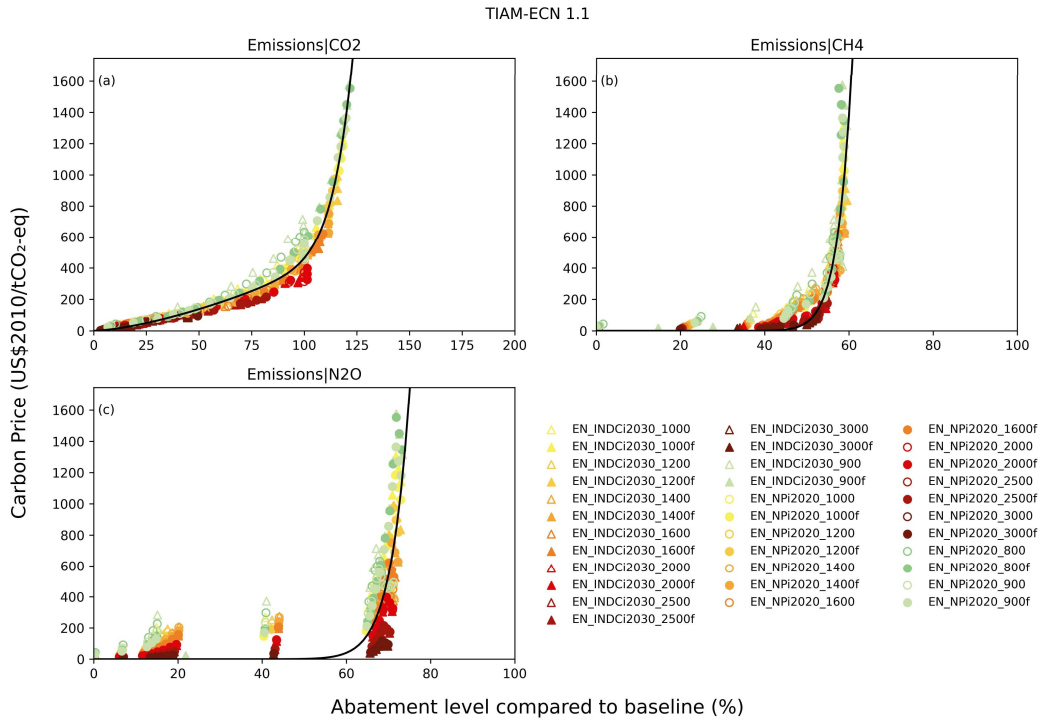


Figure S21. Global TIAM MAC curve

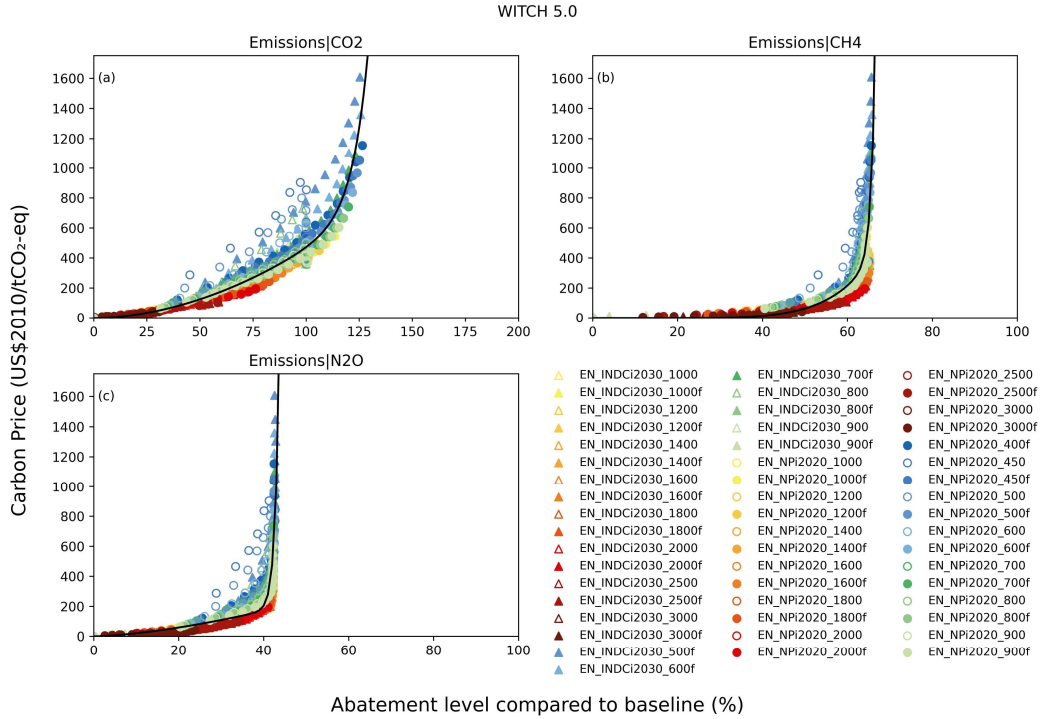


Figure S22. Global WITCH MAC curve

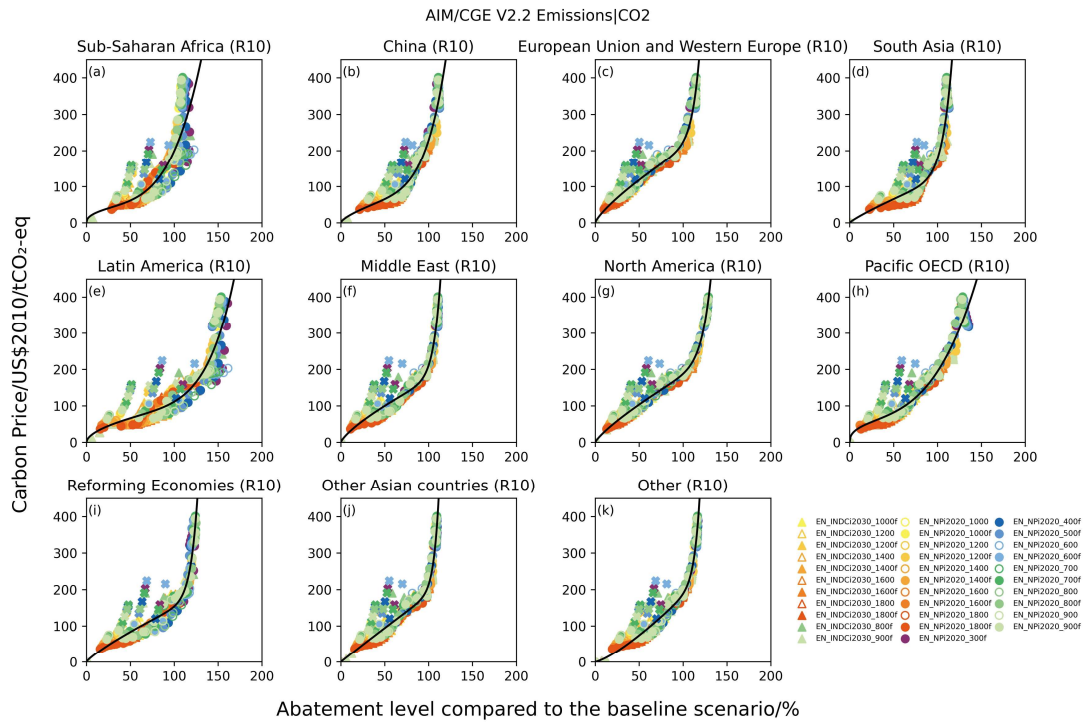


Figure S23. Regional AIM total anthropogenic CO₂ MAC curve

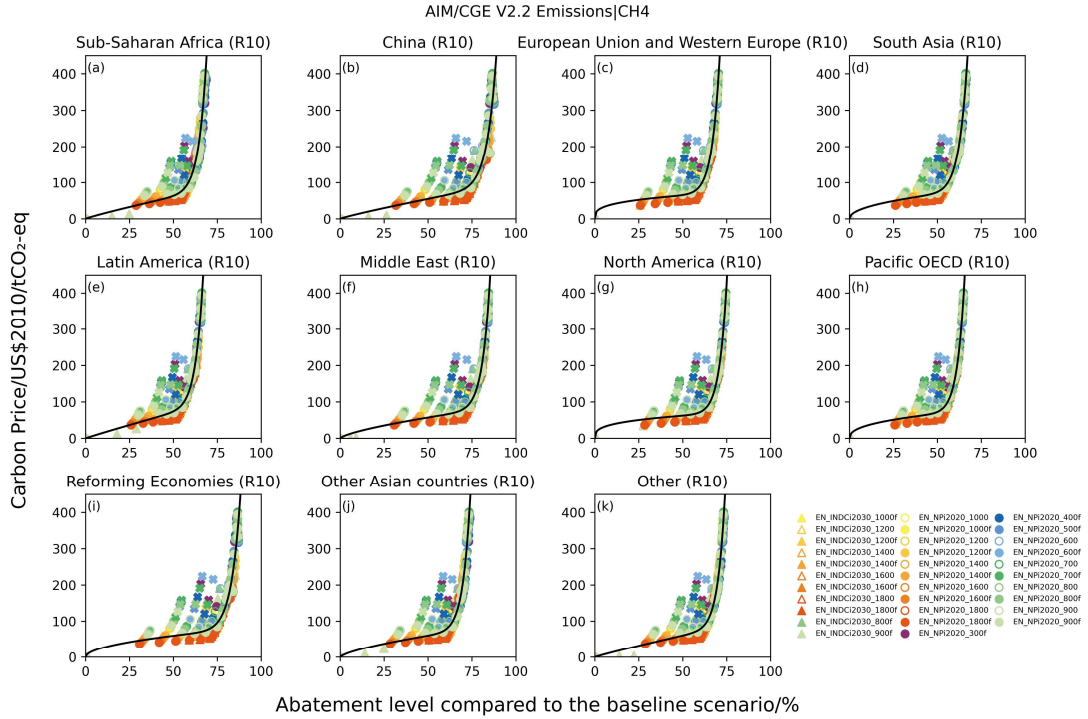


Figure S24. Regional AIM total anthropogenic CH₄ MAC curve

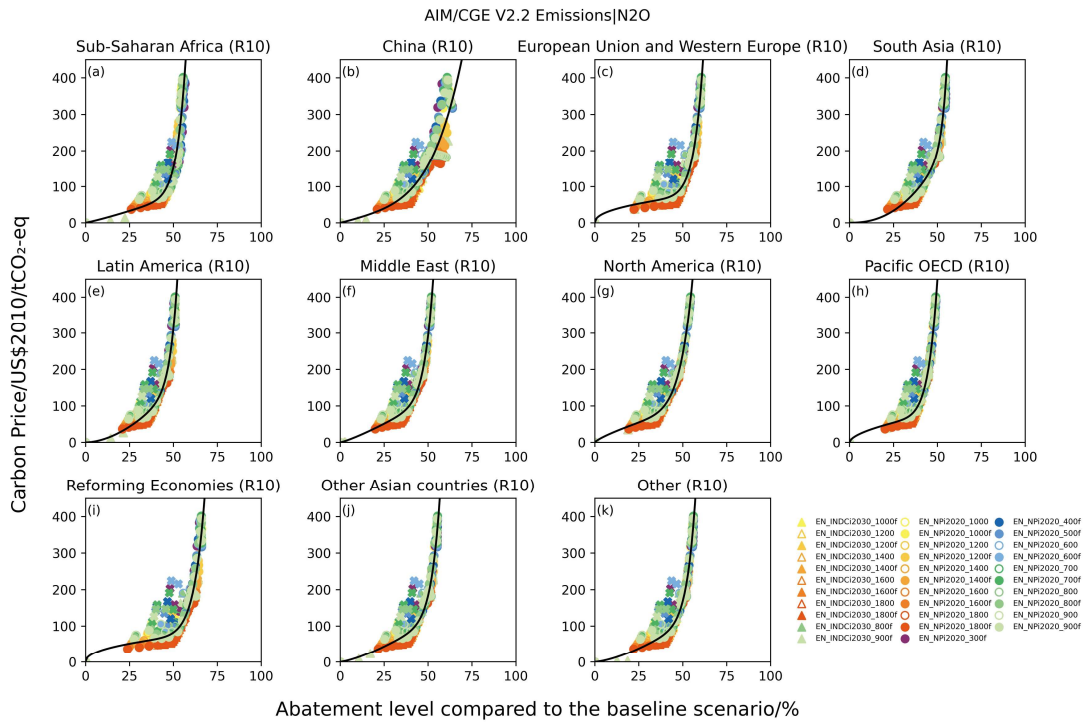


Figure S25. Regional AIM total anthropogenic N₂O MAC curve

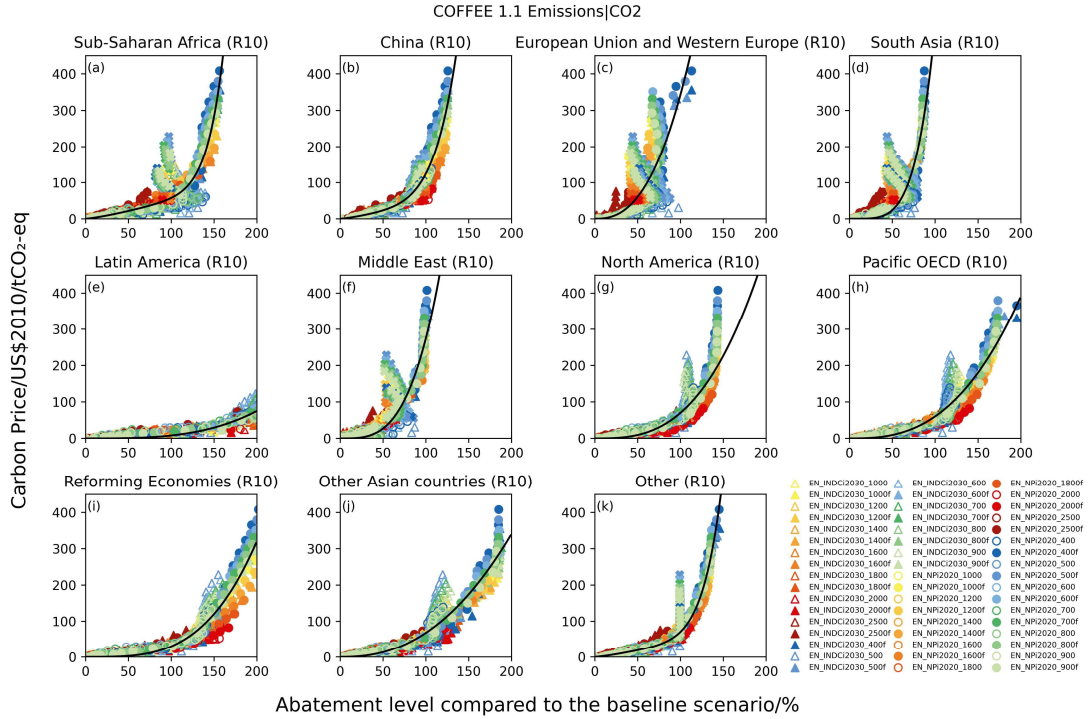


Figure S26. Regional COFFEE total anthropogenic CO₂ MAC curve

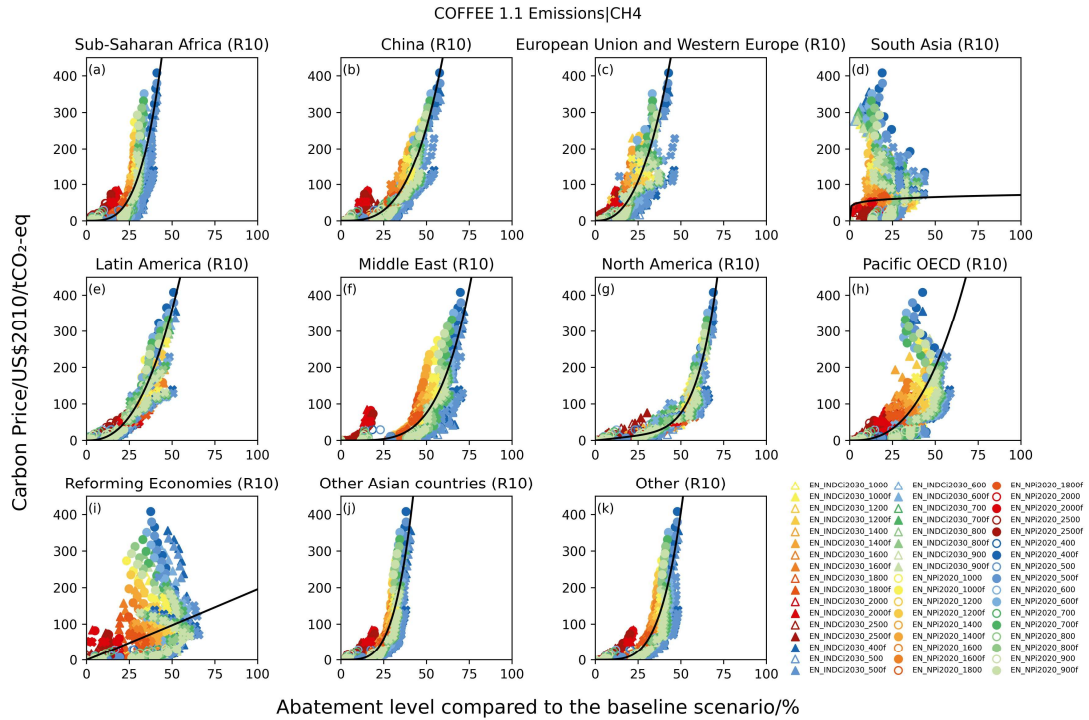


Figure S27. Regional COFFEE total anthropogenic CH₄ MAC curve

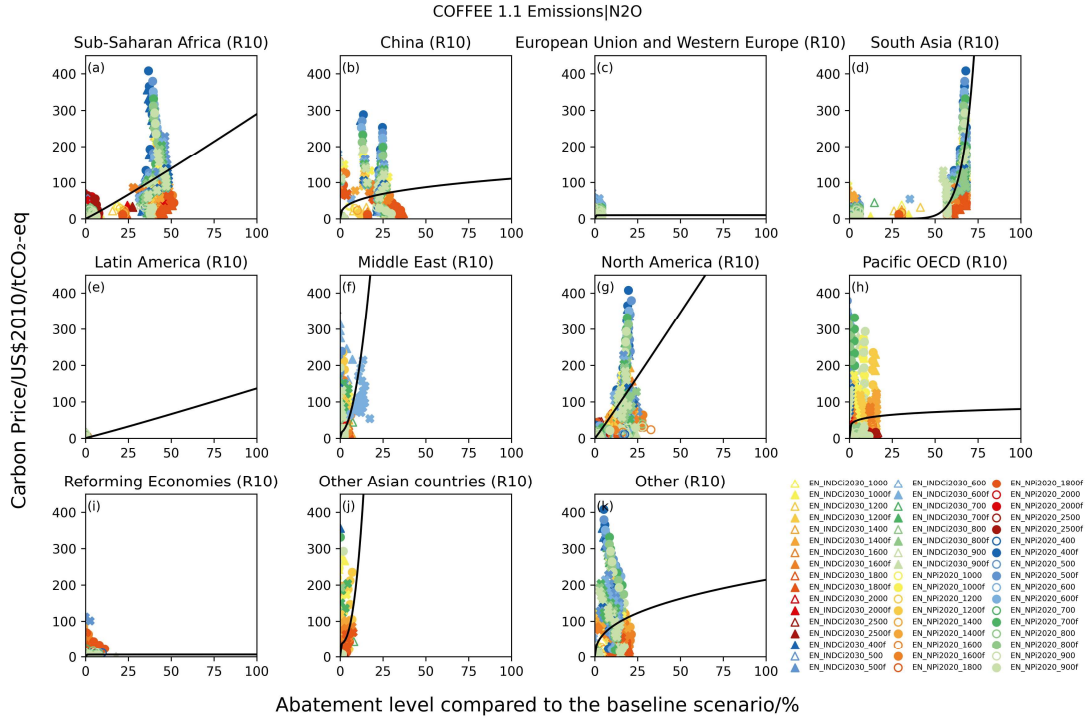


Figure S28. Regional COFFEE total anthropogenic N₂O MAC curve

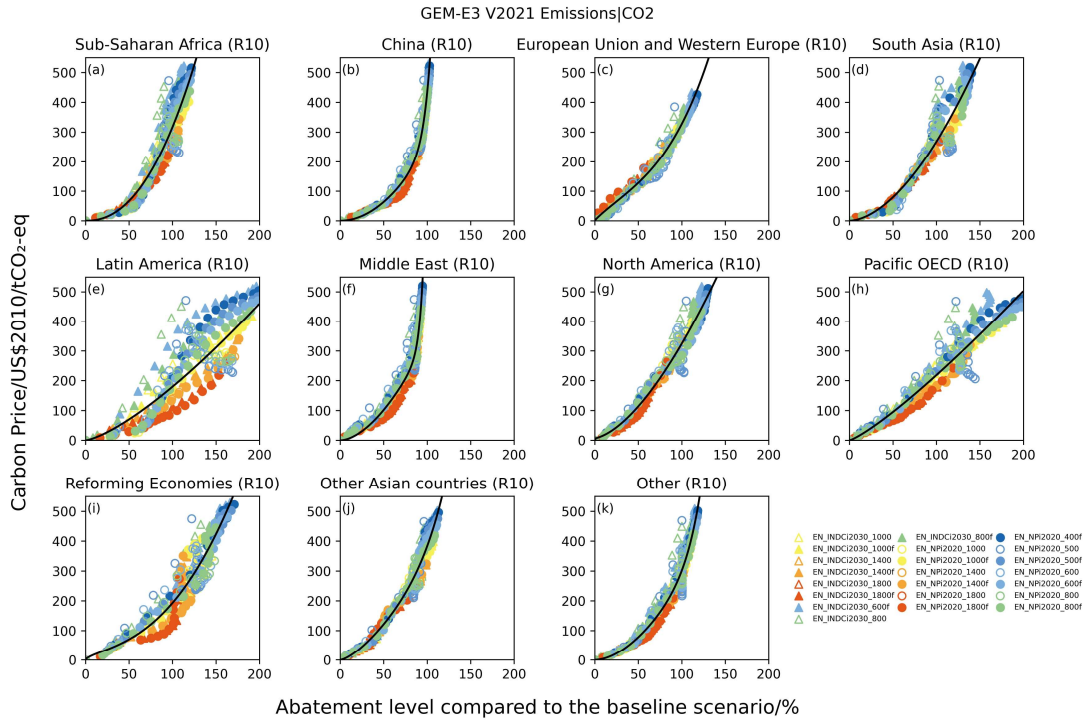


Figure S29. Regional GEM total anthropogenic CO₂ MAC curve

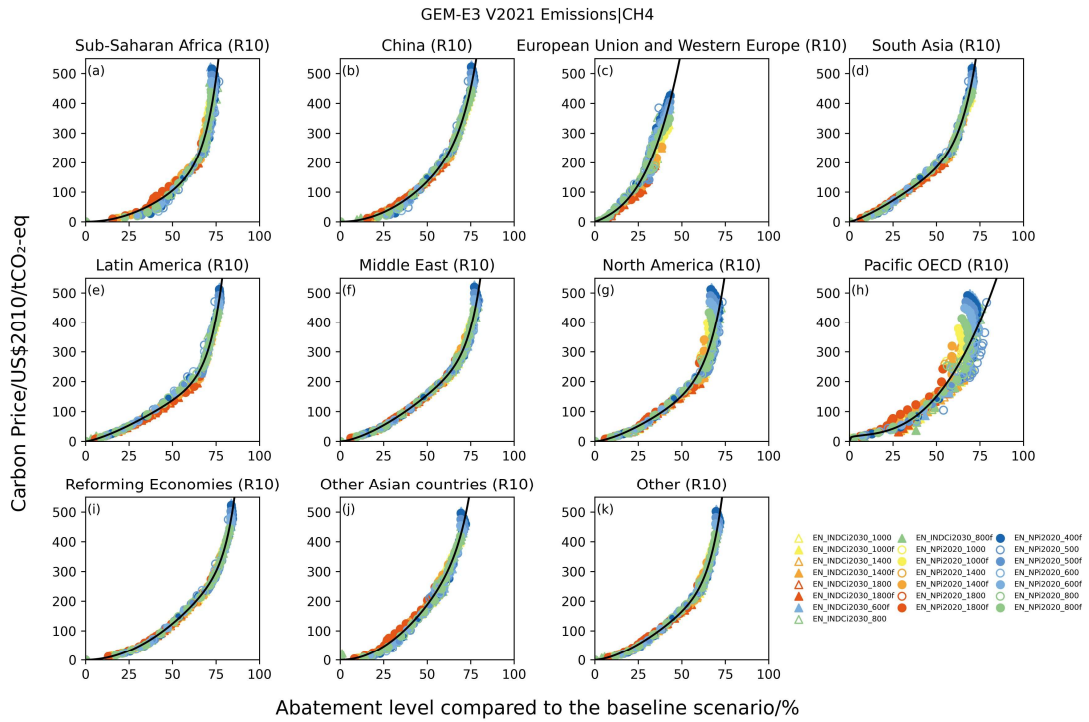


Figure S30. Regional GEM CH₄ MAC curve

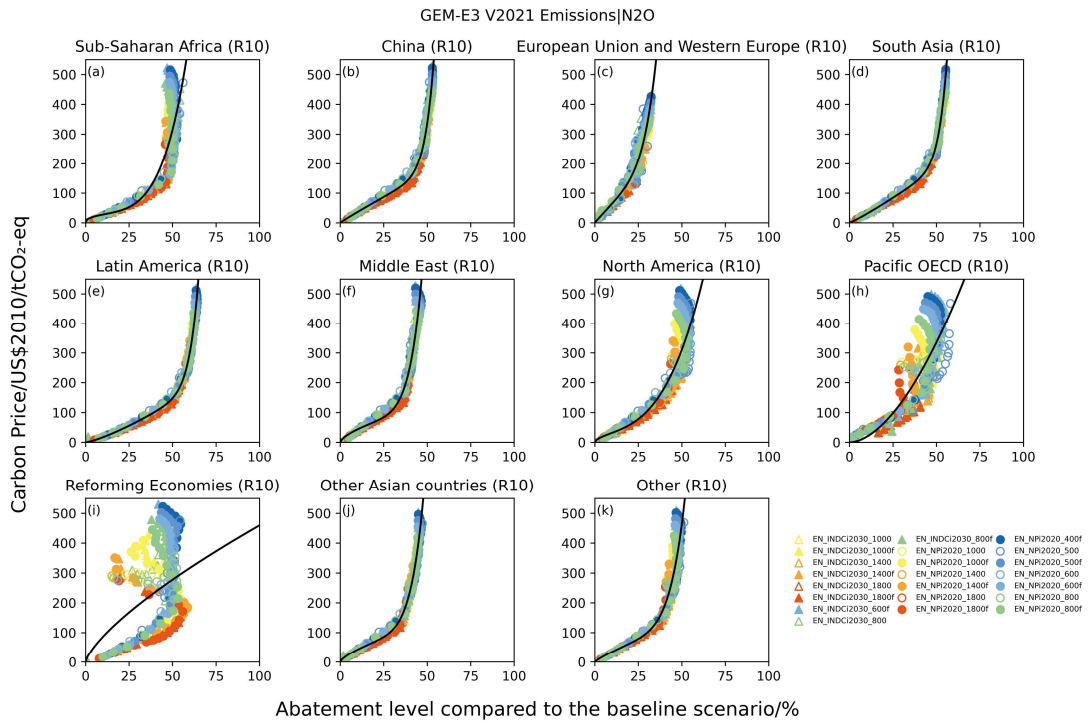


Figure S31. Regional GEM total anthropogenic N₂O MAC curve

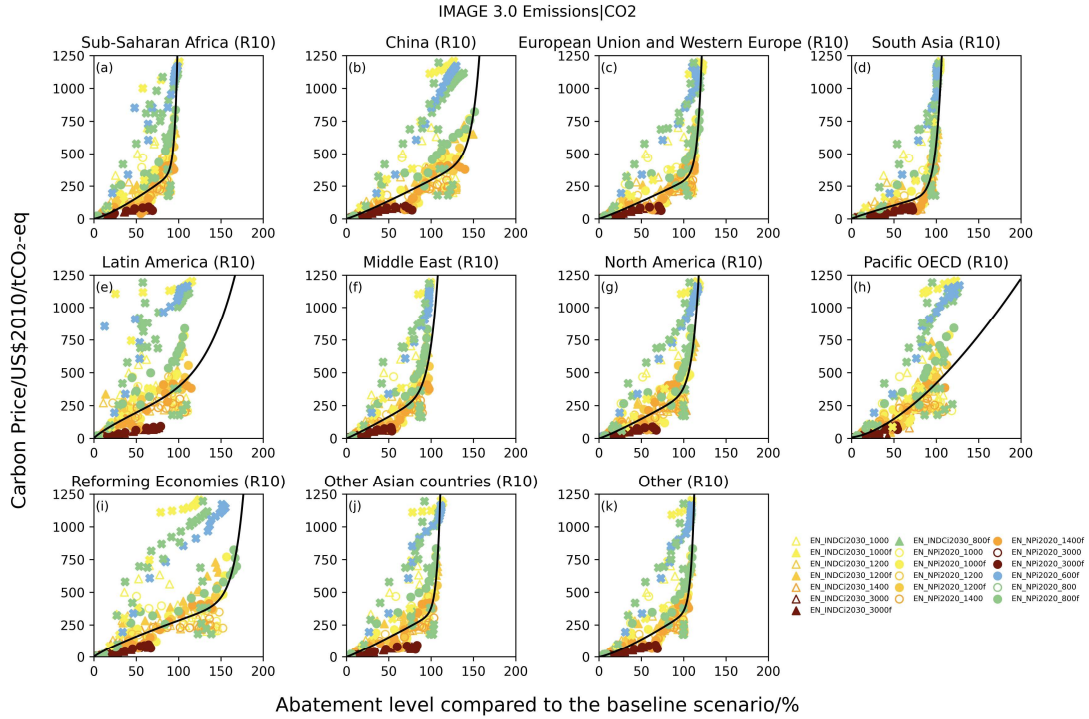


Figure S32. Regional IMAGE total anthropogenic CO₂ MAC curve

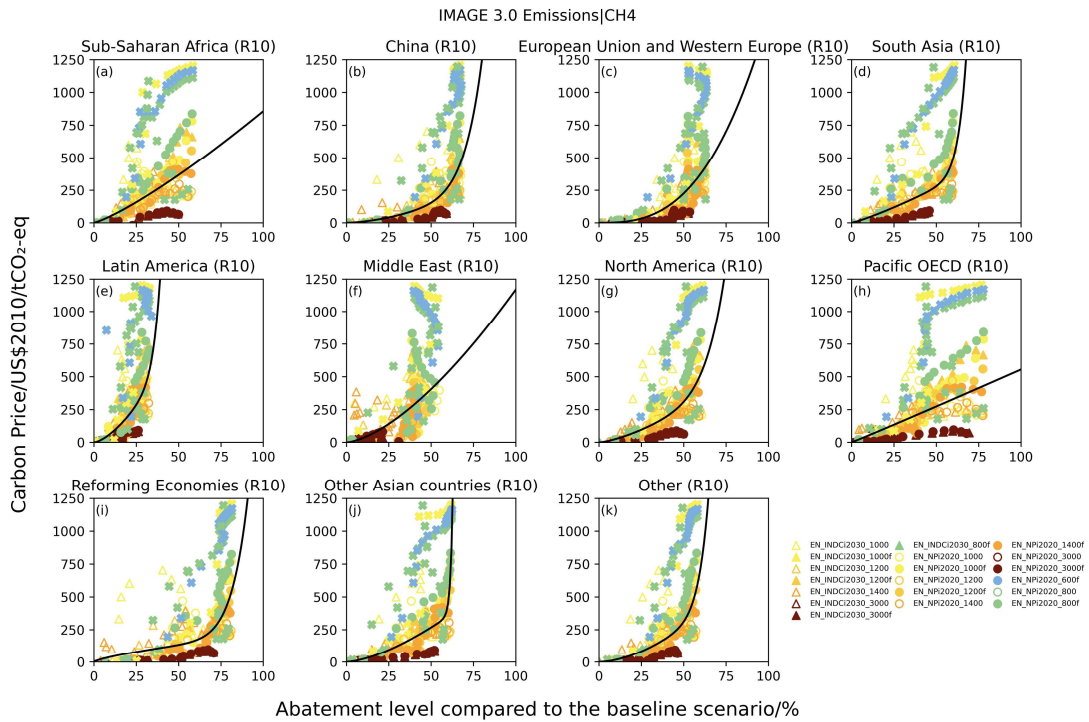


Figure S33. Regional IMAGE total anthropogenic CH₄ MAC curve

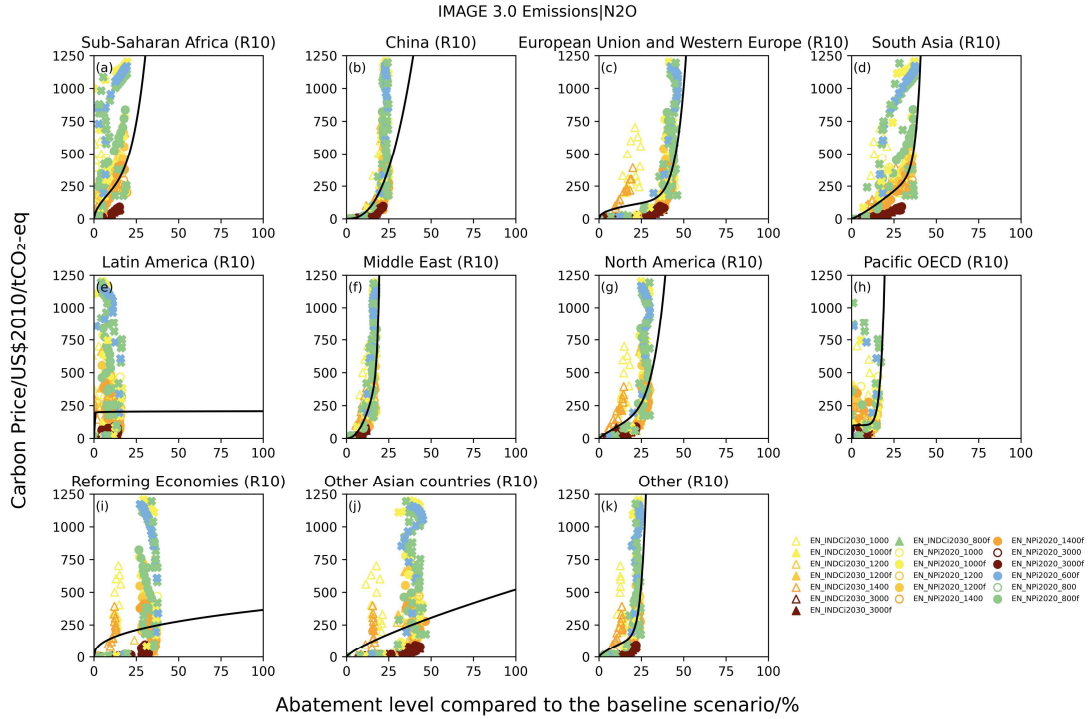


Figure S34. Regional IMAGE total anthropogenic N₂O MAC curve

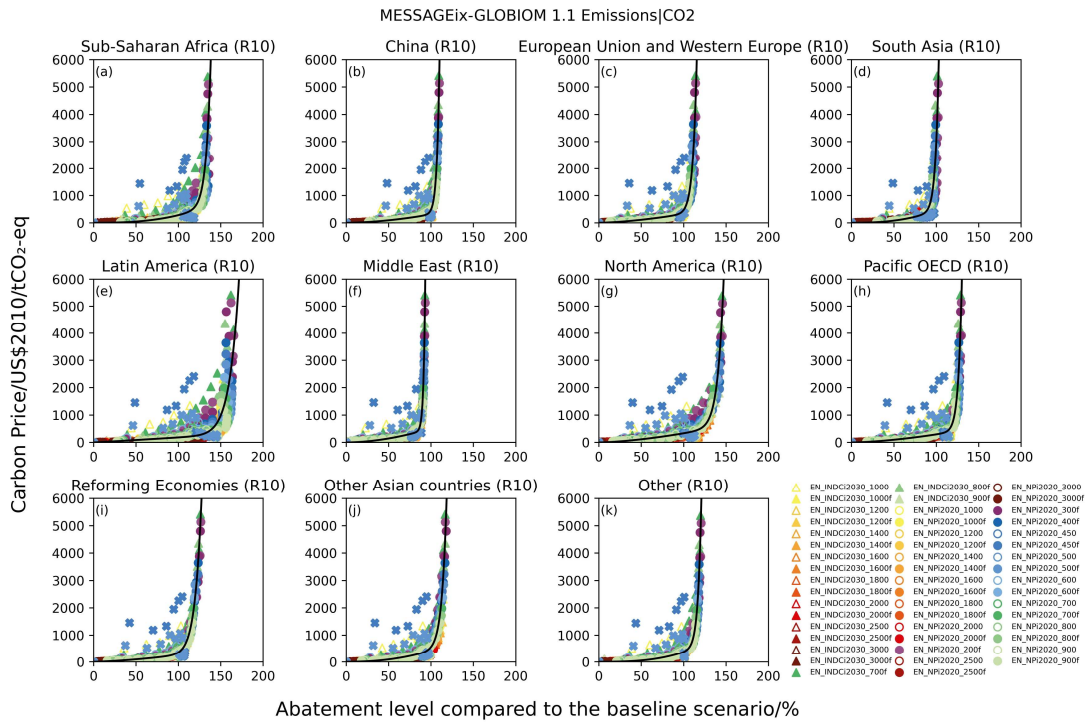


Figure S35. Regional MESSAGE total anthropogenic CO₂ MAC curve

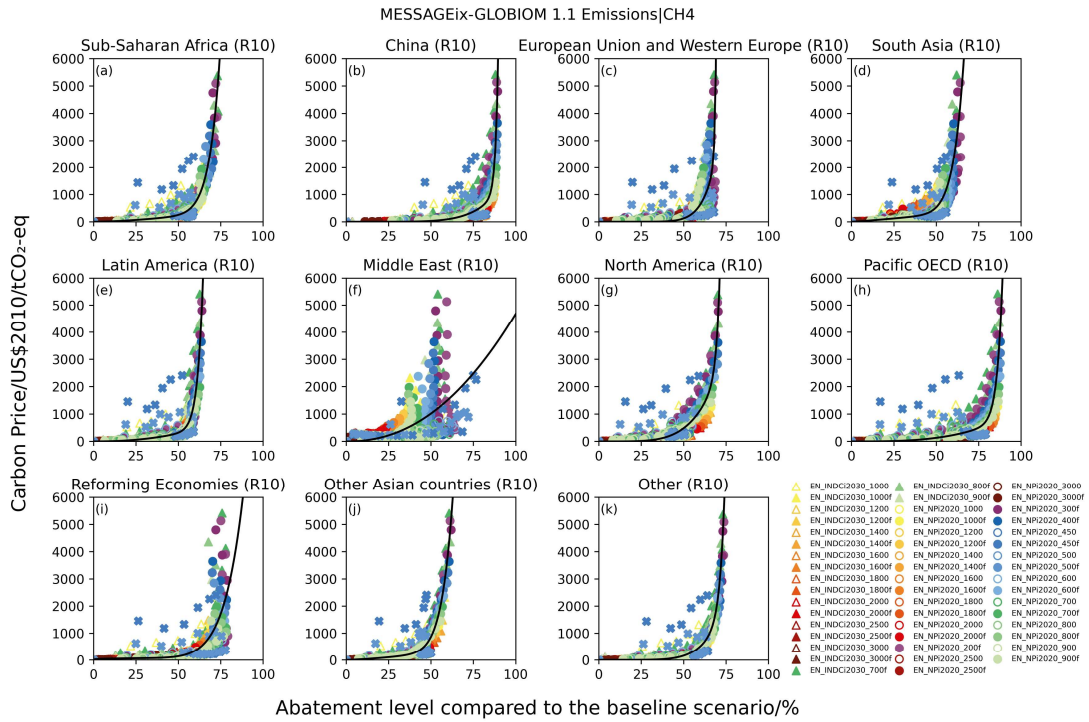


Figure S36. Regional MESSAGE total anthropogenic CH₄ MAC curve

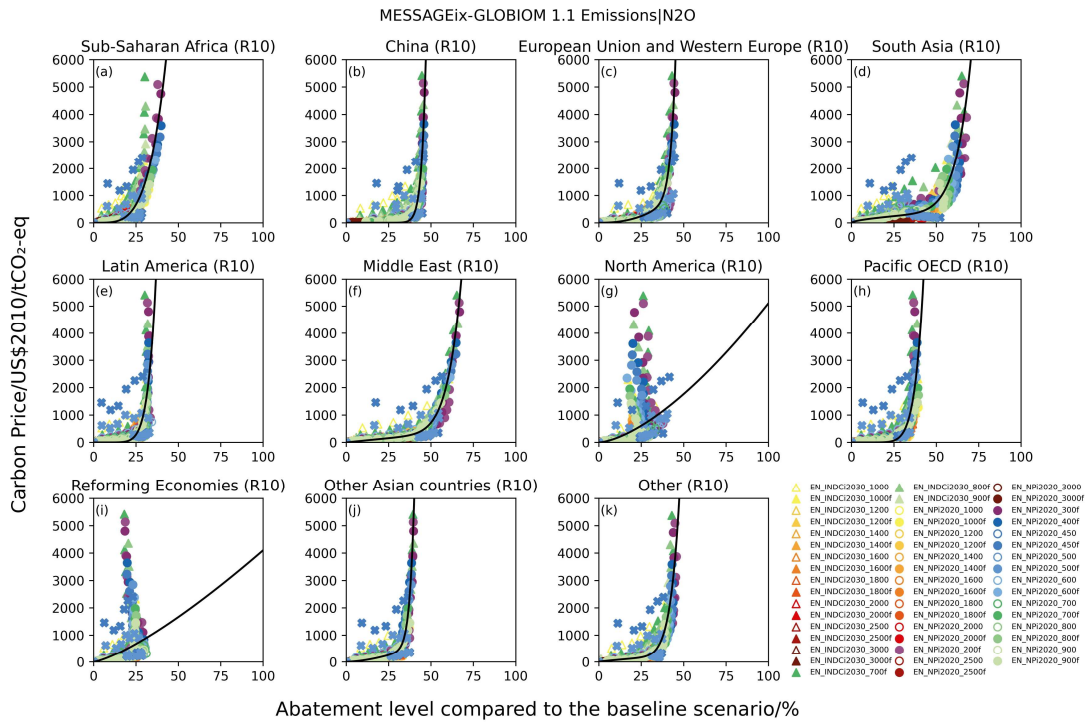


Figure S37. Regional MESSAGE total anthropogenic N₂O MAC curve

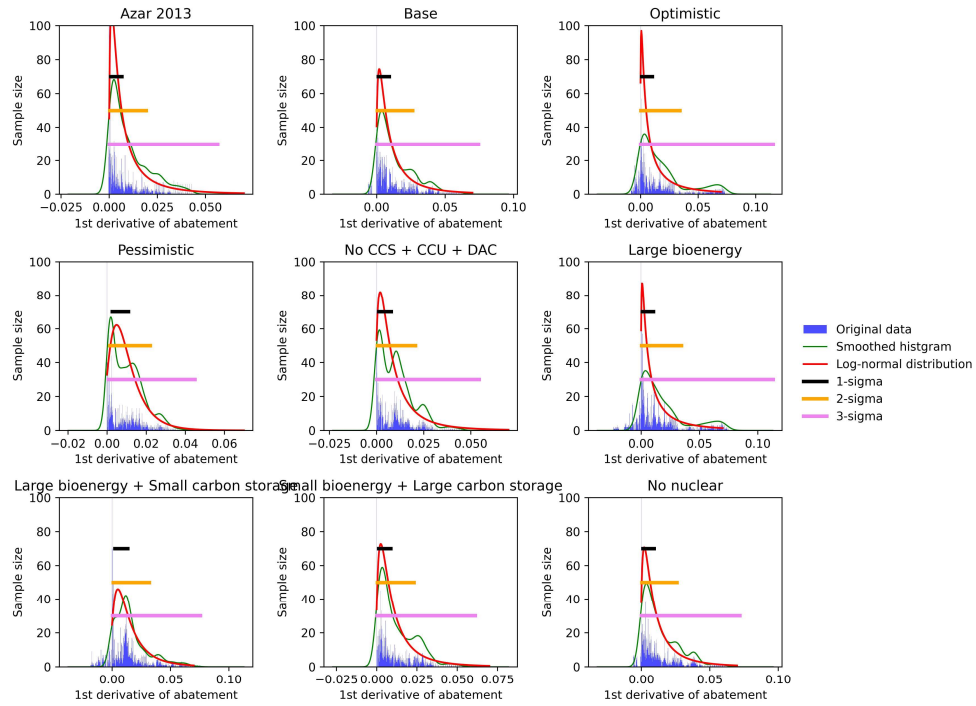


Figure S38. Global GET - Distribution of first derivative of abatement levels

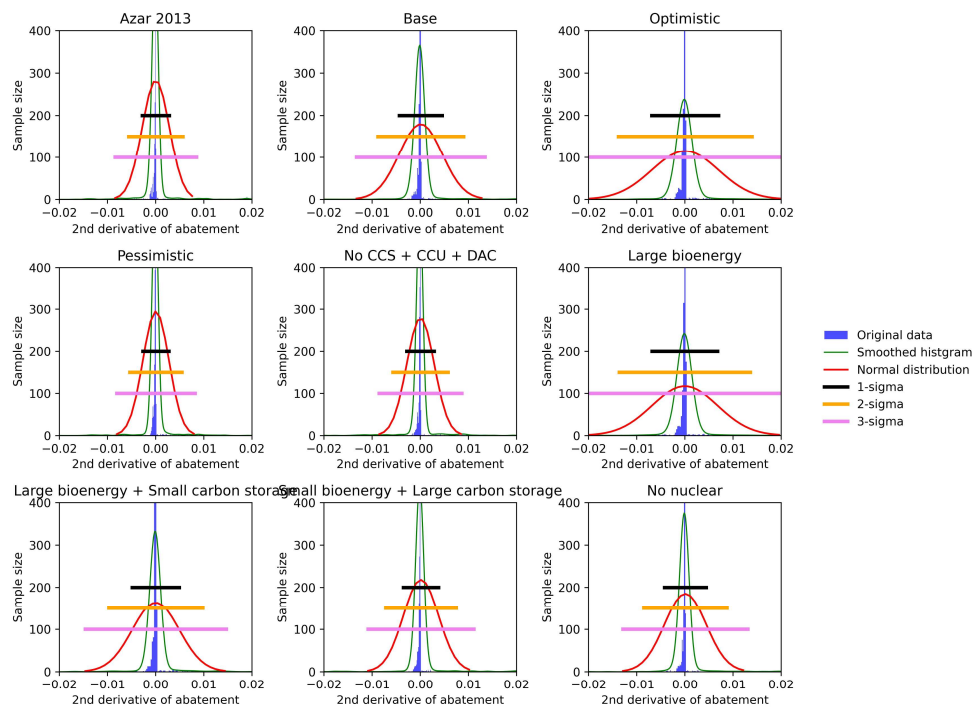


Figure S39. Global GET - Distribution of second derivative of abatement levels

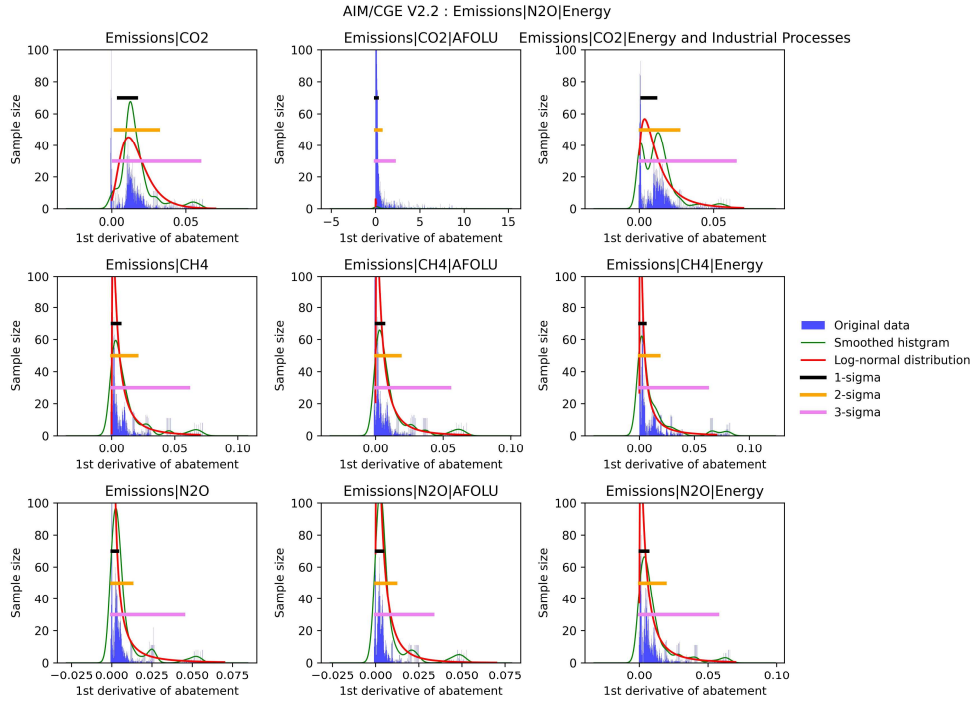


Figure S40. Global AIM - Distribution of first derivative of abatement levels

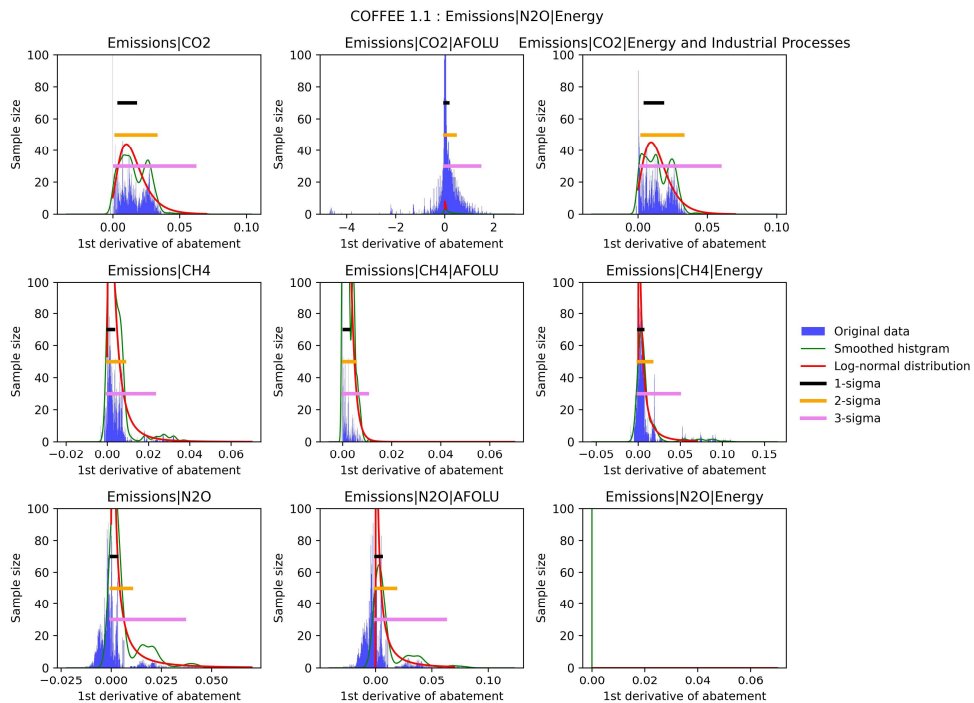


Figure S41. Global COFFEE - Distribution of first derivative of abatement levels

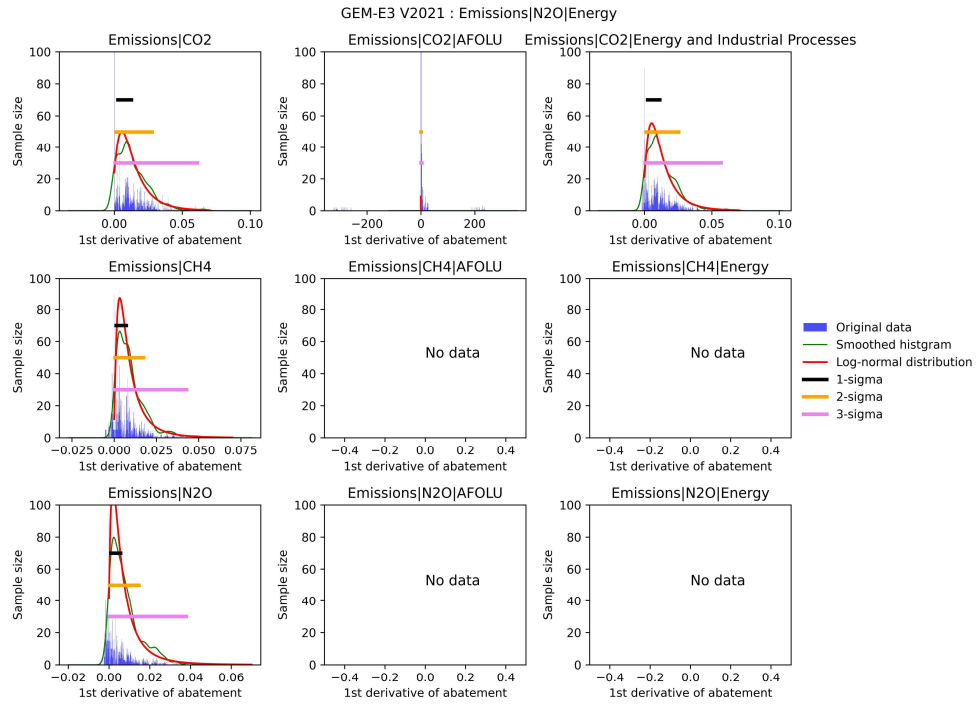


Figure S42. Global GEM - Distribution of first derivative of abatement levels

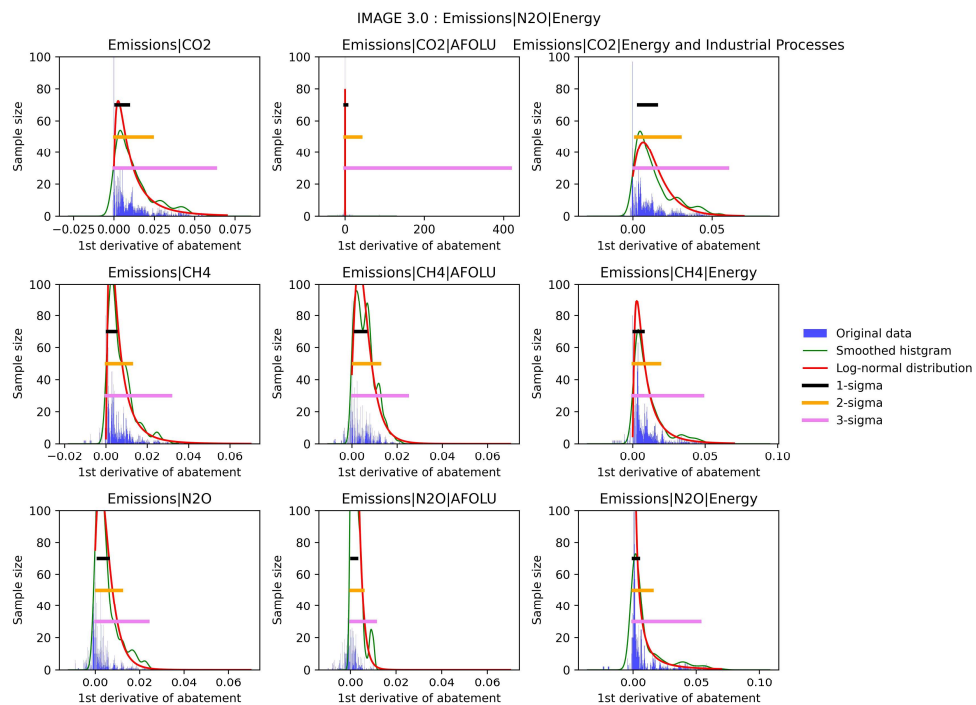


Figure S43. Global IMAGE - Distribution of first derivative of abatement levels

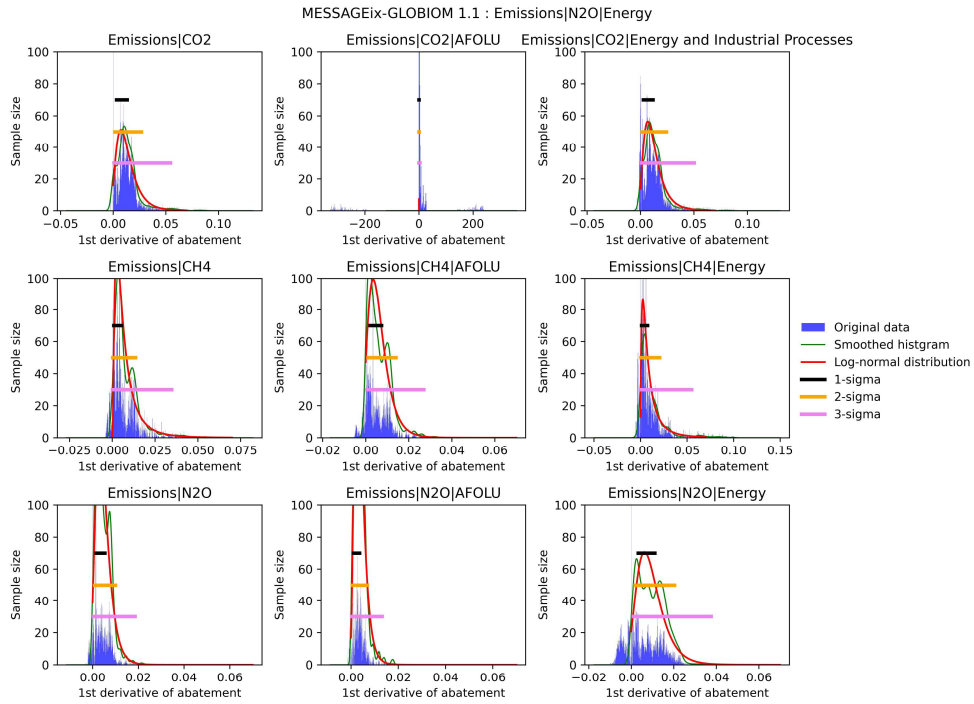


Figure S44. Global MESSAGE - Distribution of first derivative of abatement levels

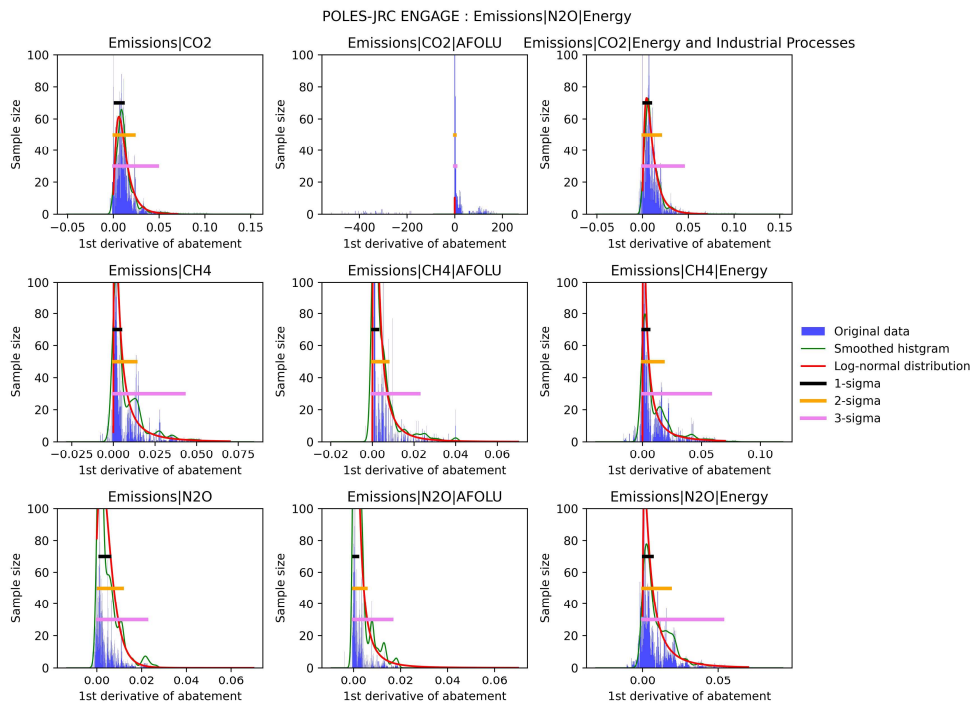


Figure S45. Global POLES - Distribution of first derivative of abatement levels

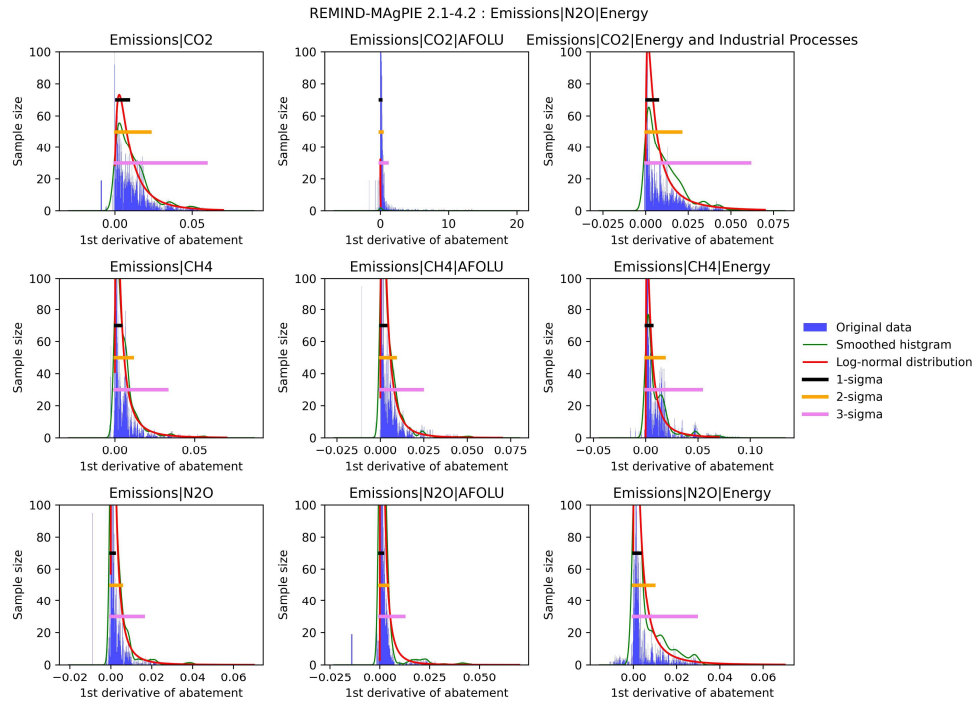


Figure S46. Global REMIND - Distribution of first derivative of abatement levels

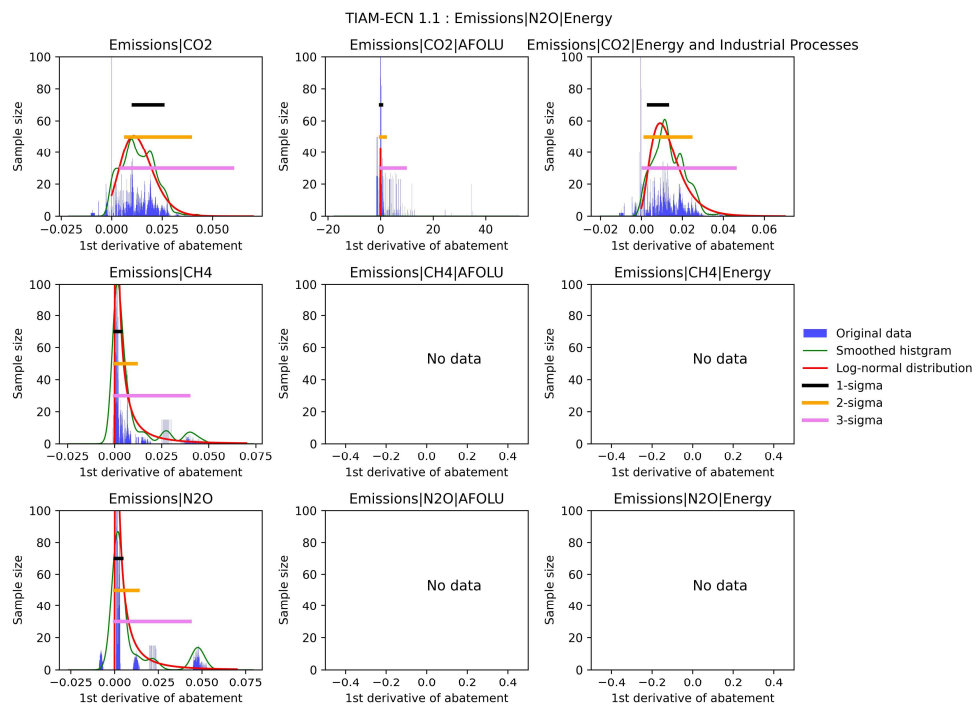


Figure S47. Global TIAM - Distribution of first derivative of abatement levels

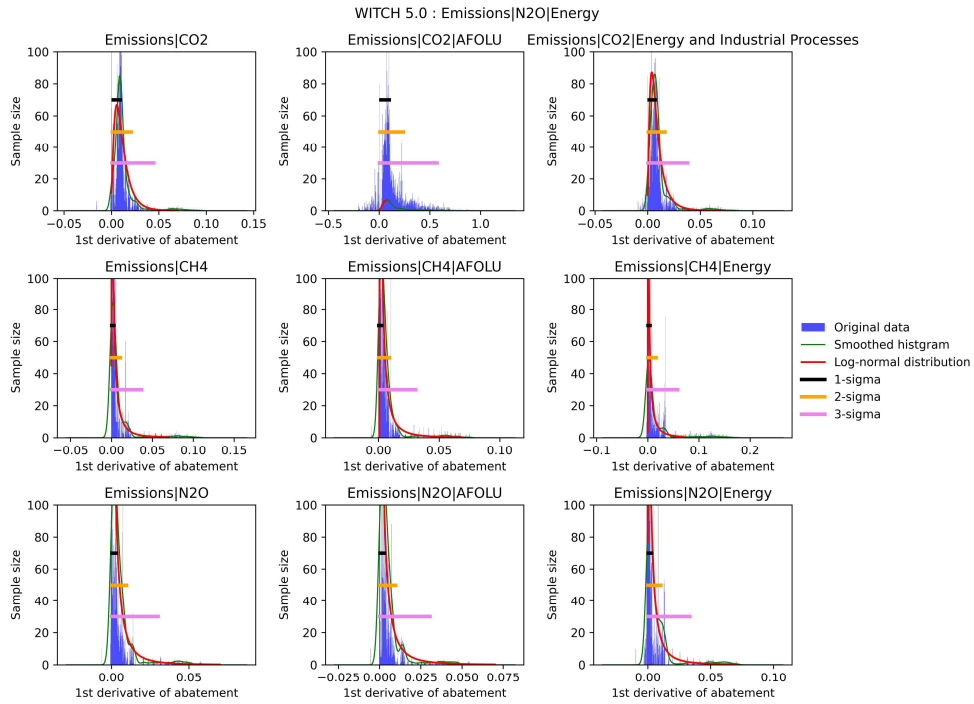


Figure S48. Global WITCH - Distribution of first derivative of abatement levels

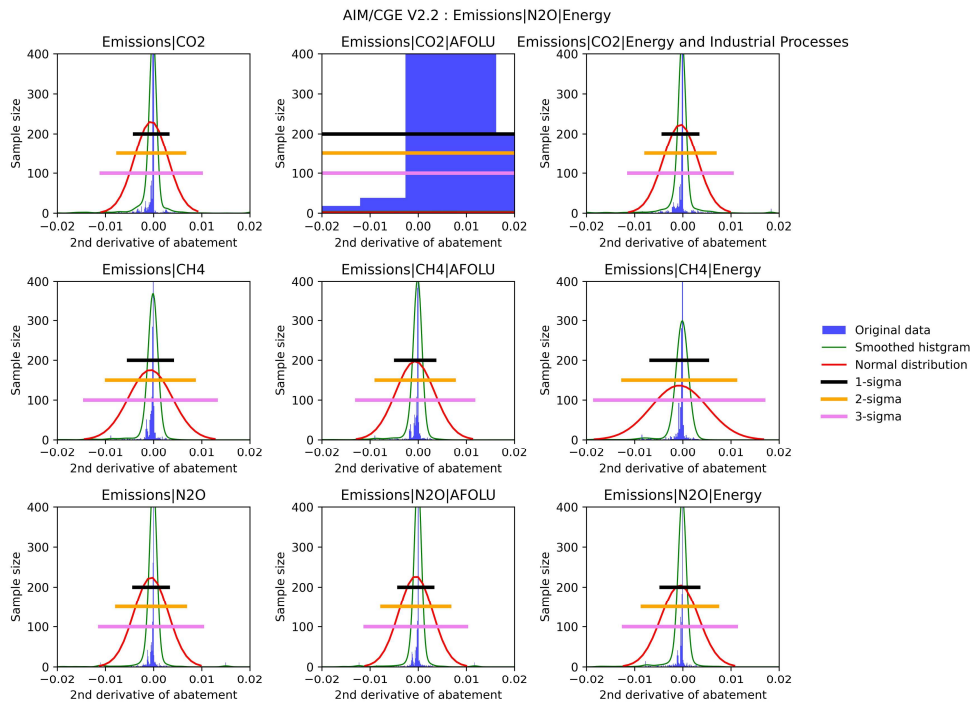


Figure S49. Global AIM - Distribution of second derivative of abatement levels

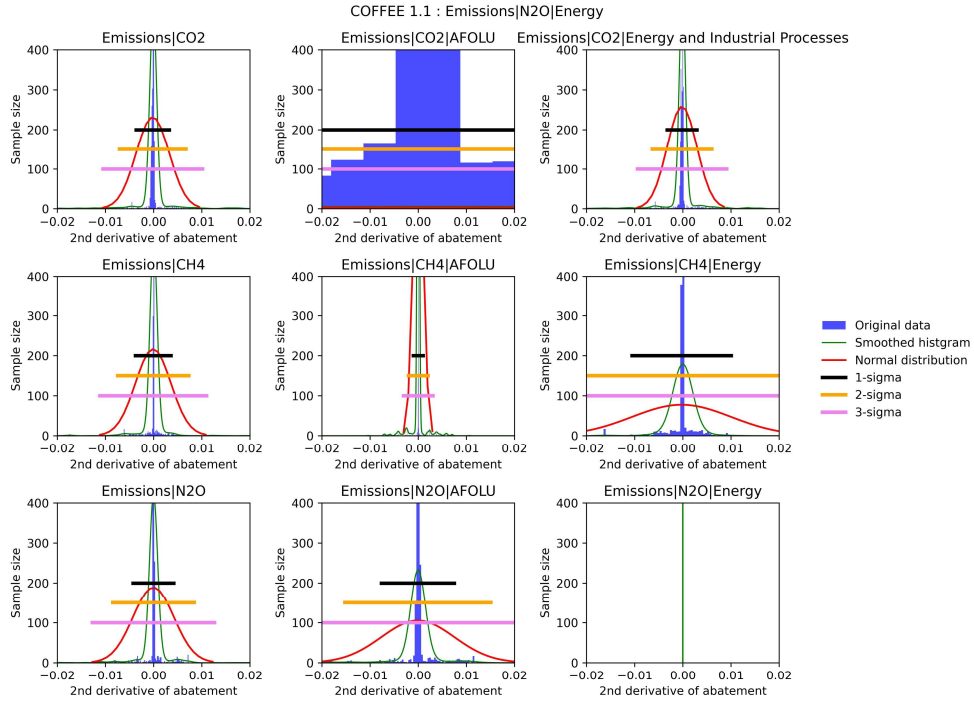


Figure S50. Global COFFEE - Distribution of second derivative of abatement levels

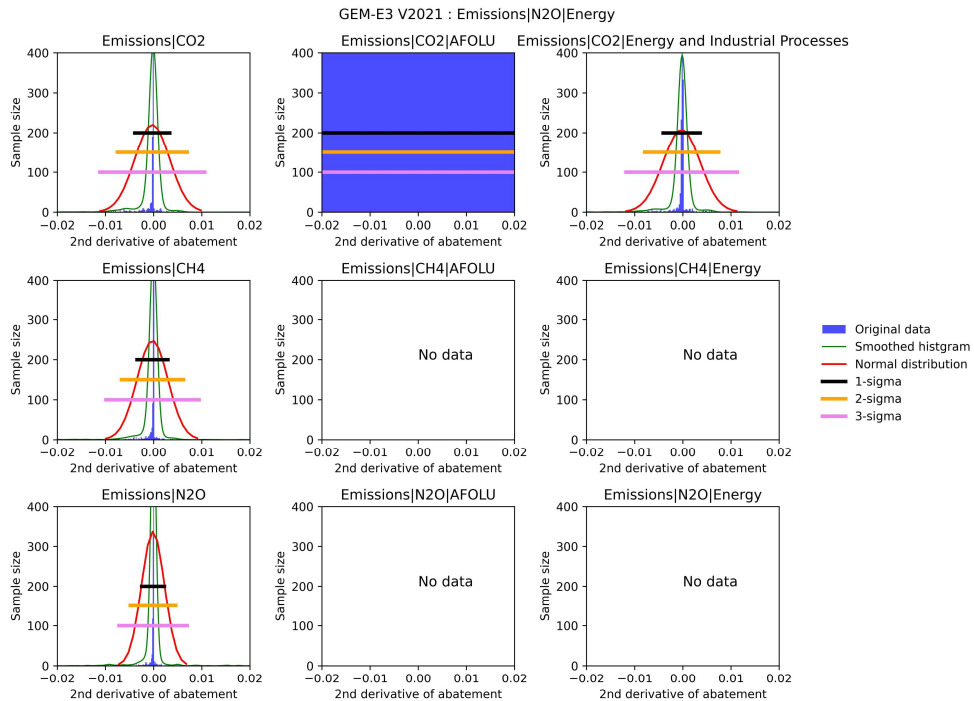


Figure S51. Global GEM - Distribution of second derivative of abatement levels

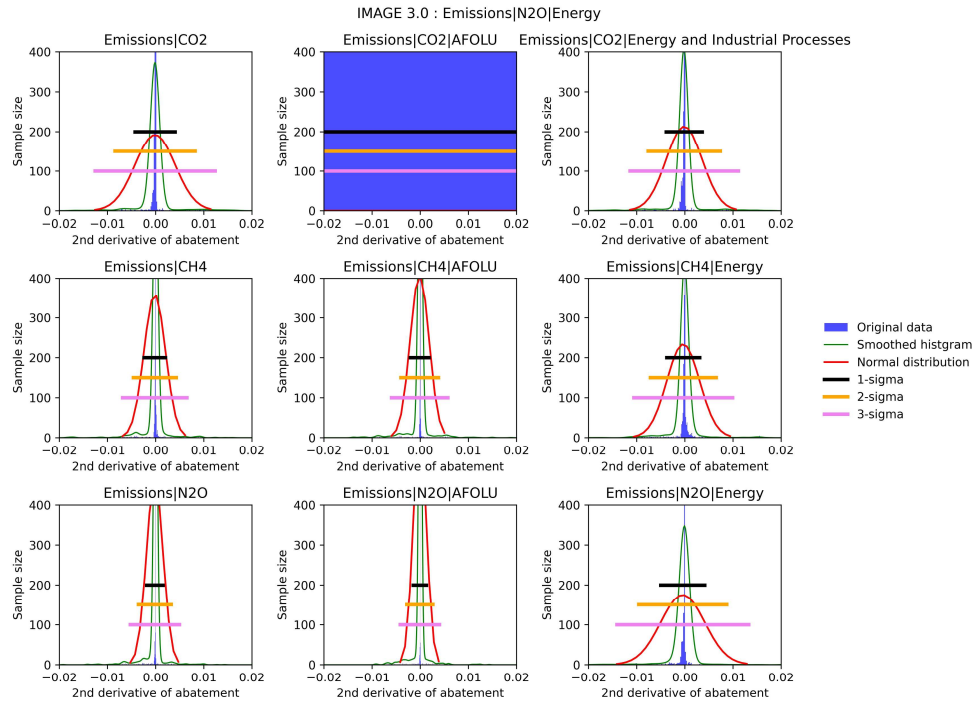


Figure S52. Global IMAGE - Distribution of second derivative of abatement levels

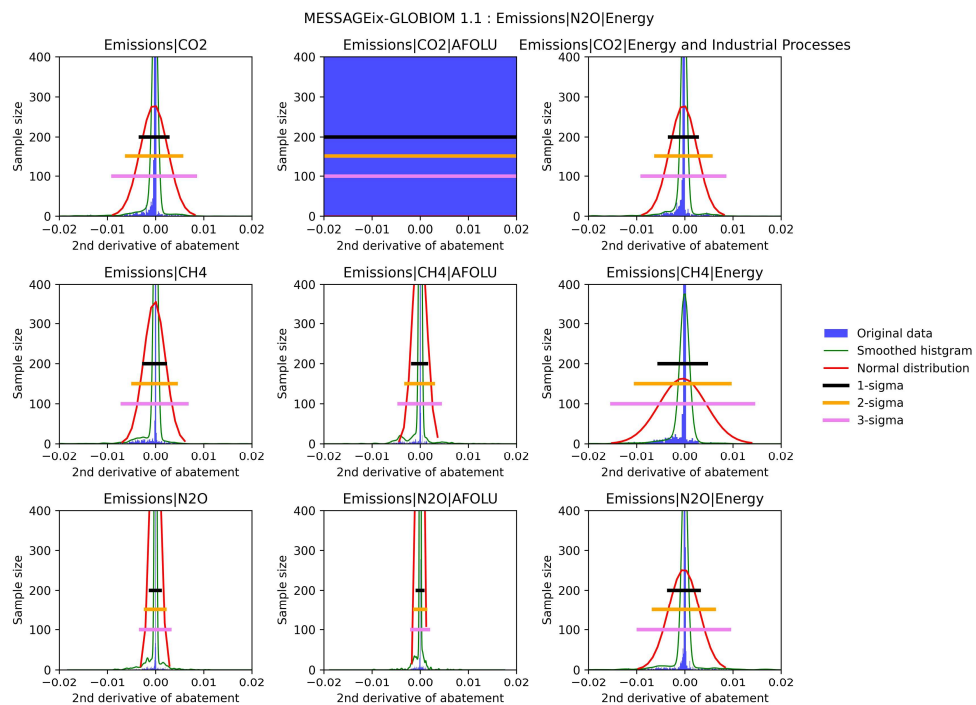


Figure S53. Global MESSAGE - Distribution of second derivative of abatement levels

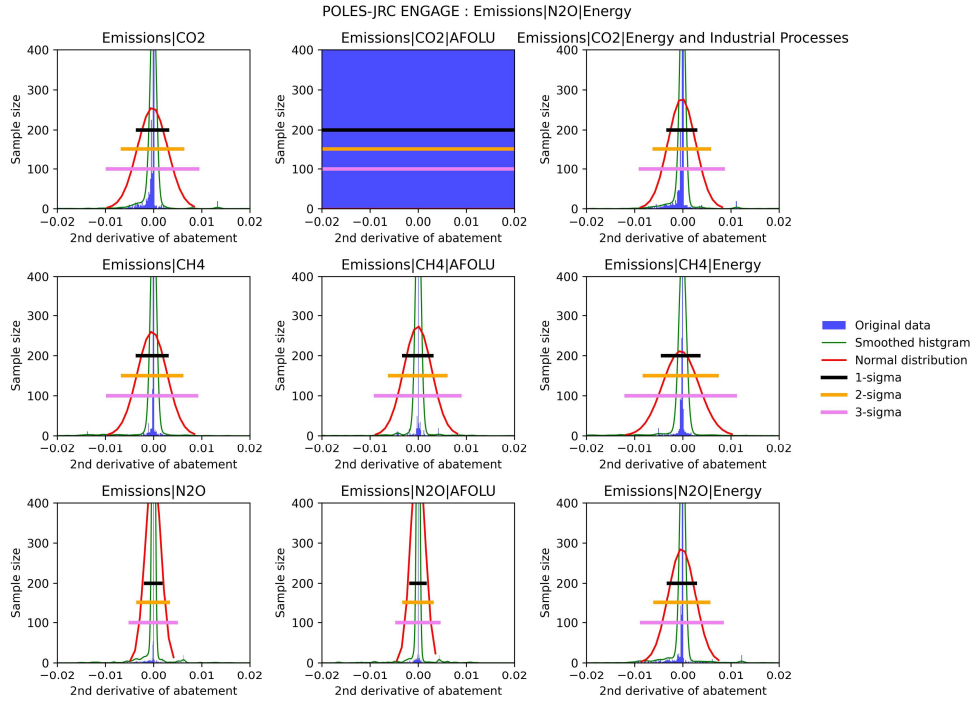


Figure S54. Global POLES - Distribution of second derivative of abatement levels

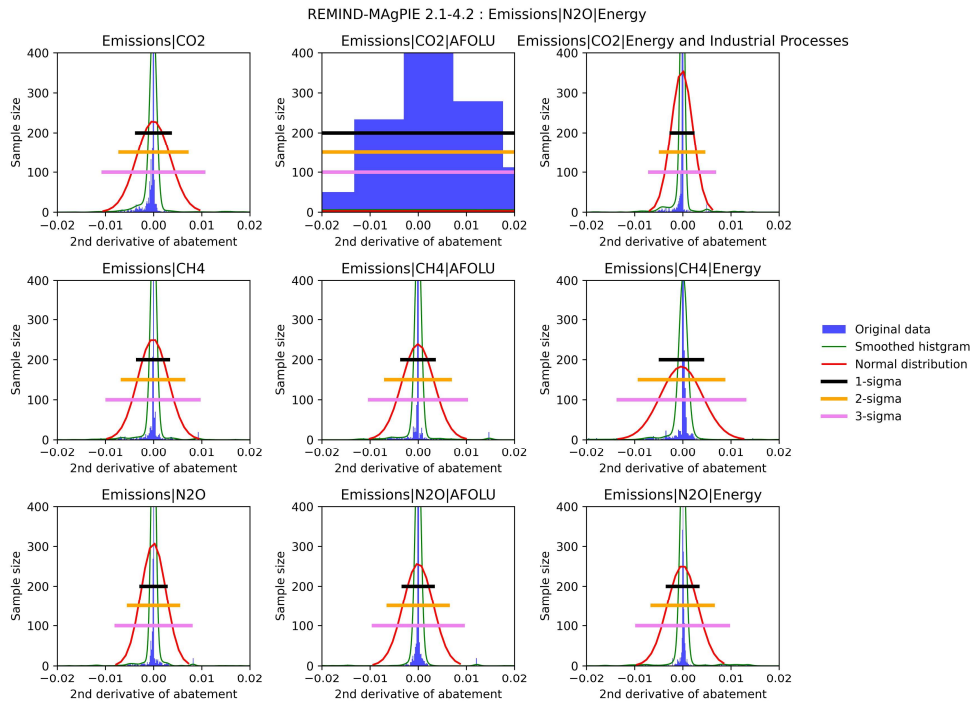


Figure S55. Global REMIND - Distribution of second derivative of abatement levels

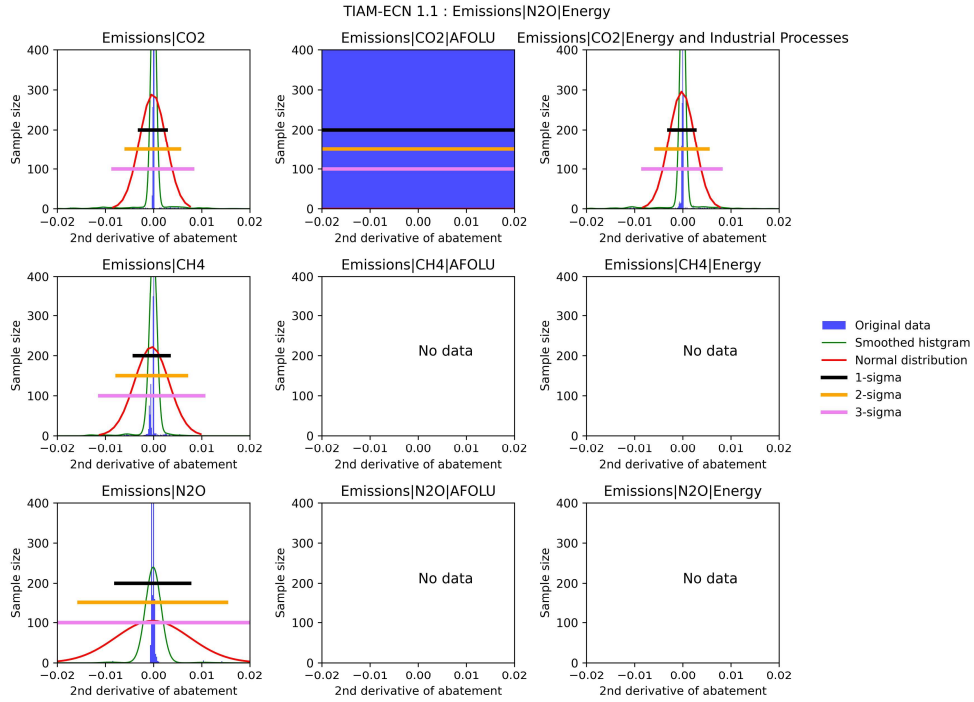


Figure S56. Global TIAM - Distribution of second derivative of abatement levels

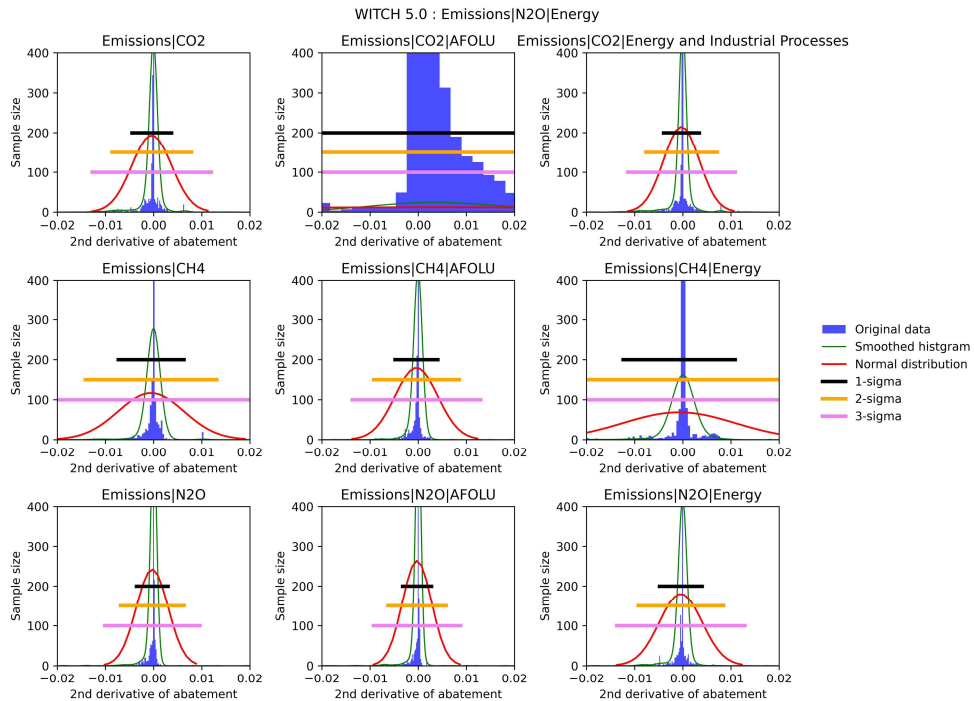


Figure S57. Global WITCH - Distribution of second derivative of abatement levels

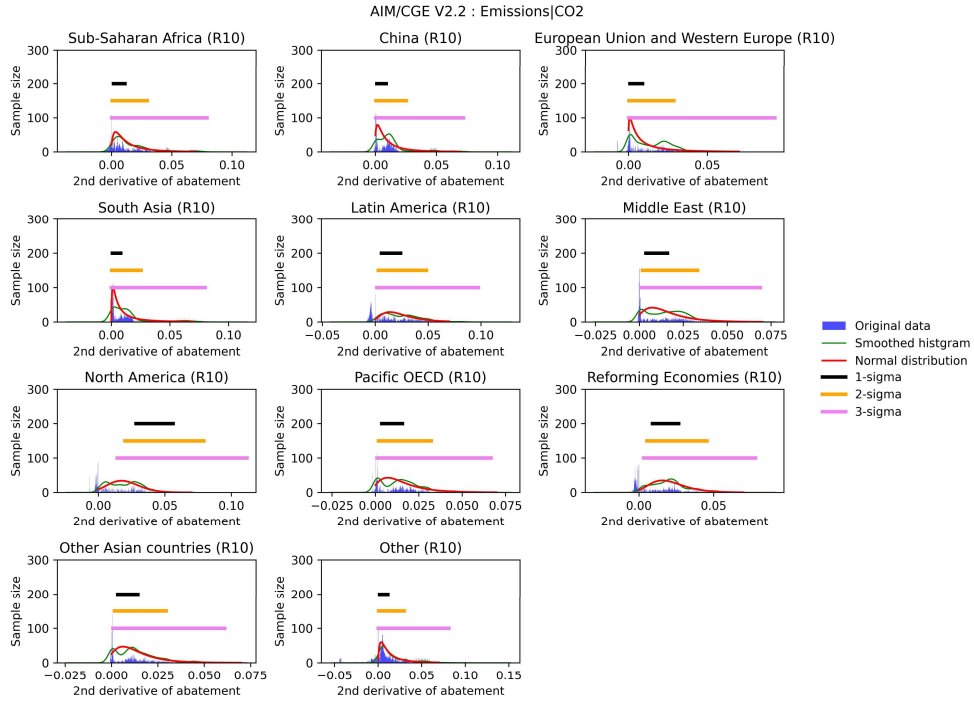


Figure S58. Regional AIM CO₂ - Distribution of first derivative of abatement levels

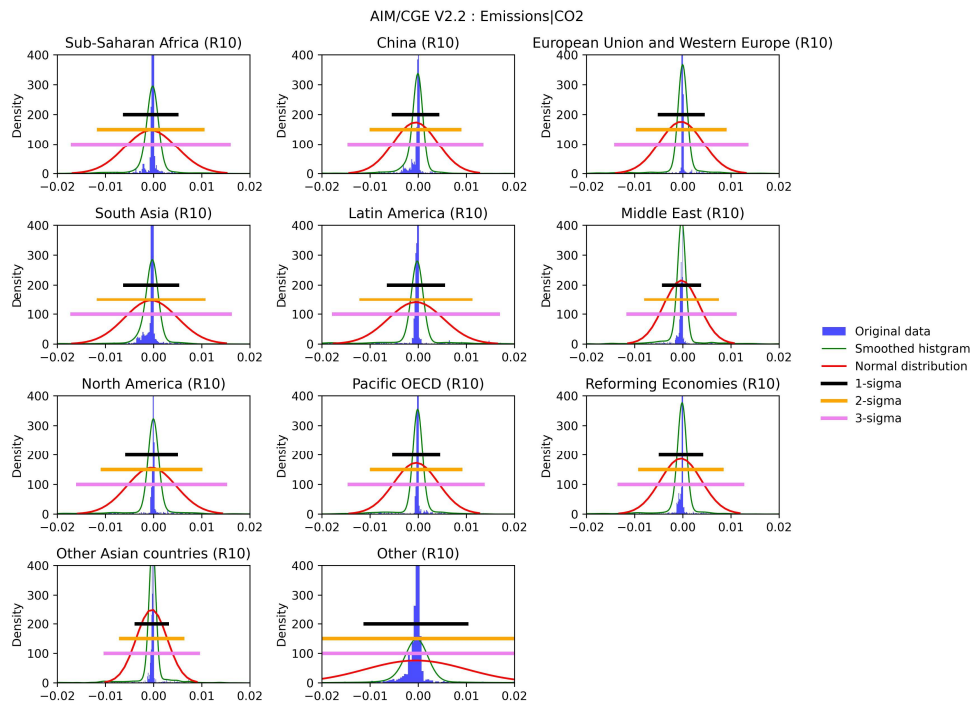


Figure S59. Regional AIM CO₂ - Distribution of first derivative of abatement levels

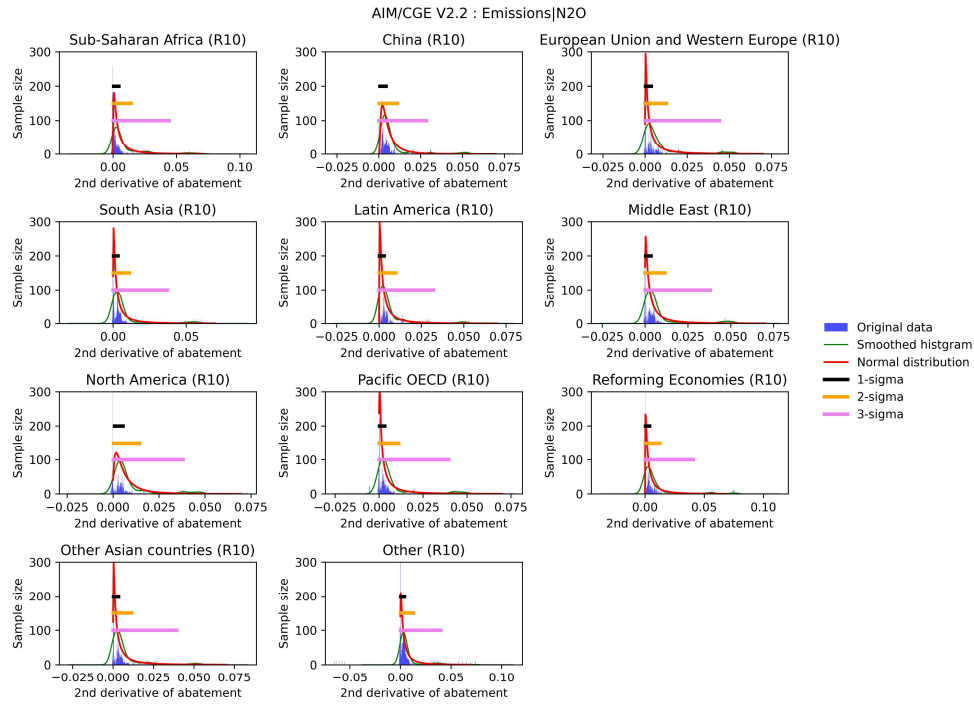


Figure S60. Regional AIM CH₄- Distribution of first derivative of abatement levels

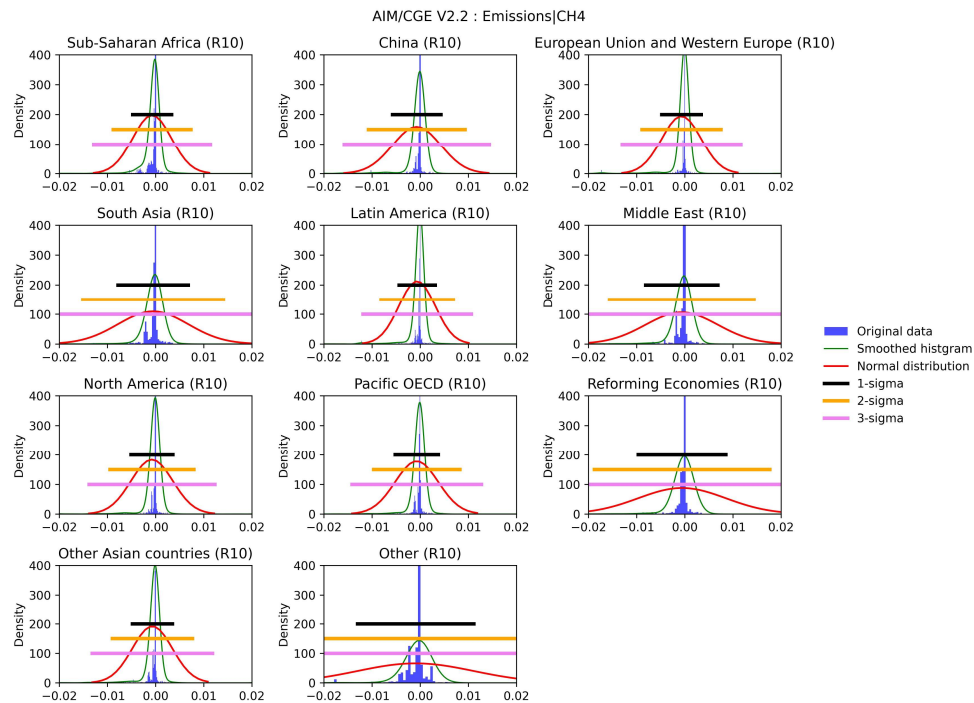


Figure S61. Regional AIM CH₄ - Distribution of second derivative of abatement levels

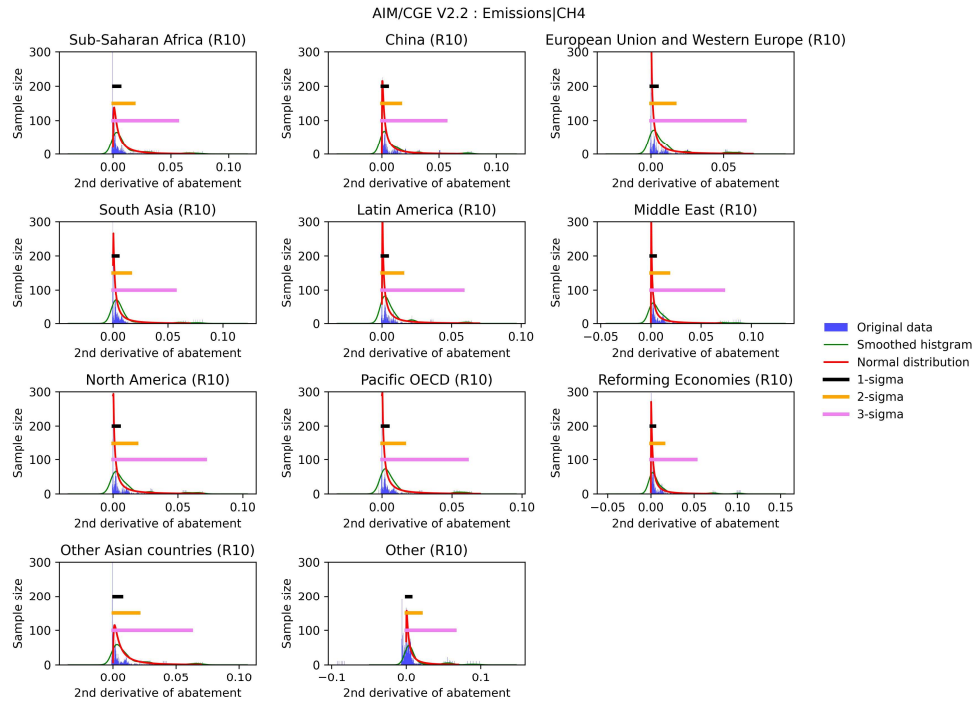


Figure S62. Regional AIM N₂O - Distribution of first derivative of abatement levels

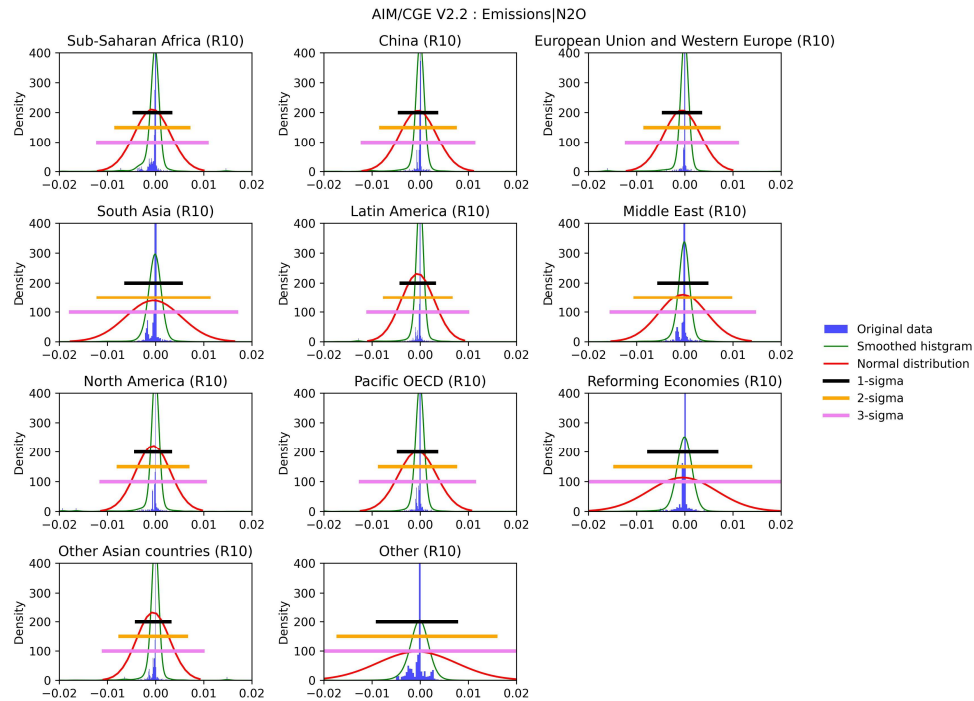


Figure S63. Regional AIM N₂O - Distribution of second derivative of abatement levels

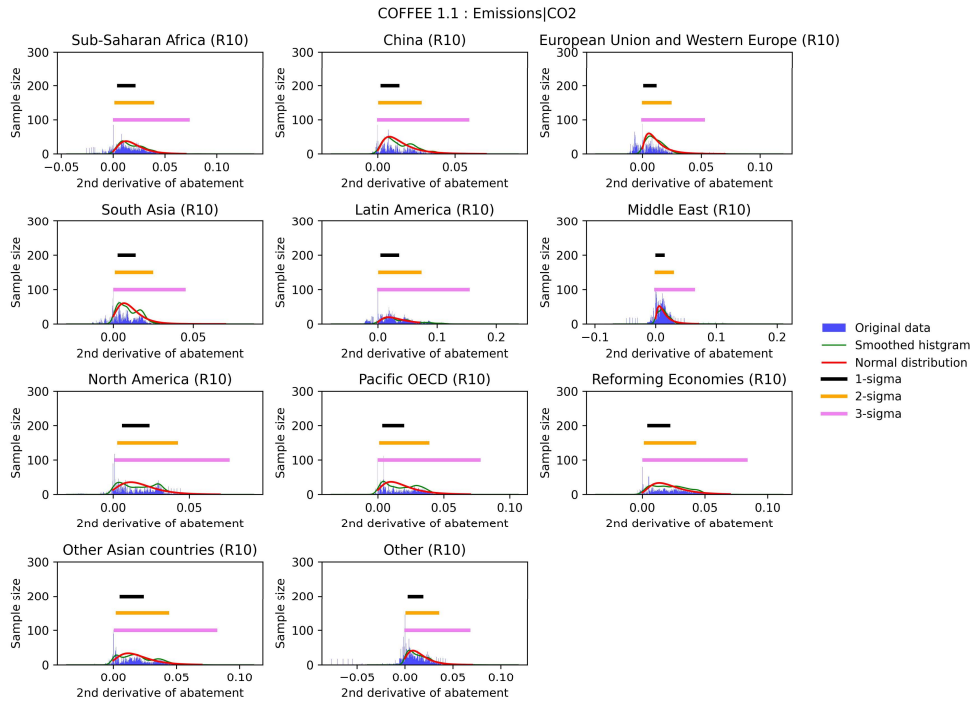


Figure S64. Regional COFFEE CO₂ - Distribution of first derivative of abatement levels

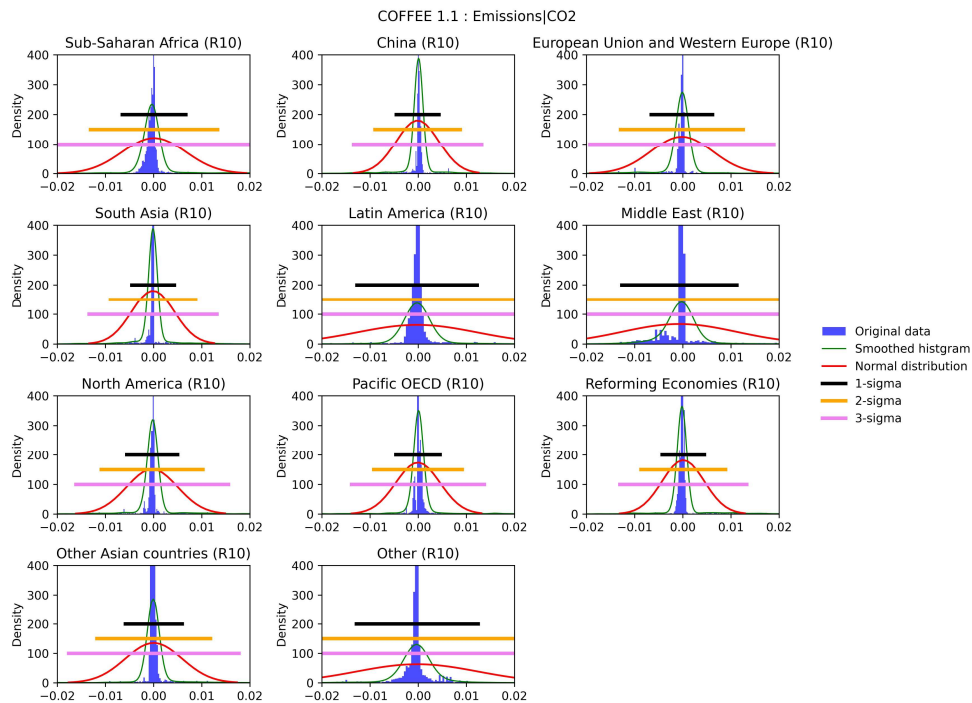


Figure S65. Regional COFFEE CO₂ - Distribution of second derivative of abatement levels

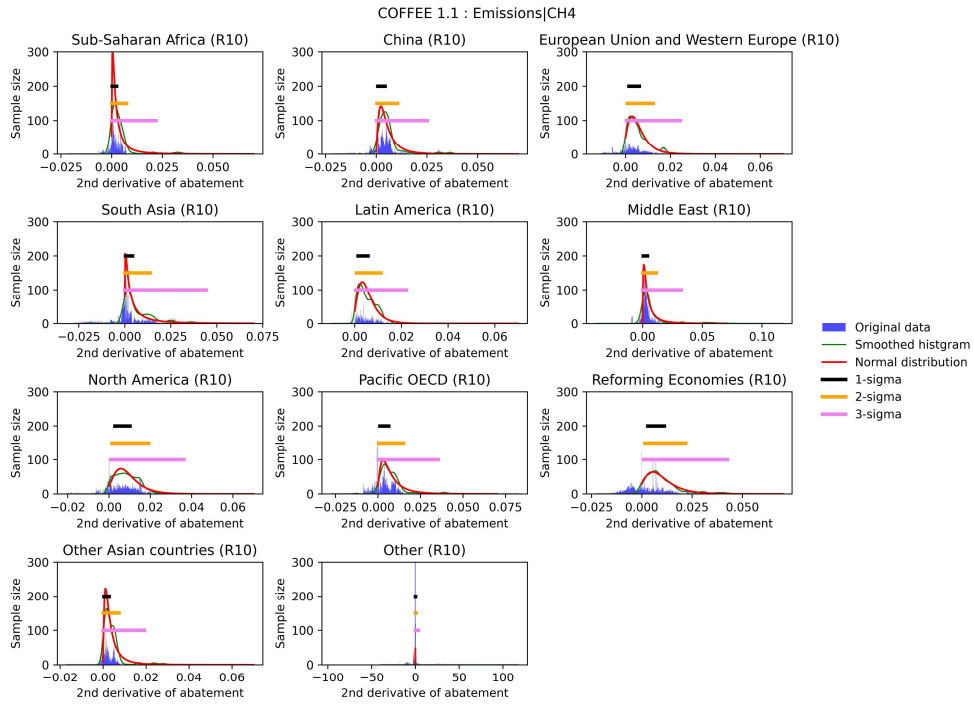


Figure S66. Regional COFFEE CH4- Distribution of first derivative of abatement levels

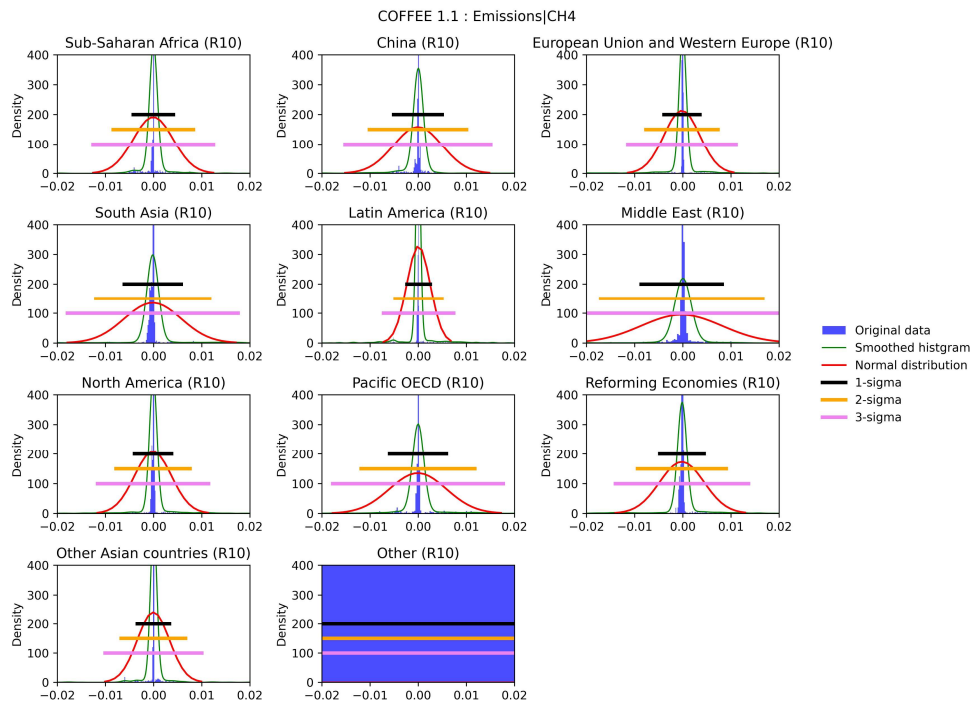


Figure S67. Regional COFFEE CH4 - Distribution of second derivative of abatement levels

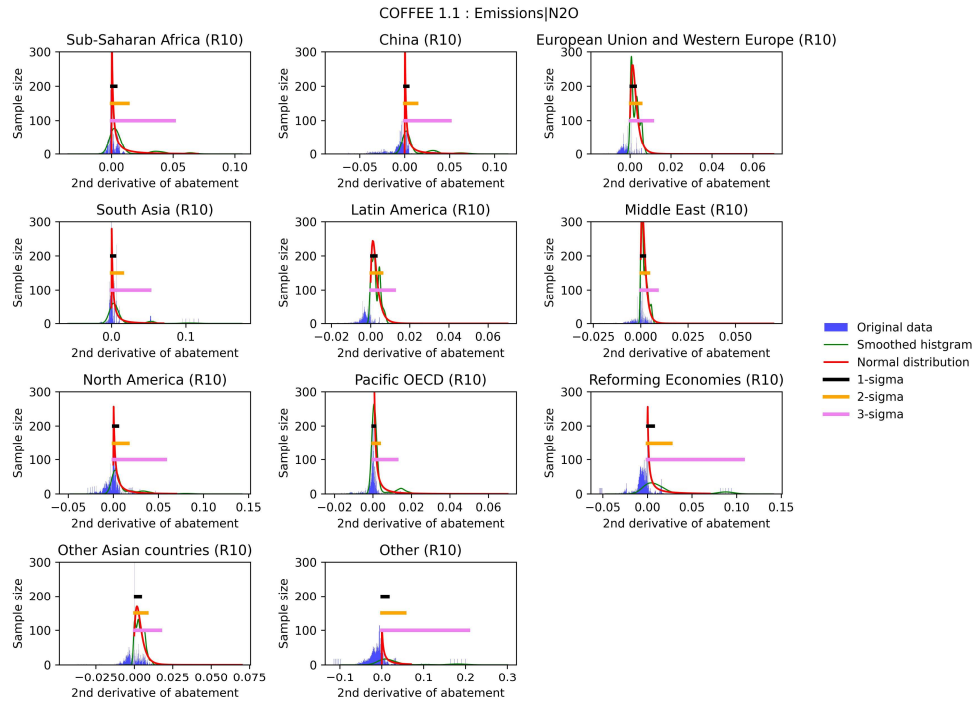


Figure S68. Regional COFFEE N₂O - Distribution of first derivative of abatement levels

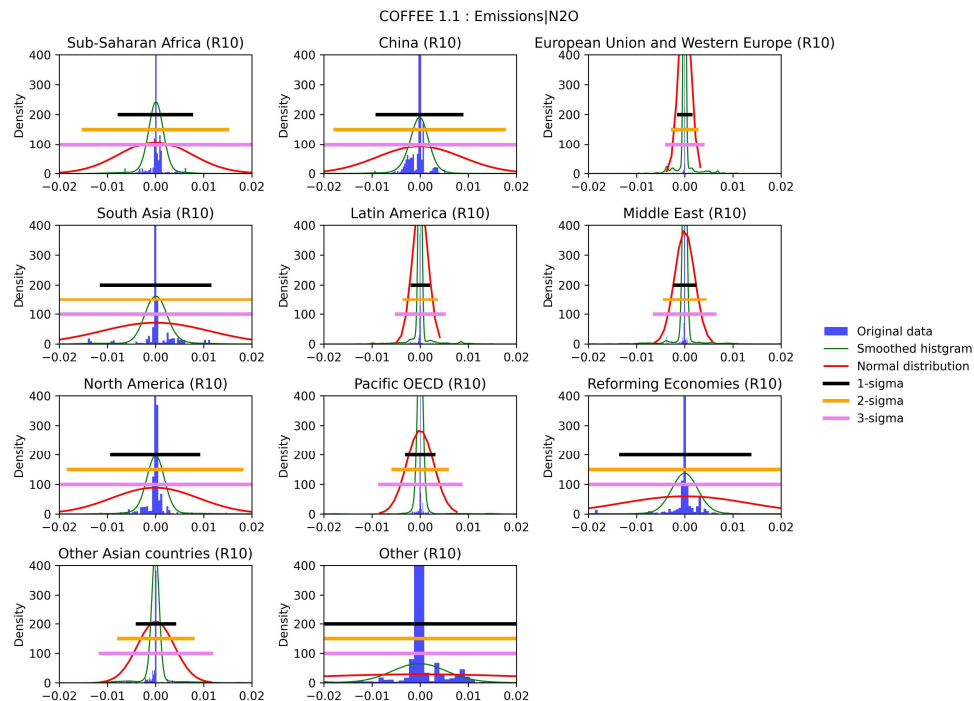


Figure S69. Regional COFFEE N₂O - Distribution of second derivative of abatement levels

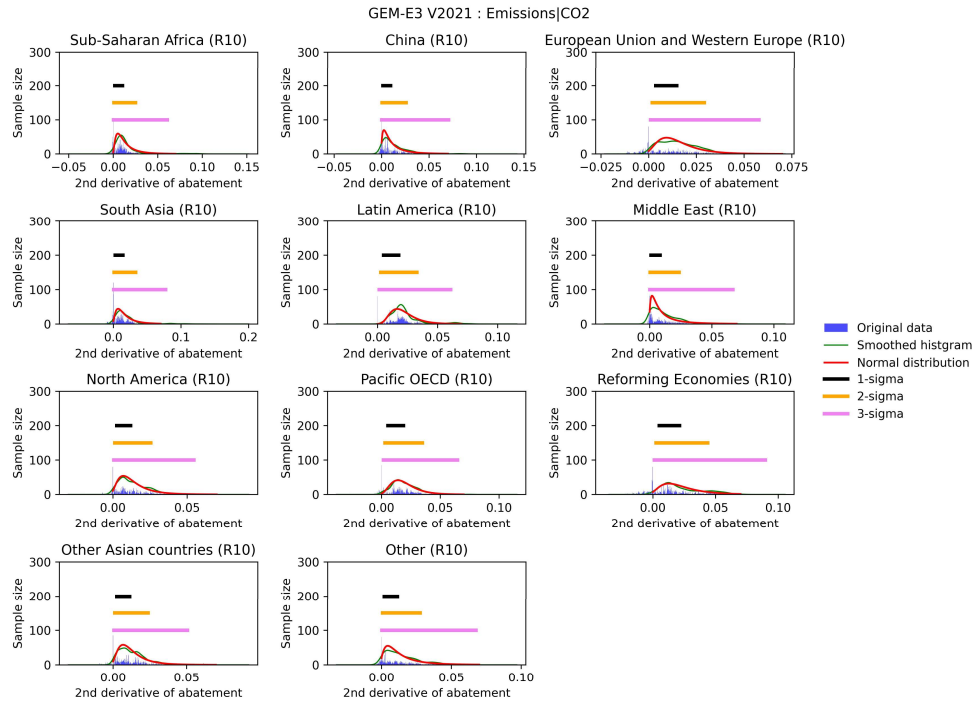


Figure S70. Regional GEM CO₂ - Distribution of first derivative of abatement levels

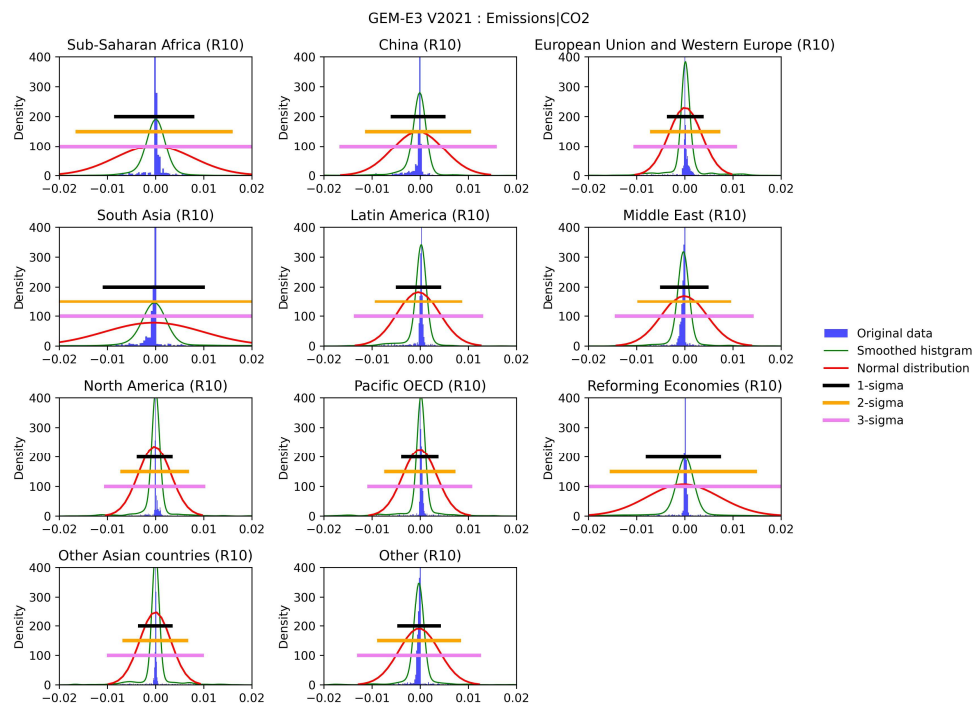


Figure S71. Regional GEM CO₂ - Distribution of second derivative of abatement levels

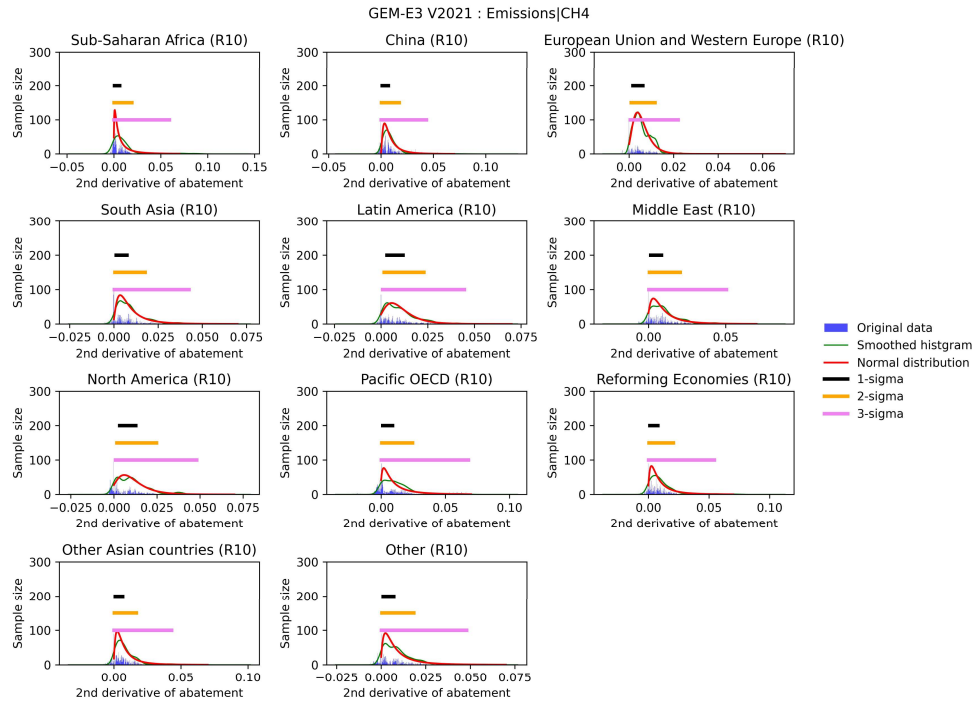


Figure S72. Regional GEM CH₄- Distribution of first derivative of abatement levels

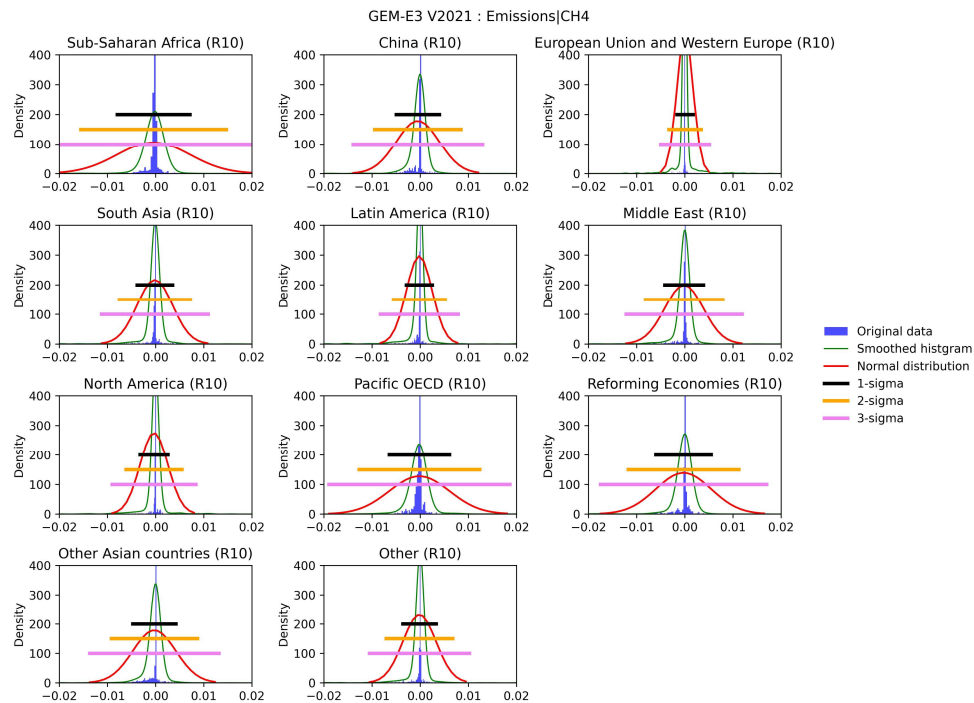
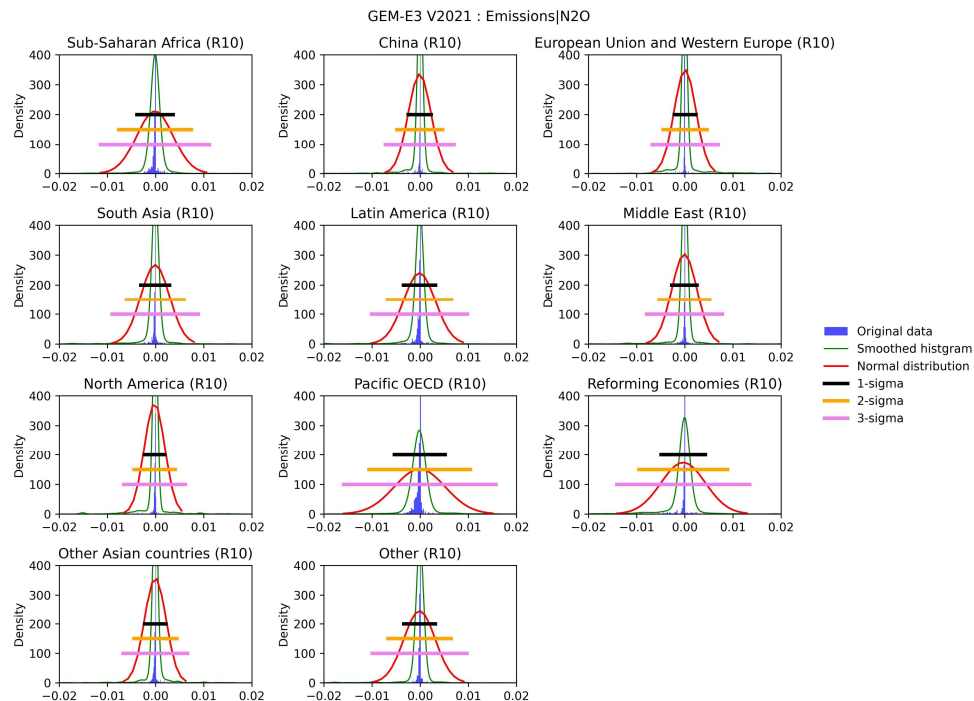
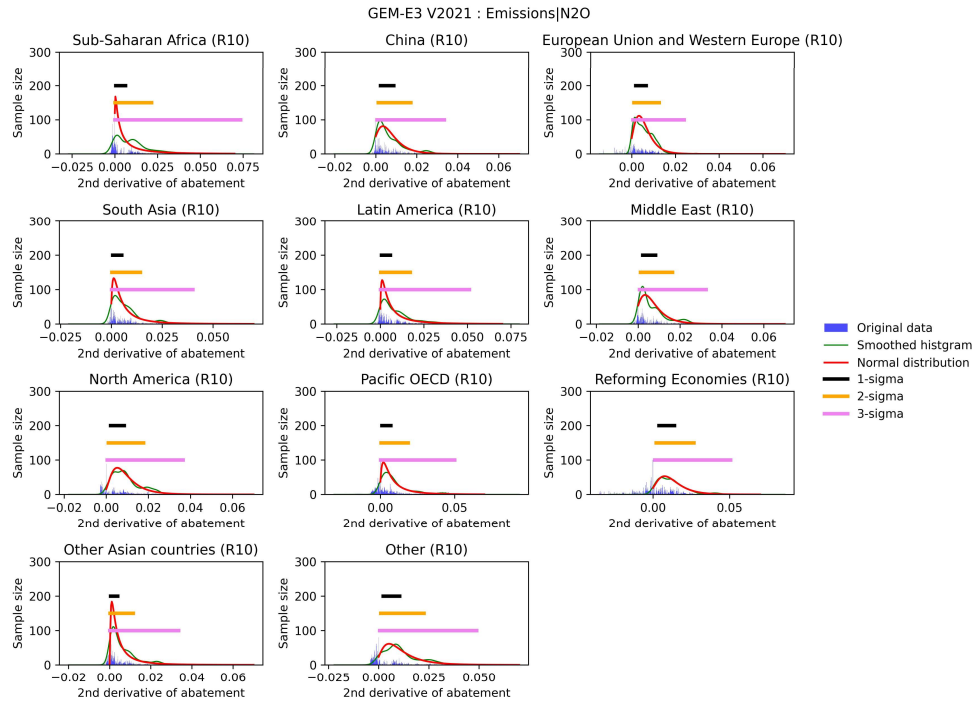


Figure S73. Regional GEM CH₄- Distribution of second derivative of abatement levels



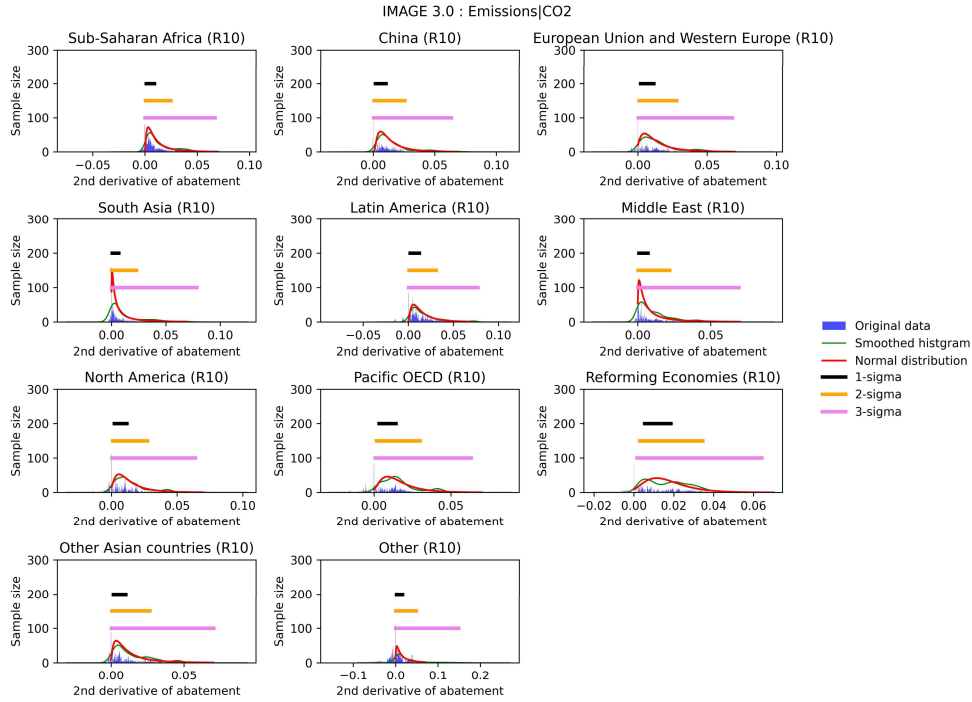


Figure S76. Regional IMAGE CO₂ - Distribution of first derivative of abatement levels

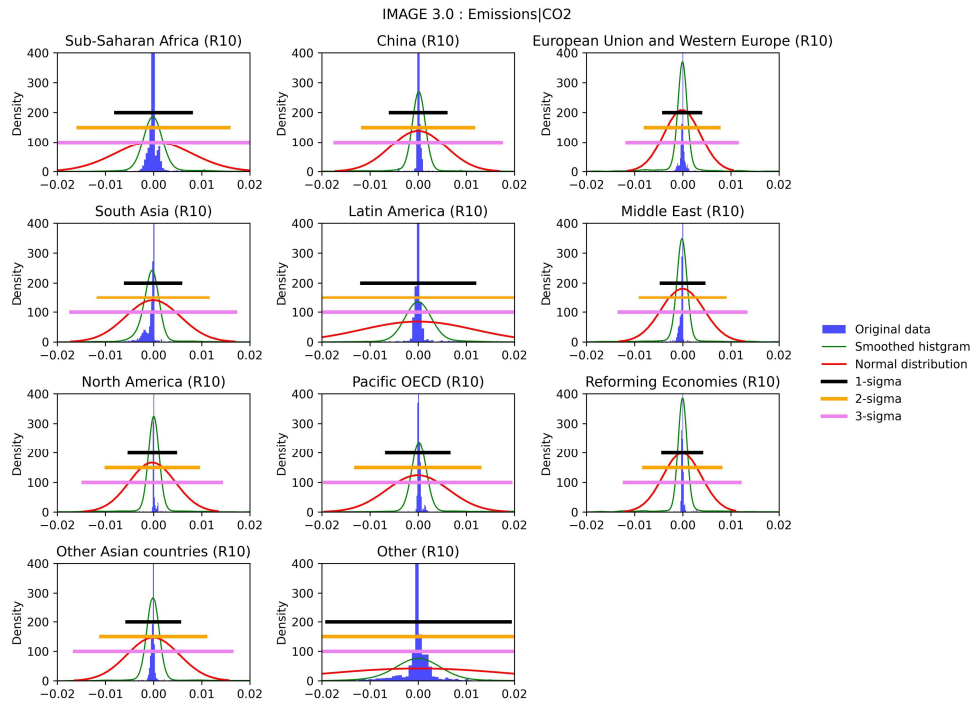


Figure S77. Regional IMAGE CO₂ - Distribution of second derivative of abatement levels

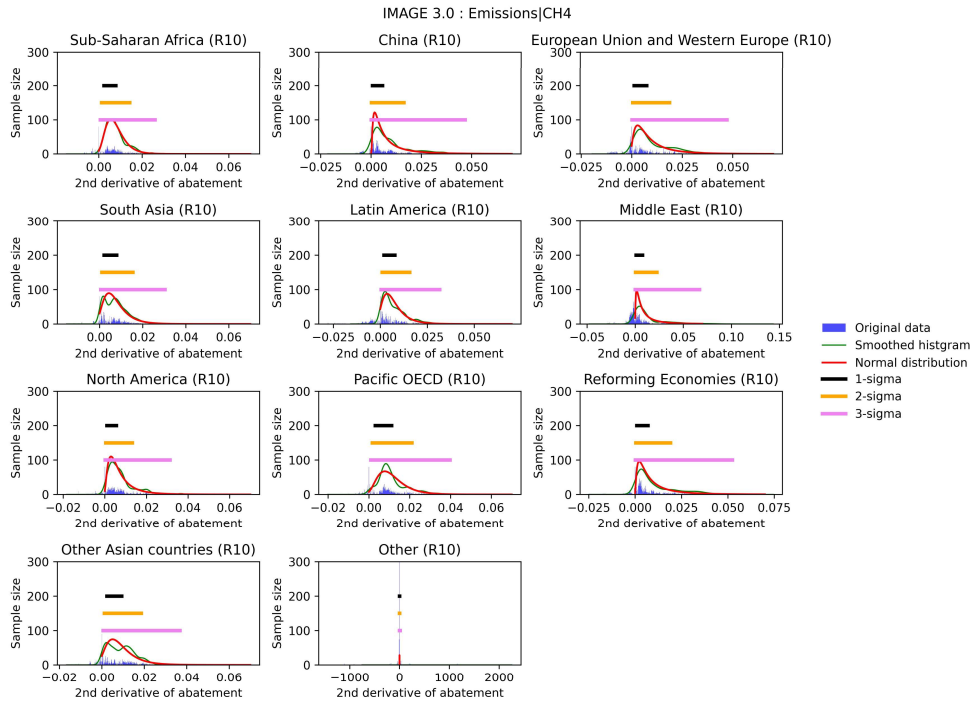


Figure S78. Regional IMAGE CH₄- Distribution of first derivative of abatement levels

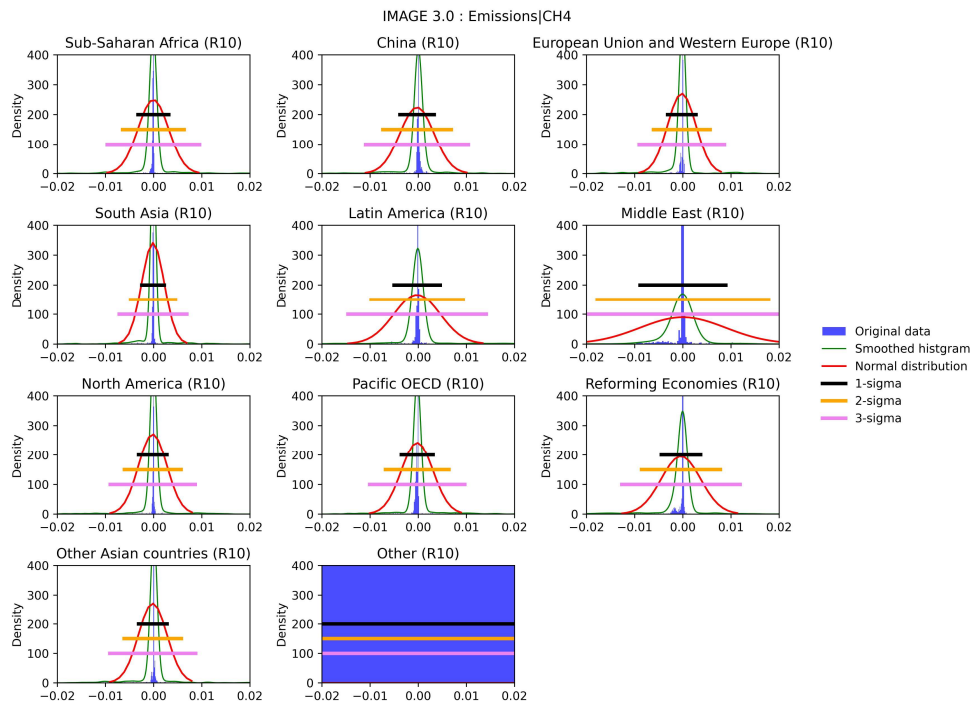


Figure S79. Regional IMAGE CH₄ - Distribution of second derivative of abatement levels

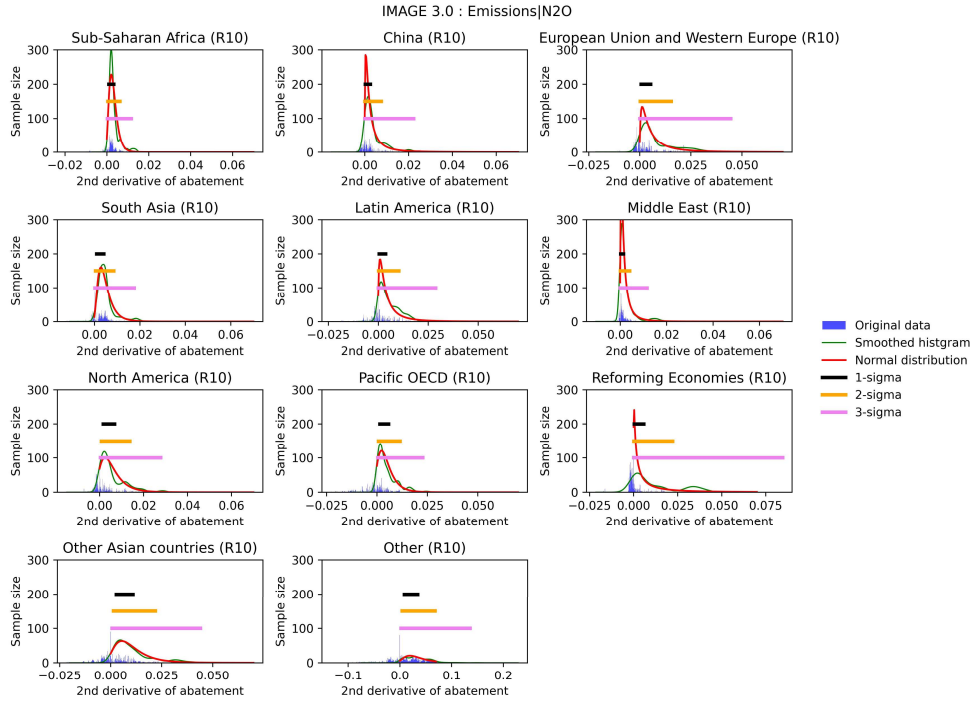


Figure S80. Regional IMAGE N₂O - Distribution of first derivative of abatement levels

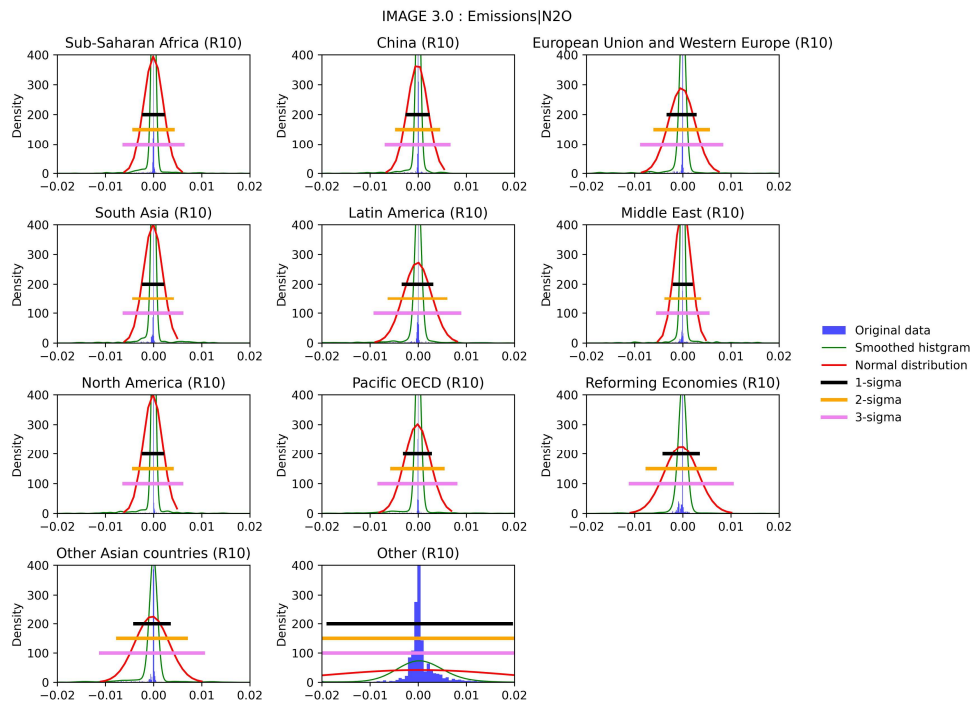


Figure S81. Regional IMAGE N₂O - Distribution of second derivative of abatement levels

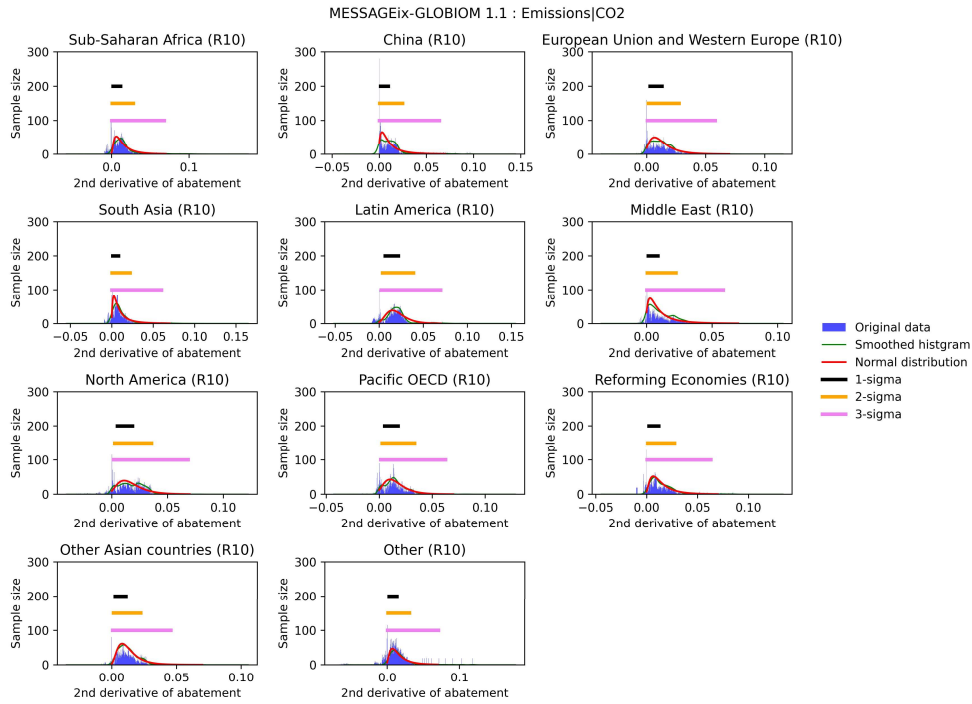


Figure S82. Regional MESSAGE CO₂ - Distribution of first derivative of abatement levels

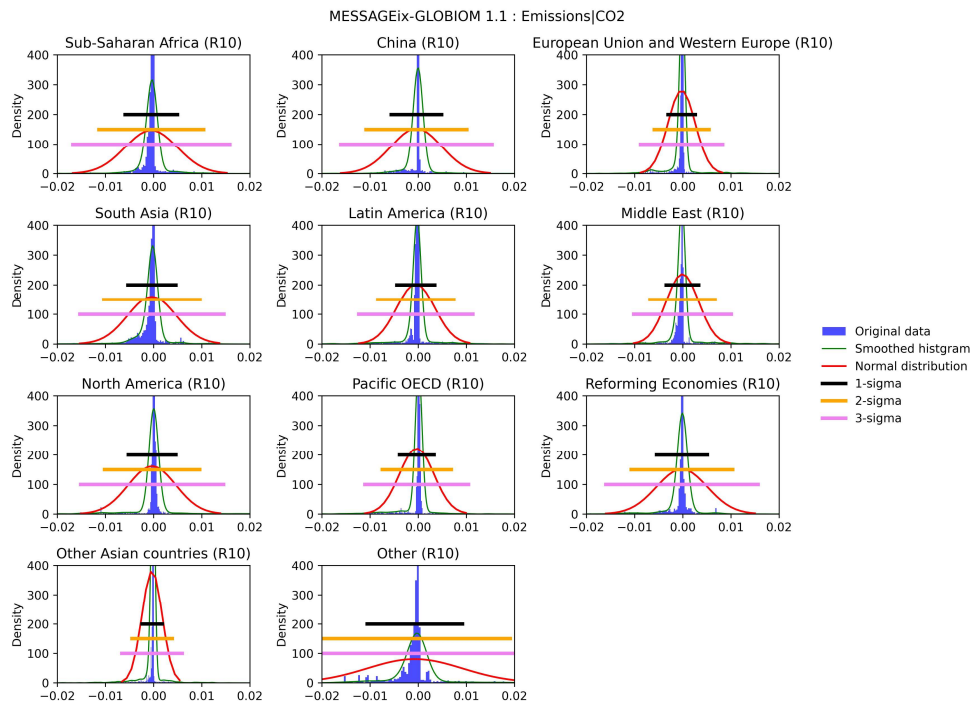


Figure S83. Regional MESSAGE CO₂ - Distribution of second derivative of abatement levels

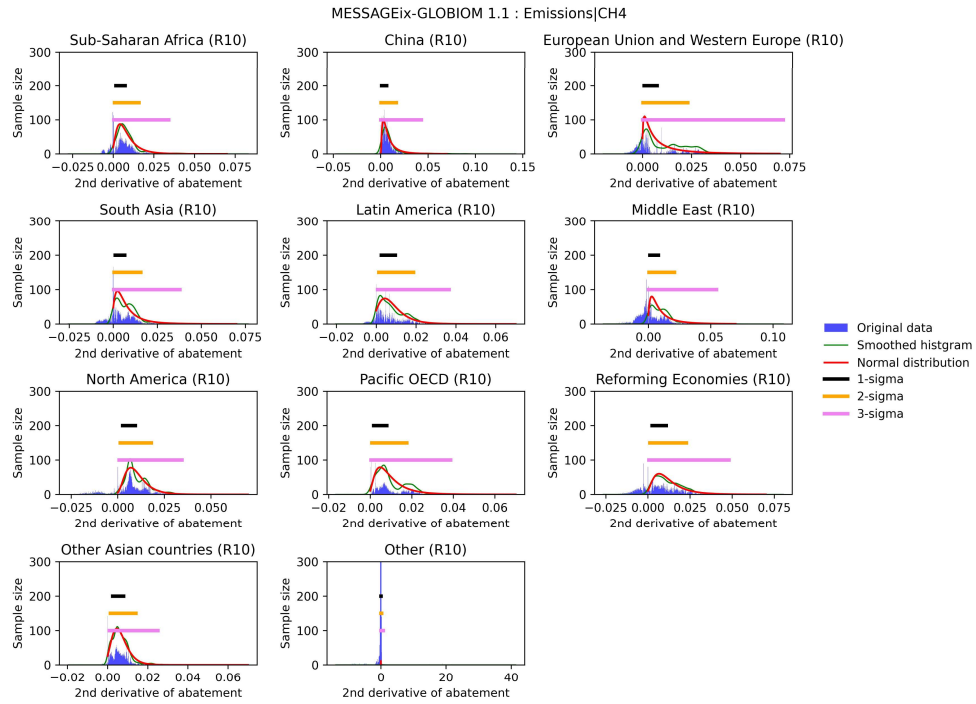


Figure S84. Regional MESSAGE CH₄ - Distribution of first derivative of abatement levels

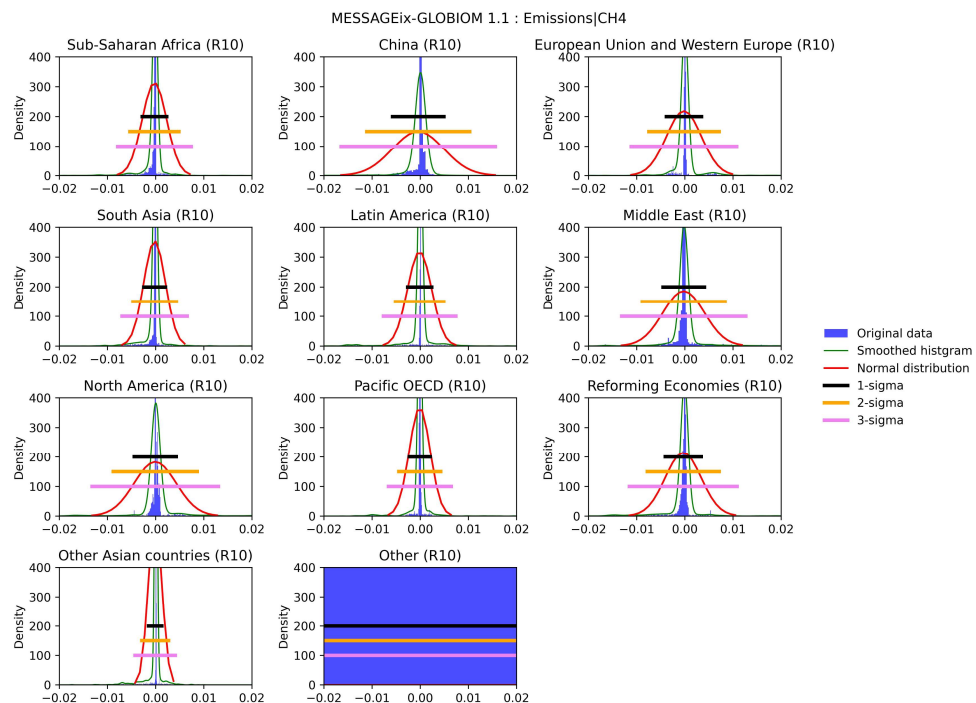


Figure S85. Regional MESSAGE CH₄ - Distribution of second derivative of abatement levels

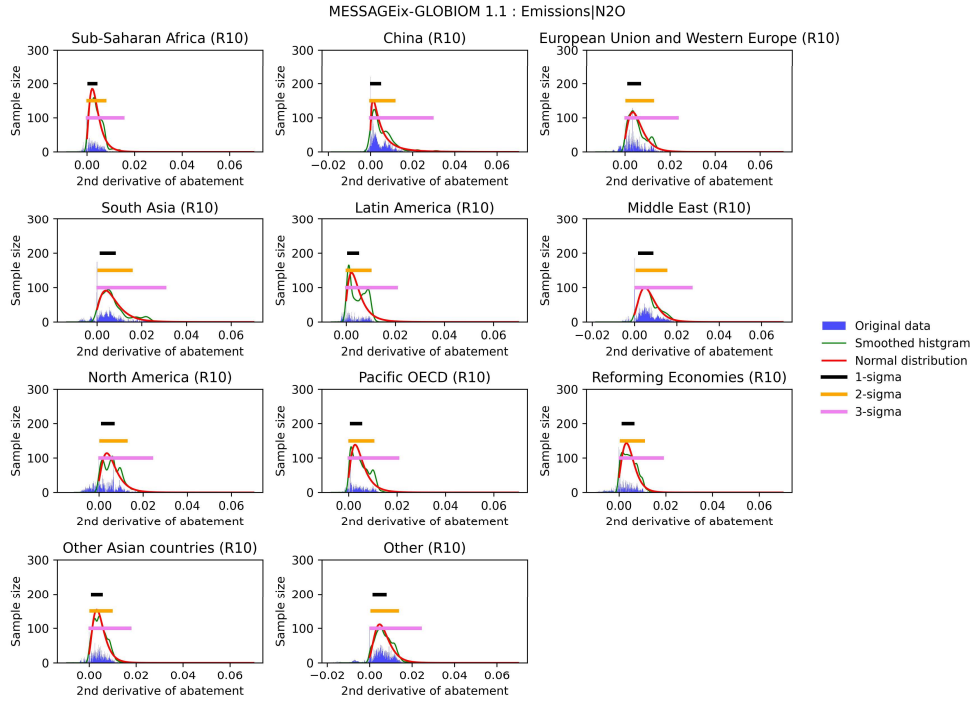


Figure S86. Regional MESSAGE N₂O - Distribution of first derivative of abatement levels

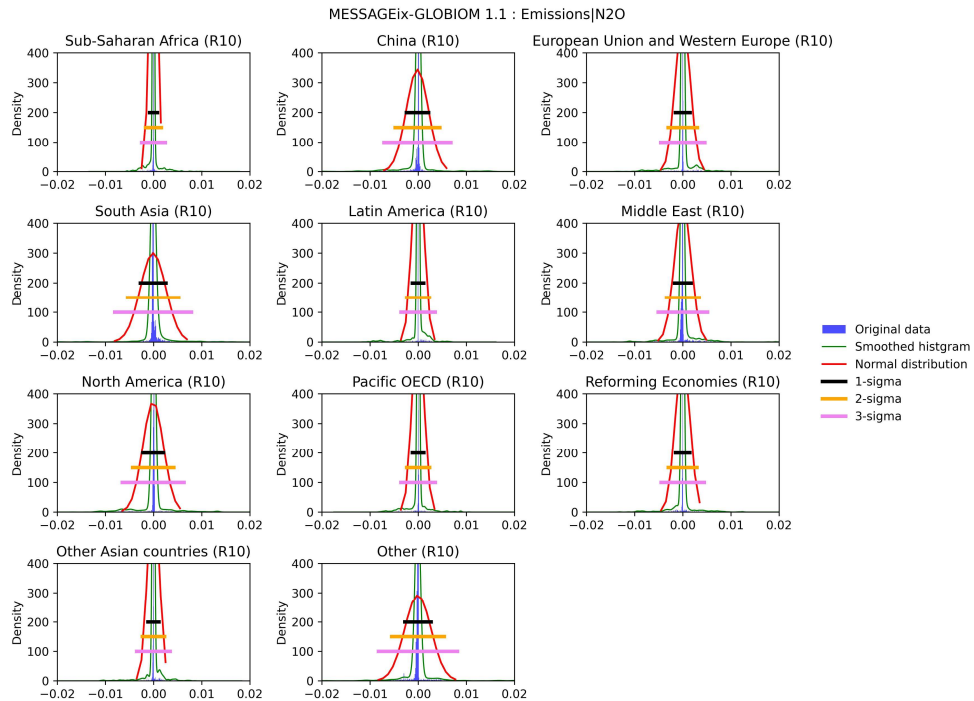


Figure S87. Regional MESSAGE N₂O - Distribution of second derivative of abatement levels

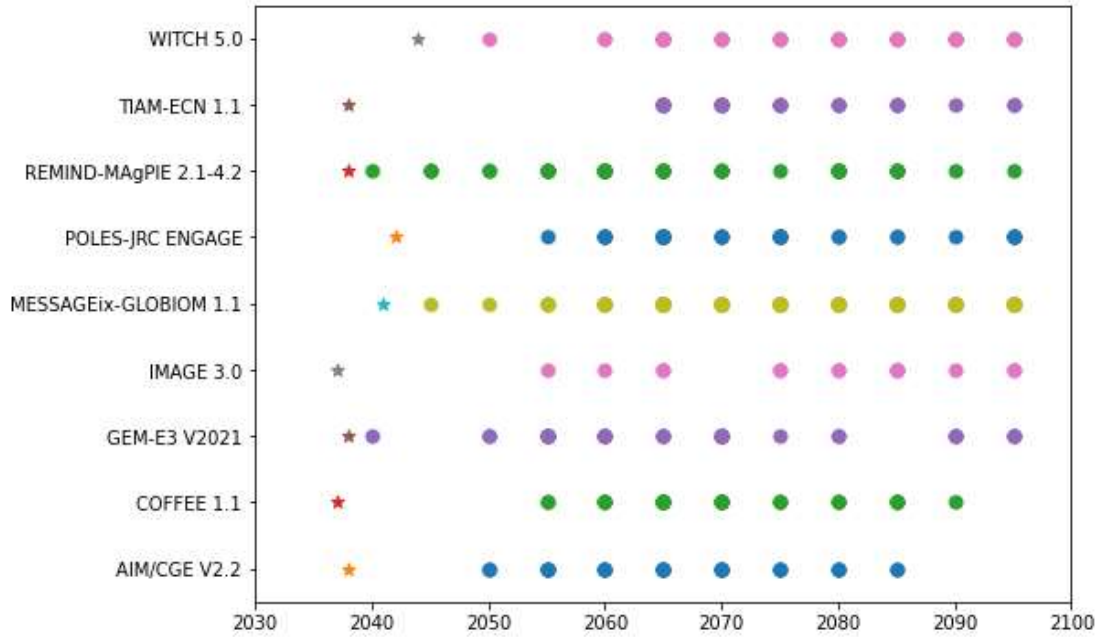


Figure S88. The earliest year to reach net zero for ENGAGE IAMs and MAC curves we derived. The circle points are the results from ENGAGE IAMs, and the star points are the results from MAC curves. We calculated the earliest time for different MACs to reach net zero using the largest 1st and 2nd derivatives.

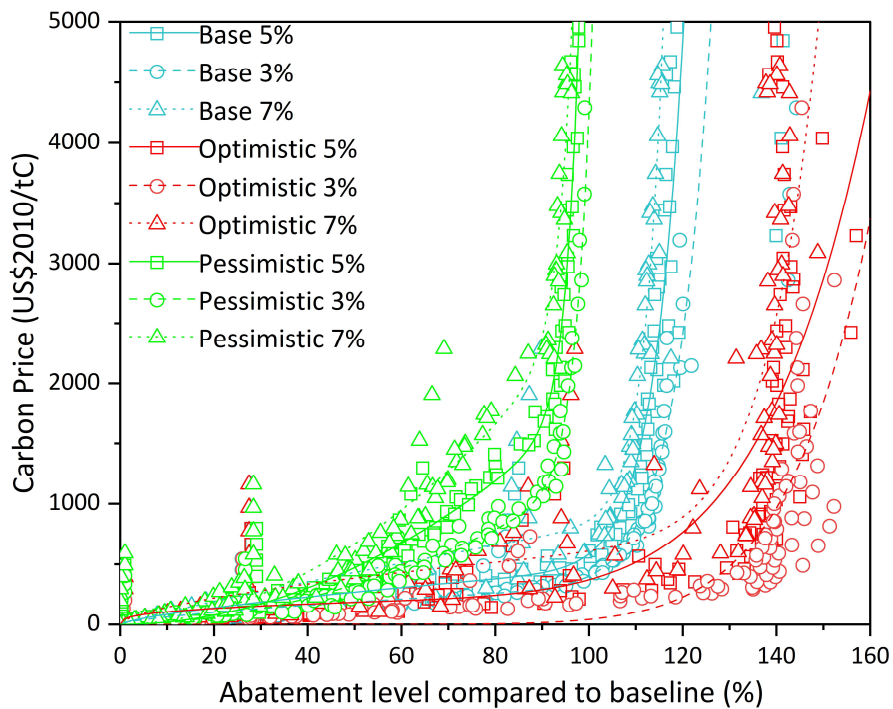


Figure S89. The relationship between abatement level and carbon price with different discount rates for policy portfolios in GET model. For individual policy portfolios, only the discount rate in the GET model is changed as 3%, 5% (default), and 7%, respectively.

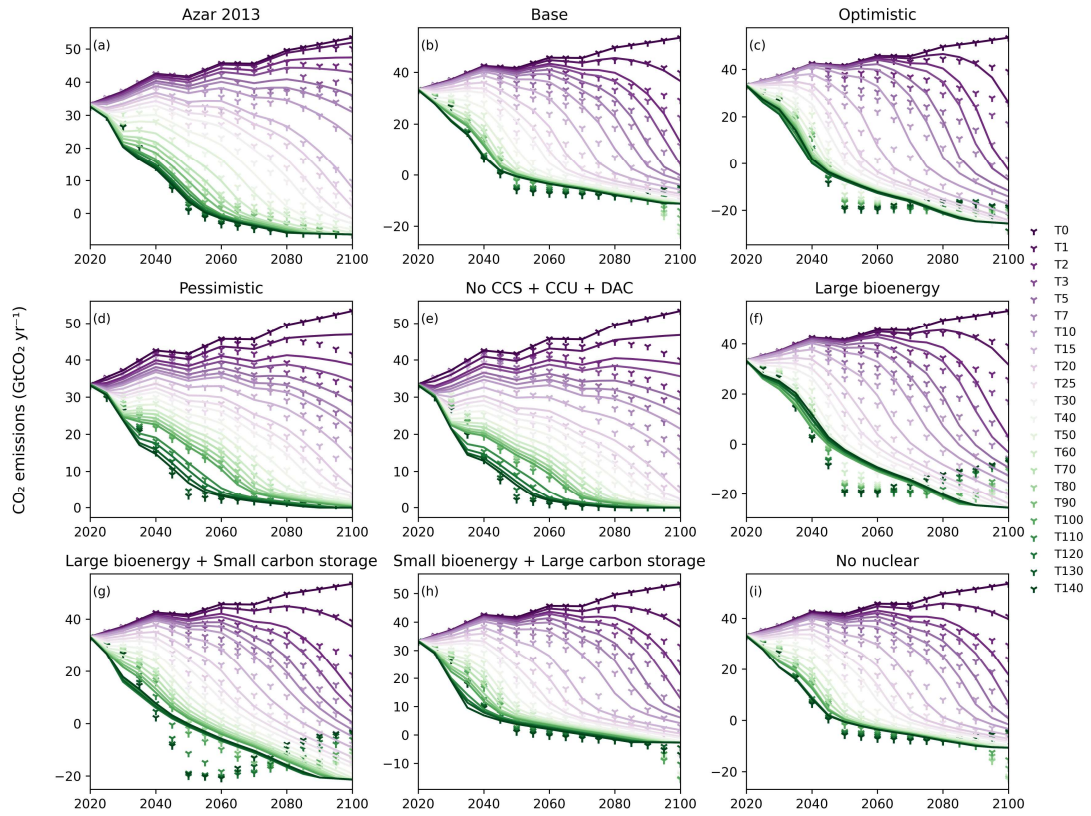


Figure S90. Test 1 – GET 9 portfolios energy-related CO₂ validation result

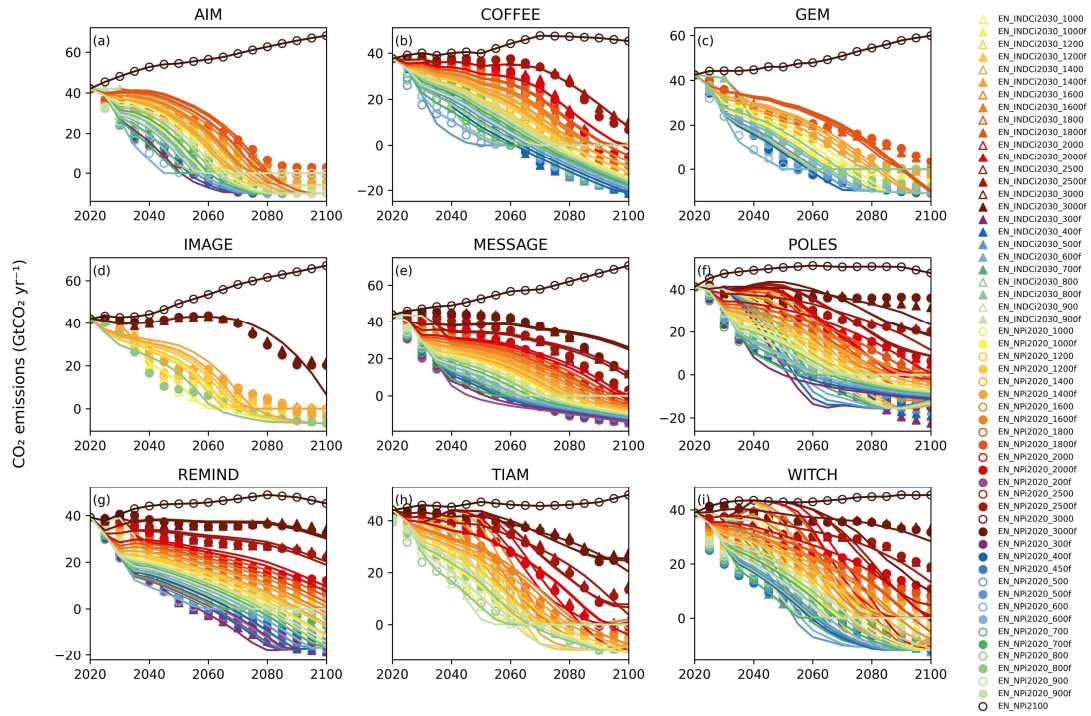


Figure S91. Test 1 – Global 9 models total anthropogenic CO₂ validation result

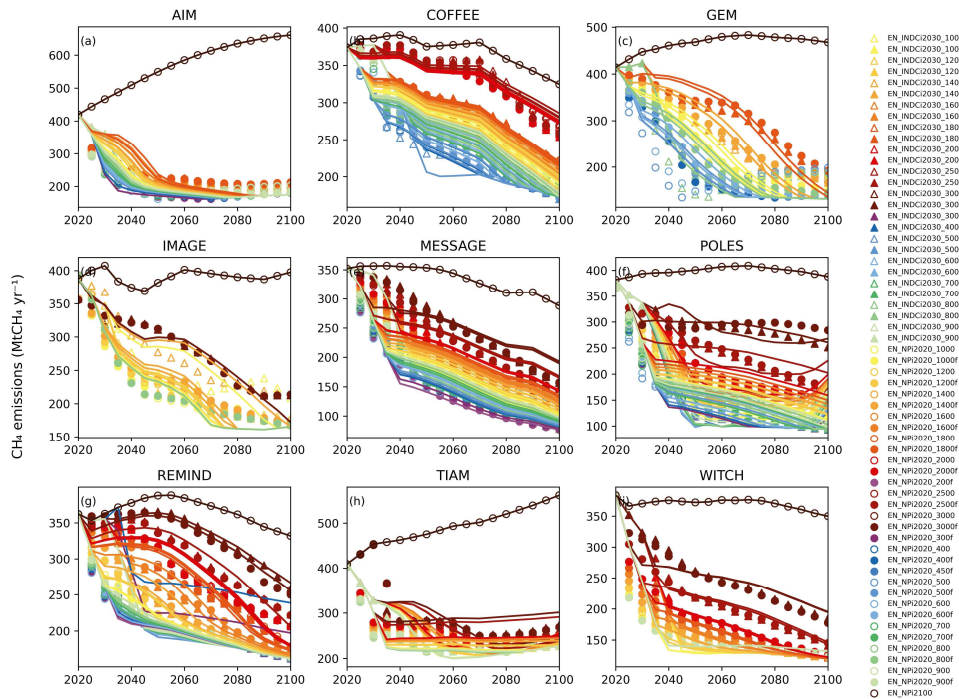


Figure S92. Test 1 – Global 9 models total anthropogenic CH₄ validation result

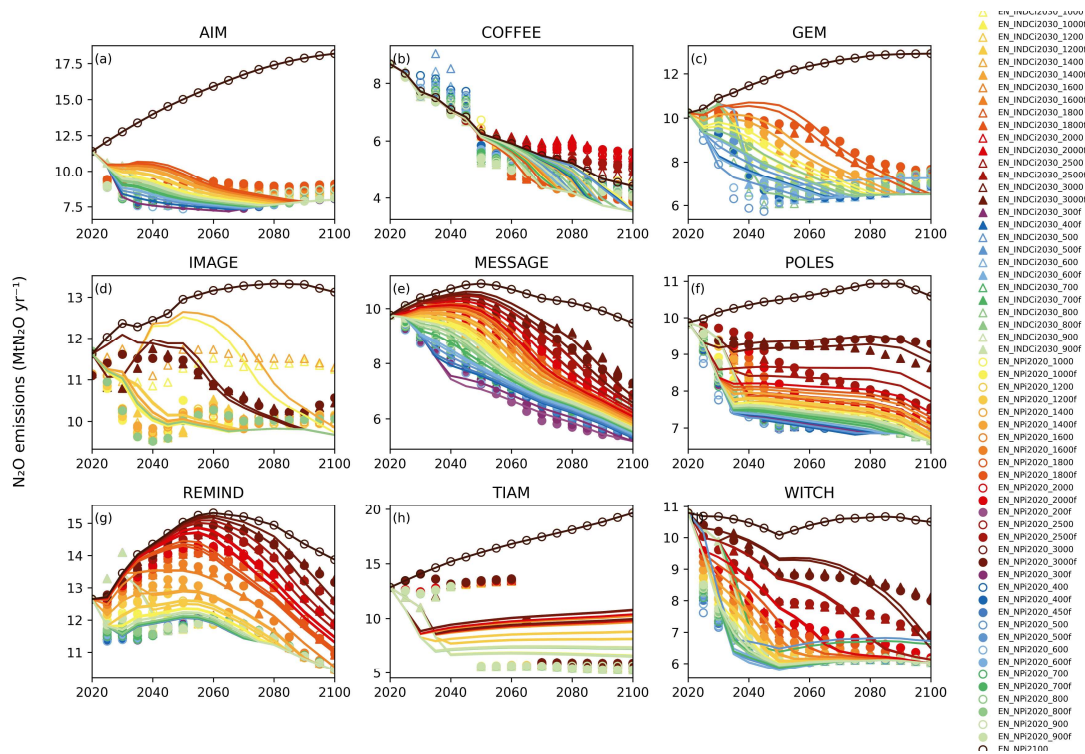


Figure S93. Test 1 – Global 9 models total anthropogenic N₂O validation result

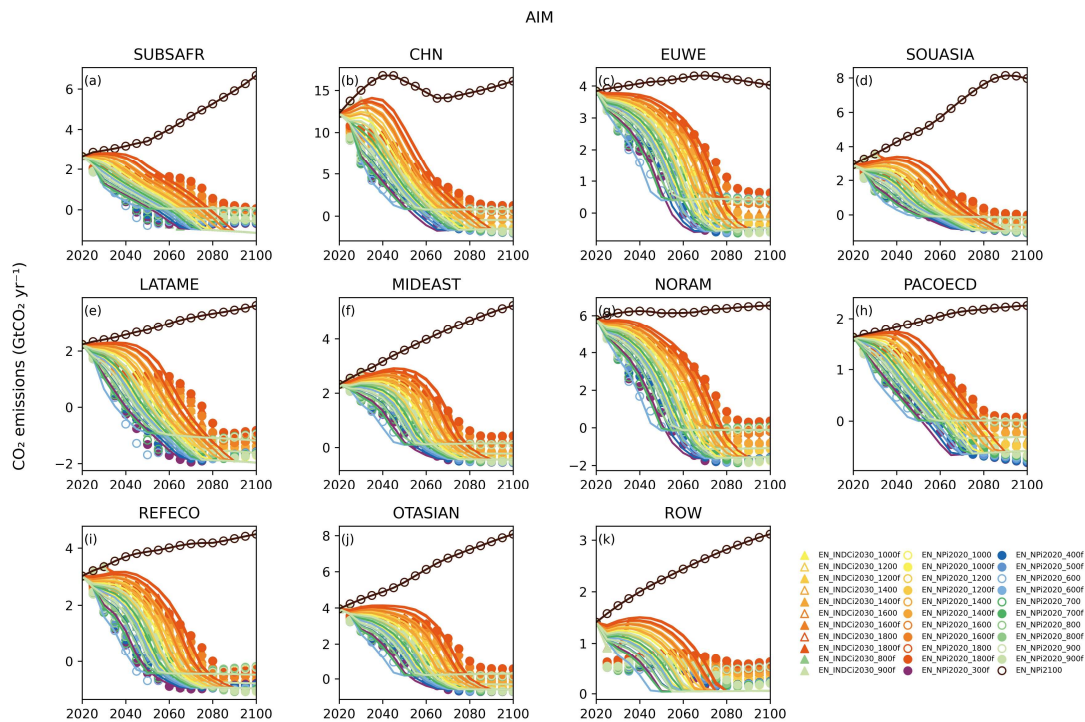


Figure S94. Test 1 - Regional AIM total anthropogenic CO₂ validation result

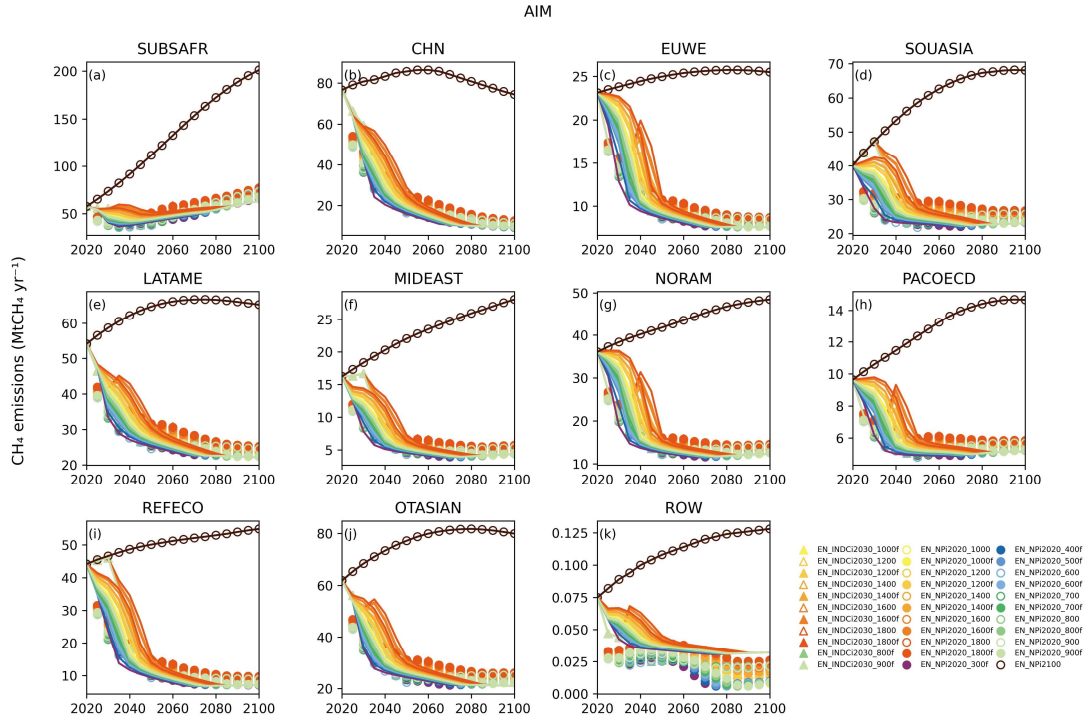


Figure S95. Test 1 - Regional AIM total anthropogenic CH₄ validation result

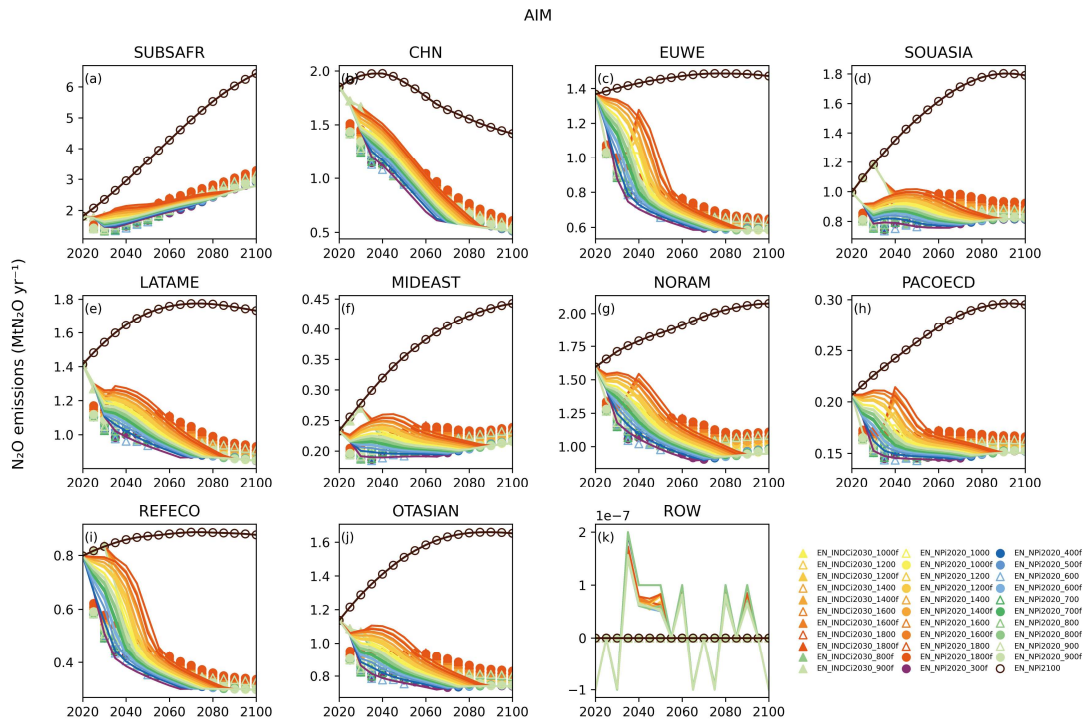


Figure S96. Test 1 - Regional AIM total anthropogenic N₂O validation result

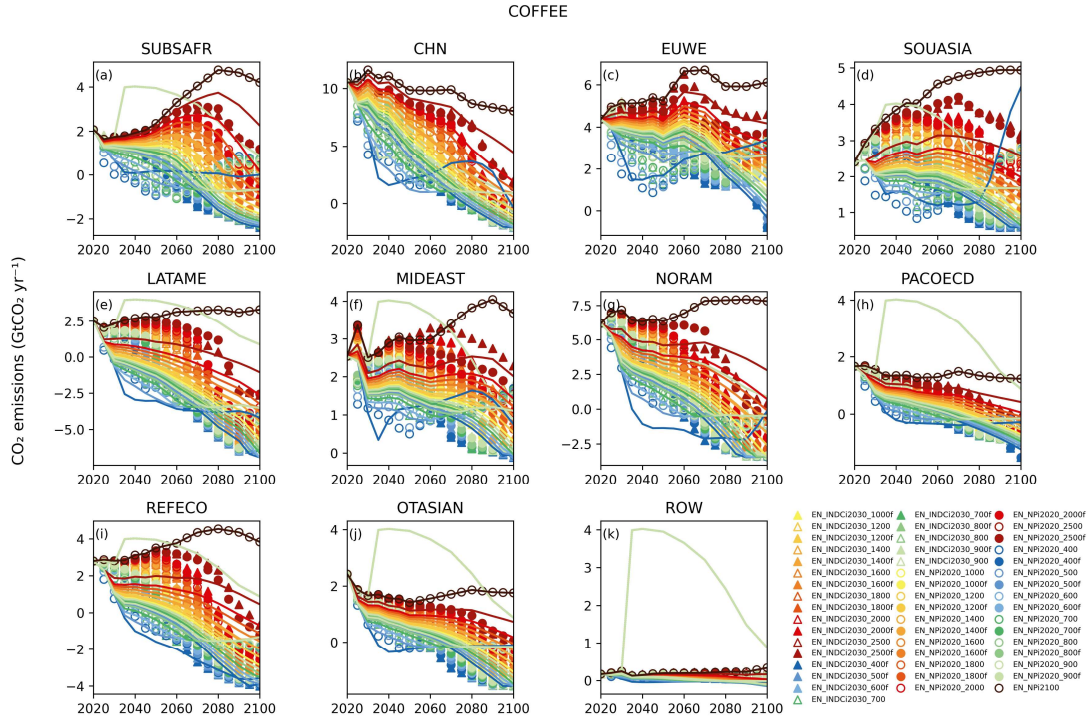


Figure S97. Test 1 - Regional COFFEE total anthropogenic CO₂ validation result

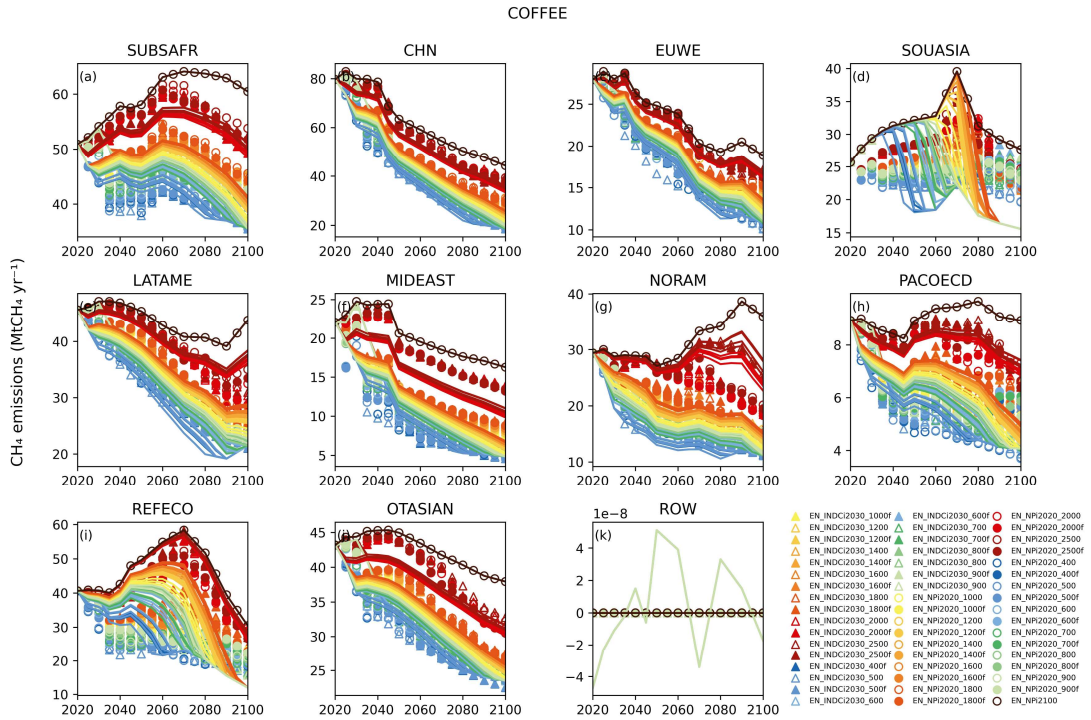


Figure S98. Test 1 - Regional COFFEE total anthropogenic CH₄ validation result

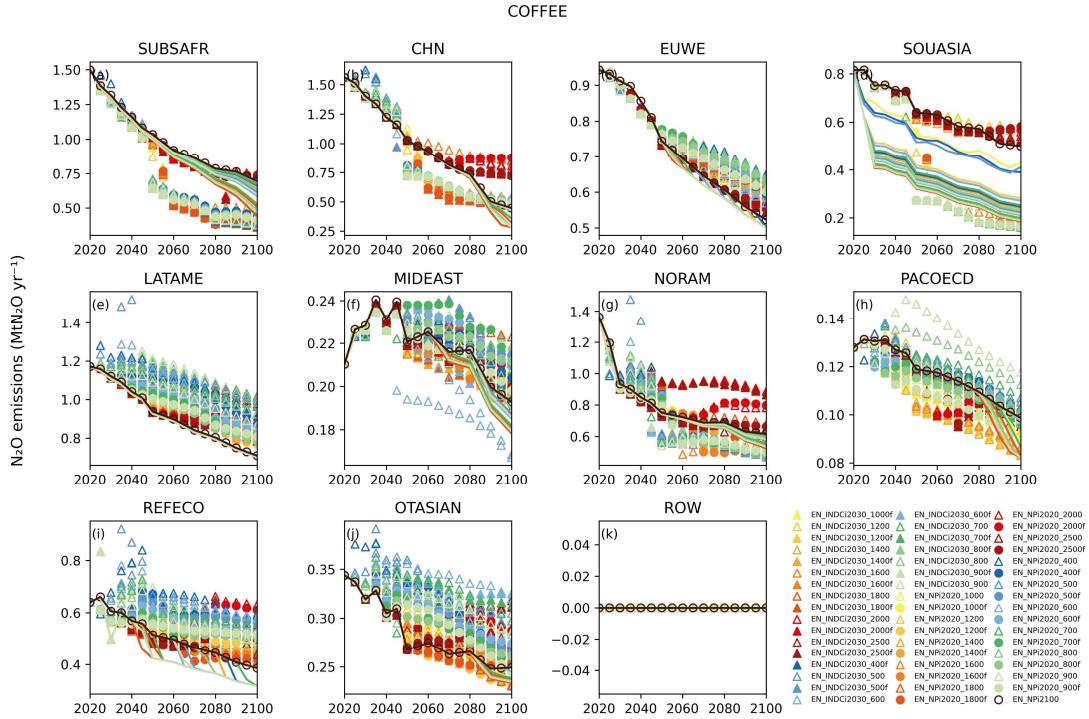


Figure S99. Test 1 - Regional COFFEE total anthropogenic N₂O validation result

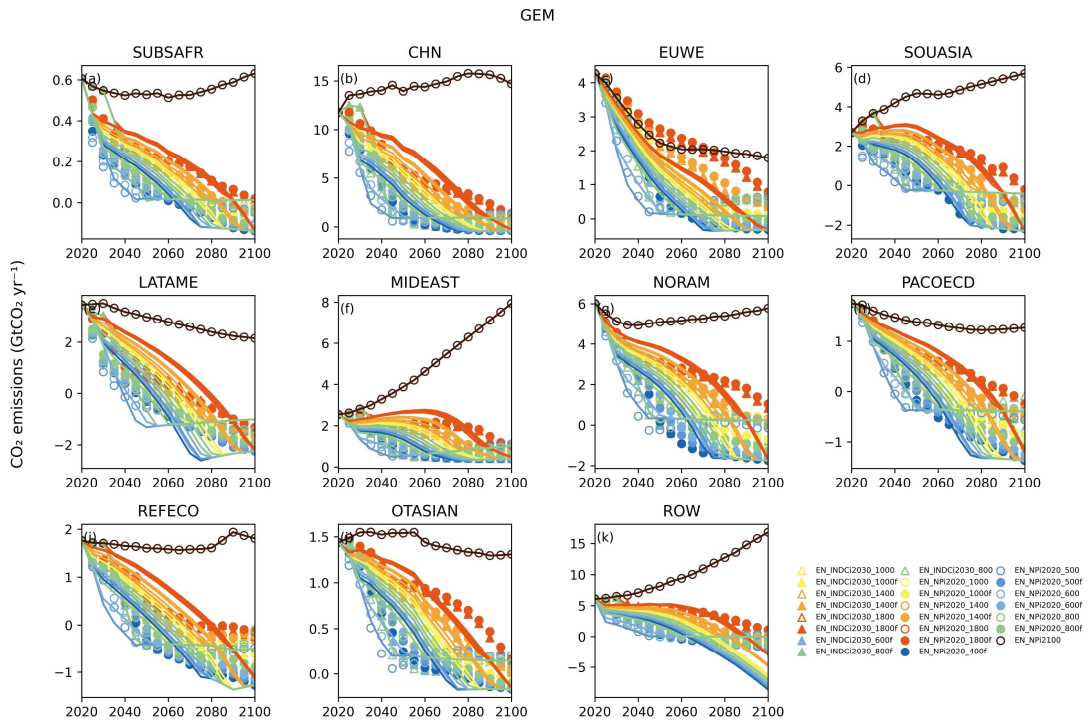


Figure S100. Test 1 - Regional GEM total anthropogenic CO₂ validation result

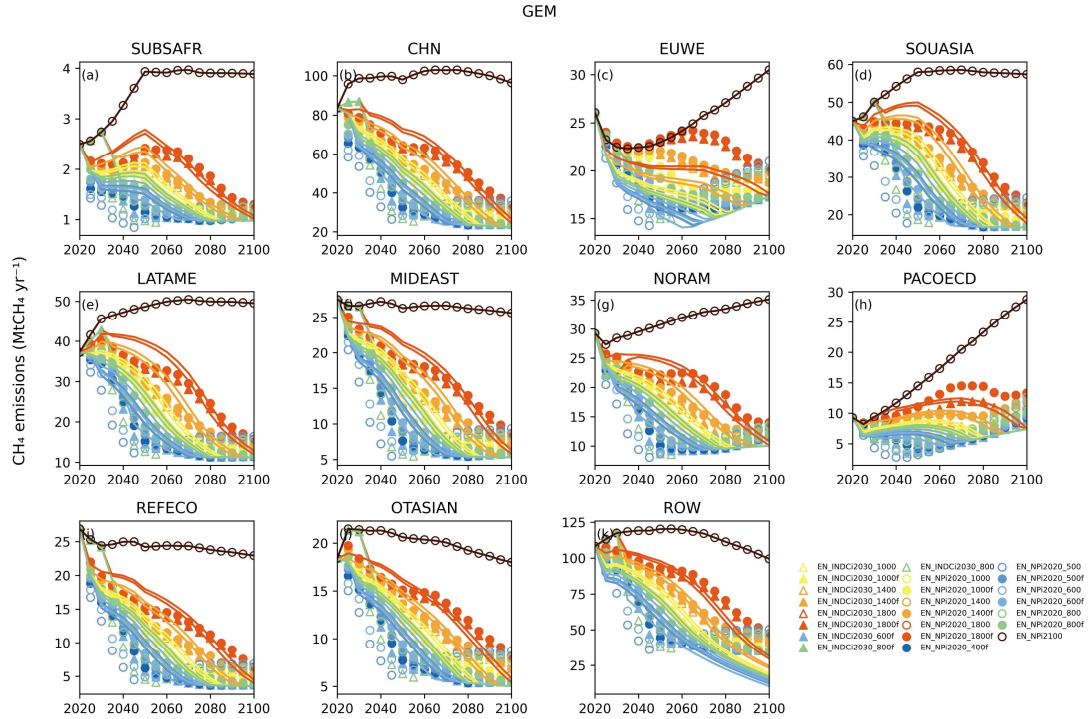


Figure S101. Test 1 - Regional GEM total anthropogenic CH₄ validation result

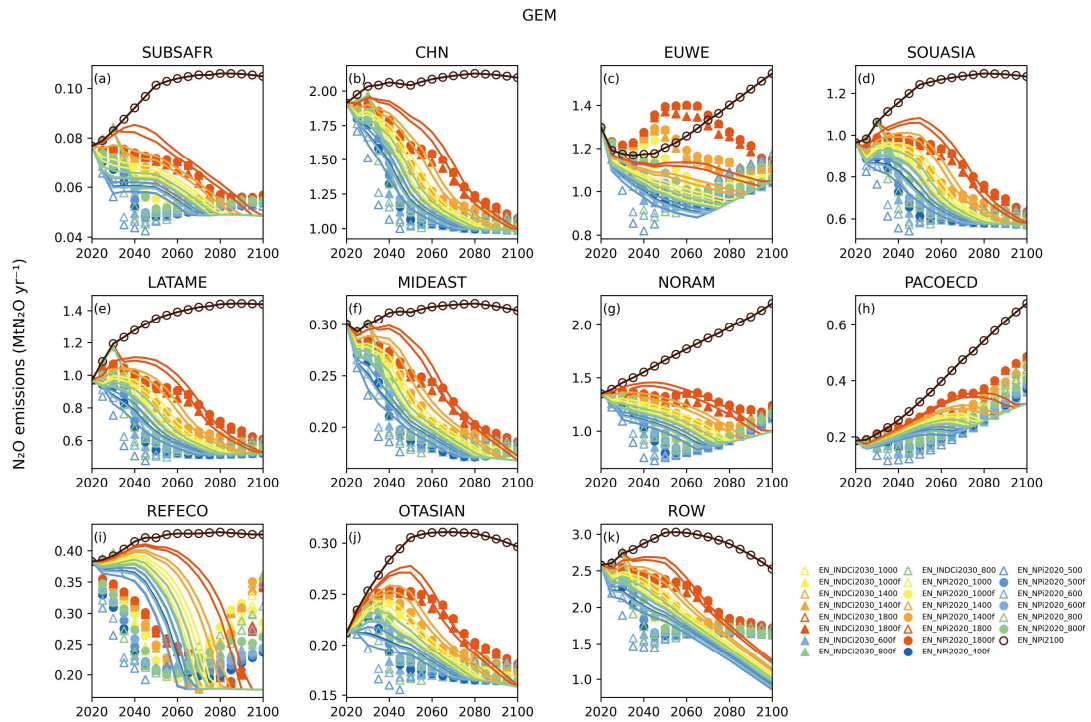


Figure S102. Test 1 - Regional GEM total anthropogenic N₂O validation result

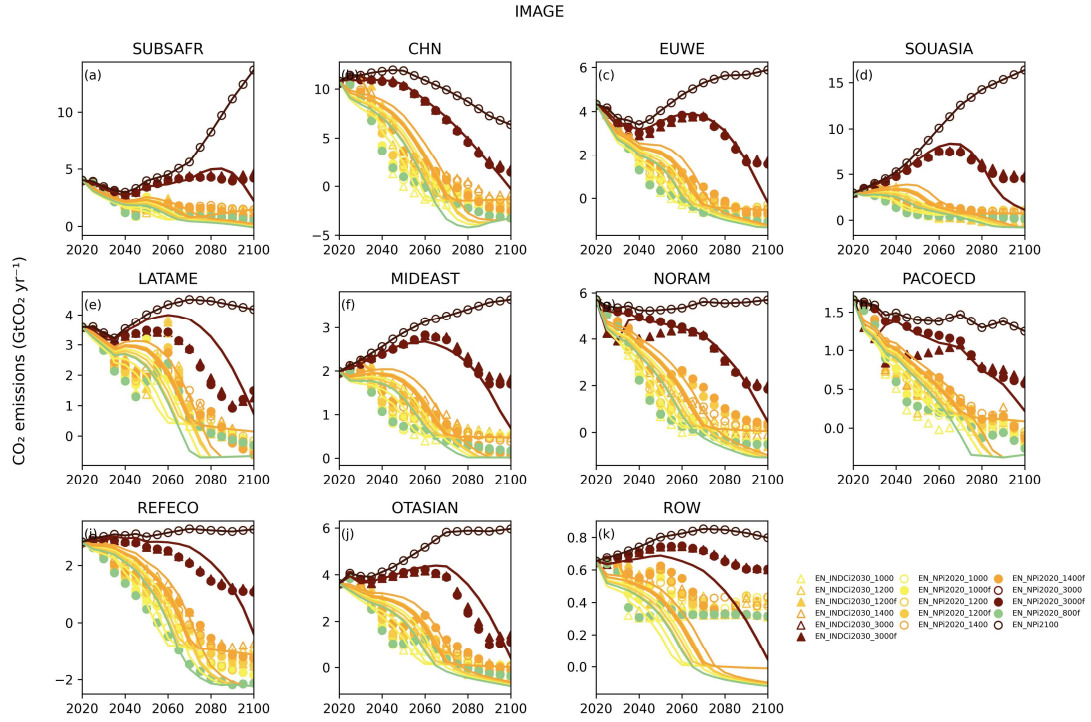


Figure S103. Test 1 - Regional IMAGE total anthropogenic CO₂ validation result

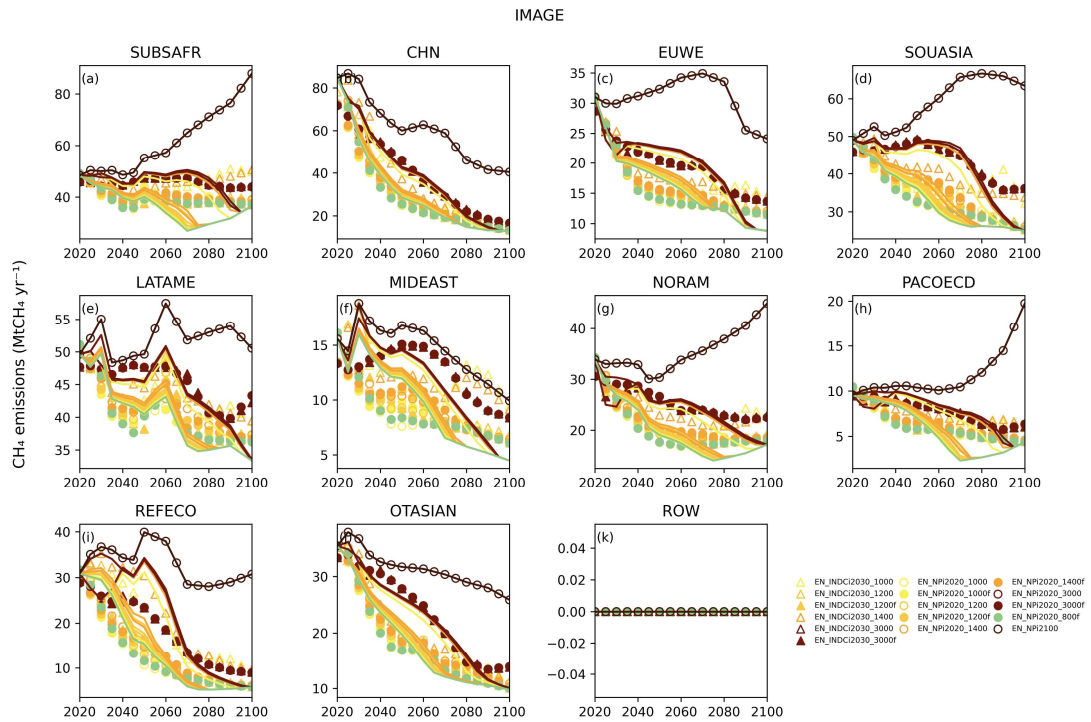


Figure S104. Test 1 - Regional IMAGE total anthropogenic CH₄ validation result

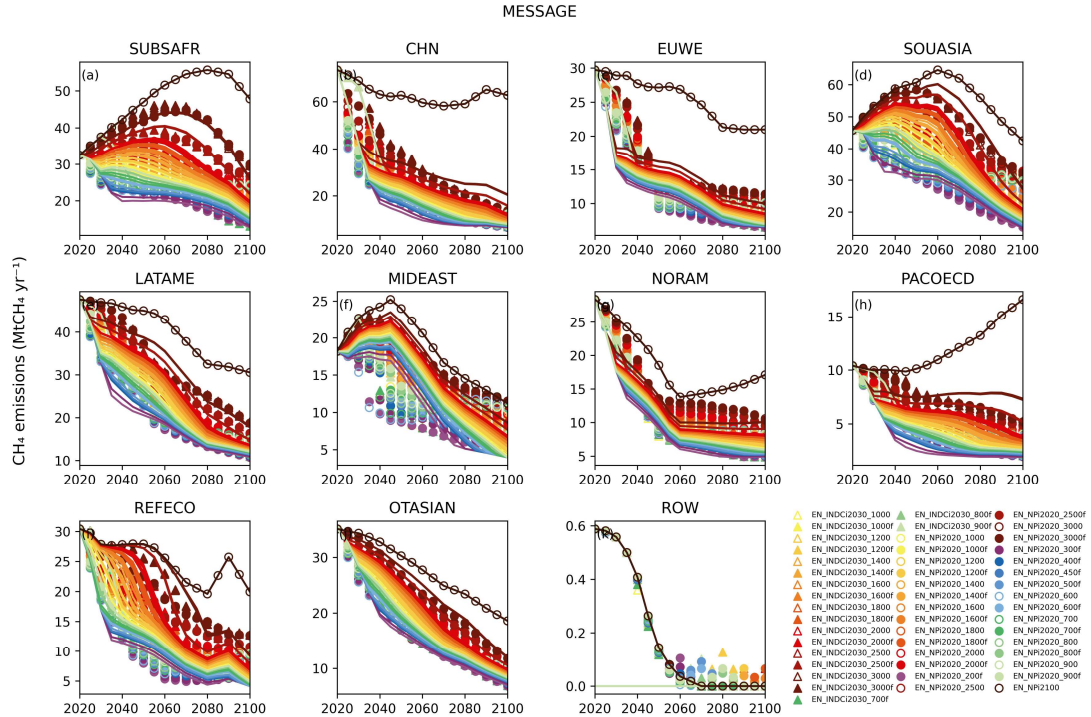


Figure S107. Test 1 - Regional MESSAGE total anthropogenic CH₄ validation result

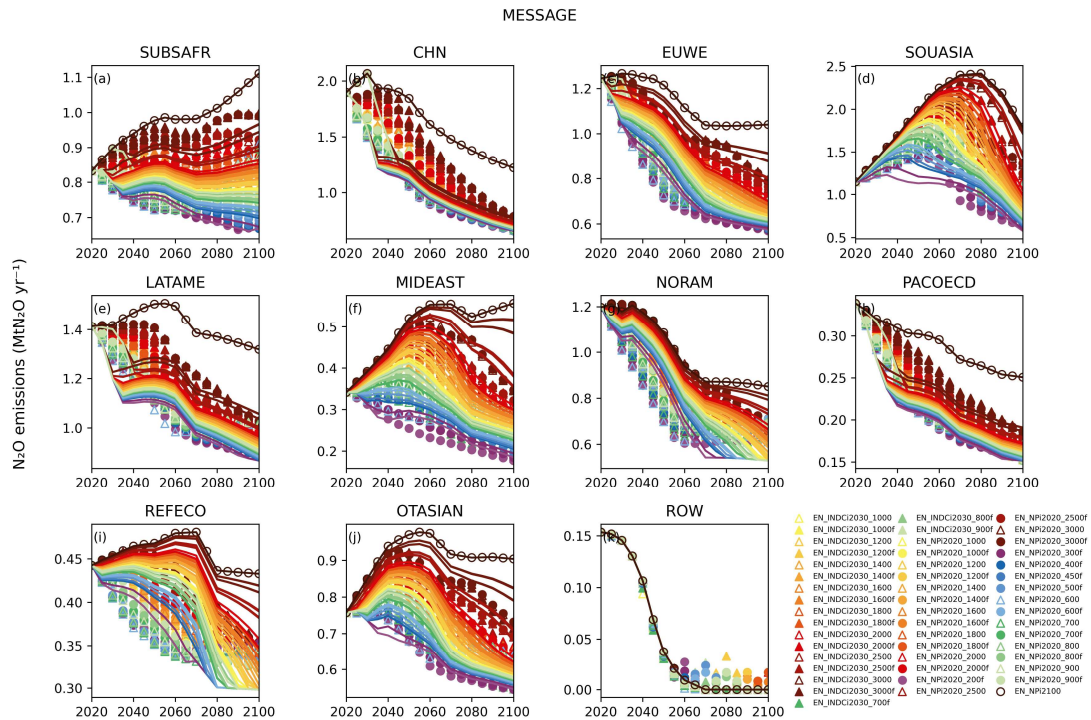


Figure S108. Test 1 - Regional MESSAGE total anthropogenic N₂O validation result

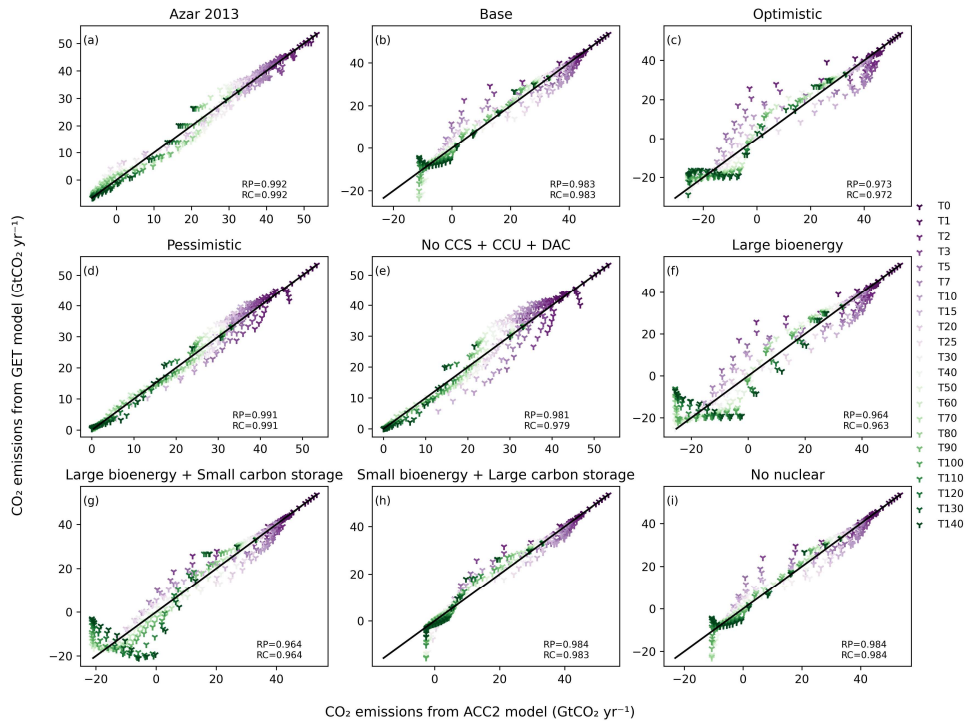


Figure S109. Test 1 - GET Reproducibility of total anthropogenic CO₂

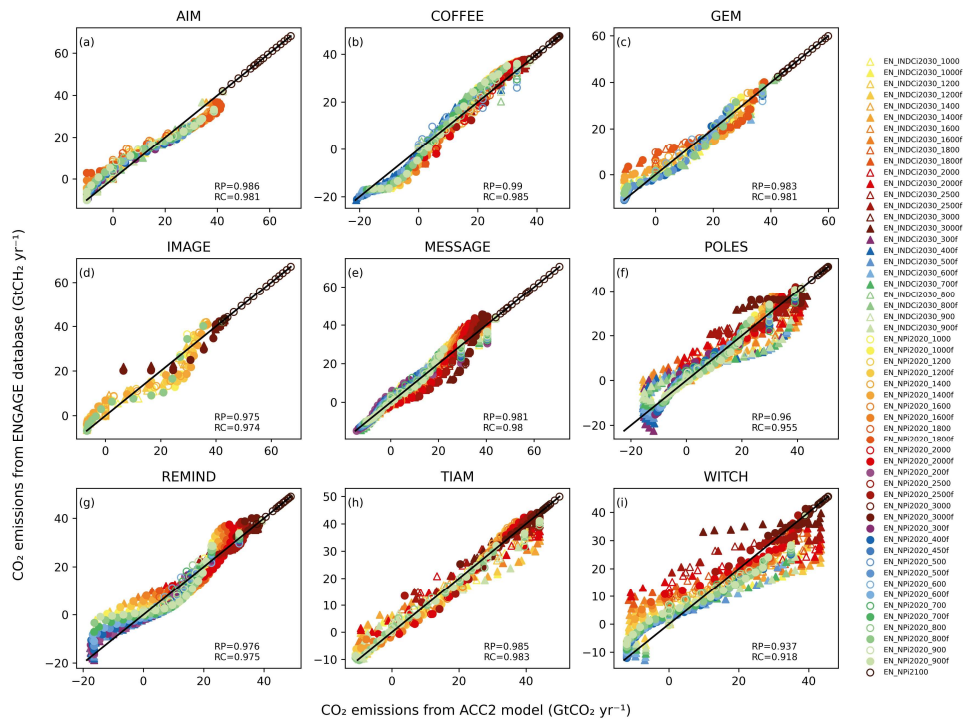


Figure S110. Test 1 - Global 9 models - Reproducibility of total anthropogenic CO₂

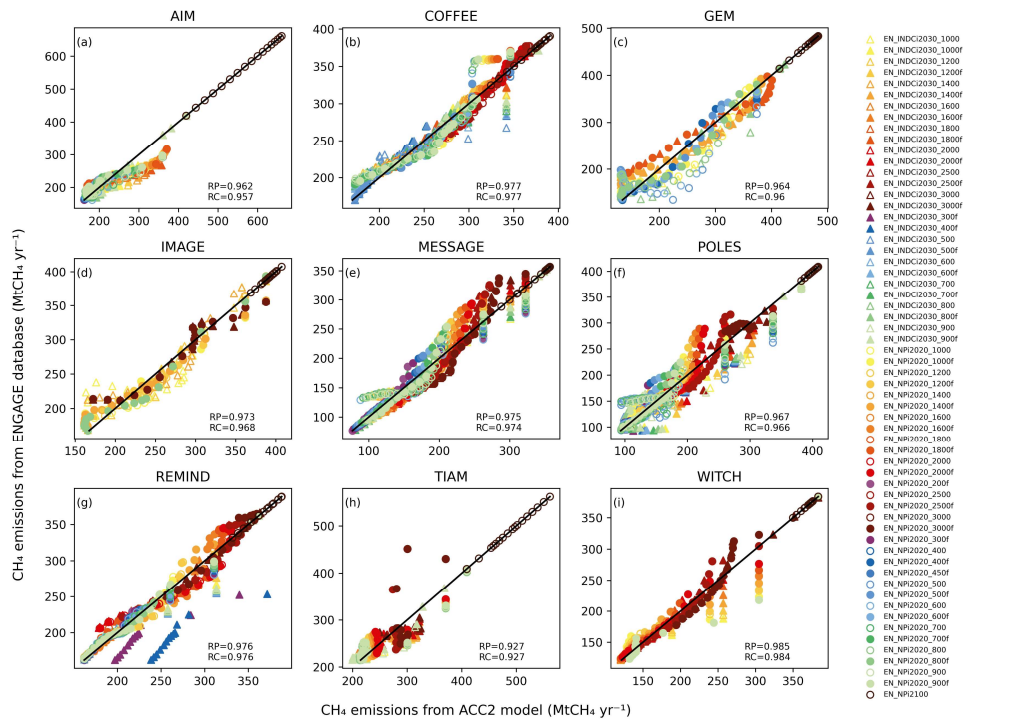


Figure S111. Test 1 - Global 9 models - Reproducibility of total anthropogenic CH₄

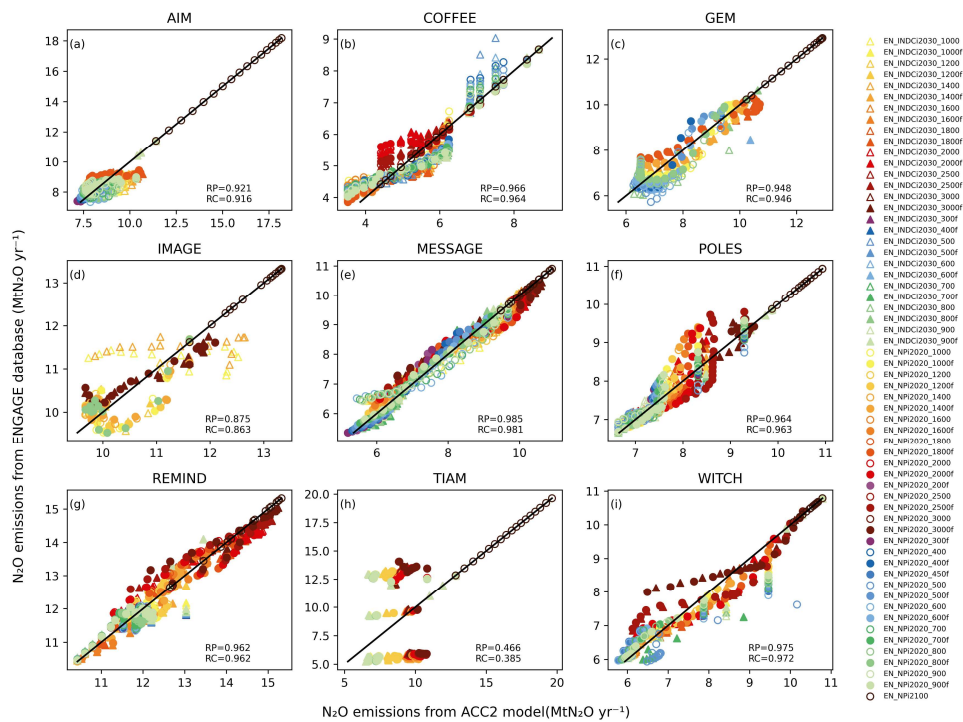


Figure S112. Test 1 - Global 9 models - Reproducibility of total anthropogenic N₂O

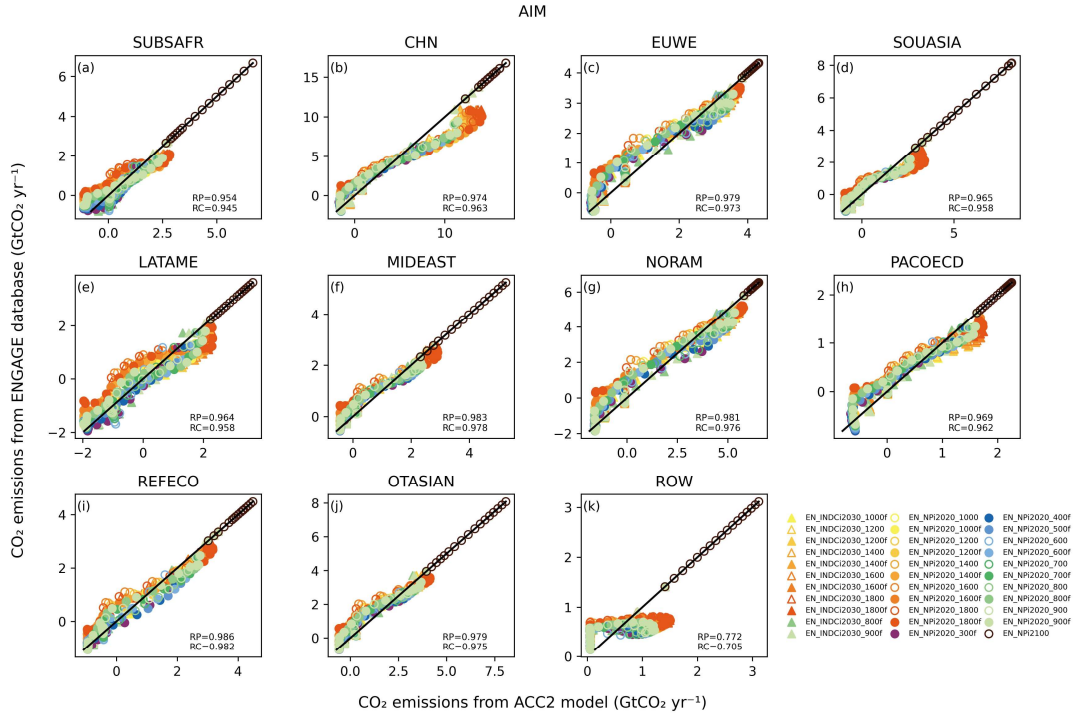


Figure S113. Test 1 - Regional AIM - Reproducibility of total anthropogenic CO₂

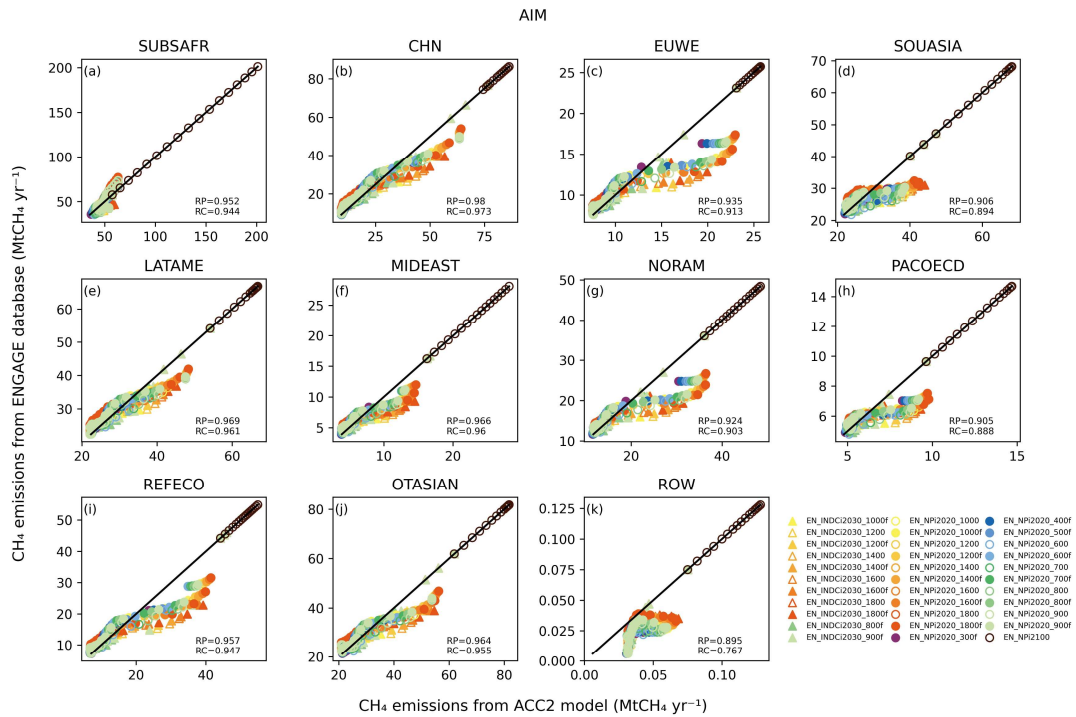


Figure S114. Test 1 - Regional AIM - Reproducibility of total anthropogenic CH₄

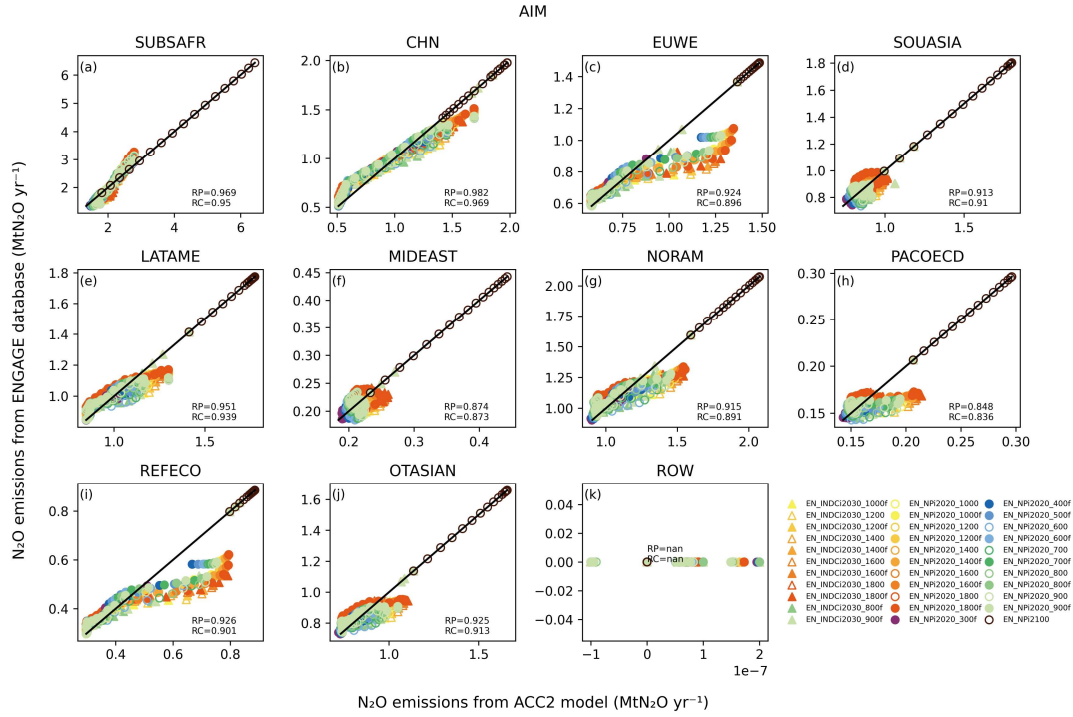


Figure S115. Test 1 - Regional AIM - Reproducibility of total anthropogenic N₂O

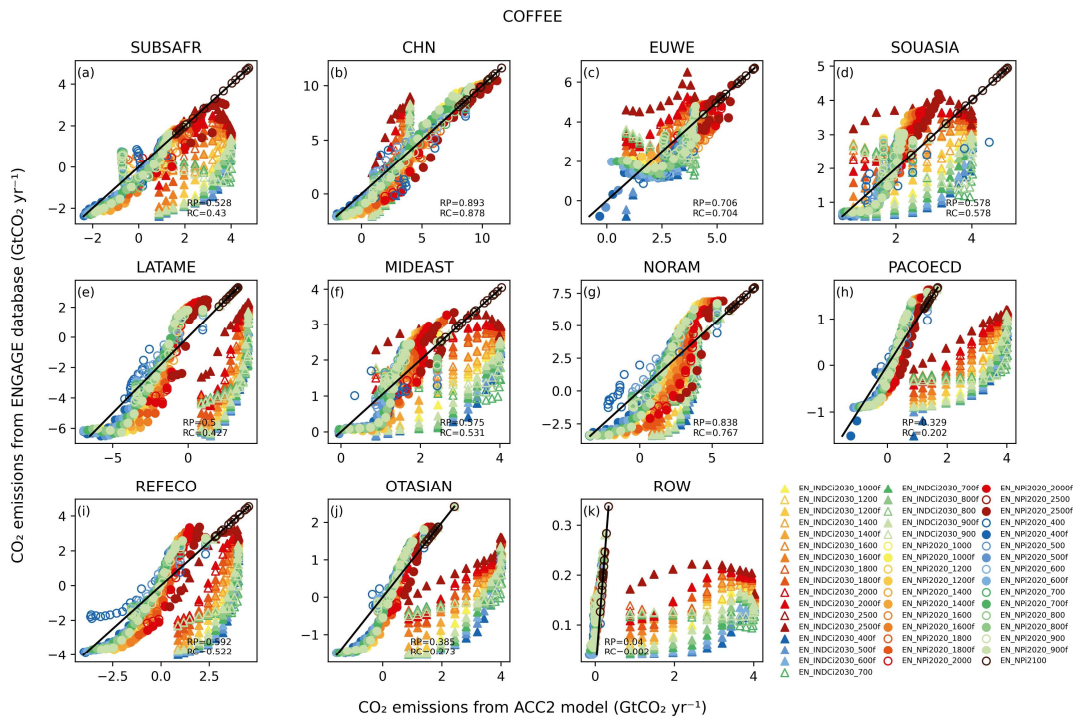


Figure S116. Test 1 - Regional COFFEE - Reproducibility of total anthropogenic CO₂

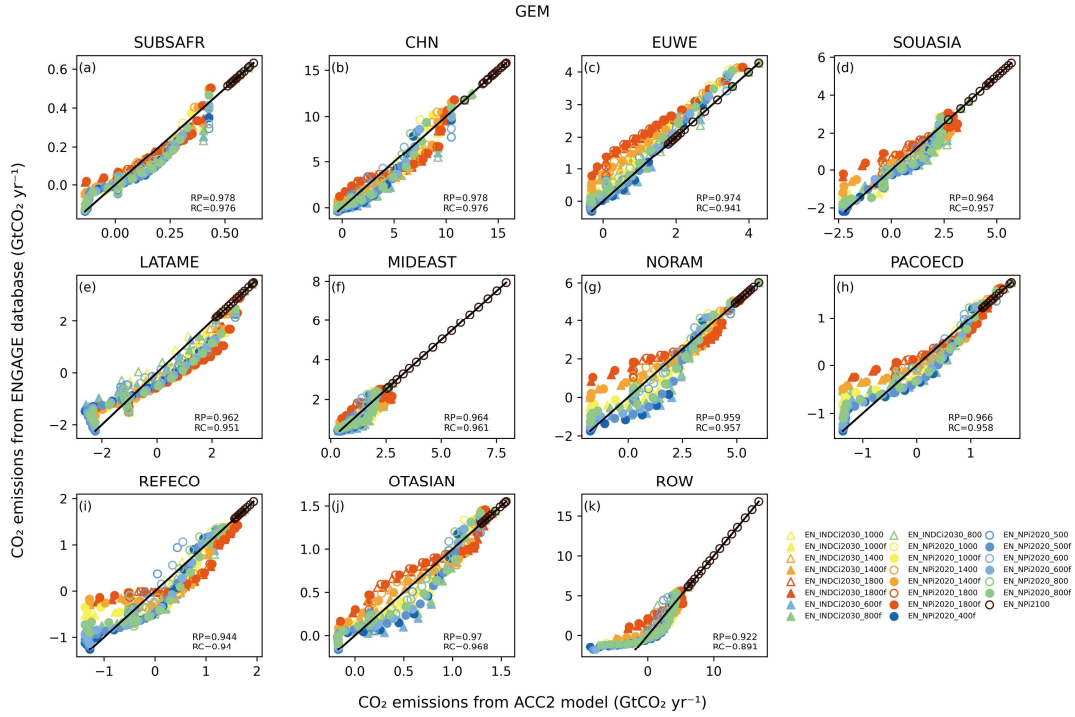


Figure S119. Test 1 - Regional GEM - Reproducibility of total anthropogenic CO₂

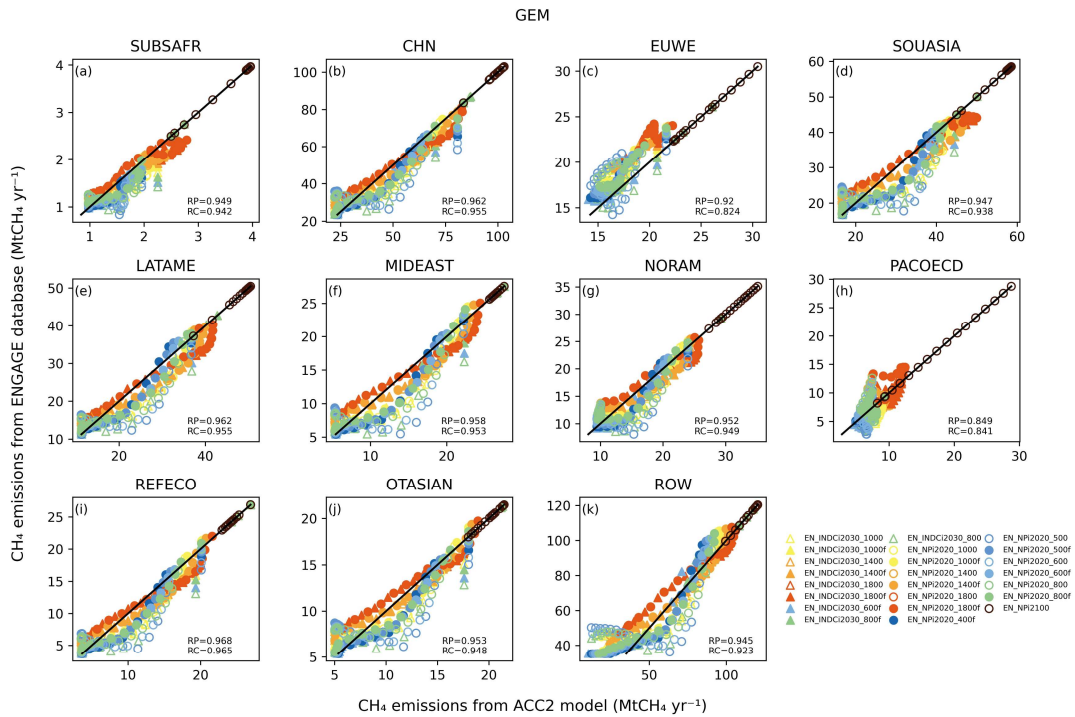


Figure S120. Test 1 - Regional GEM - Reproducibility of total anthropogenic CH₄

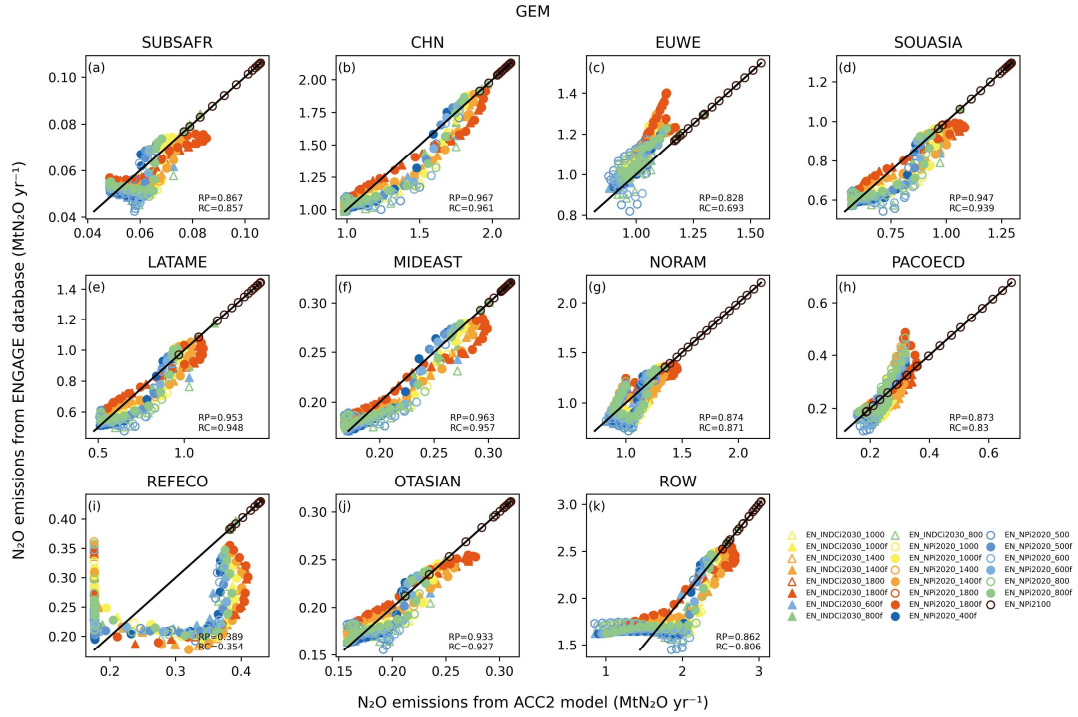


Figure S121. Test 1 - Regional GEM - Reproducibility of total anthropogenic N₂O

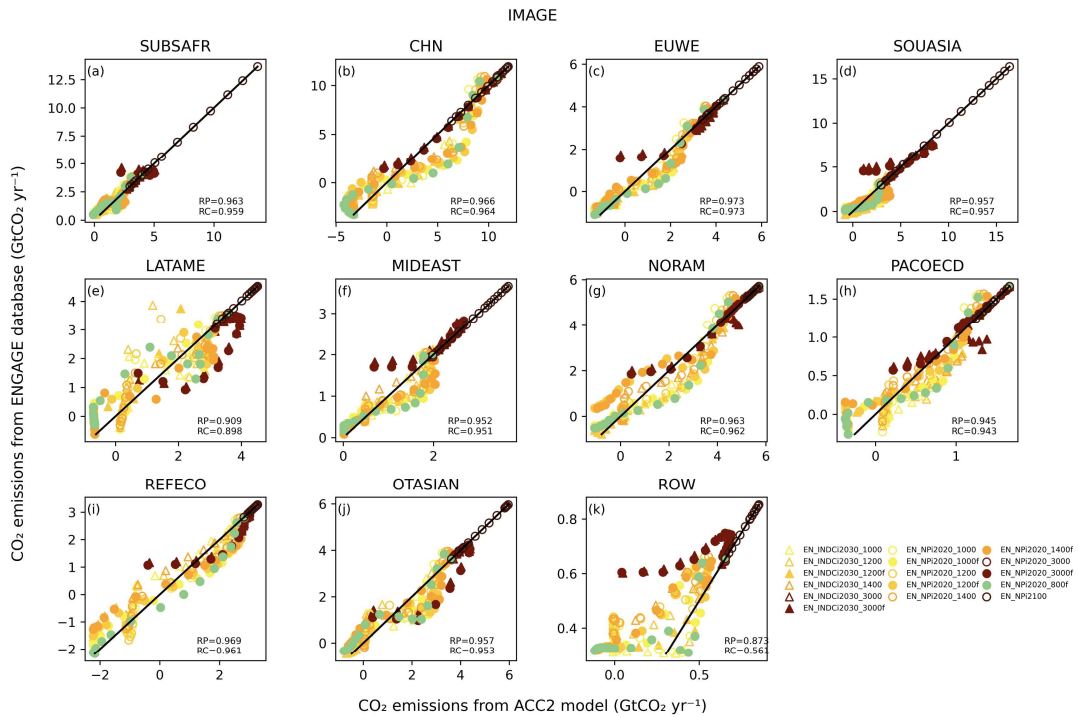


Figure S122. Test 1 - Regional IMAGE - Reproducibility of total anthropogenic CO₂

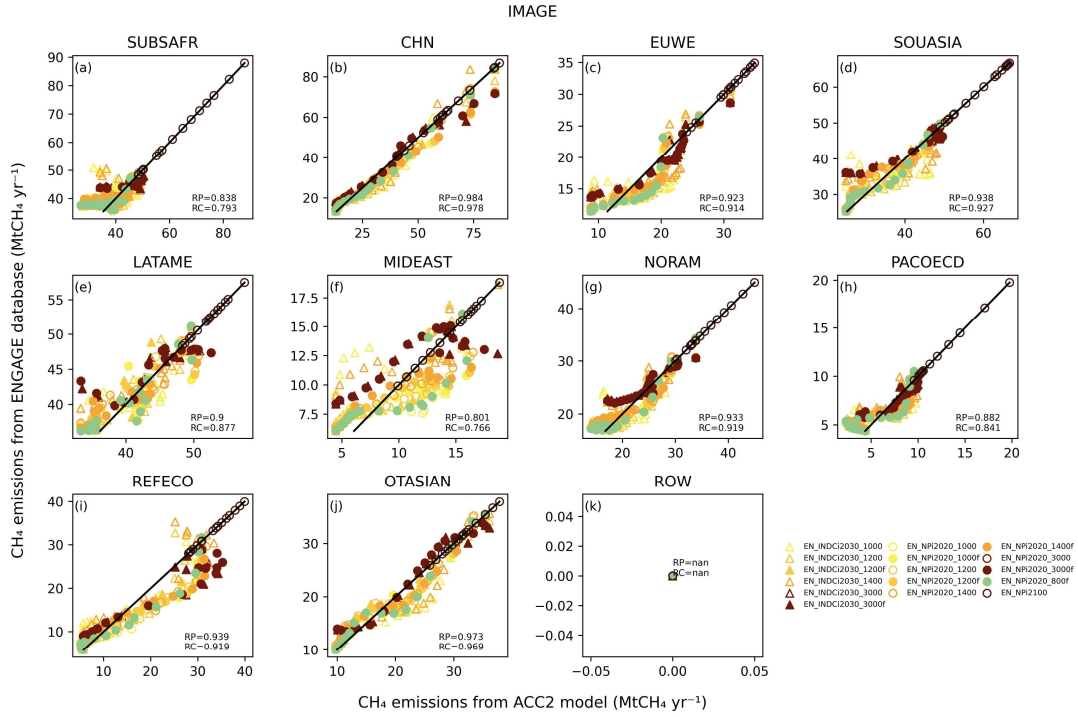


Figure S123. Test 1 - Regional IMAGE - Reproducibility of total anthropogenic CH₄

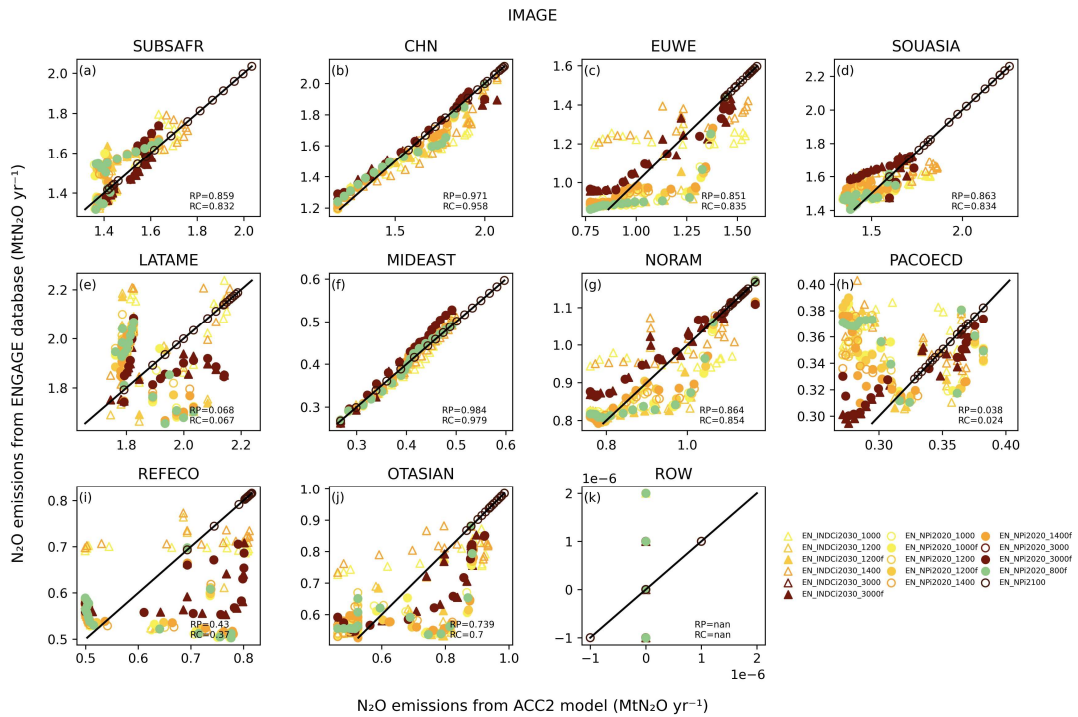


Figure S124. Test 1 - Regional IMAGE - Reproducibility of total anthropogenic N₂O

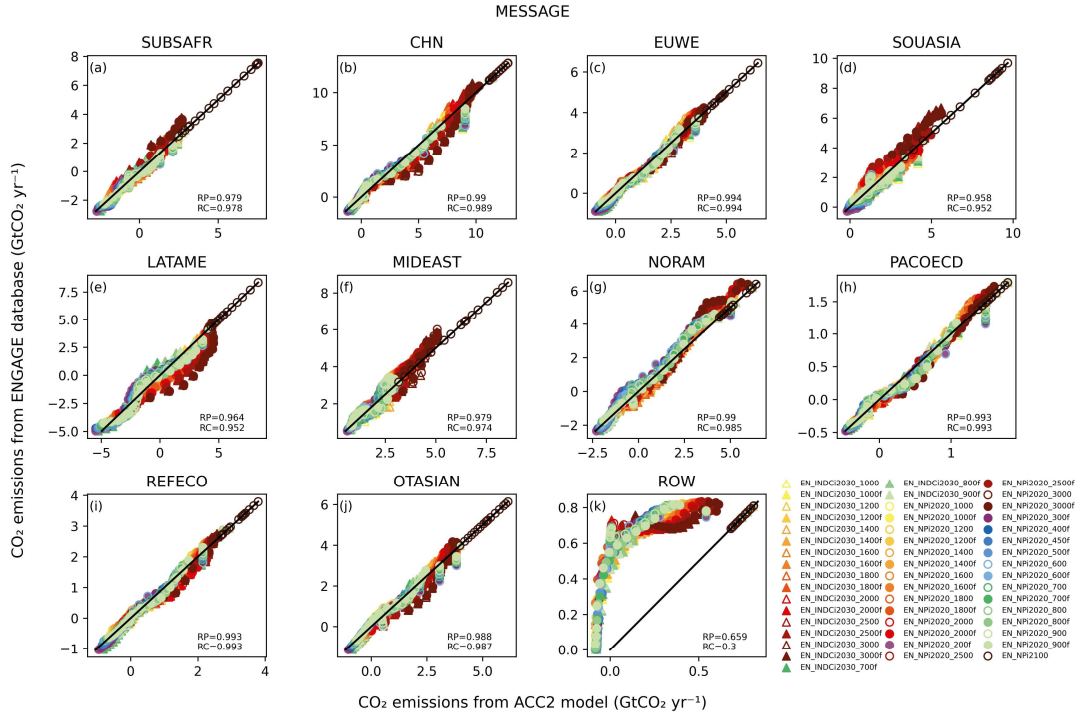


Figure S125. Test 1 - Regional MESSAGE - Reproducibility of total anthropogenic CO₂

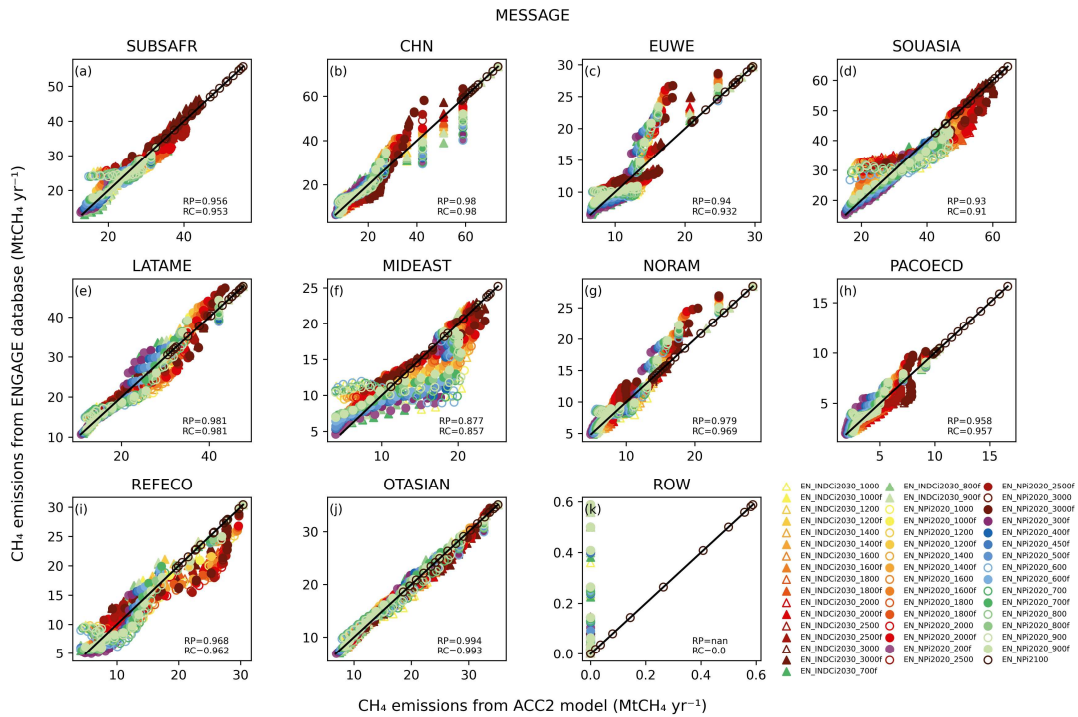


Figure S126. Test 1 - Regional MESSAGE - Reproducibility of total anthropogenic CH₄

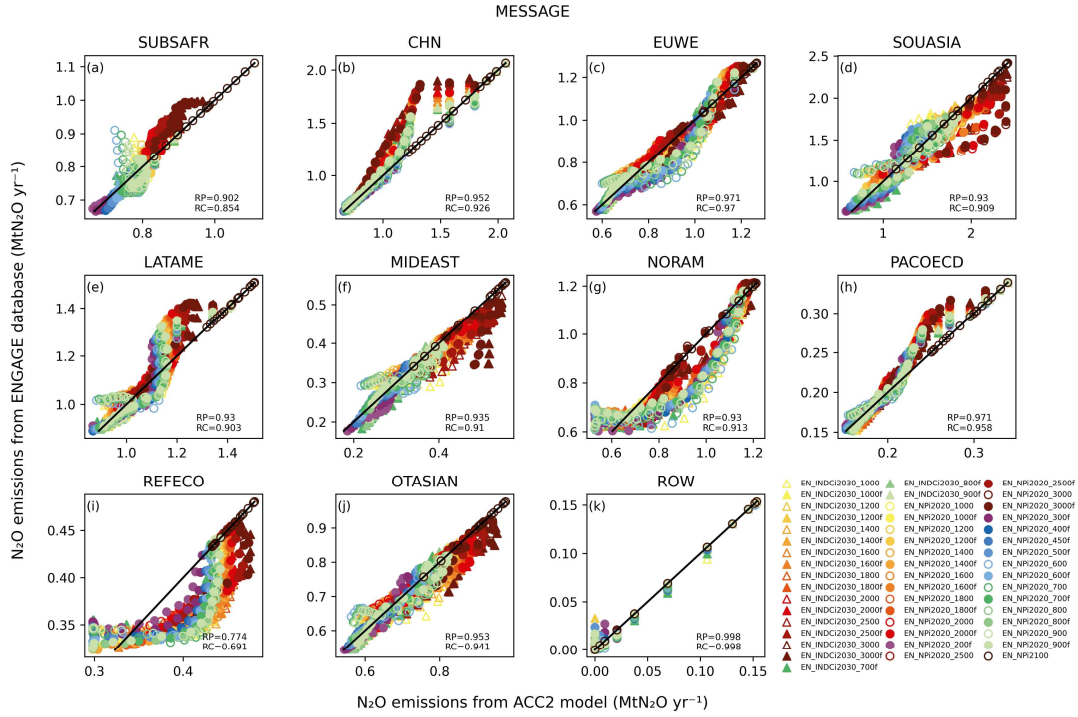


Figure S127. Test 1 - Regional MESSAGE - Reproducibility of total anthropogenic N₂O

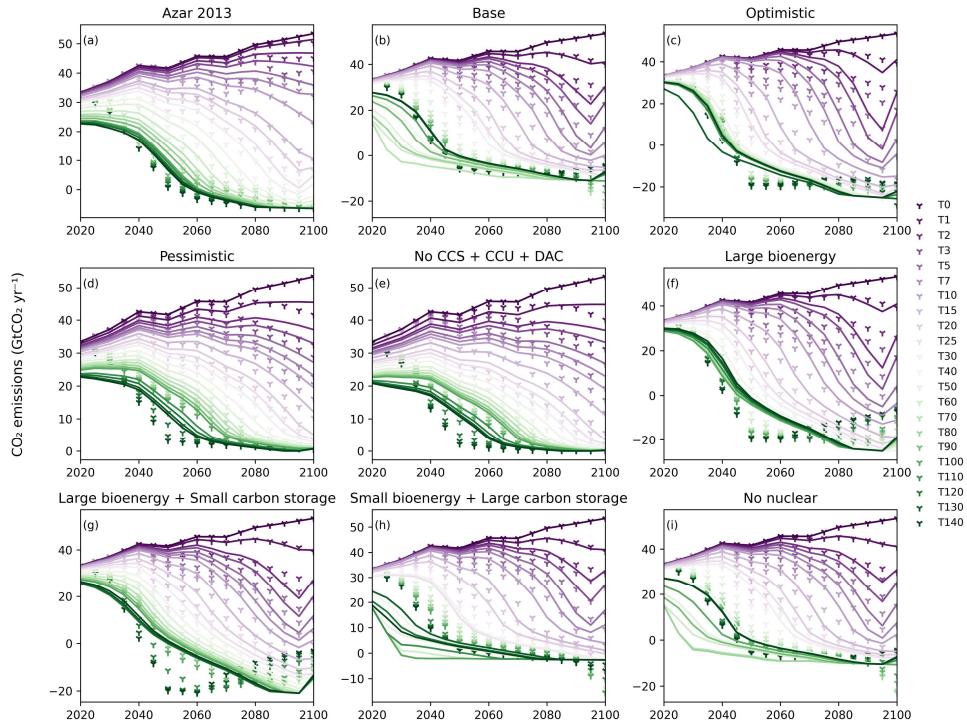


Figure S128. Test 2 – GET 9 portfolios energy-related CO₂ validation result

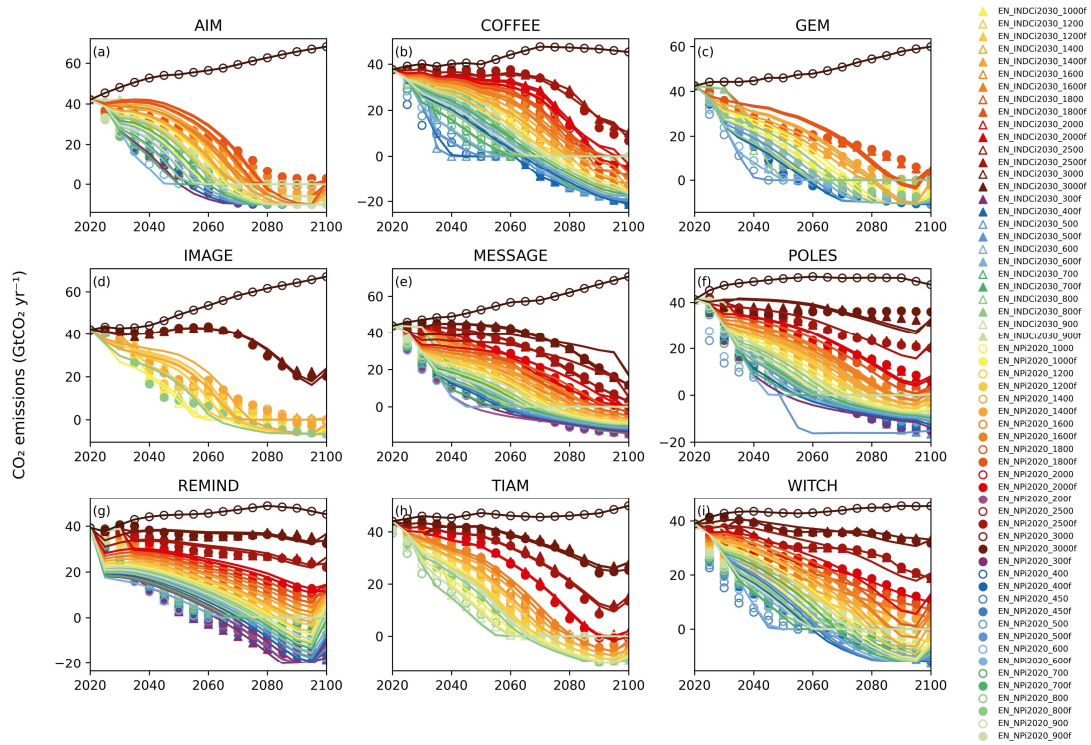


Figure S129. Test 2 – Global 9 models total anthropogenic CO₂ validation result

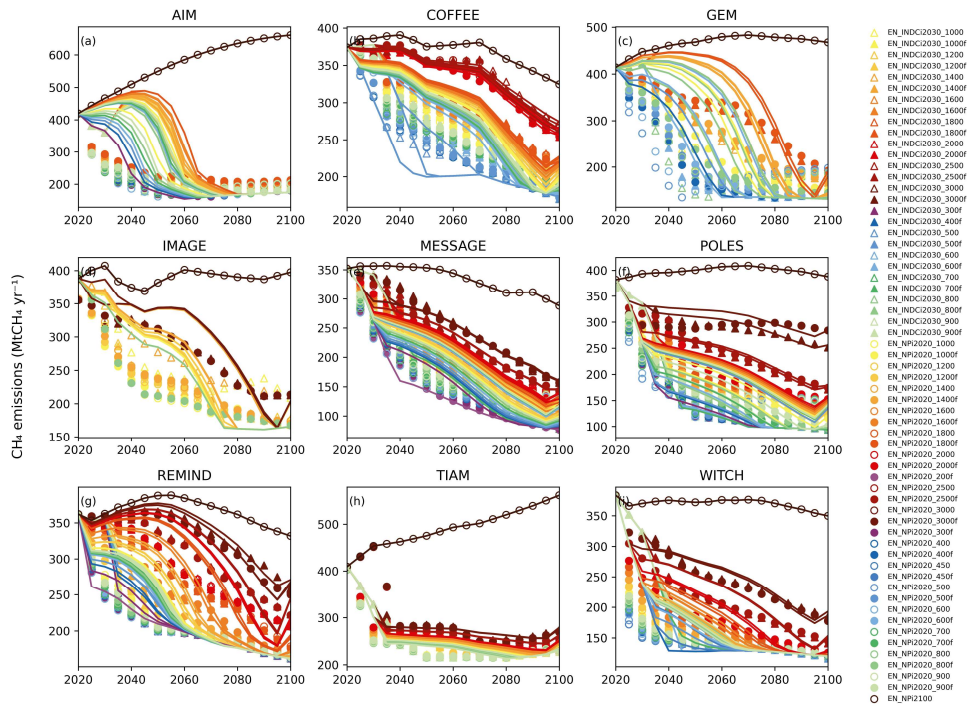


Figure S130. Test 2 – Global 9 models total anthropogenic CH₄ validation result

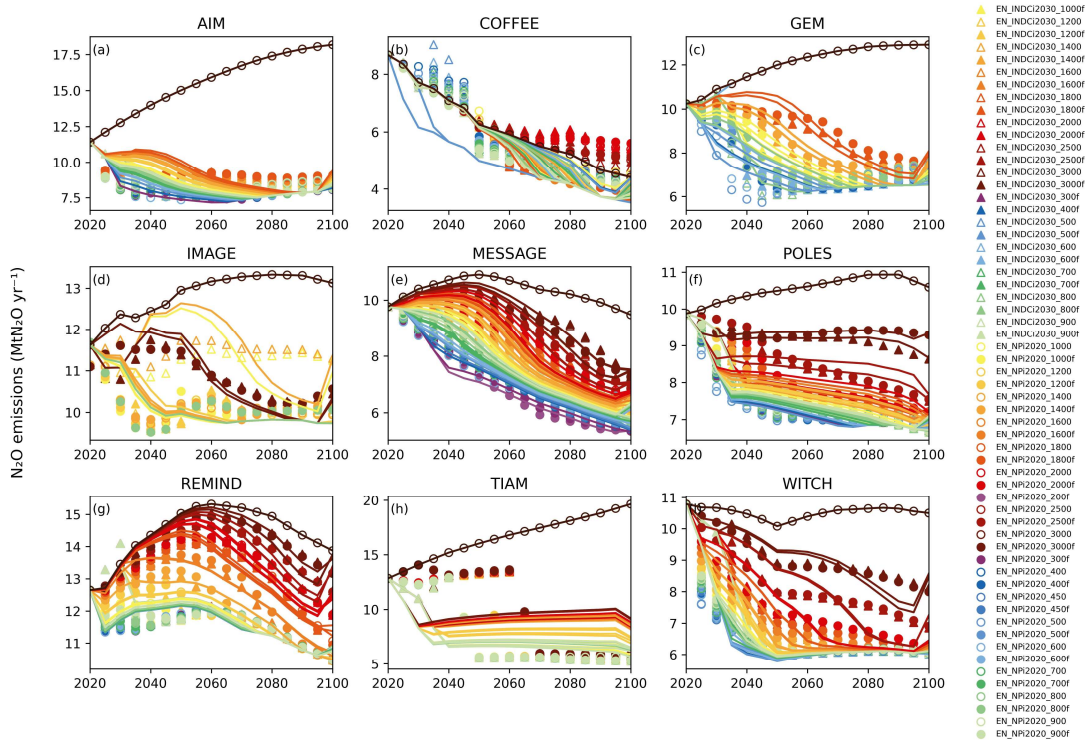


Figure S131. Test 2 – Global 9 models total anthropogenic N_2O validation result

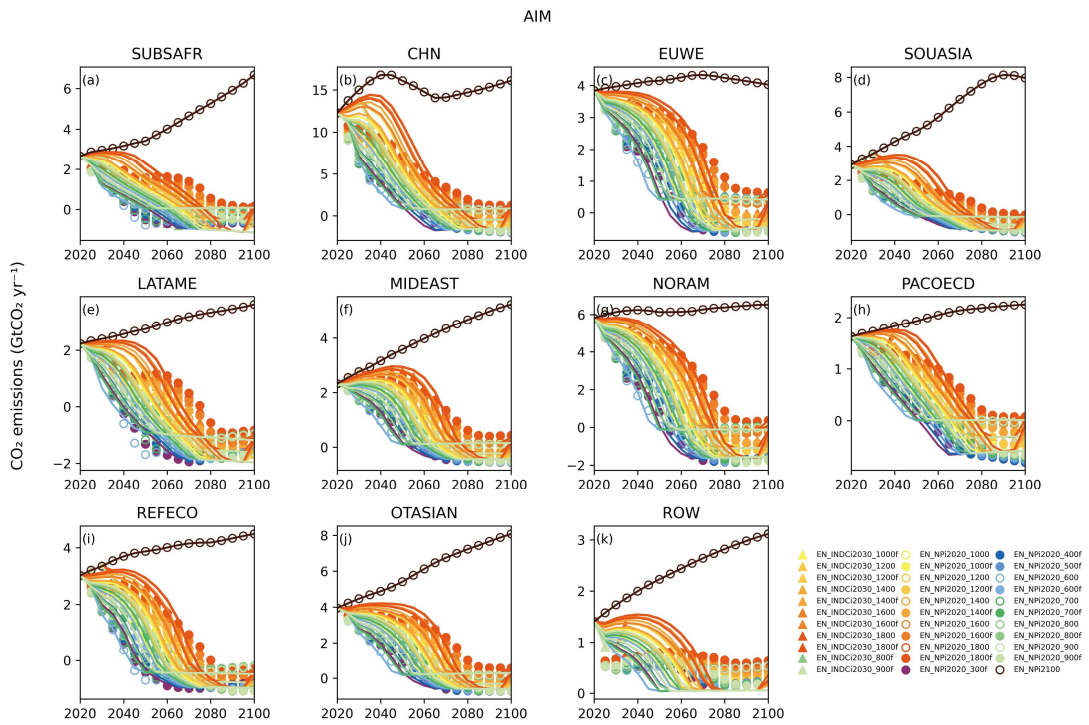


Figure S132. Test 2 - Regional AIM total anthropogenic CO_2 validation result

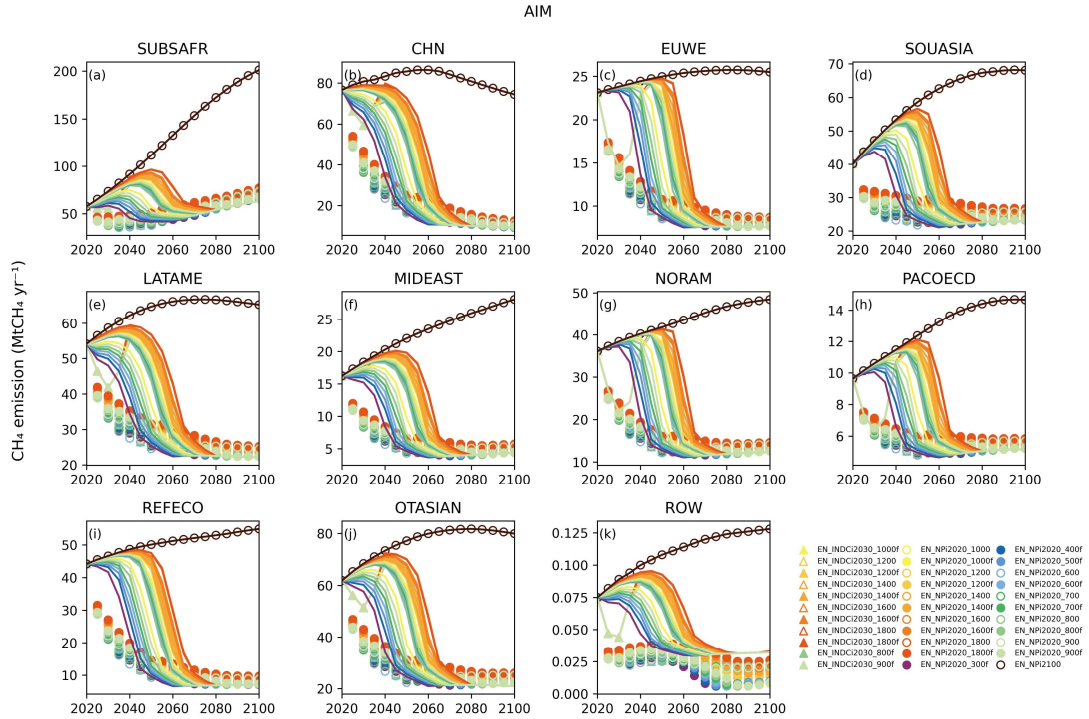


Figure S133. Test 2 - Regional AIM total anthropogenic CH₄ validation result

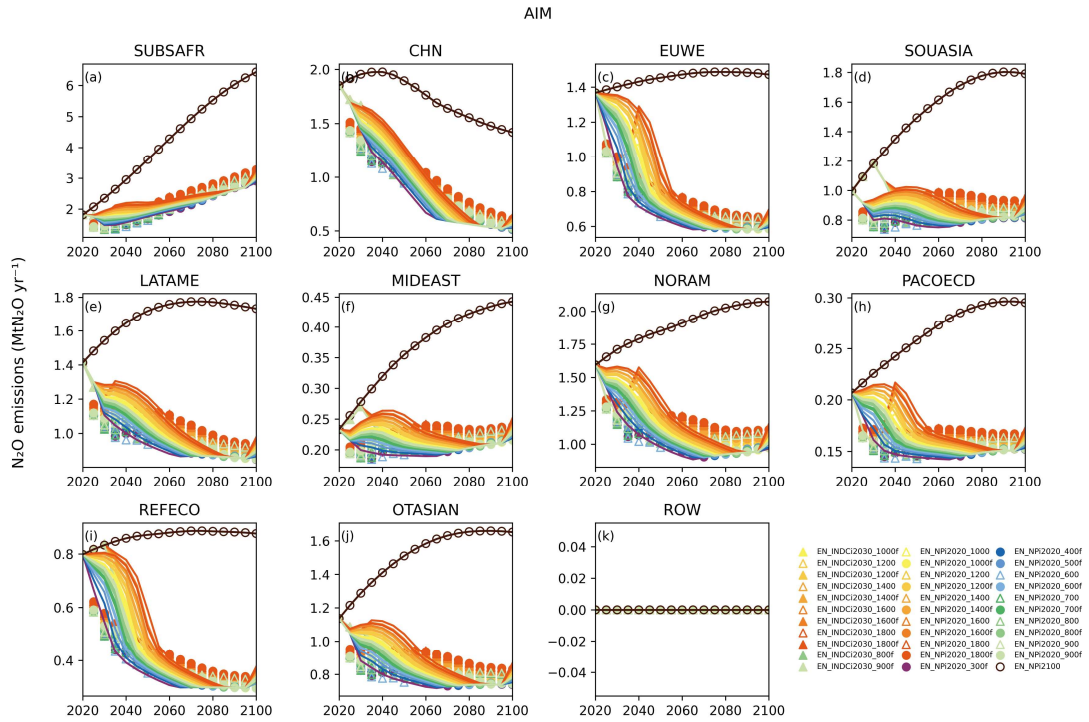


Figure S134. Test 2 - Regional AIM total anthropogenic N₂O validation result

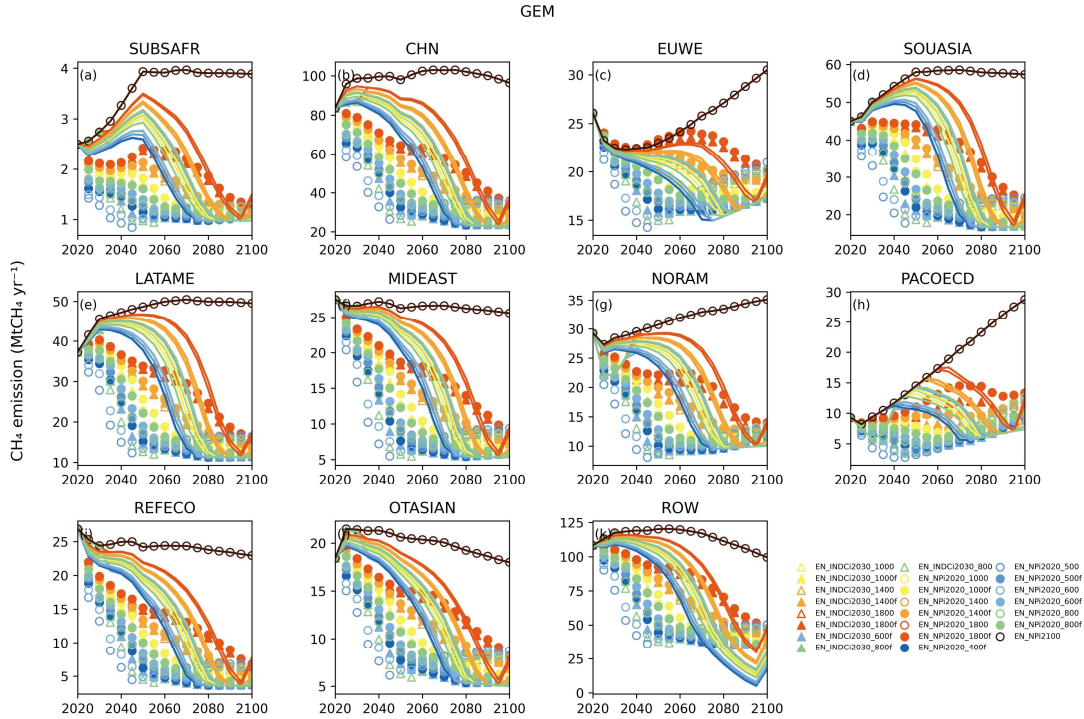


Figure S139. Test 2 - Regional GEM total anthropogenic CH₄ validation result

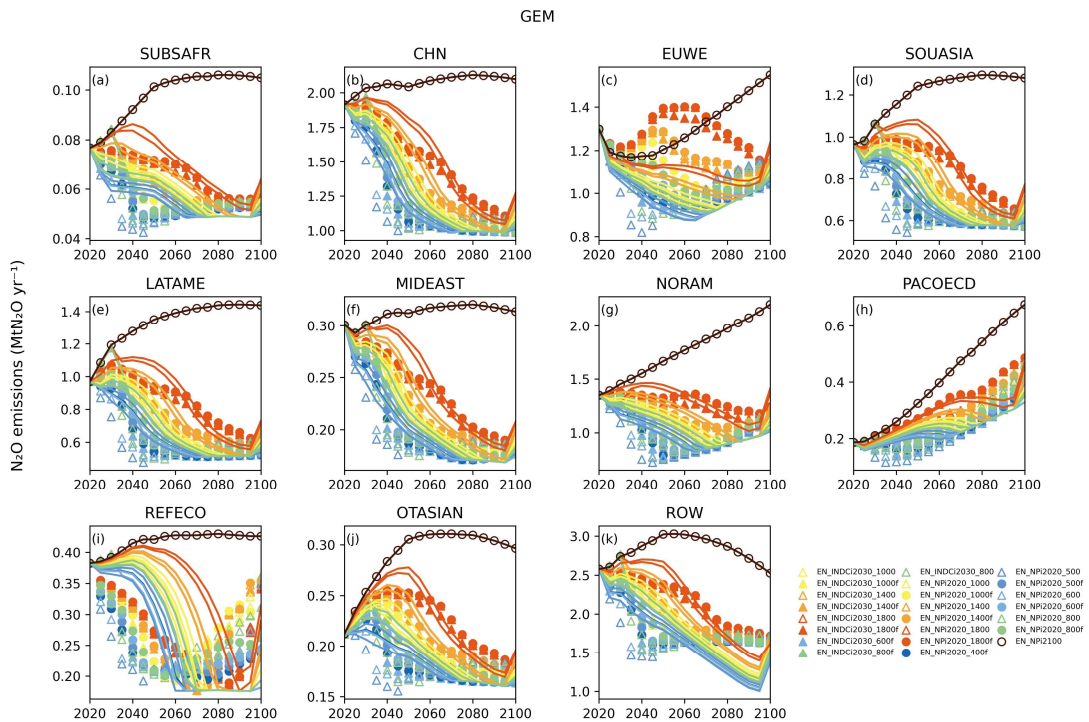


Figure S140. Test 2 - Regional GEM total anthropogenic N₂O validation result

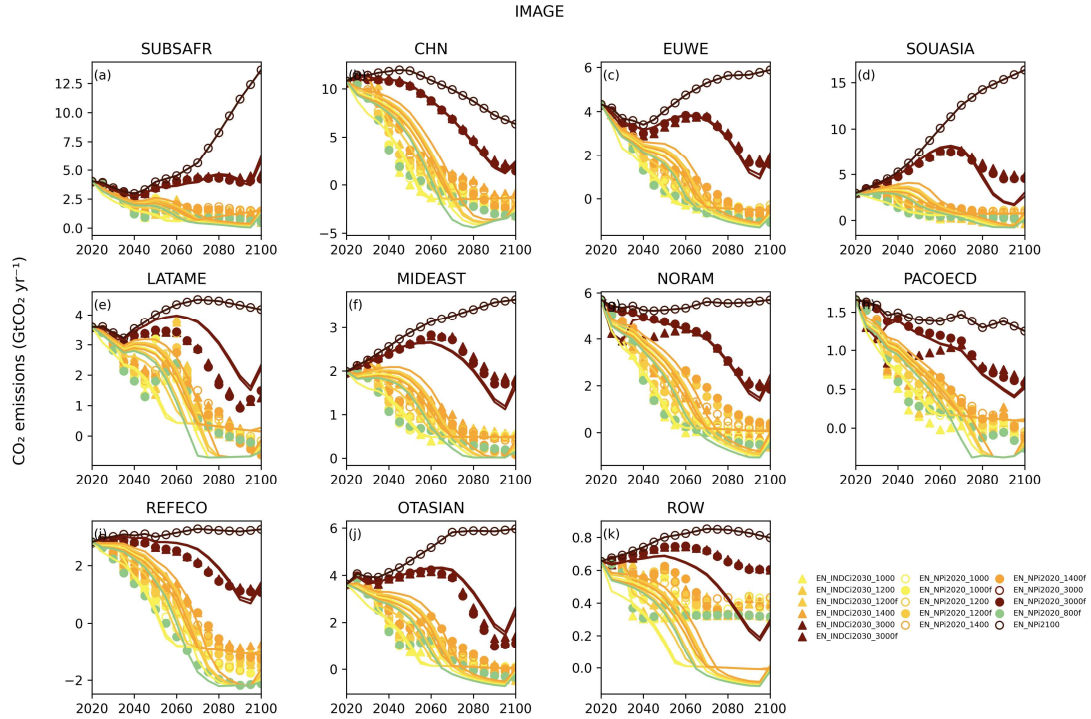


Figure S141. Test 2 - Regional IMAGE total anthropogenic CO₂ validation result

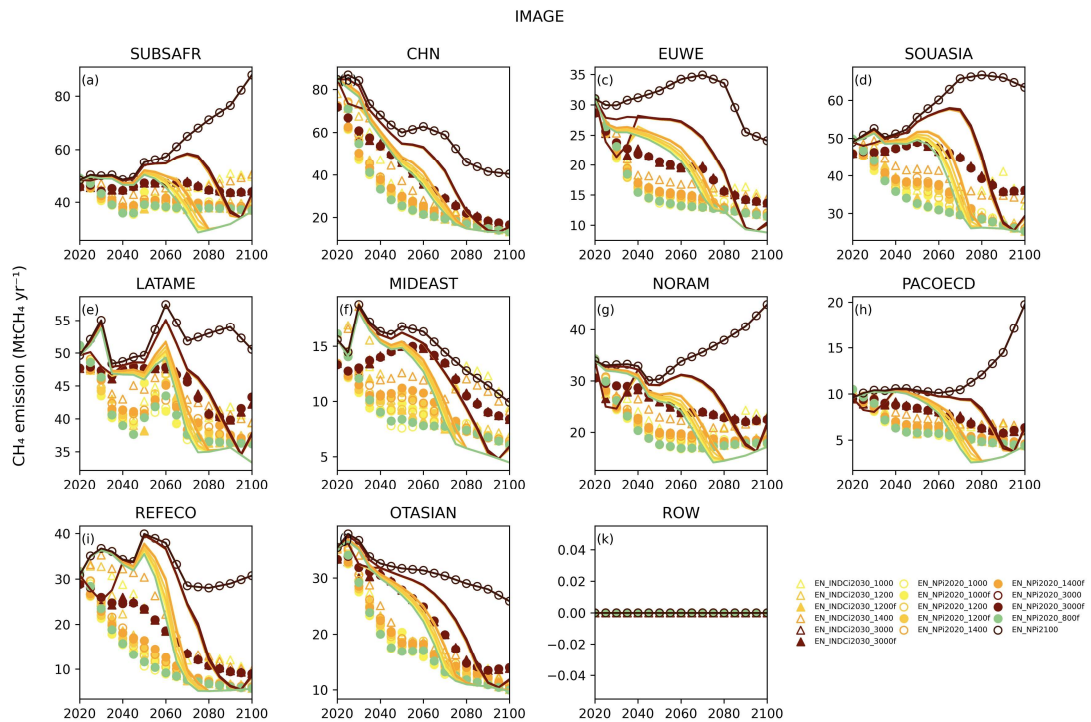


Figure S142. Test 2 - Regional IMAGE total anthropogenic CH₄ validation result

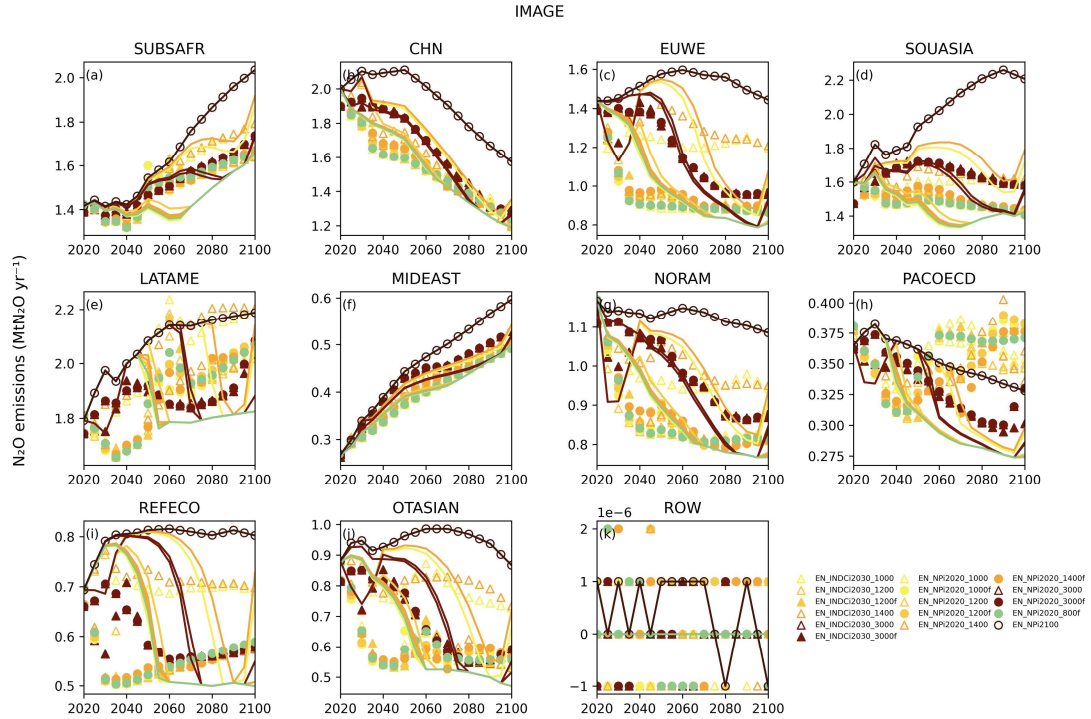


Figure S143. Test 2 - Regional IMAGE total anthropogenic N₂O validation result

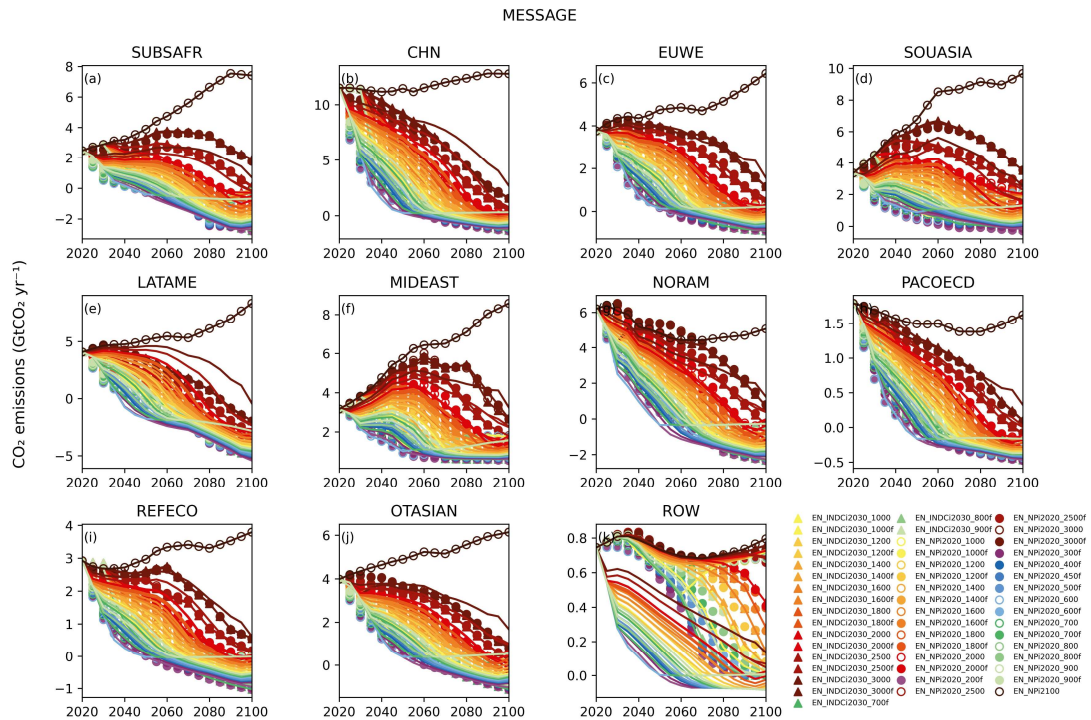


Figure S144. Test 2 - Regional MESSAGE total anthropogenic CO₂ validation result

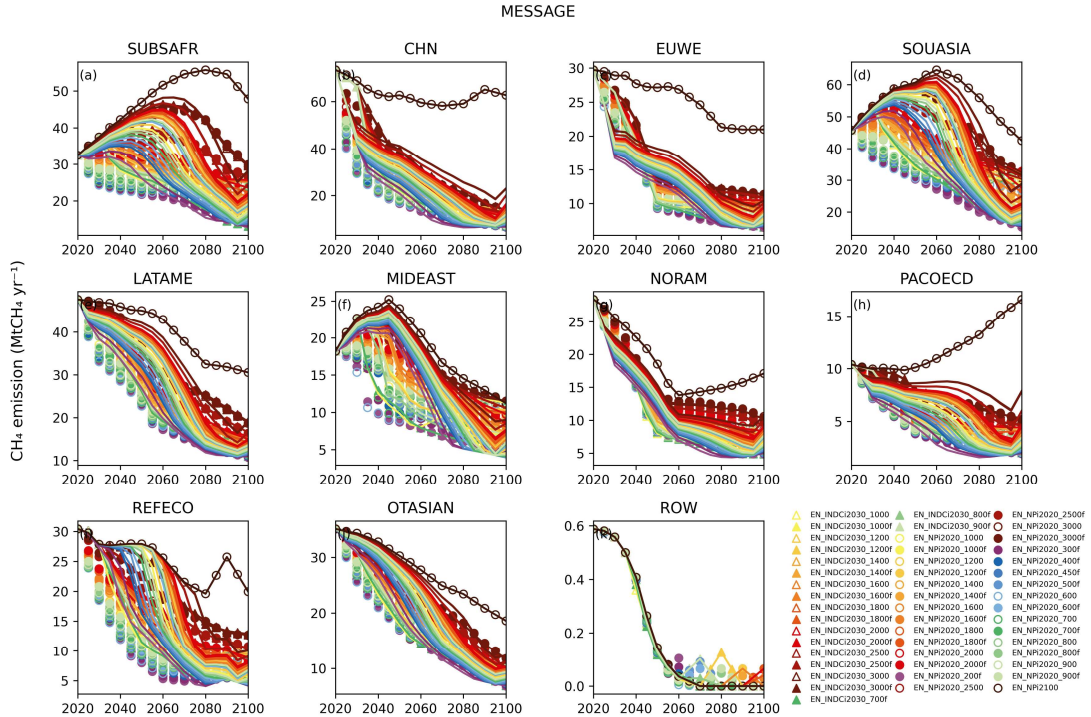


Figure S145. Test 2 - Regional MESSAGE total anthropogenic CH₄ validation result

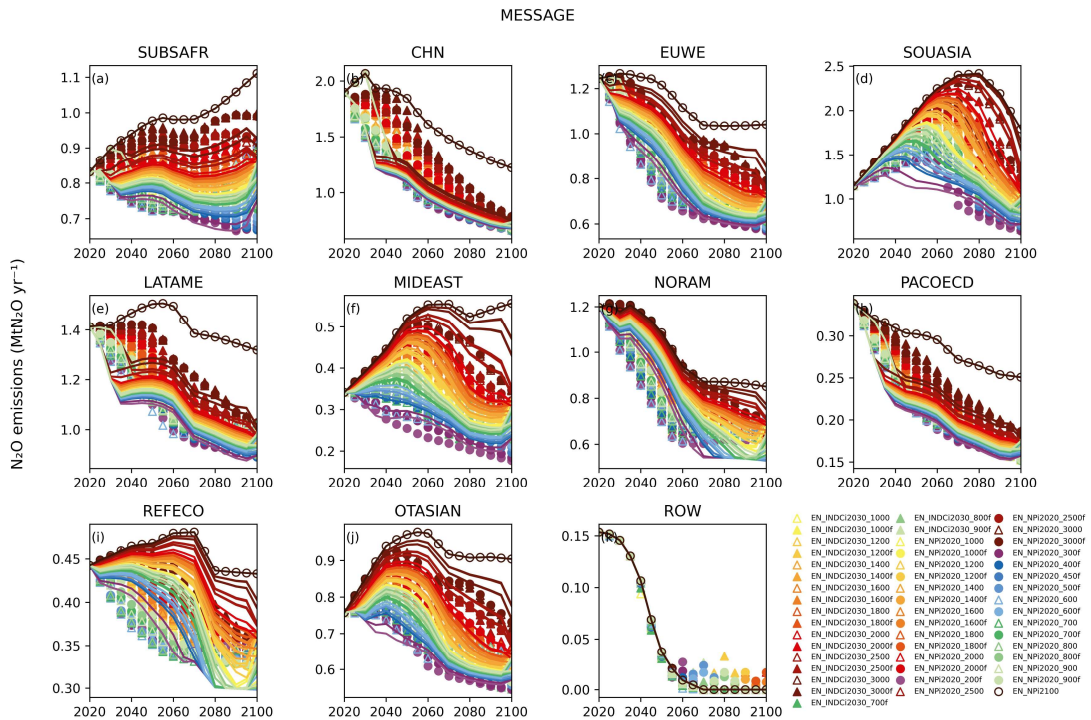


Figure S146. Test 2 - Regional MESSAGE total anthropogenic N₂O validation result

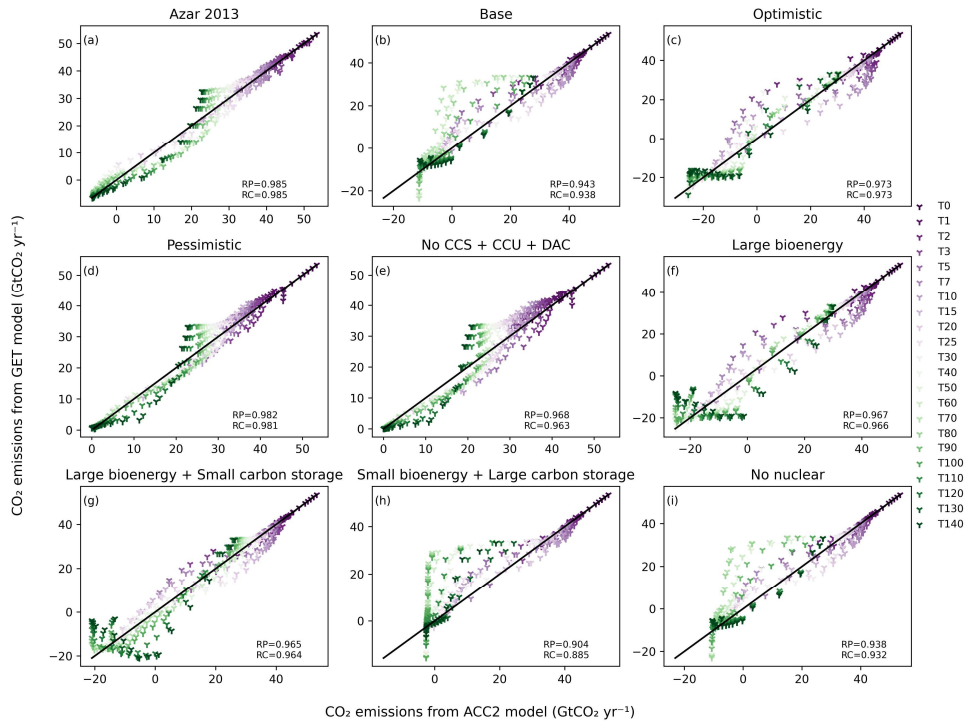


Figure S147. Test 2 - GET Reproducibility of energy-related CO₂

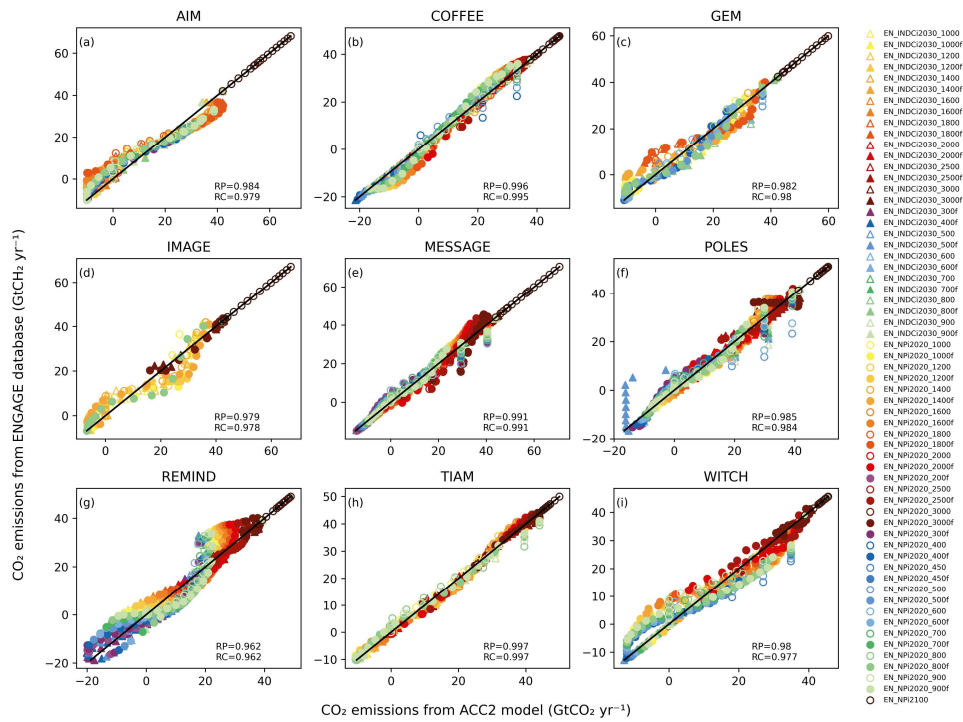


Figure S148. Test 2 - Global 9 models - Reproducibility of total anthropogenic CO₂

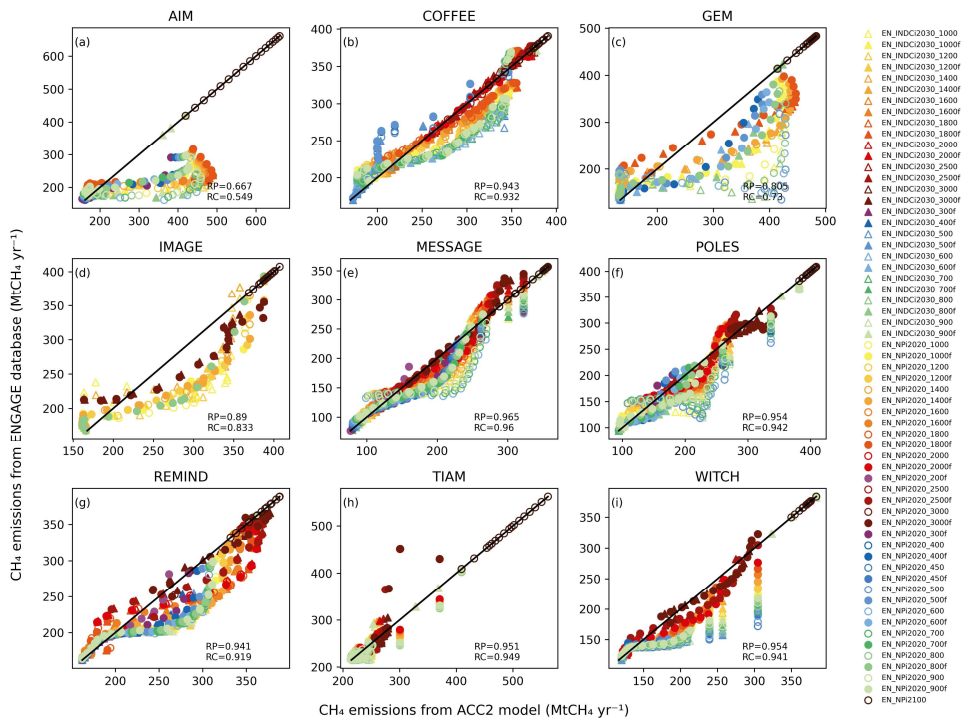


Figure S149. Test 2 - Global 9 models - Reproducibility of total anthropogenic CH₄

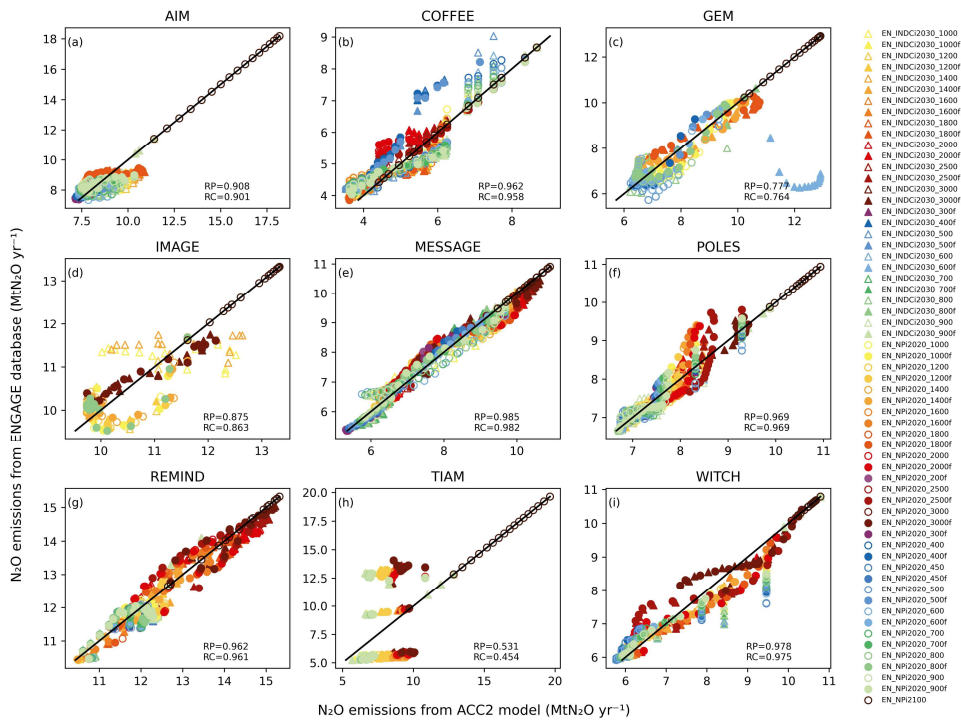


Figure S150. Test 2 - Global 9 models - Reproducibility of total anthropogenic N₂O

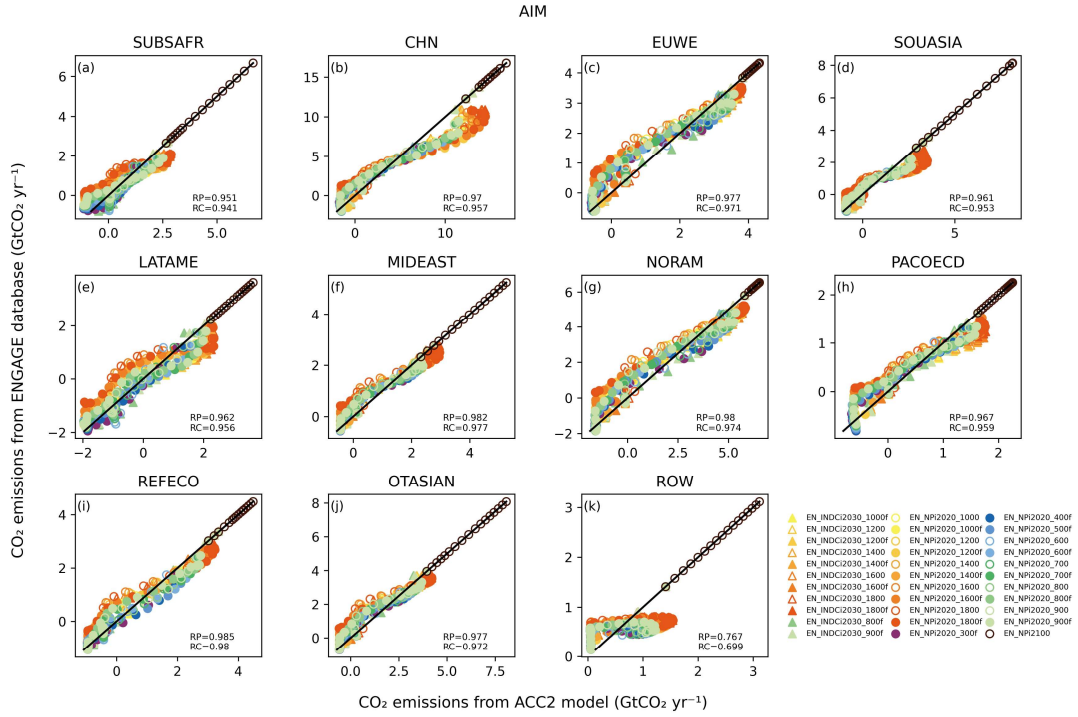


Figure S151. Test 2 - Regional AIM - Reproducibility of total anthropogenic CO₂

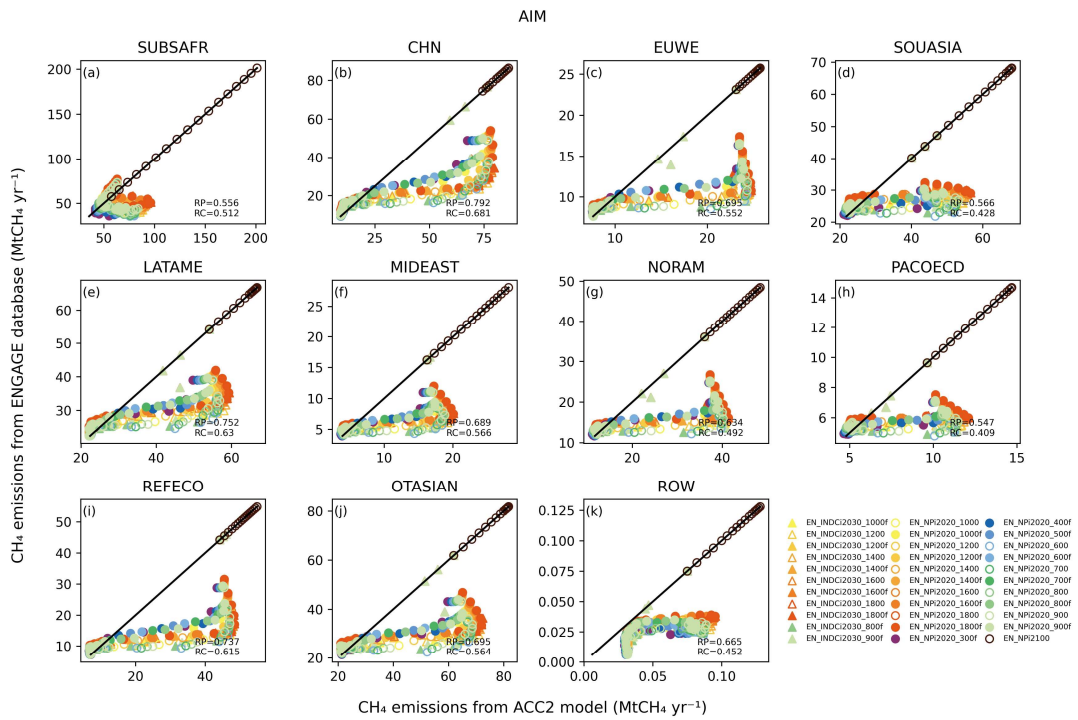


Figure S152. Test 2 - Regional AIM - Reproducibility of total anthropogenic CH₄

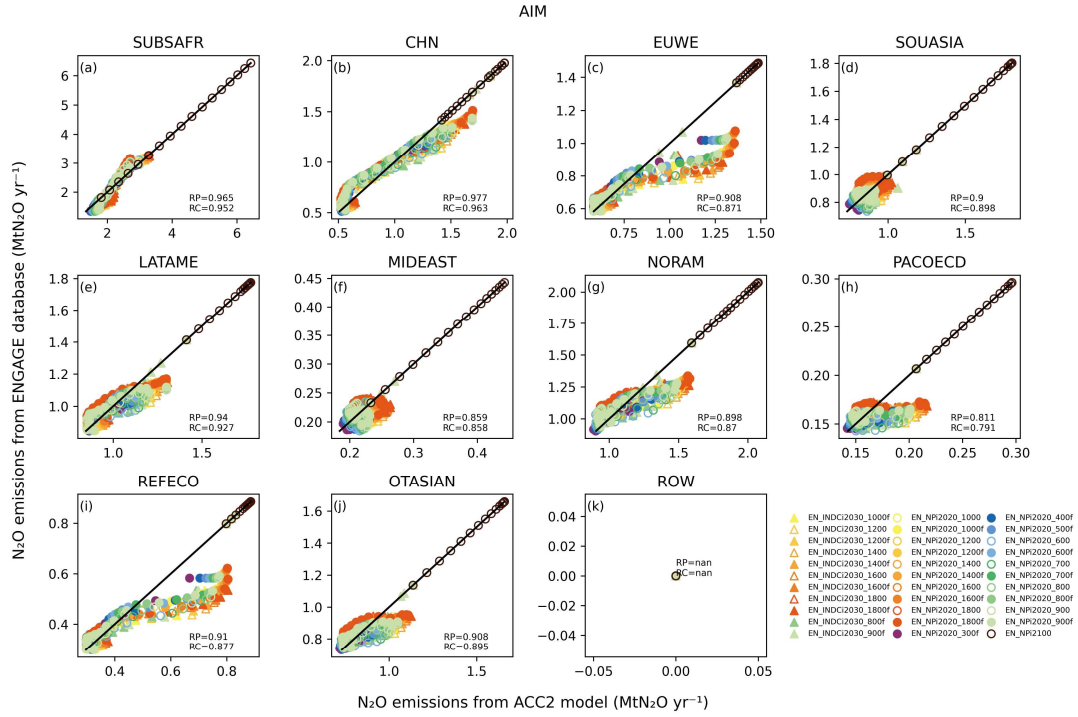


Figure S153. Test 2 - Regional AIM - Reproducibility of total anthropogenic N₂O

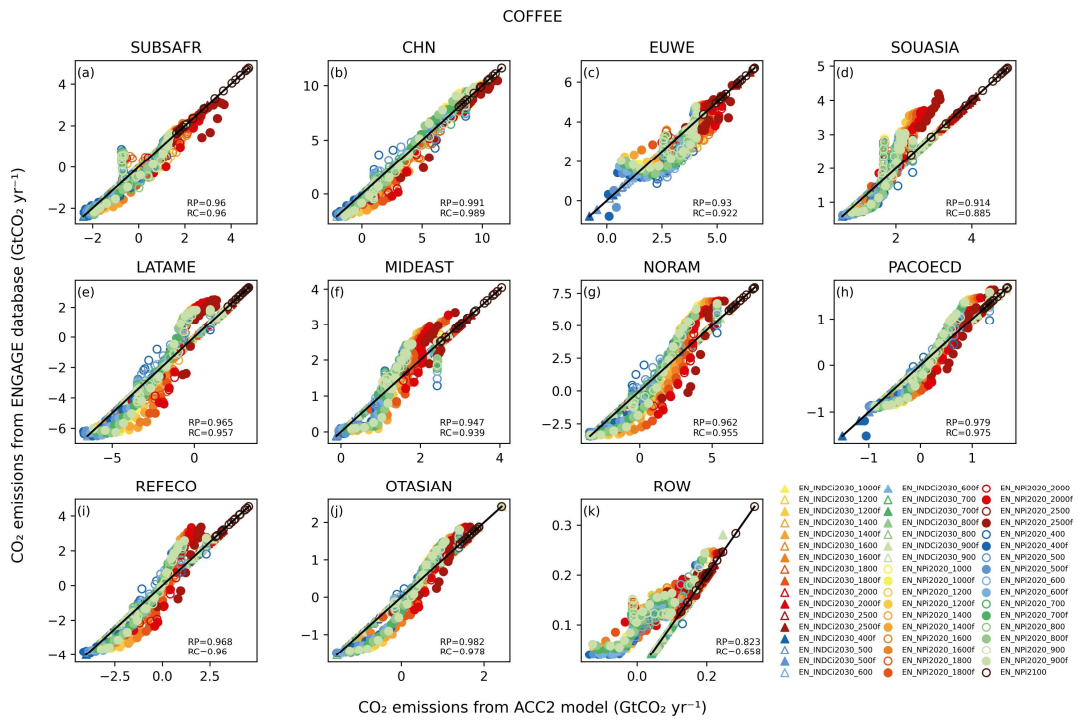


Figure S154. Test 2 - Regional COFFEE - Reproducibility of total anthropogenic CO₂

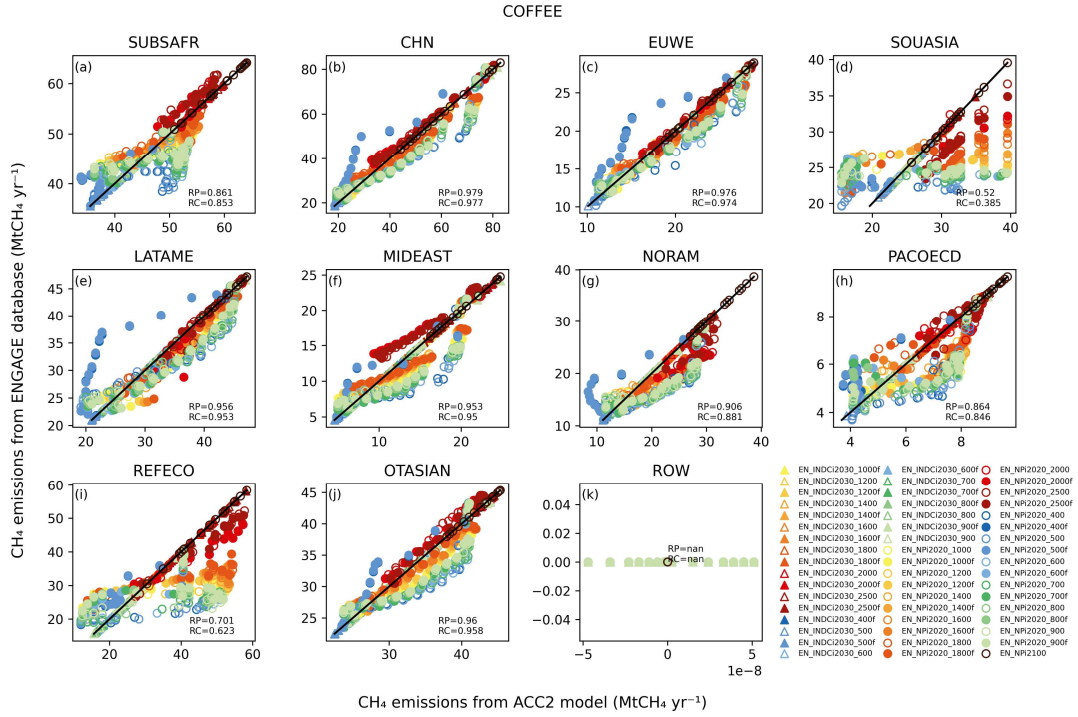


Figure S155. Test 2 - Regional COFFEE - Reproducibility of total anthropogenic CH₄

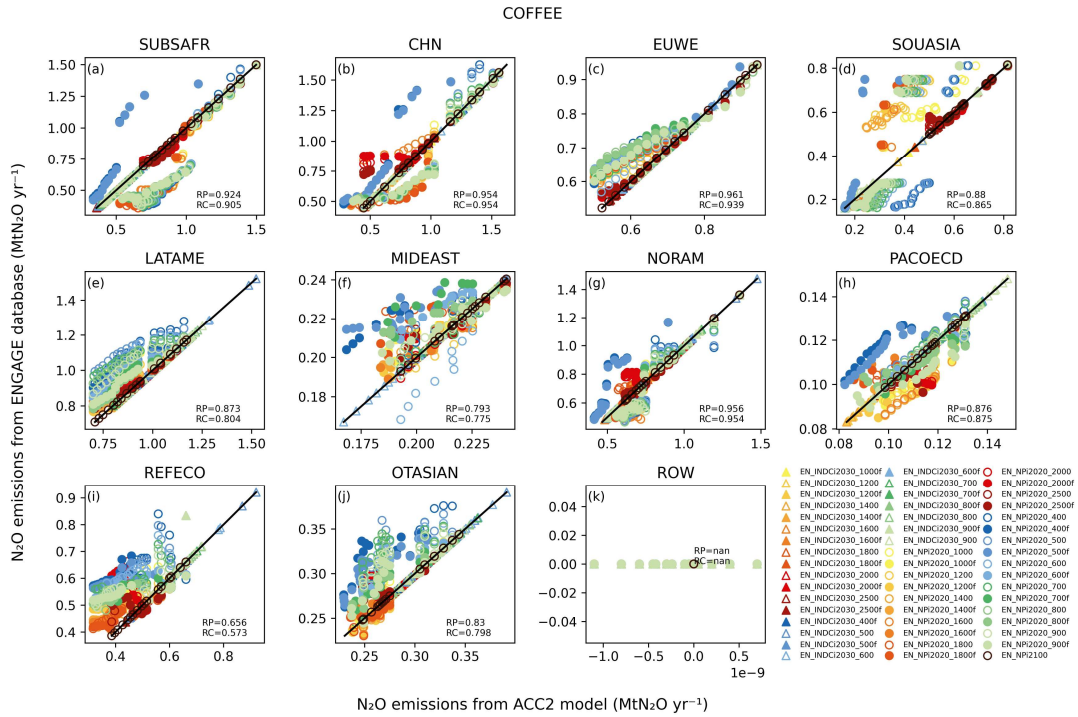


Figure S156. Test 2 - Regional COFFEE - Reproducibility of total anthropogenic N₂O

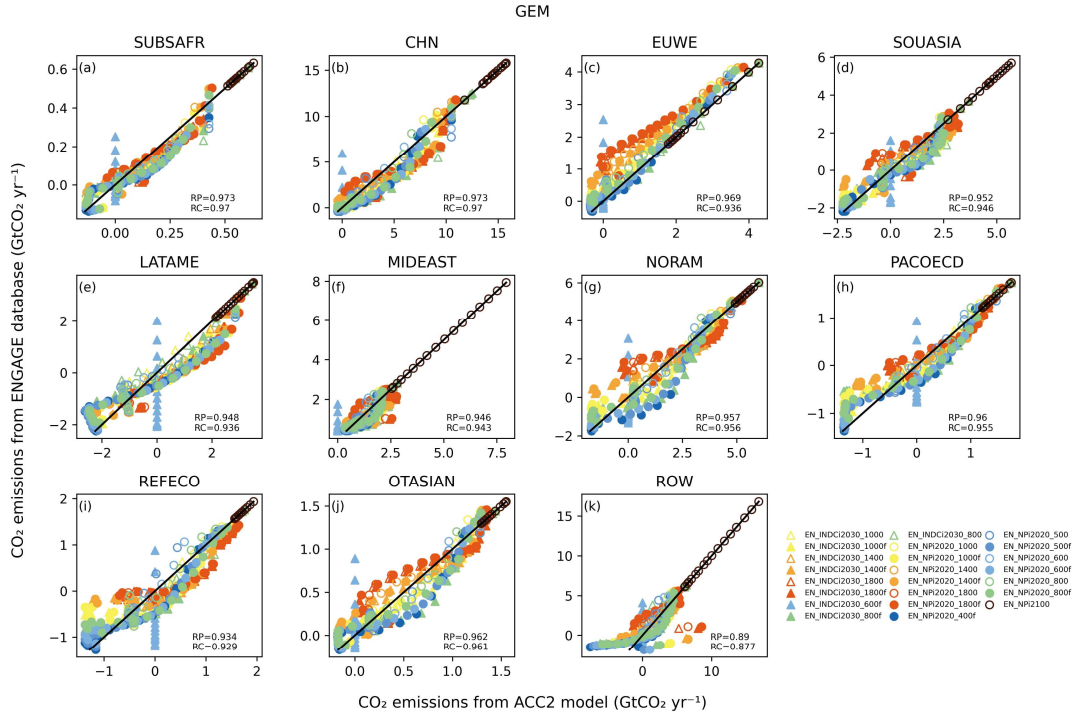


Figure S157. Test 2 - Regional GEM - Reproducibility of total anthropogenic CO₂

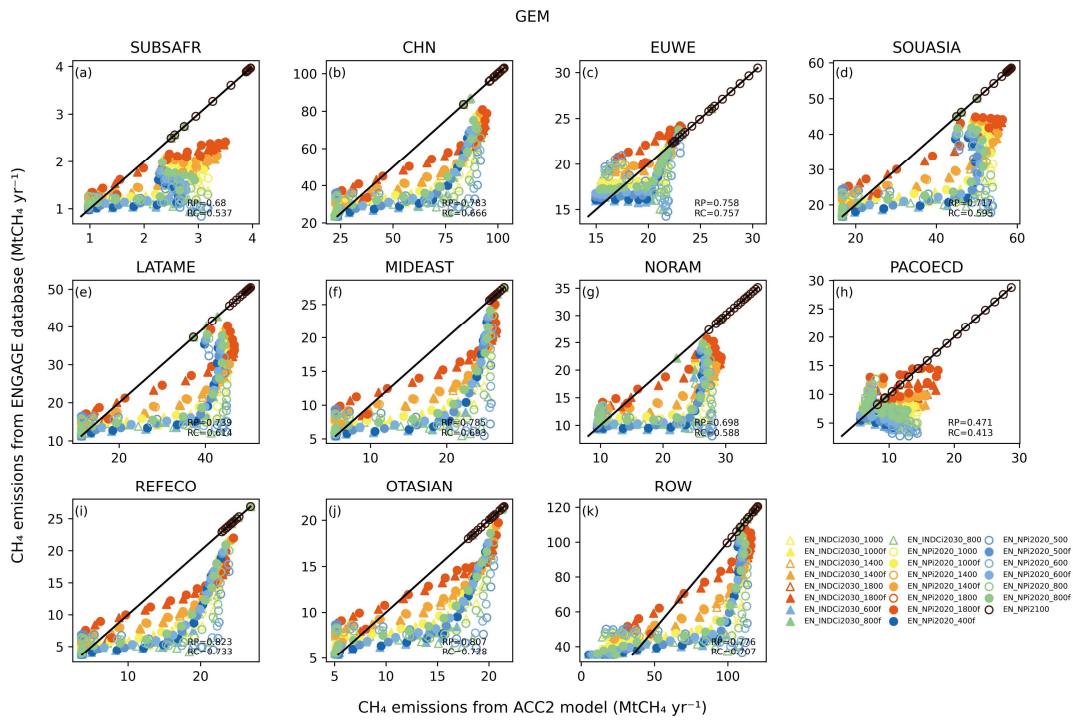


Figure S158. Test 2 - Regional GEM - Reproducibility of total anthropogenic CH₄

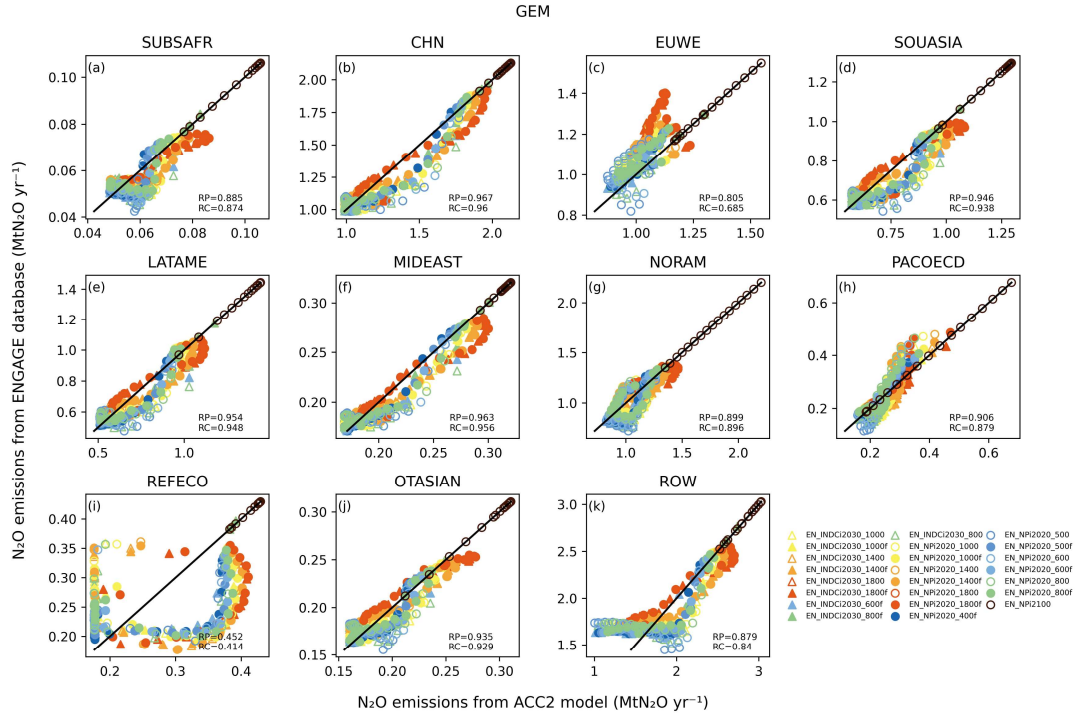


Figure S159. Test 2 - Regional GEM - Reproducibility of total anthropogenic N₂O

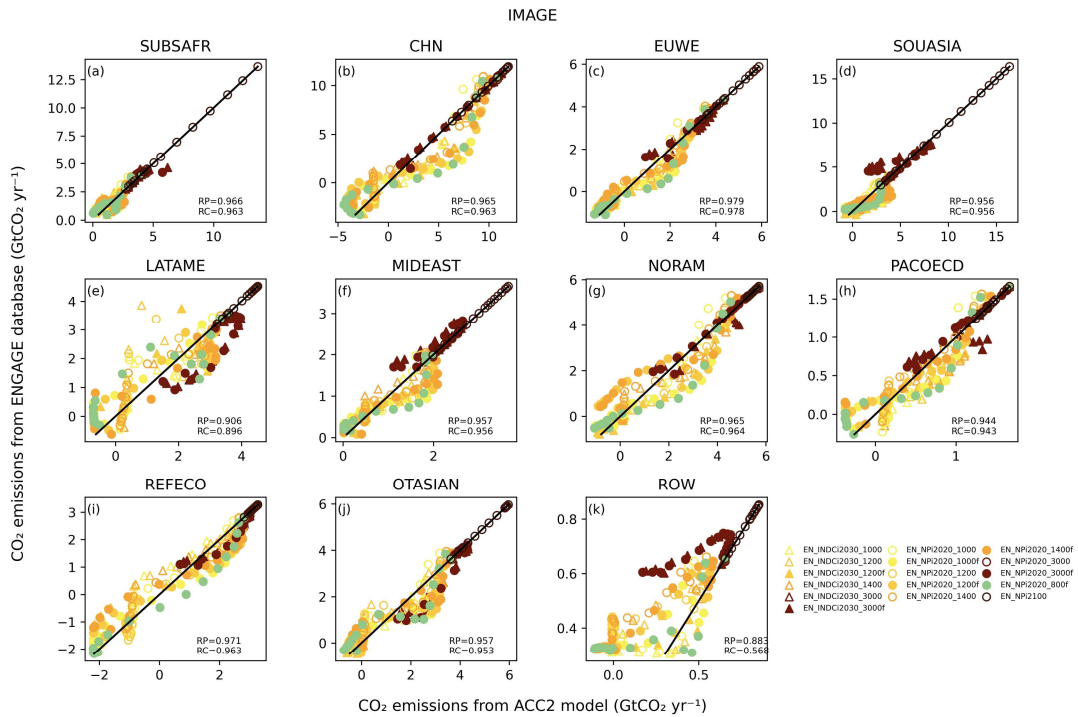


Figure S160. Test 2 - Regional IMAGE - Reproducibility of total anthropogenic CO₂

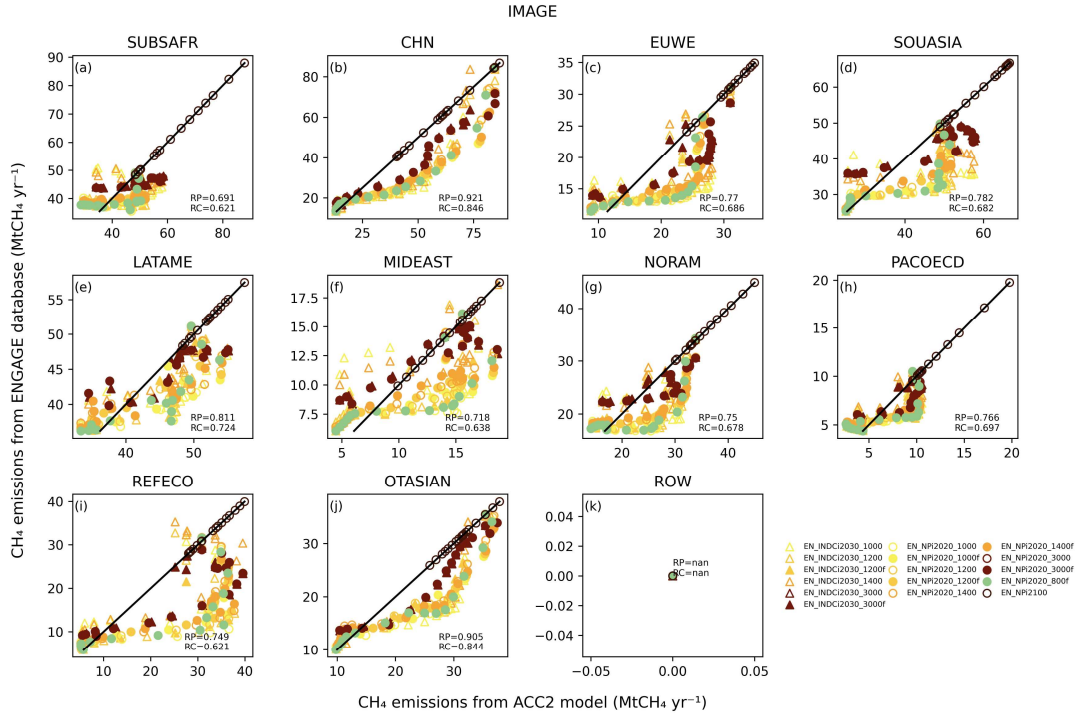


Figure S161. Test 2 - Regional IMAGE - Reproducibility of total anthropogenic CH₄

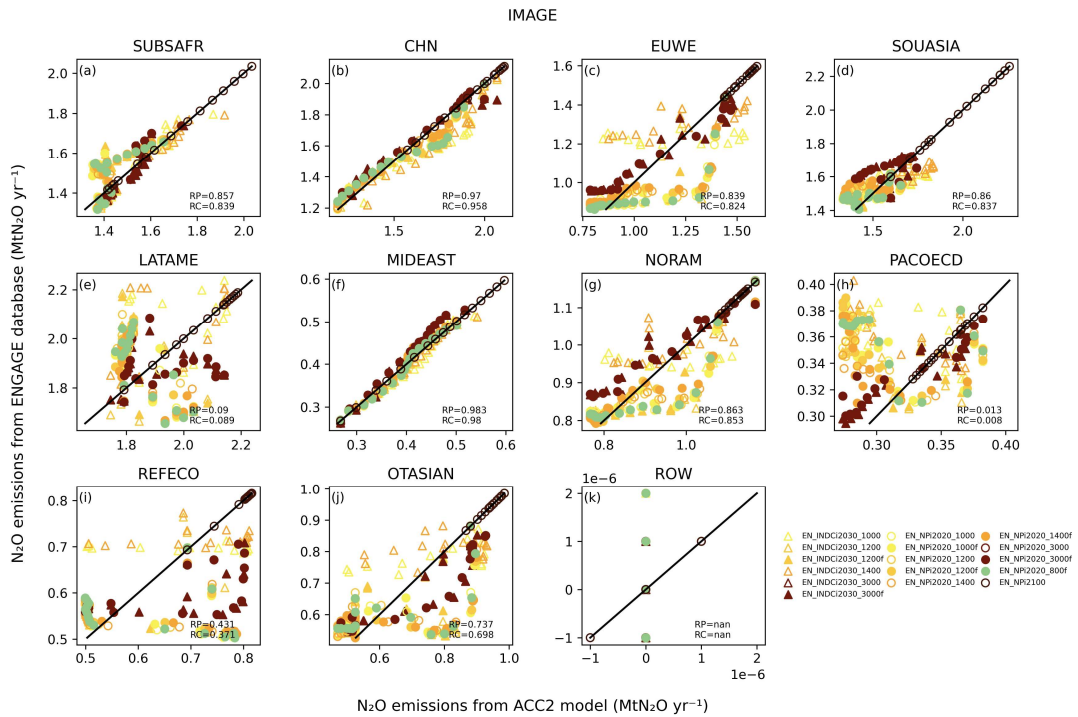


Figure S162. Test 2 - Regional IMAGE - Reproducibility of total anthropogenic N₂O

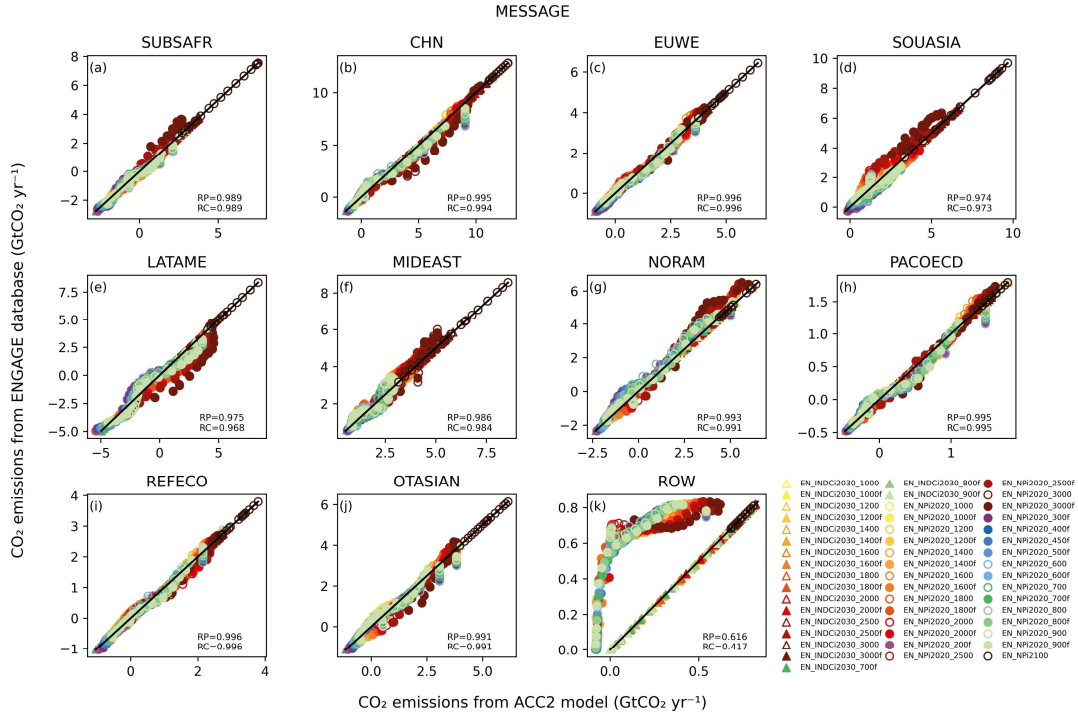


Figure S163. Test 2 - Regional MESSAGE - Reproducibility of CO₂

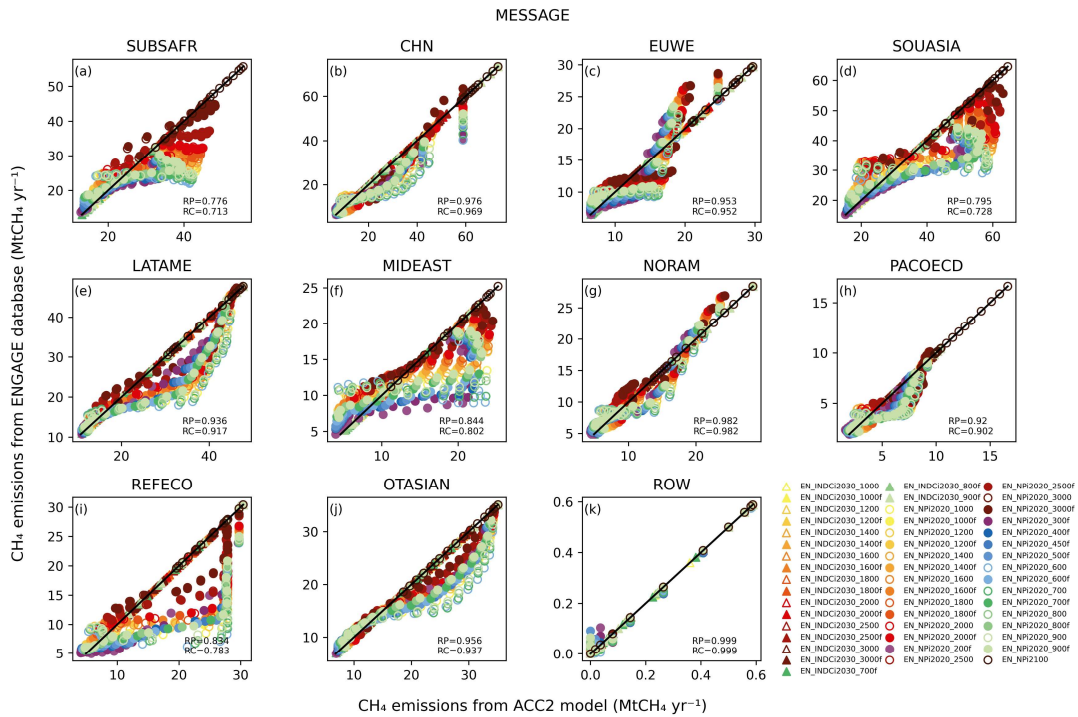


Figure S164. Test 2 - Regional MESSAGE - Reproducibility of total anthropogenic CH₄

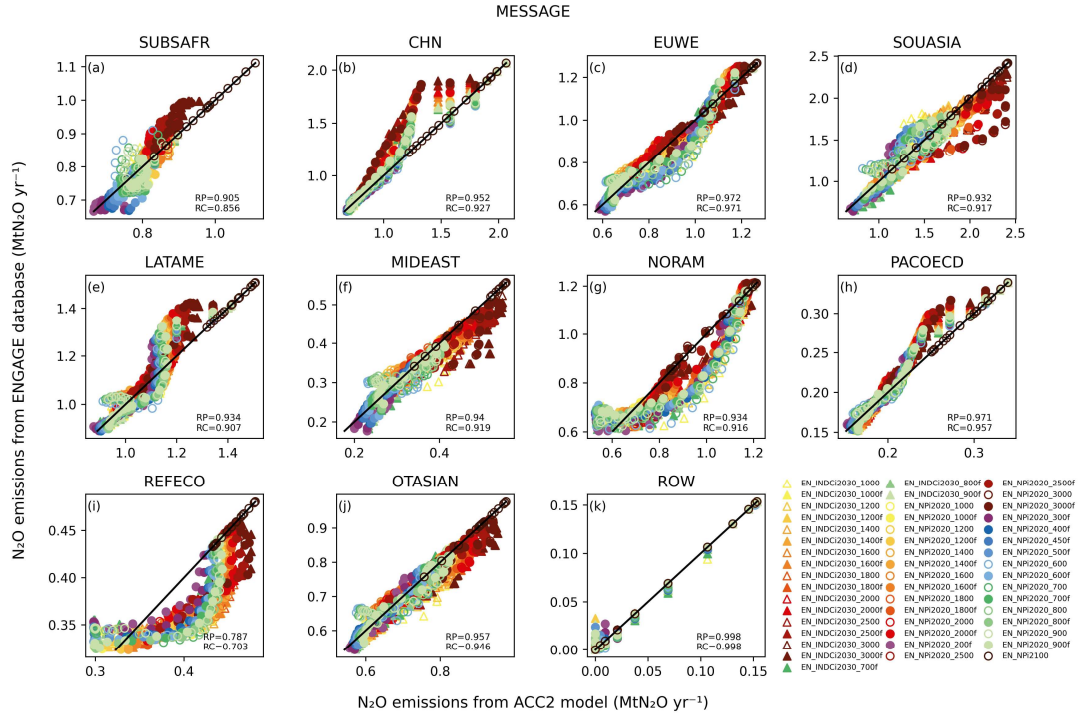


Figure S165. Test 2 - Regional MESSAGE - Reproducibility of total anthropogenic N_2O

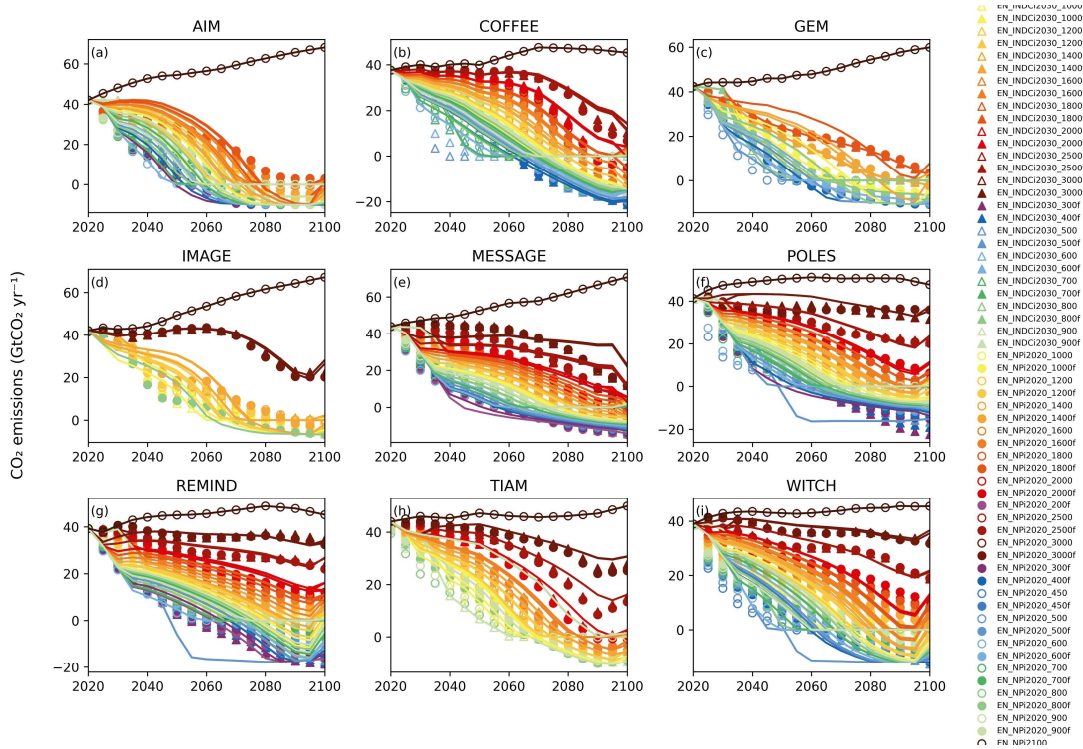


Figure S166. Test 3 - Global 9 models total anthropogenic CO_2 validation result

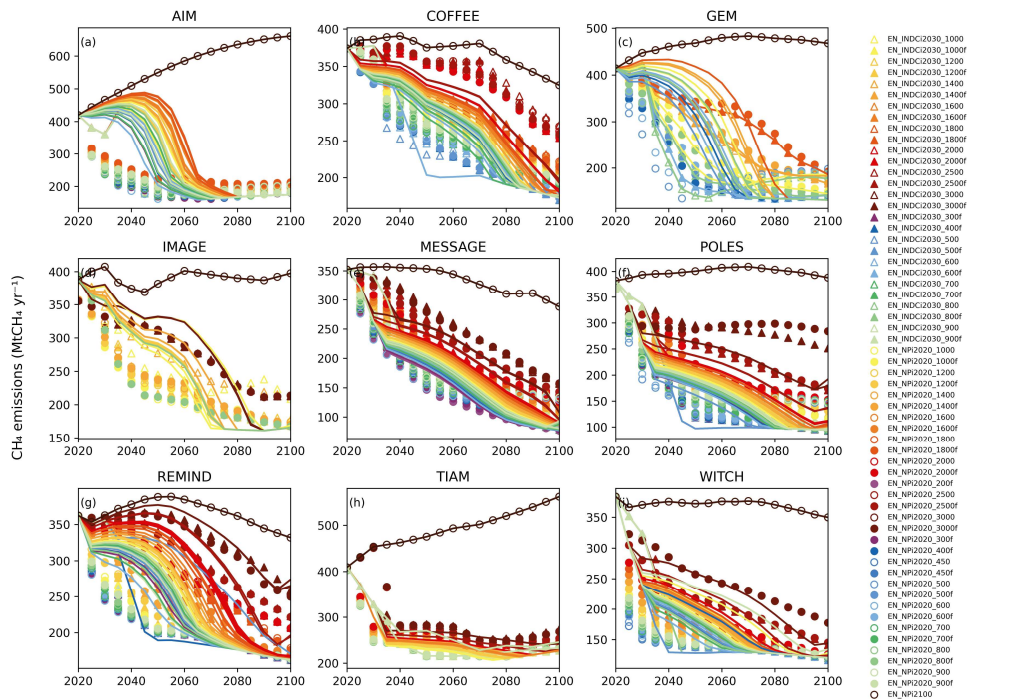


Figure S167. Test 3 – Global 9 models total anthropogenic CH₄ validation result

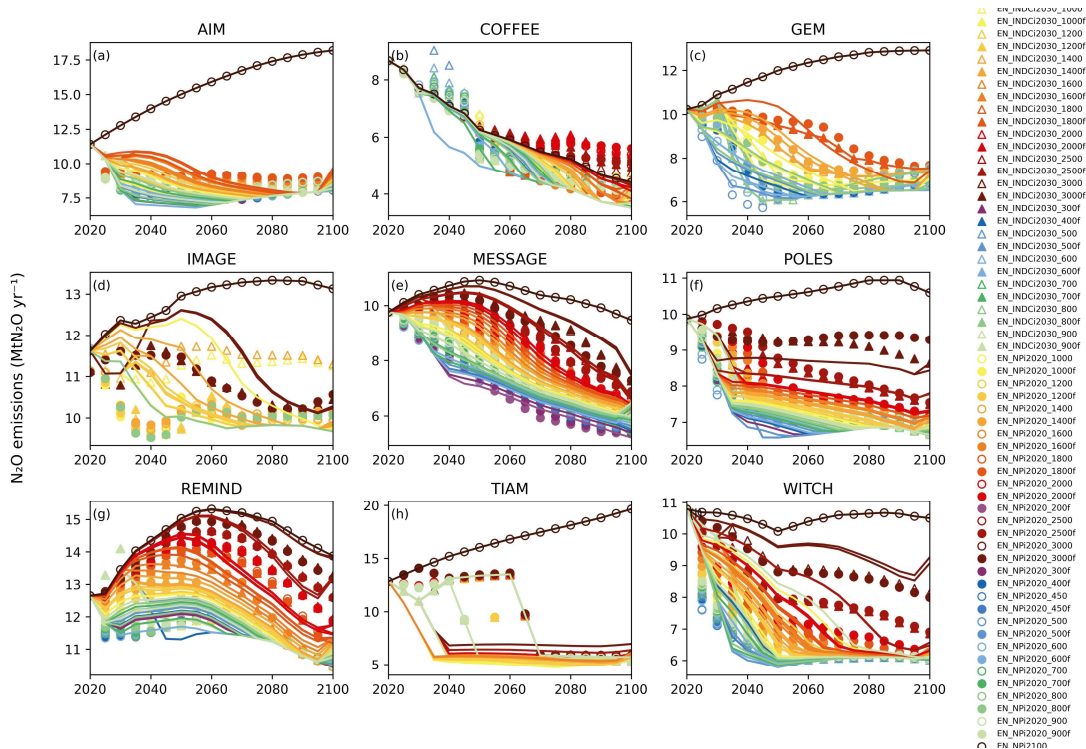


Figure S168. Test 3 – Global 9 models total anthropogenic N₂O validation result

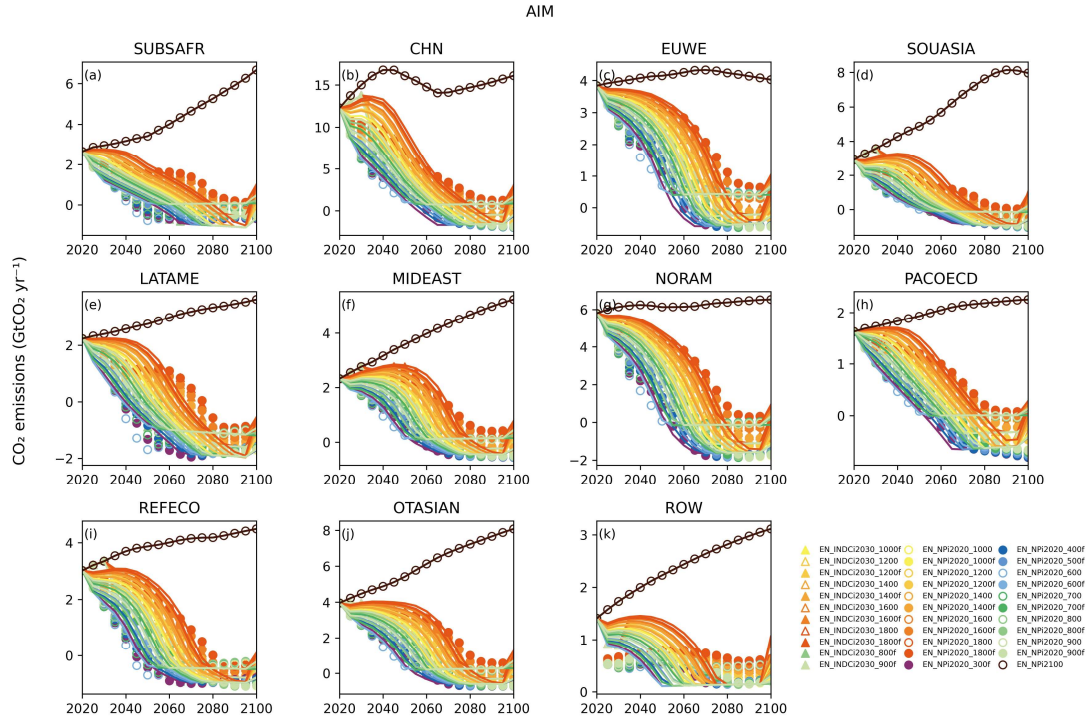


Figure S169. Test 3 - Regional AIM total anthropogenic CO₂ validation result

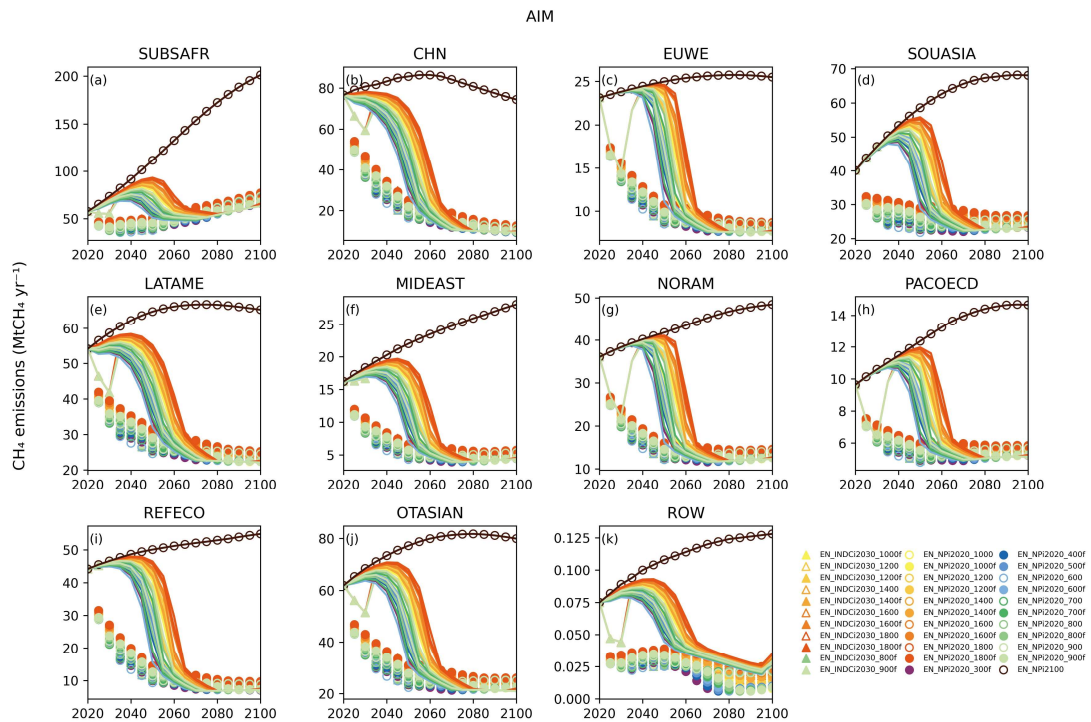


Figure S170. Test 3 - Regional AIM total anthropogenic CH₄ validation result

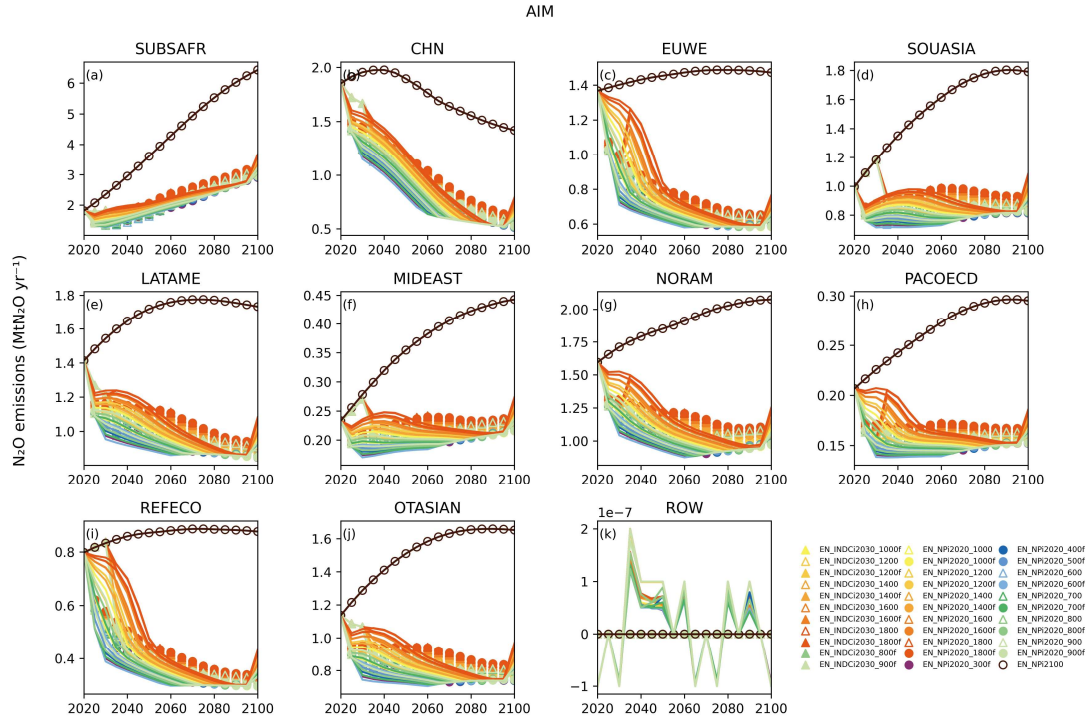


Figure S171. Test 3 - Regional AIM total anthropogenic N₂O validation result

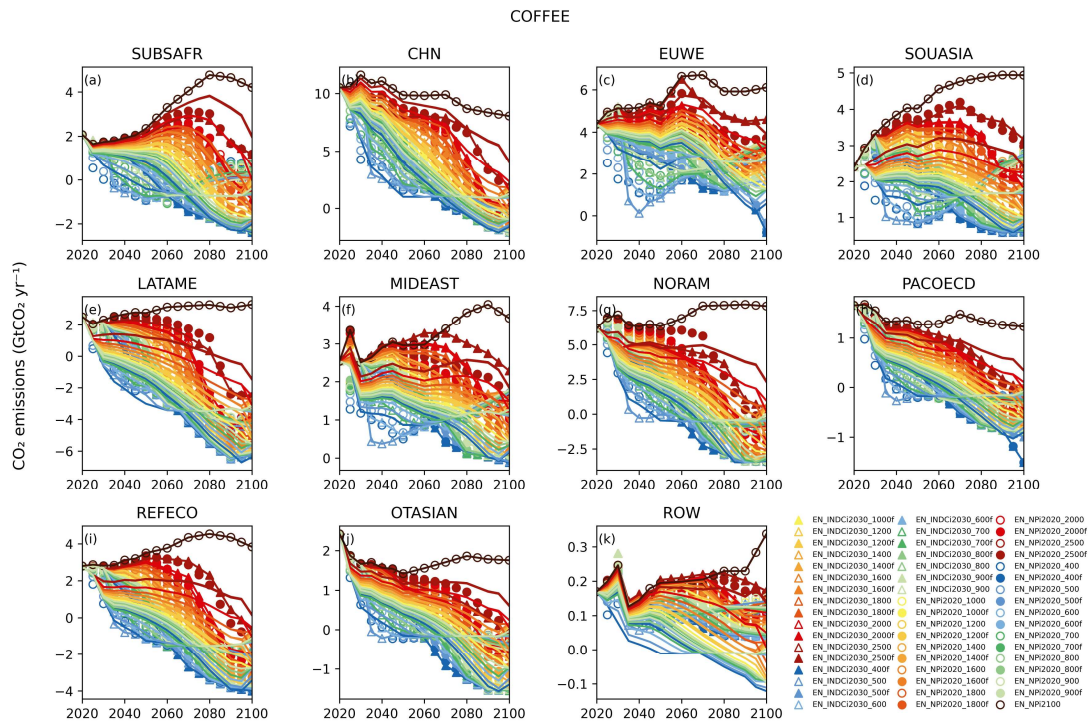


Figure S172. Test 3 - Regional COFFEE total anthropogenic CO₂ validation result

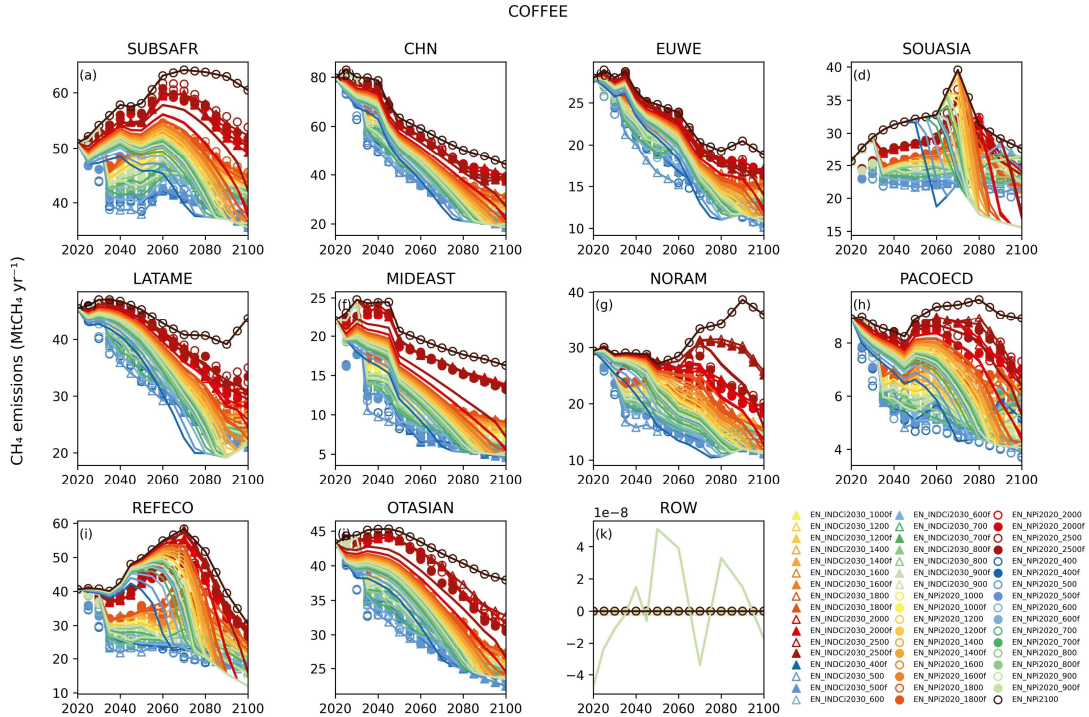


Figure S173. Test 3 - Regional COFFEE total anthropogenic CH₄ validation result

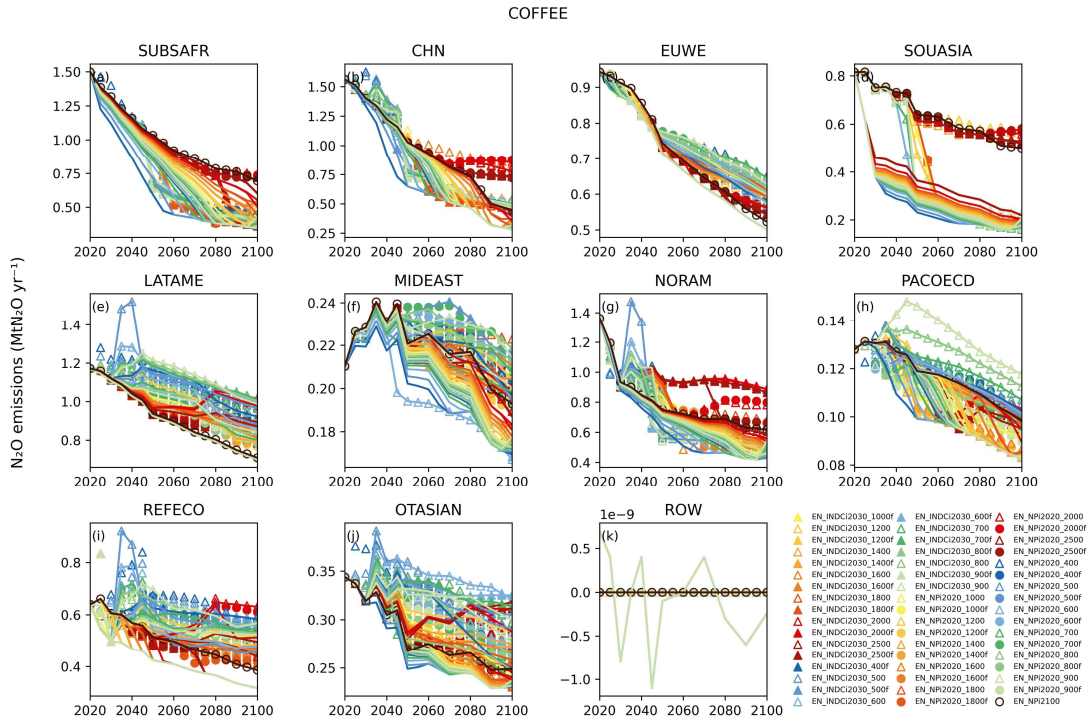


Figure S174. Test 3 - Regional COFFEE total anthropogenic N₂O validation result

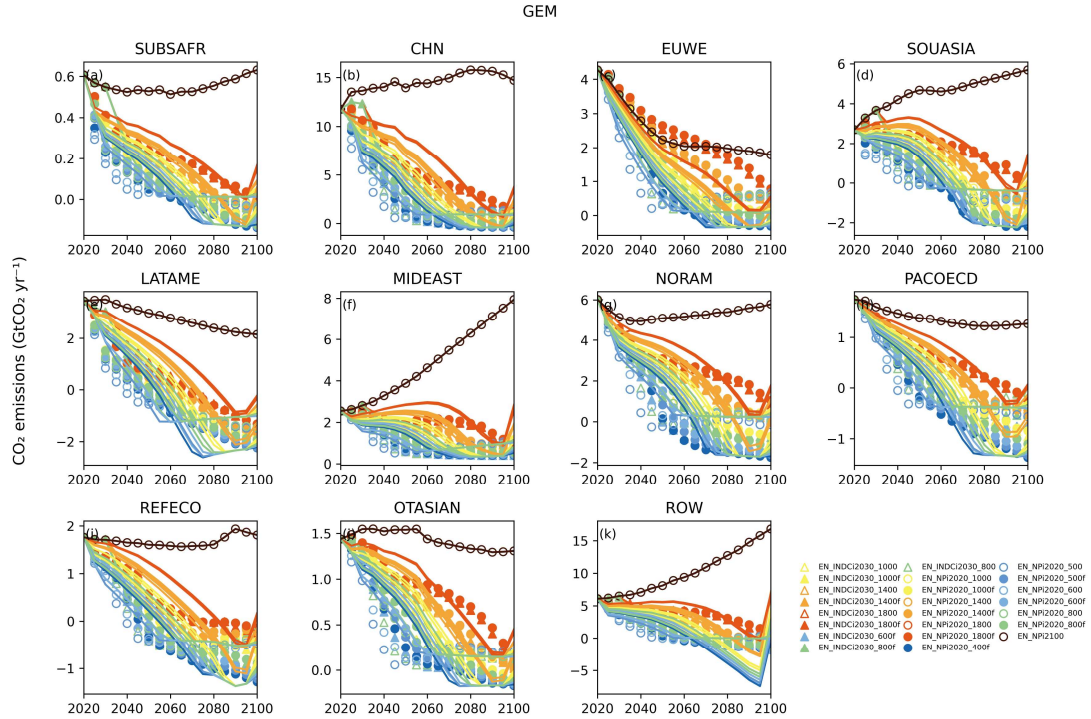


Figure S175. Test 3 - Regional GEM total anthropogenic CO₂ validation result

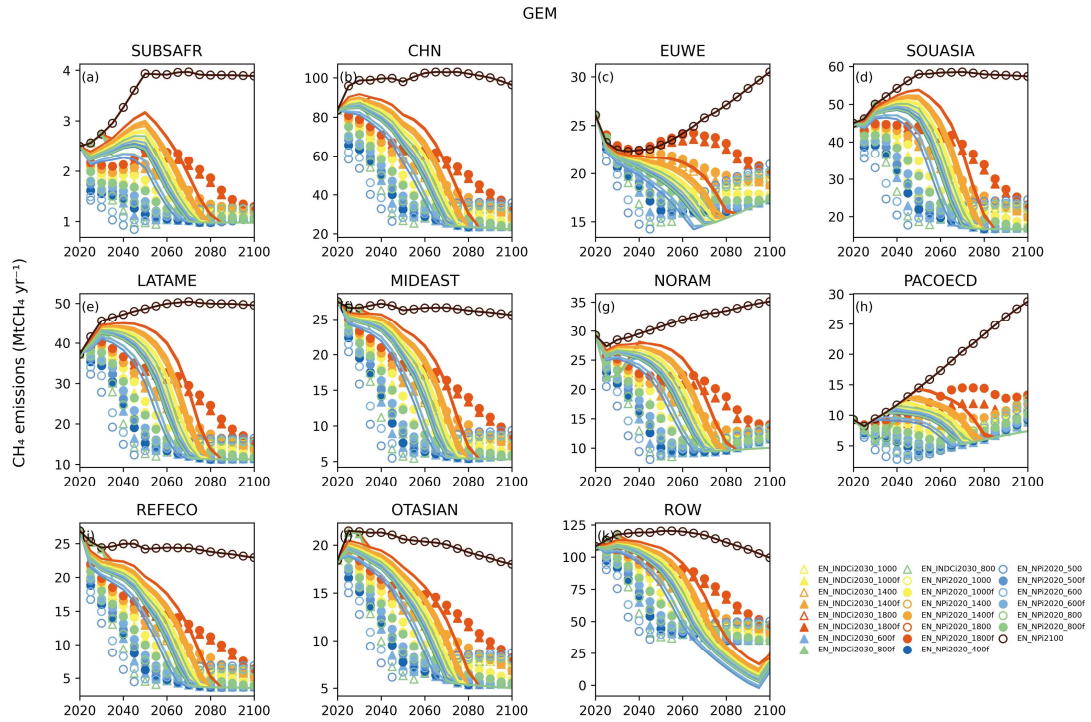


Figure S176. Test 3 - Regional GEM total anthropogenic CH₄ validation result

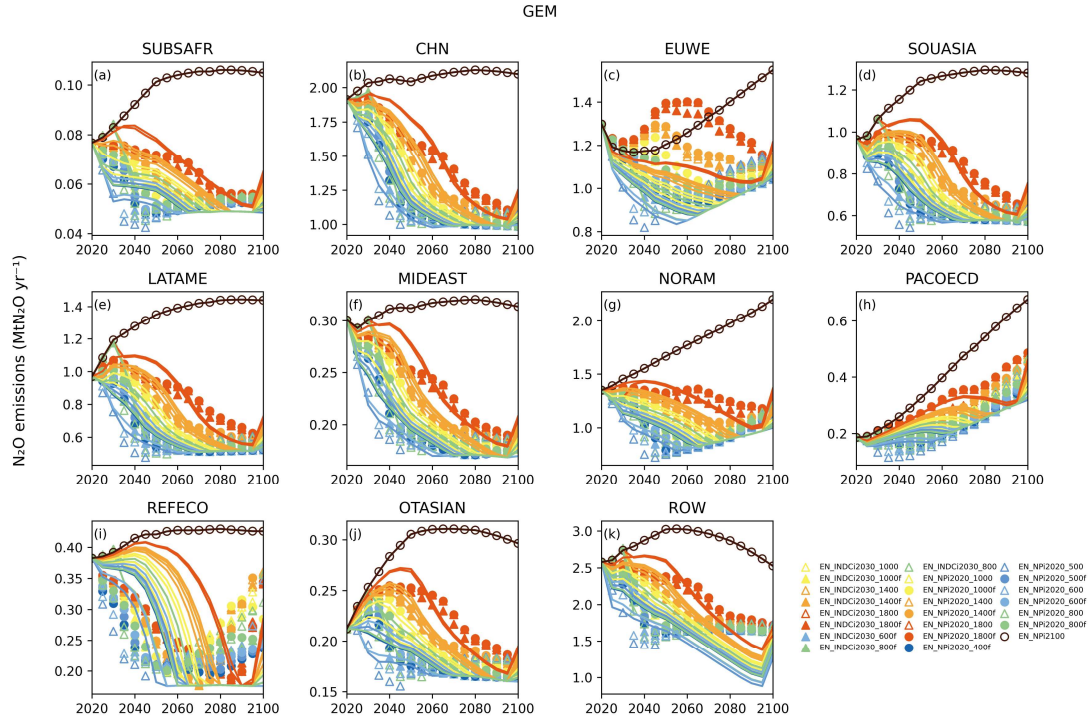


Figure S177. Test 3 - Regional GEM total anthropogenic N₂O validation result

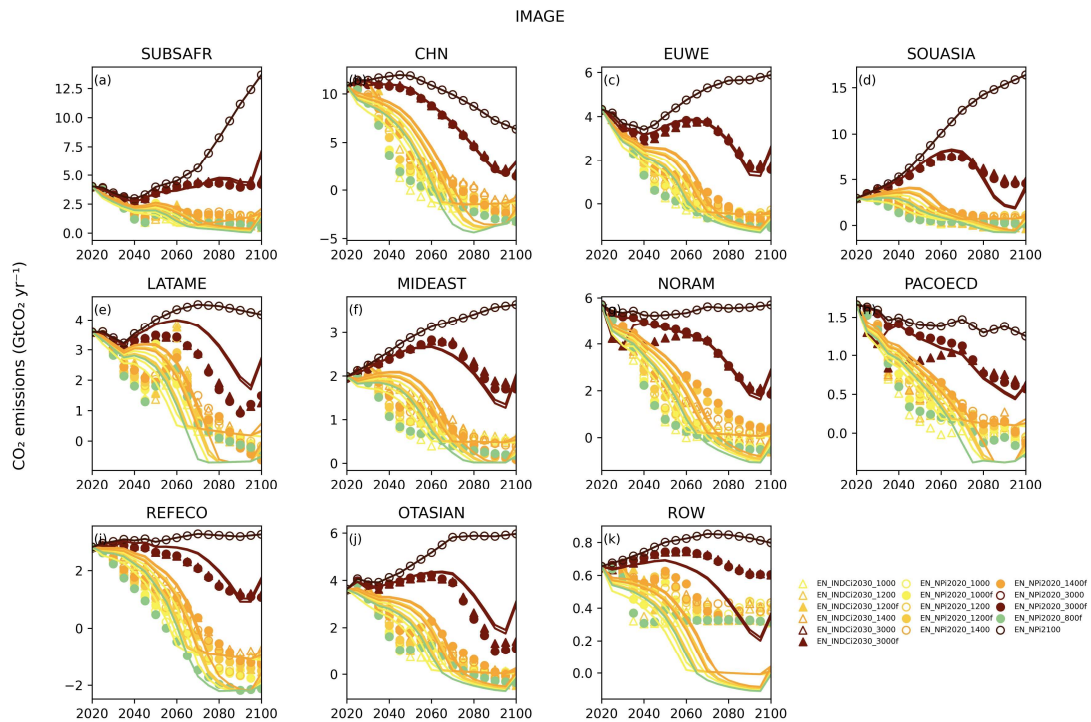


Figure S178. Test 3 - Regional IMAGE total anthropogenic CO₂ validation result

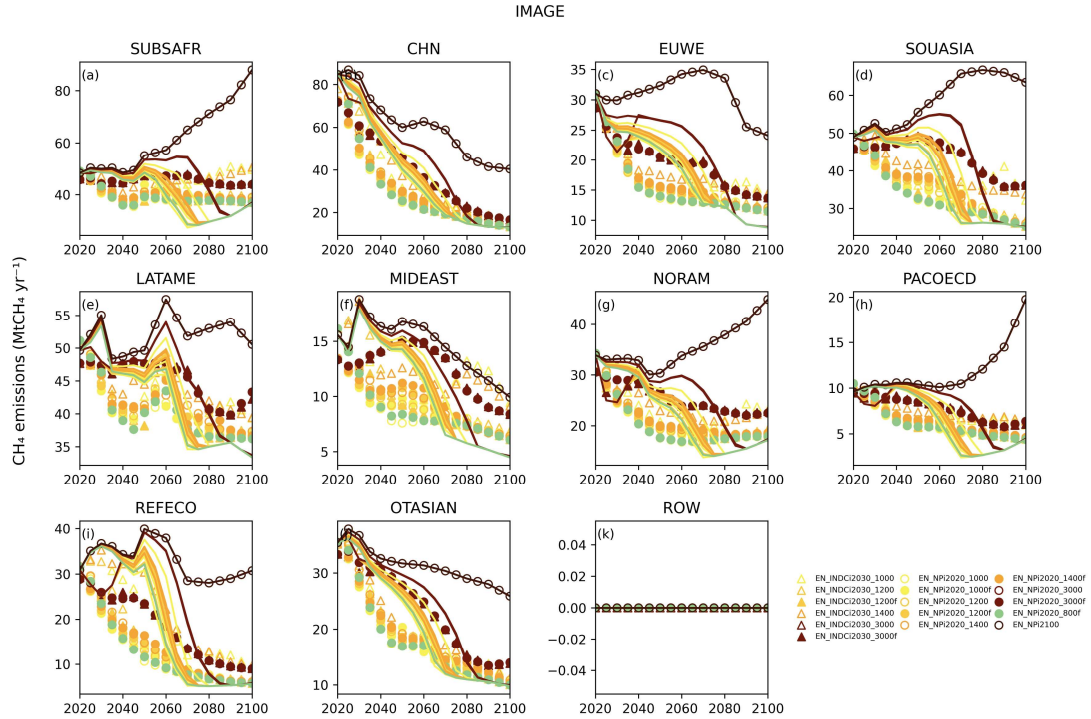


Figure S179. Test 3 - Regional IMAGE total anthropogenic CH₄ validation result

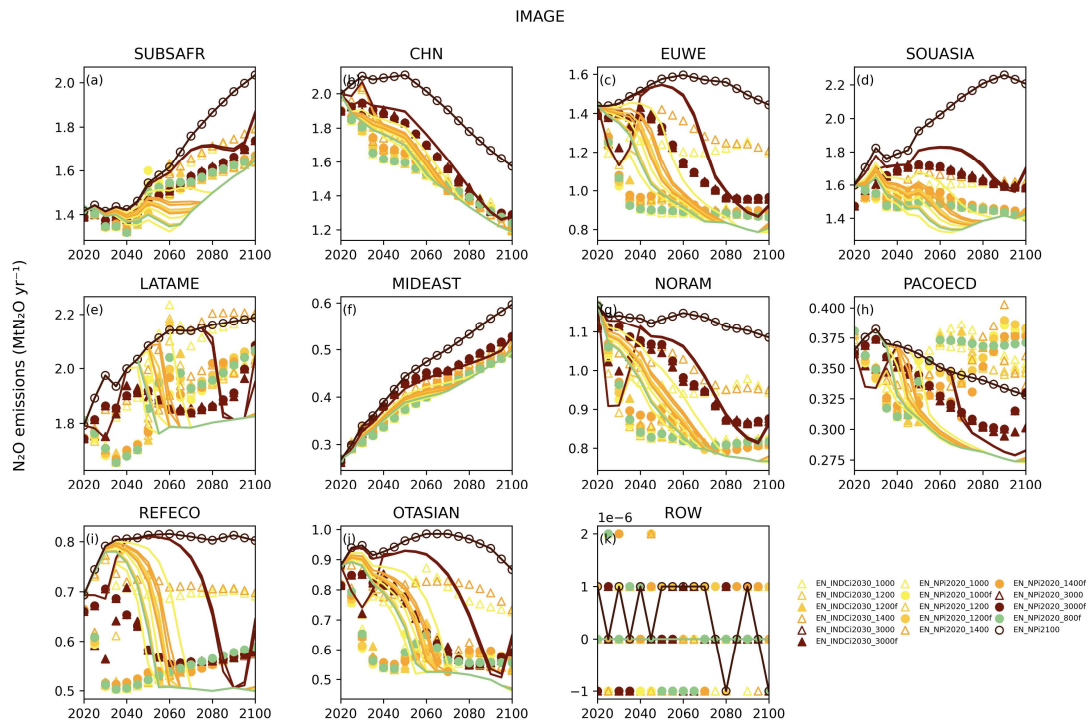


Figure S180. Test 3 - Regional IMAGE total anthropogenic N₂O validation result

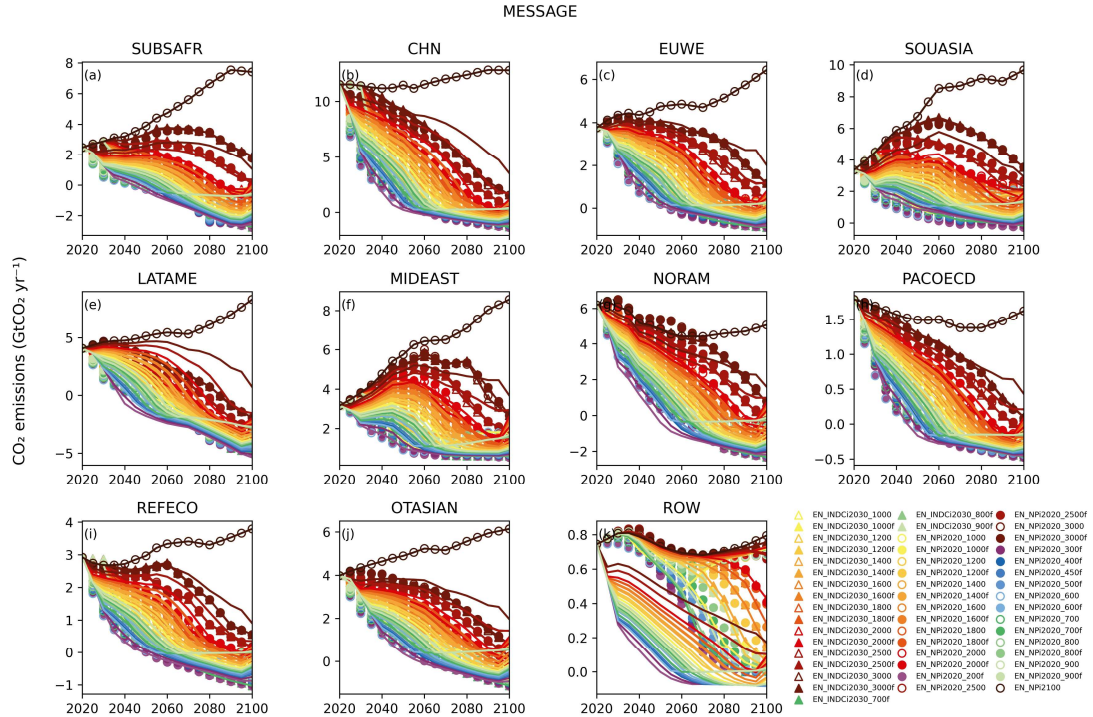


Figure S181. Test 3 - Regional MESSAGE total anthropogenic CO₂ validation result

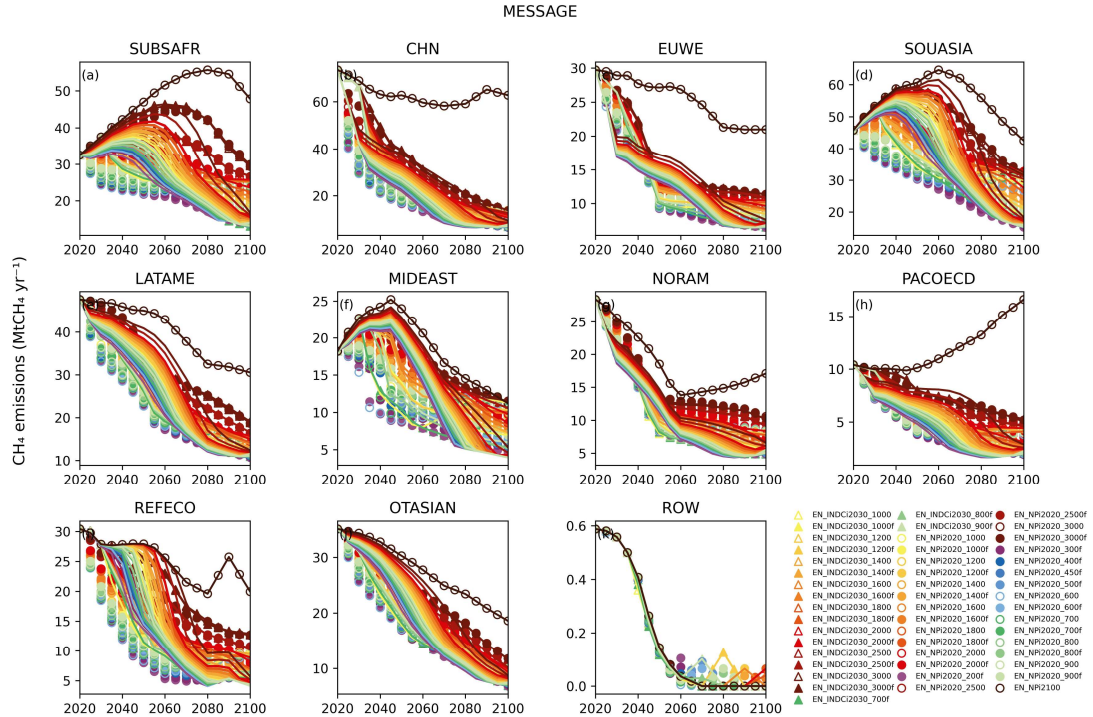


Figure S182. Test 3 - Regional MESSAGE total anthropogenic CH₄ validation result

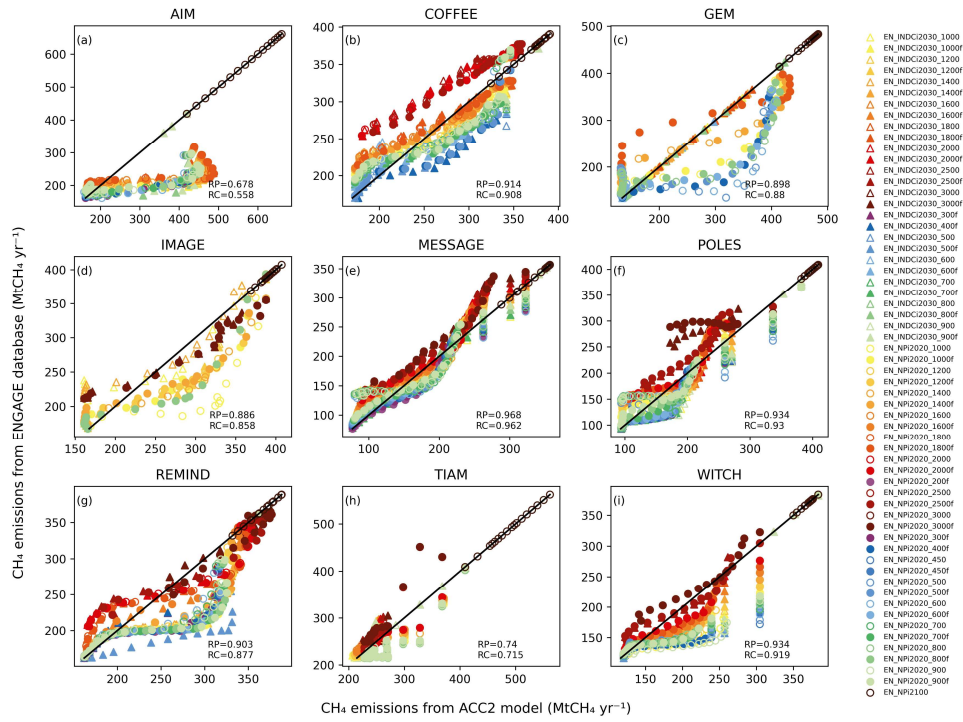


Figure S185. Test 3 - Global 9 models - Reproducibility of total anthropogenic CH₄

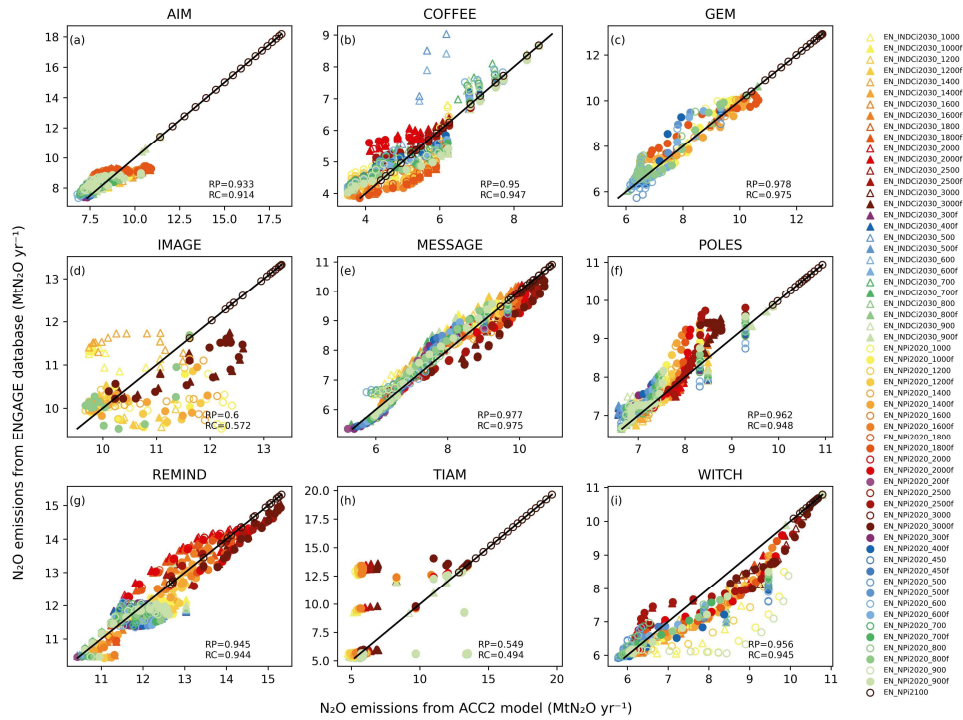


Figure S186. Test 3 - Global 9 models - Reproducibility of total anthropogenic N₂O

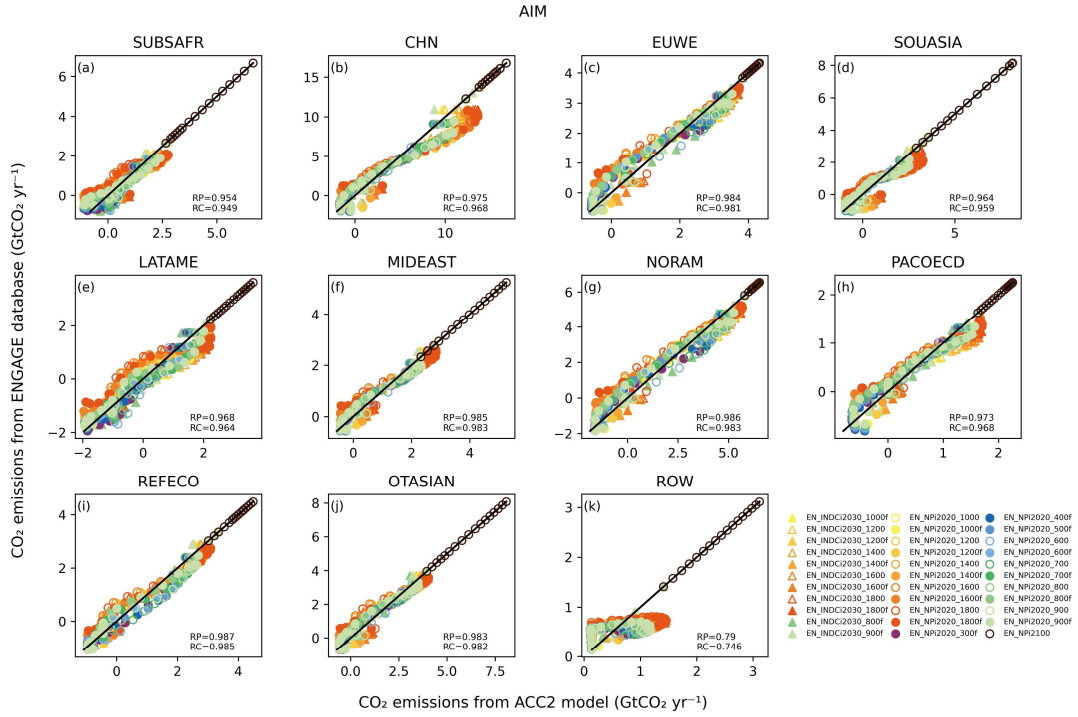


Figure S187. Test 3 - Regional AIM - Reproducibility of total anthropogenic CO₂

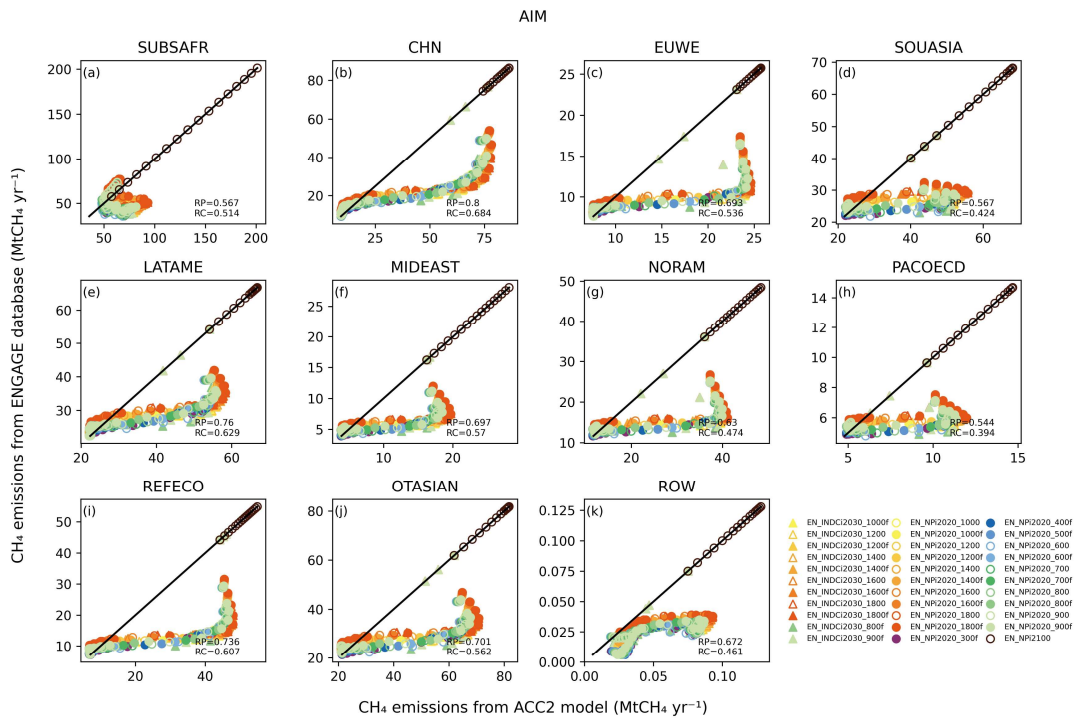


Figure S188. Test 3 - Regional AIM - Reproducibility of total anthropogenic CH₄

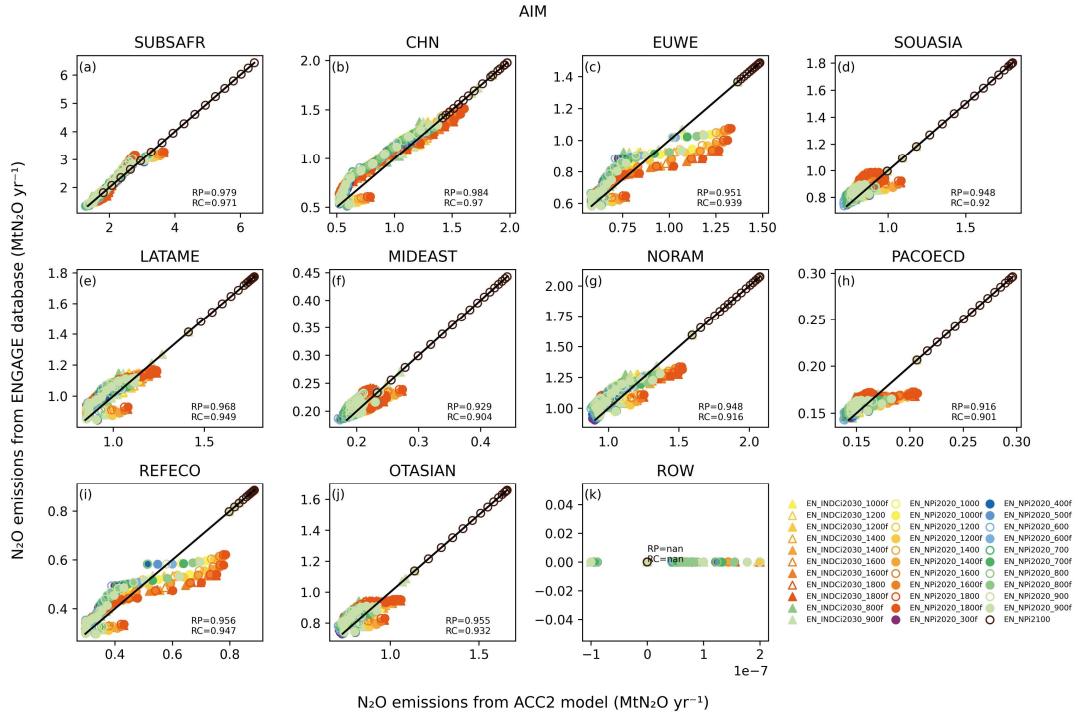


Figure S189. Test 3 - Regional AIM - Reproducibility of total anthropogenic N₂O

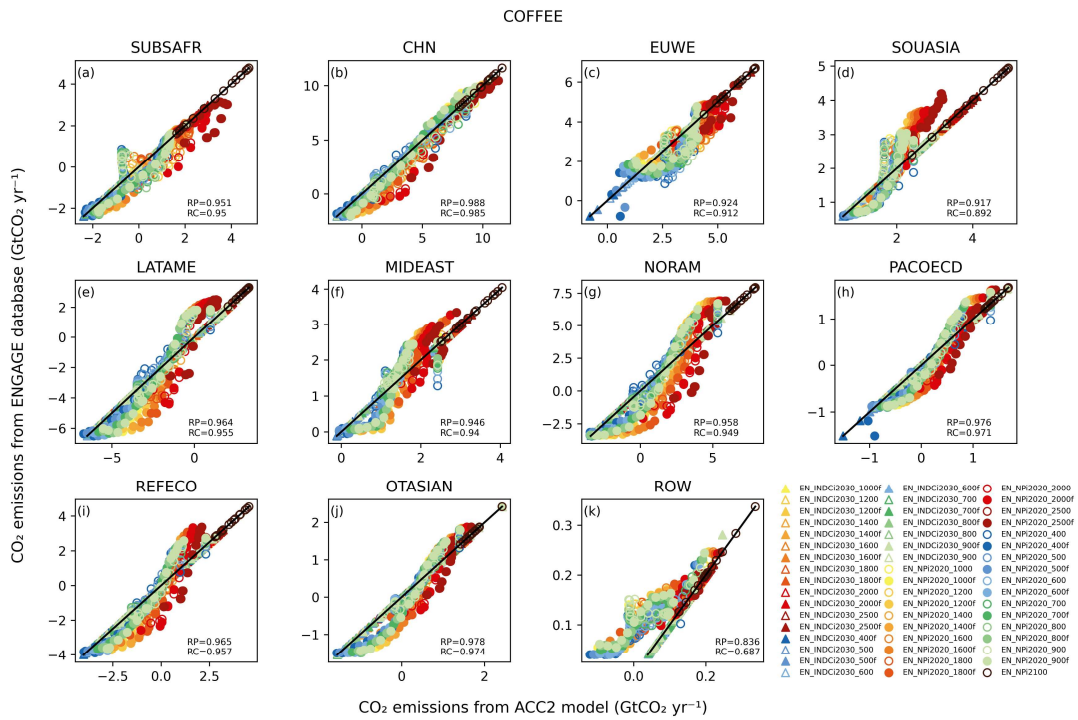


Figure S190. Test 3 - Regional COFFEE - Reproducibility of total anthropogenic CO₂

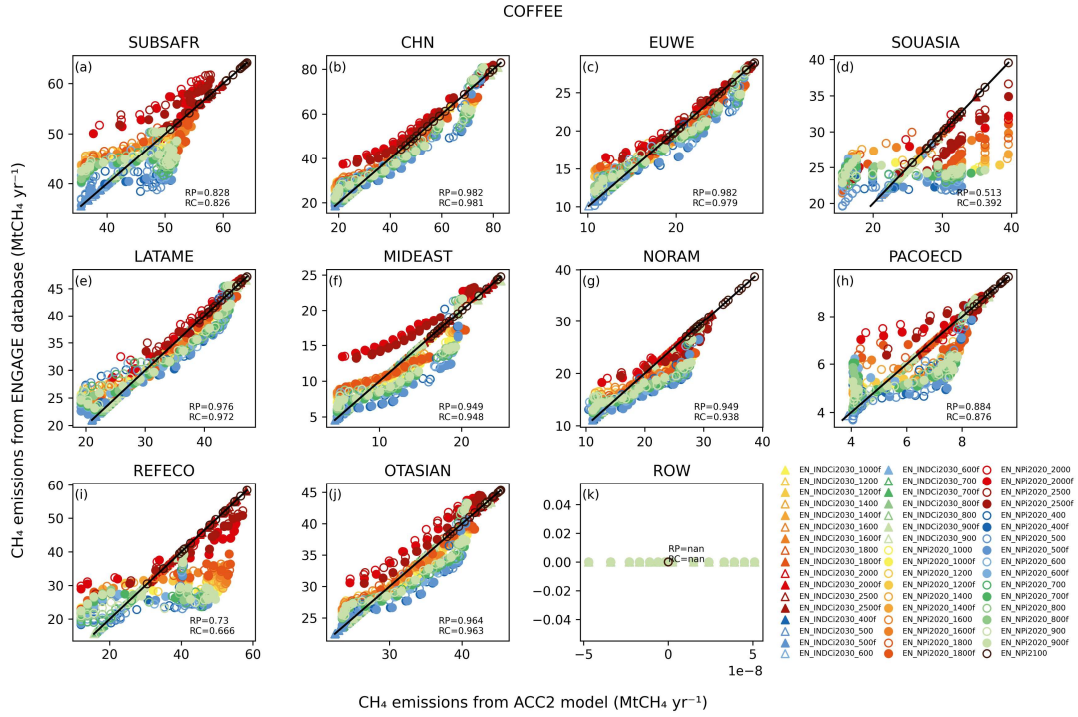


Figure S191. Test 3 - Regional COFFEE - Reproducibility of total anthropogenic CH₄

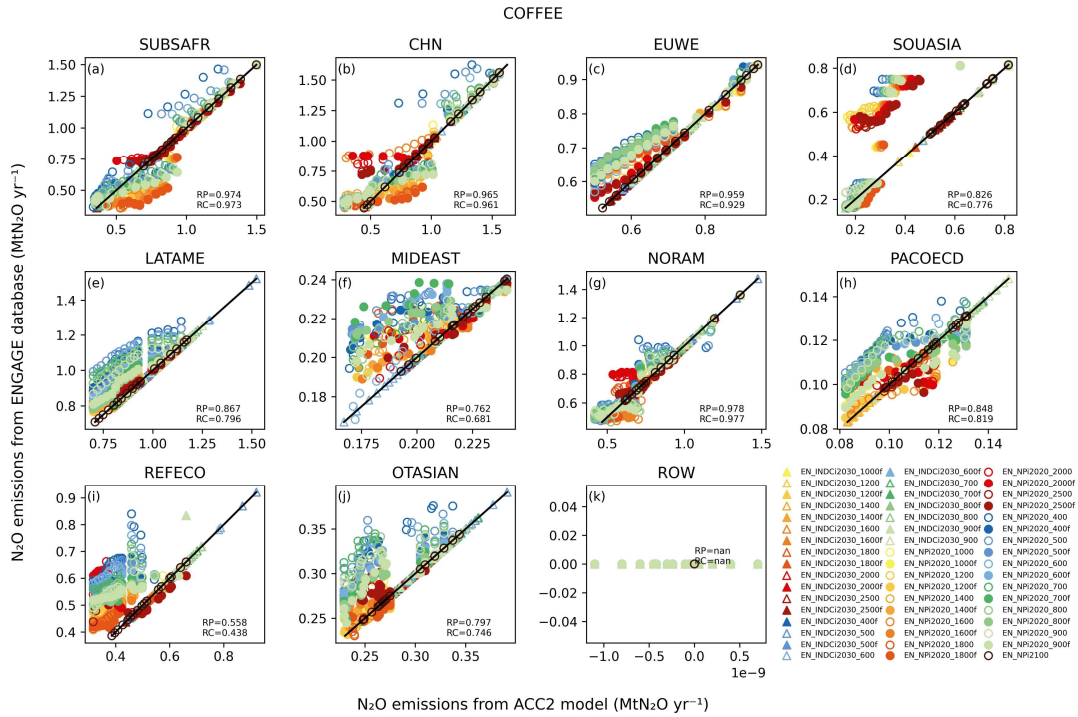


Figure S192. Test 3 - Regional COFFEE - Reproducibility of total anthropogenic N₂O

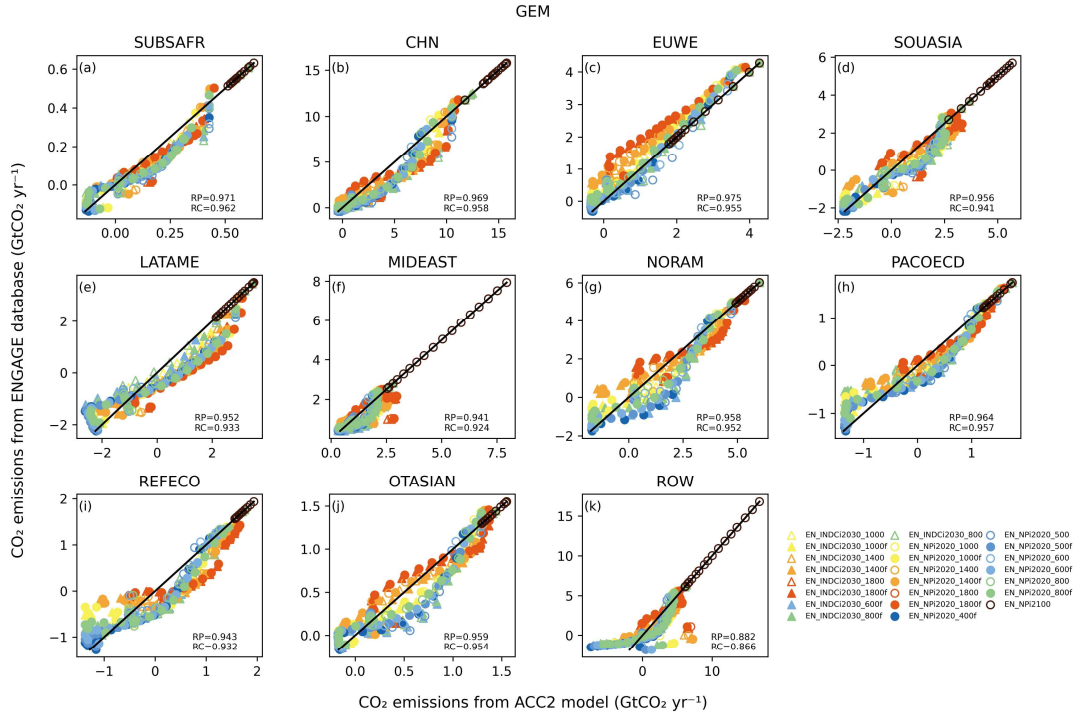


Figure S193. Test 3 - Regional GEM - Reproducibility of total anthropogenic CO₂

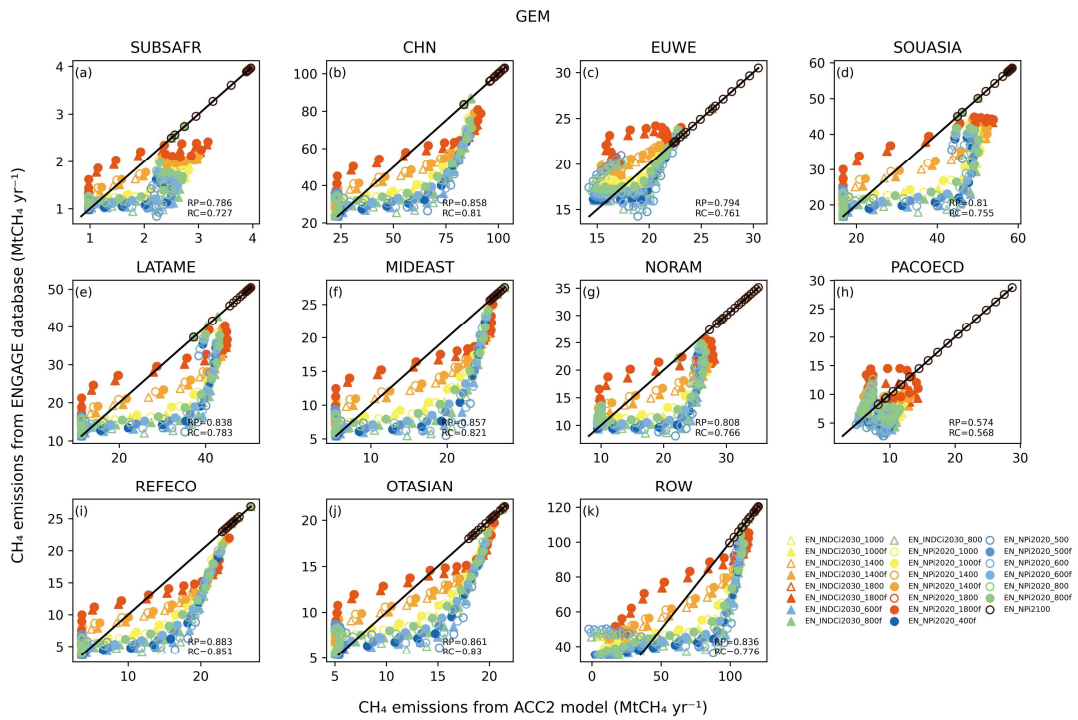


Figure S194. Test 3 - Regional GEM - Reproducibility of total anthropogenic CH₄

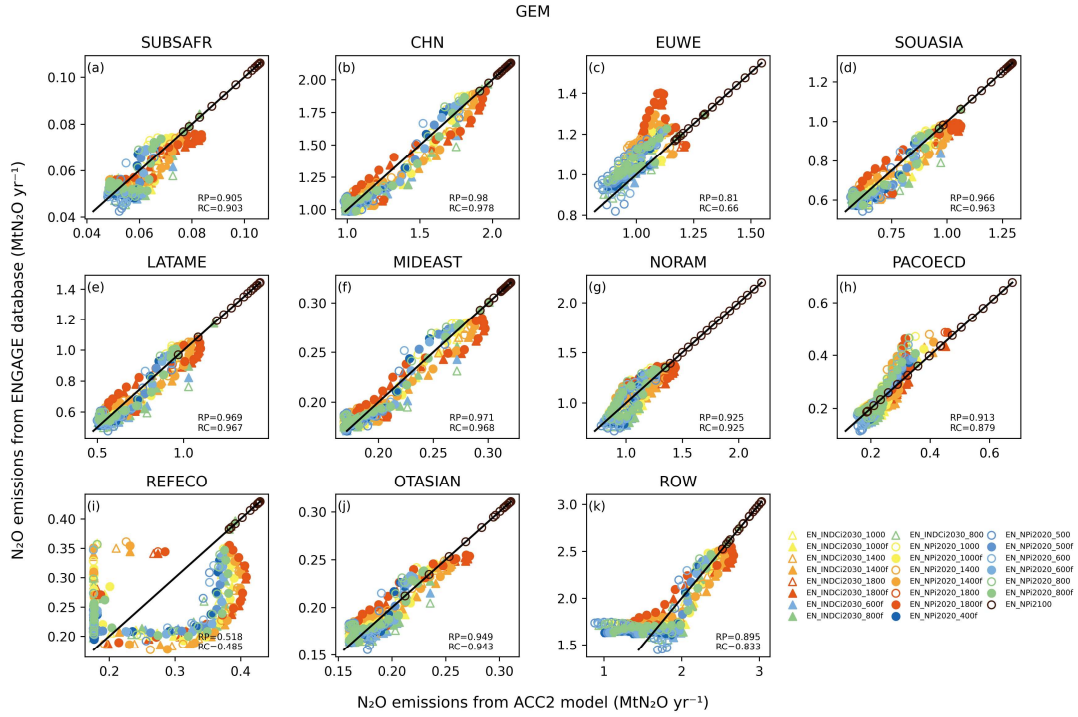


Figure S195. Test 3 - Regional GEM - Reproducibility of total anthropogenic N₂O

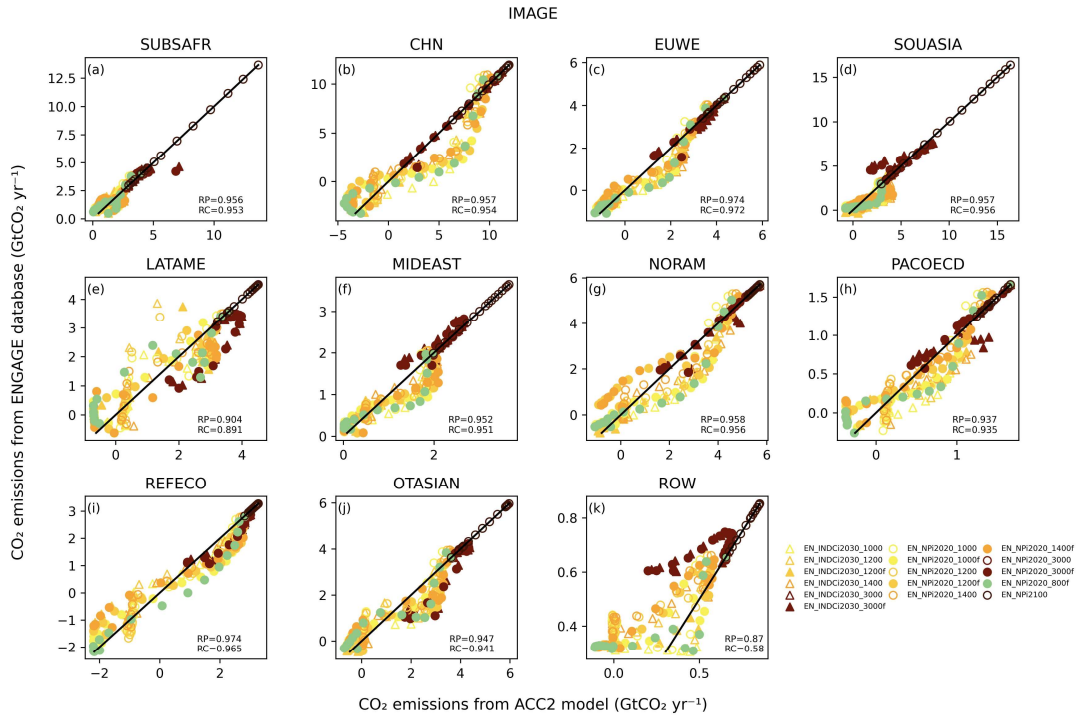


Figure S196. Test 3 - Regional IMAGE - Reproducibility of total anthropogenic CO₂

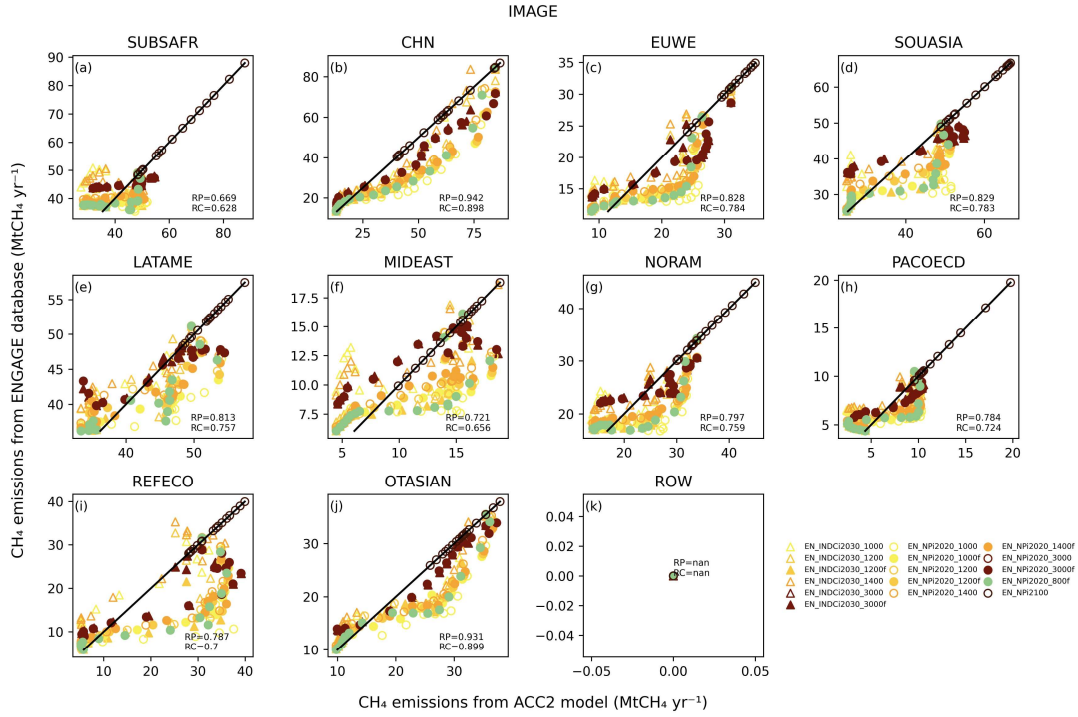


Figure S197. Test 3 - Regional IMAGE - Reproducibility of total anthropogenic CH₄

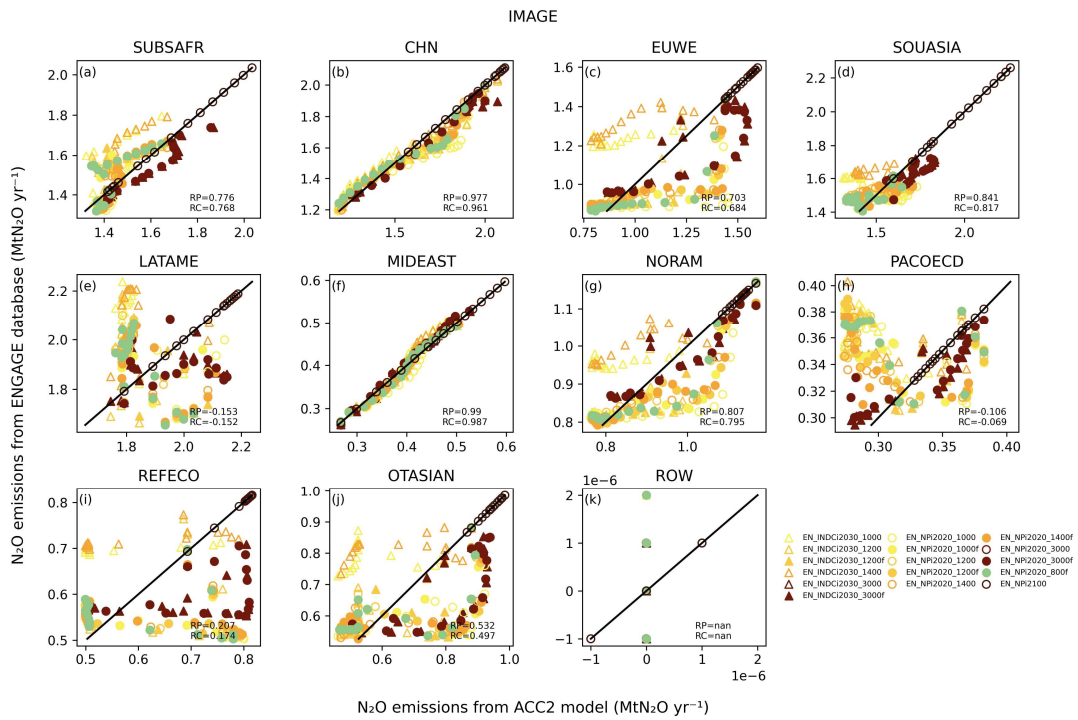


Figure S198. Test 3 - Regional IMAGE - Reproducibility of total anthropogenic N₂O

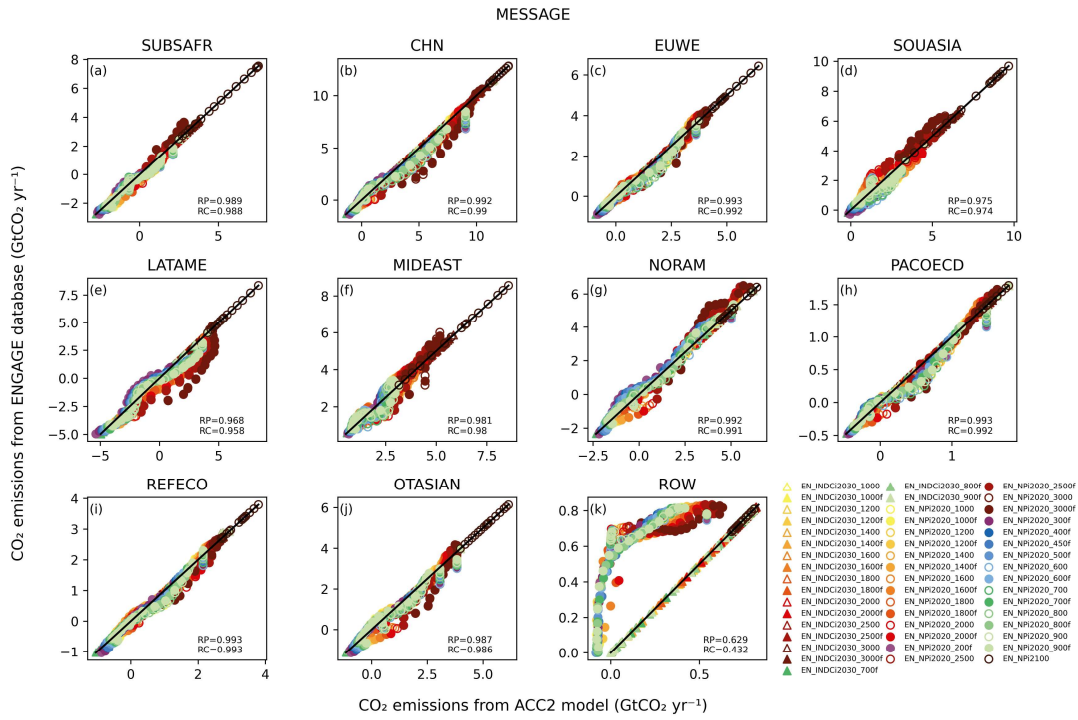


Figure S199. Test 3 - Regional MESSAGE - Reproducibility of total anthropogenic CO₂

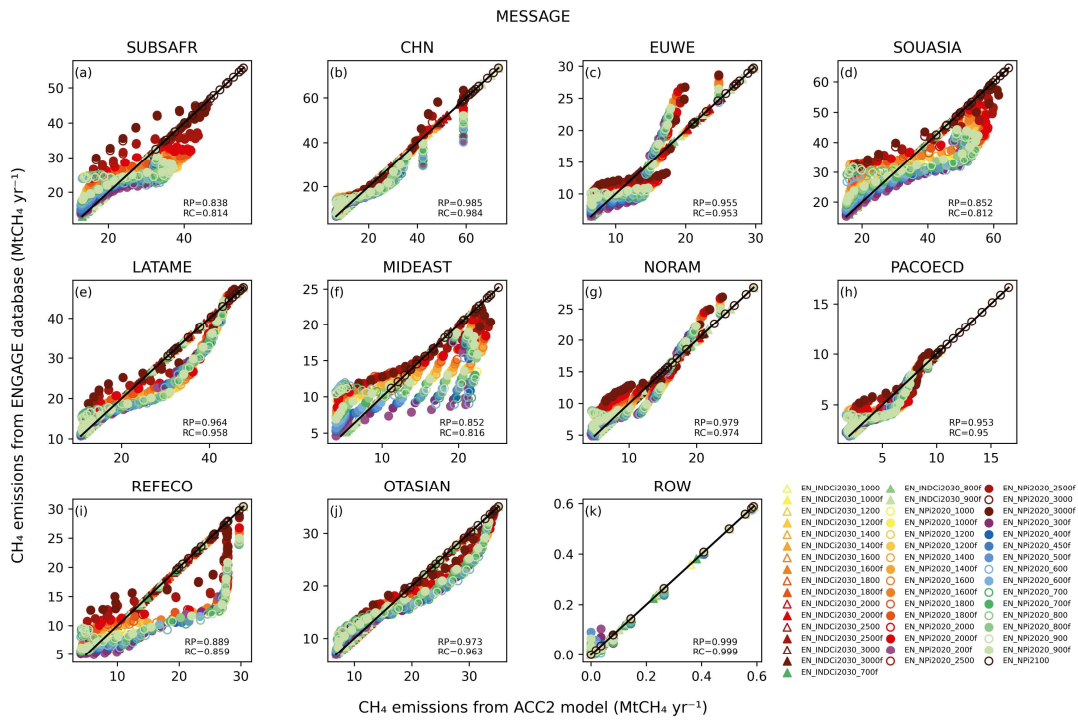


Figure S200. Test 3 - Regional MESSAGE - Reproducibility of total anthropogenic CH₄

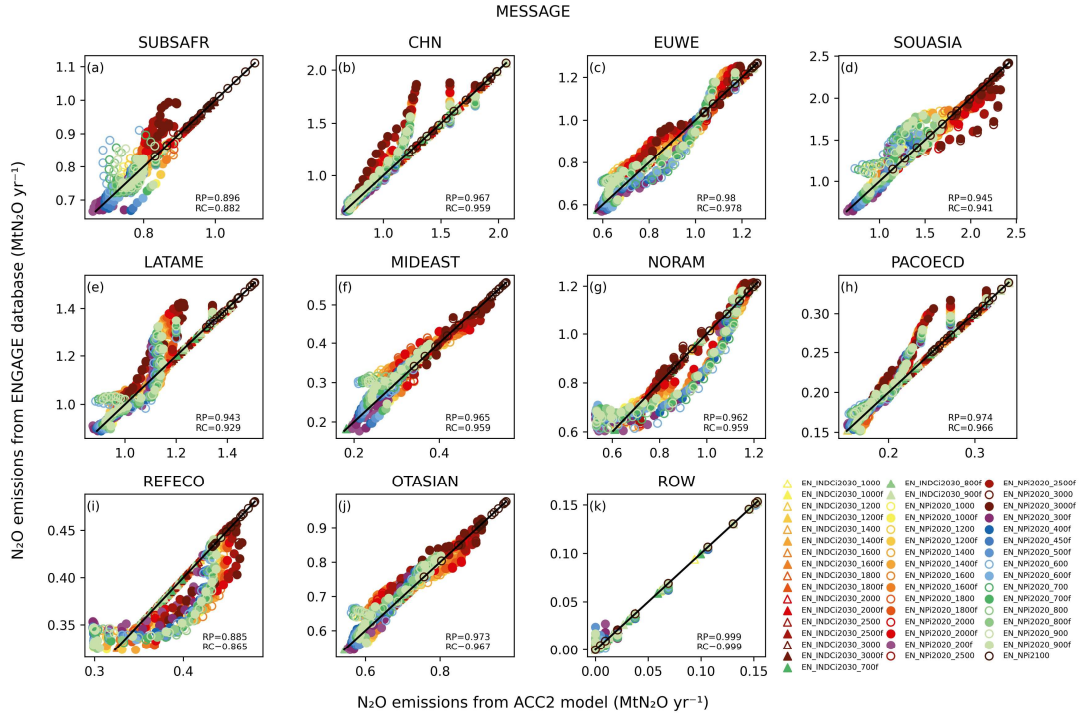


Figure S201. Test 3 - Regional MESSAGE total anthropogenic N₂O validation result

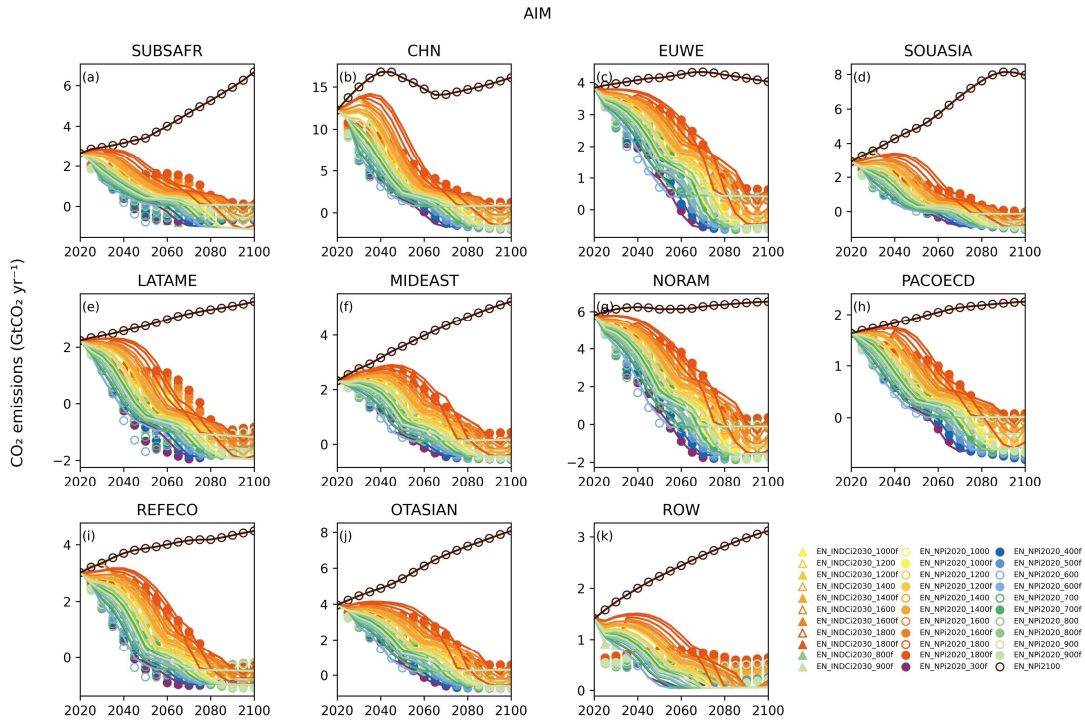


Figure S202. Test 4 - Regional AIM total anthropogenic CO₂ validation result

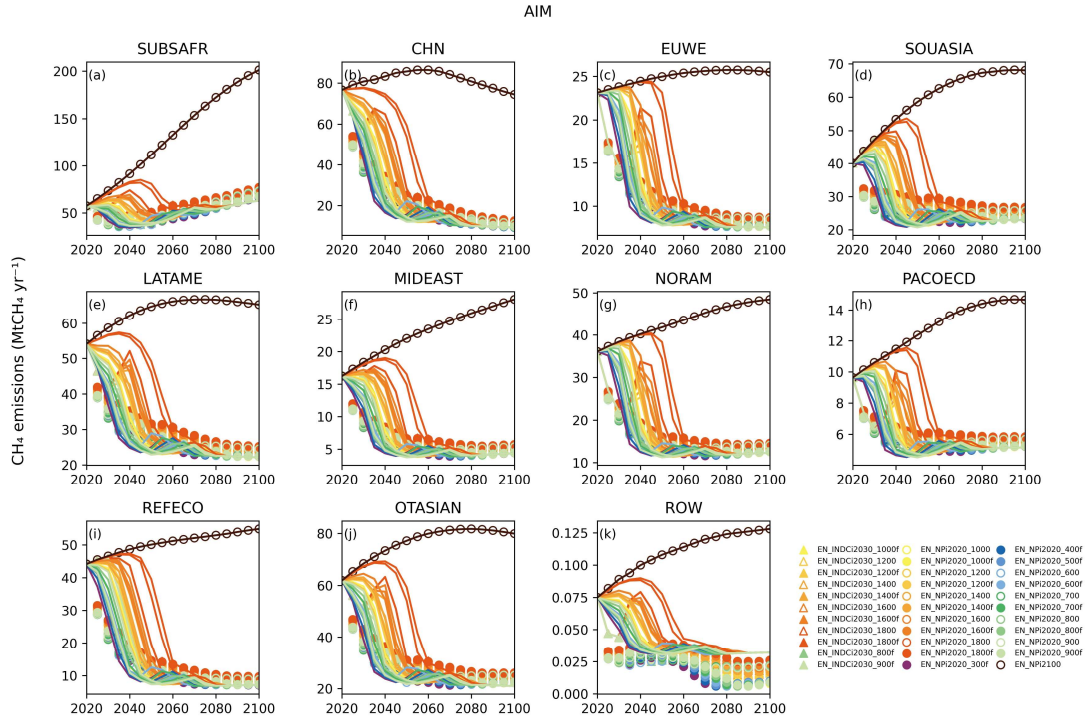


Figure S203. Test 4 - Regional AIM total anthropogenic CH₄ validation result

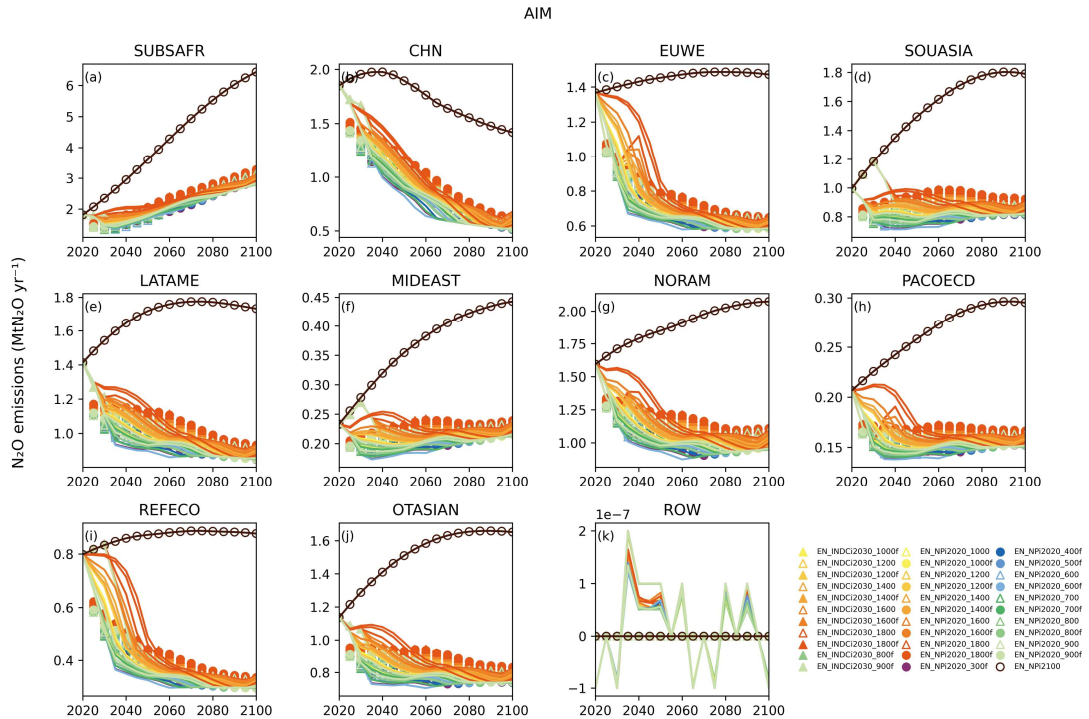


Figure S204. Test 4 - Regional AIM total anthropogenic N₂O validation result

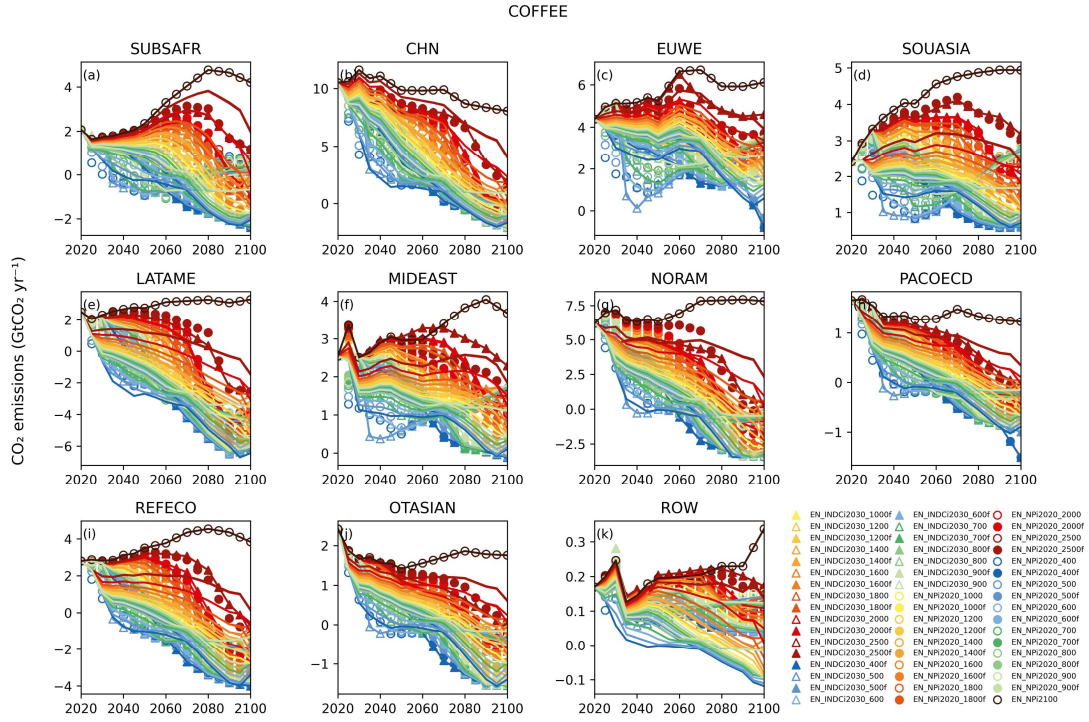


Figure S205. Test 4 - Regional COFFEE total anthropogenic CO₂ validation result

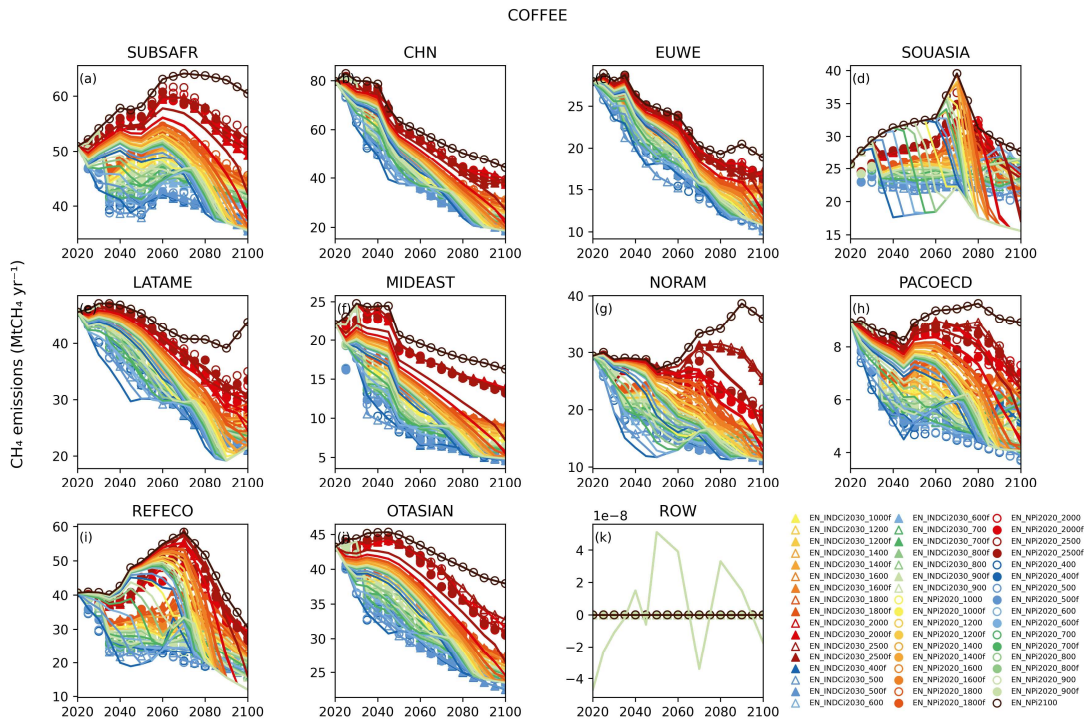


Figure S206. Test 4 - Regional COFFEE total anthropogenic CH₄ validation result

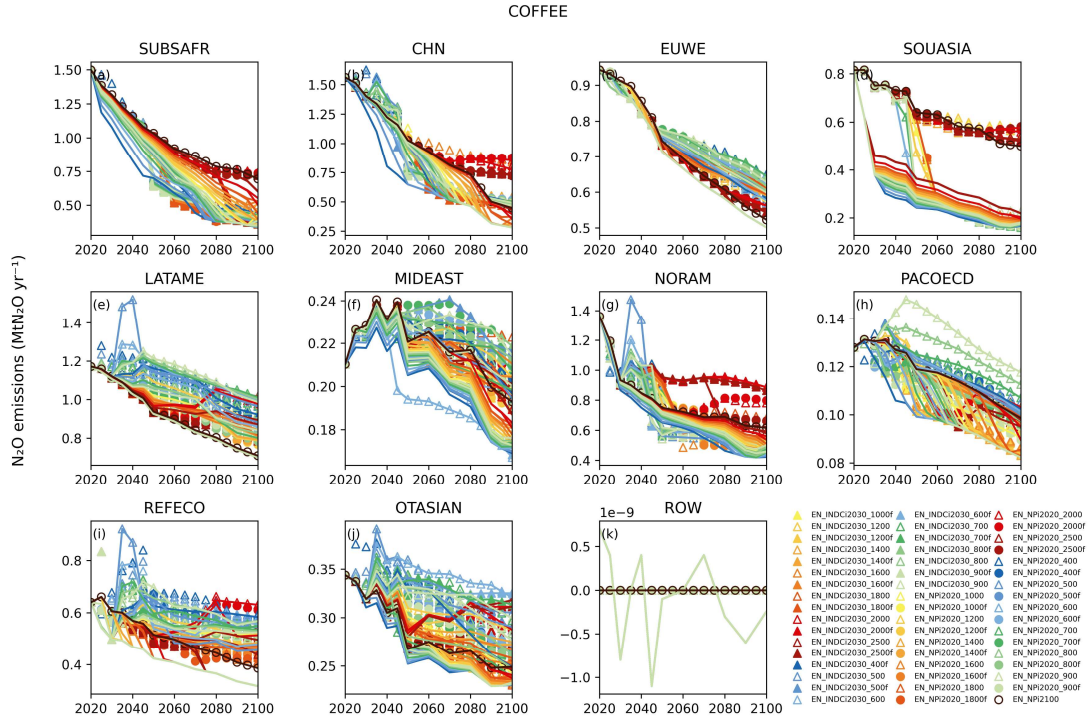


Figure S207. Test 4 - Regional COFFEE total anthropogenic N₂O validation result

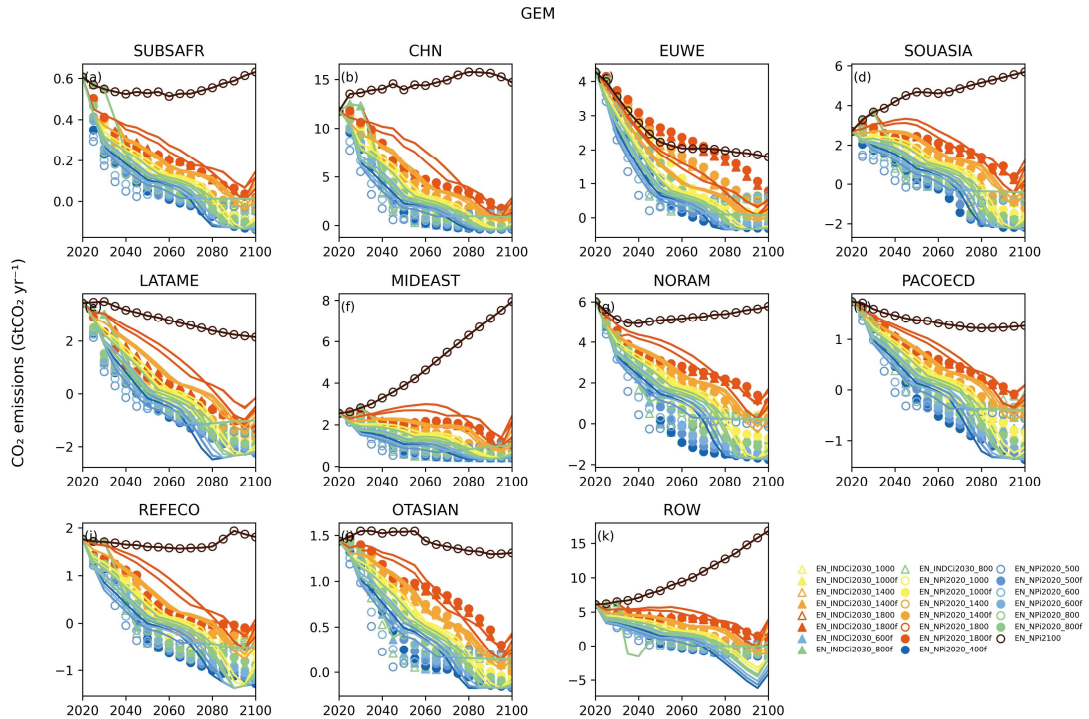


Figure S208. Test 4 - Regional GEM total anthropogenic CO₂ validation result

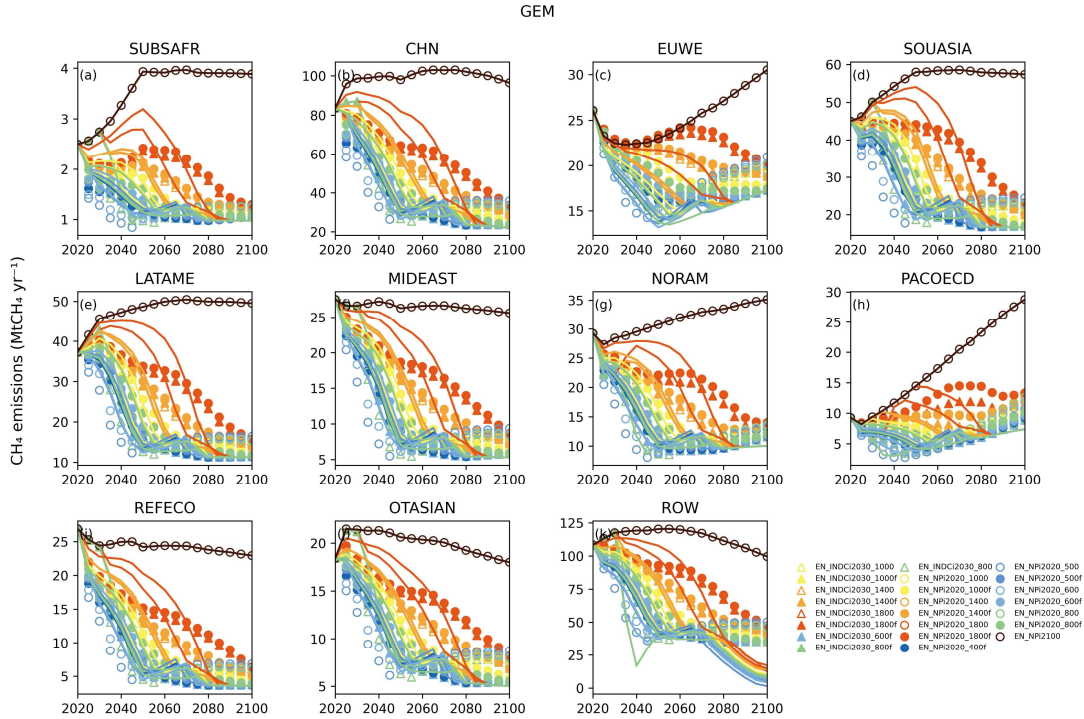


Figure S209. Test 4 - Regional GEM total anthropogenic CH₄ validation result

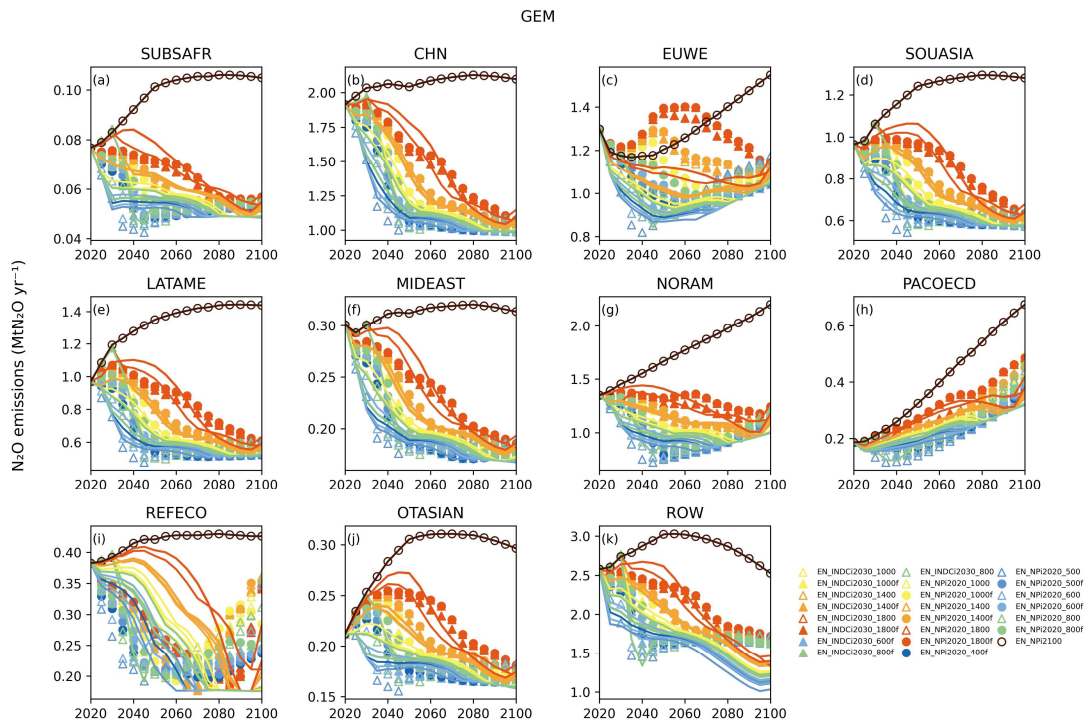


Figure S210. Test 4 - Regional GEM total anthropogenic N₂O validation result

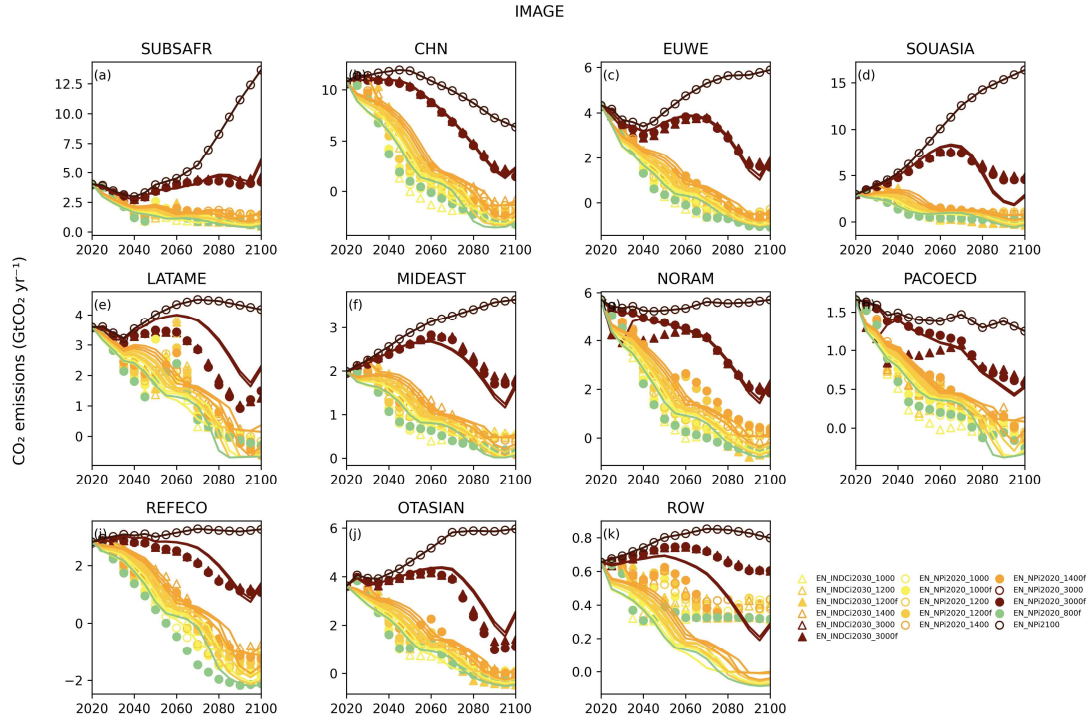


Figure S211. Test 4 - Regional IMAGE total anthropogenic CO₂ validation result

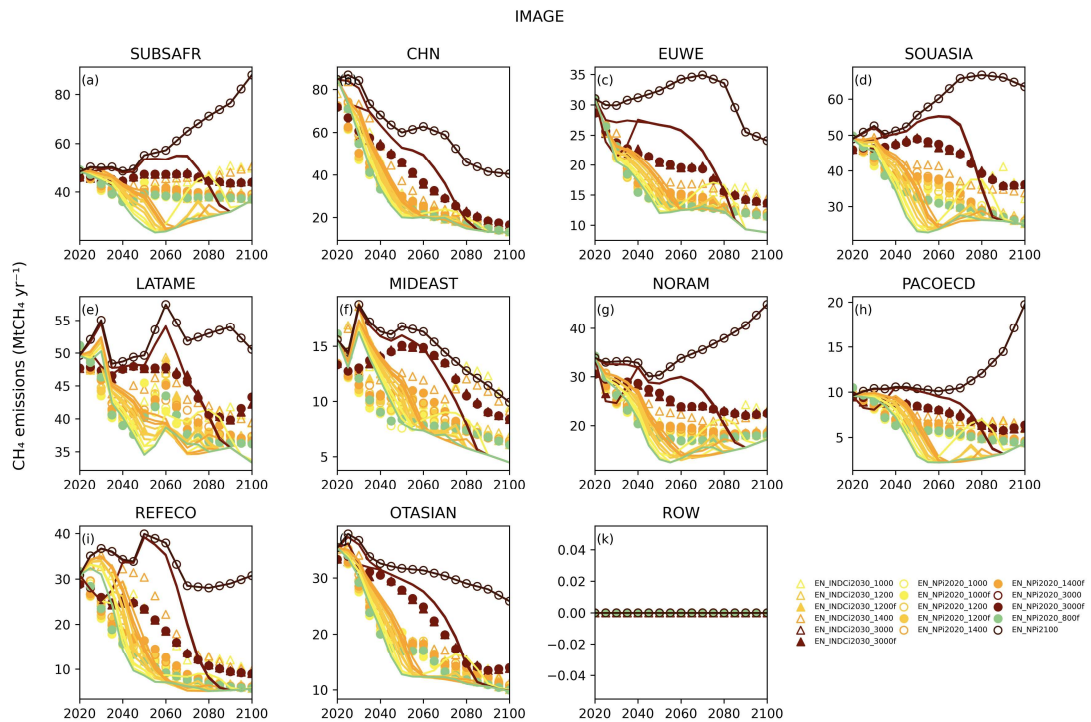


Figure S212. Test 4 - Regional IMAGE total anthropogenic CH₄ validation result

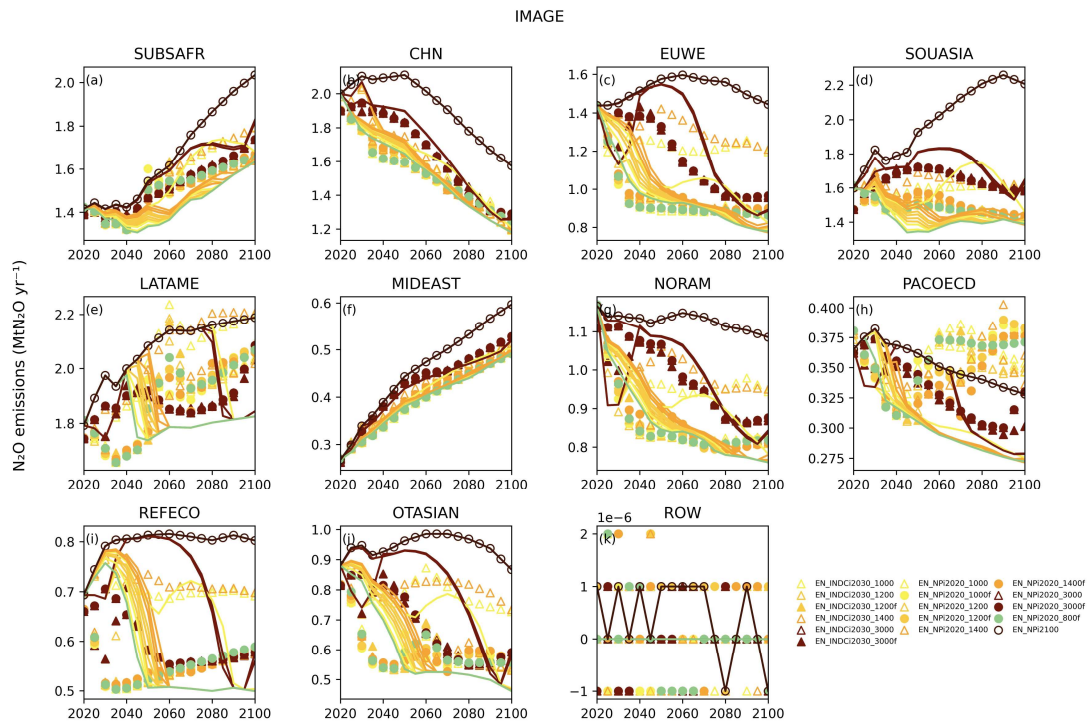


Figure S213. Test 4 - Regional IMAGE total anthropogenic N_2O validation result

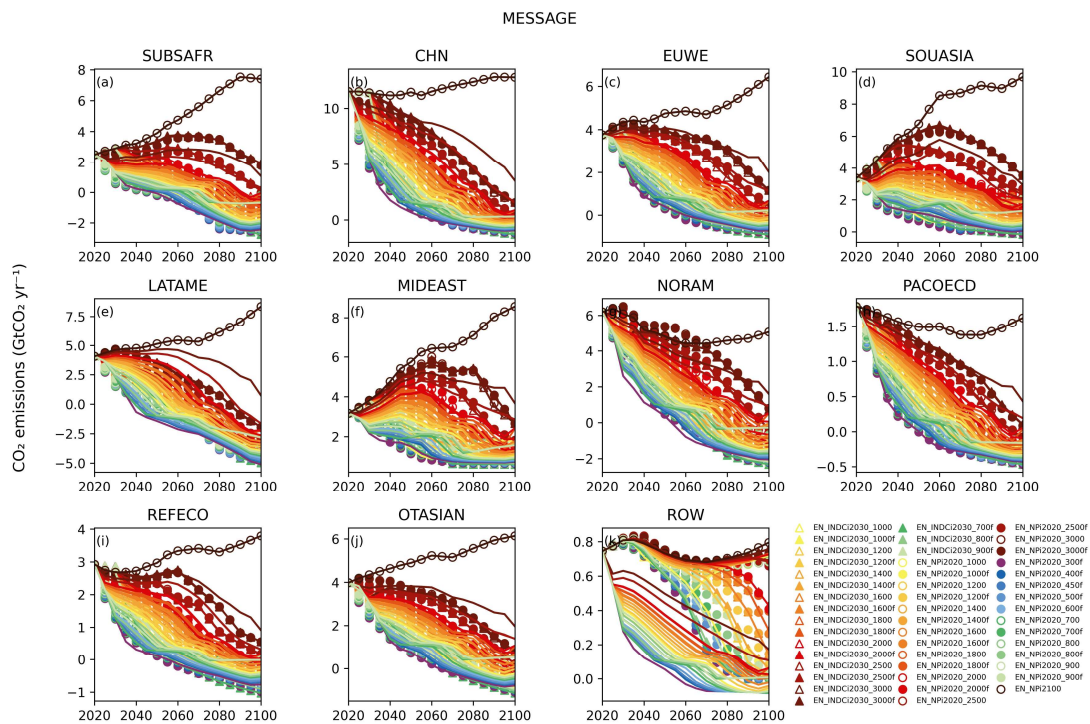


Figure S214. Test 4 - Regional MESSAGE total anthropogenic CO_2 validation result

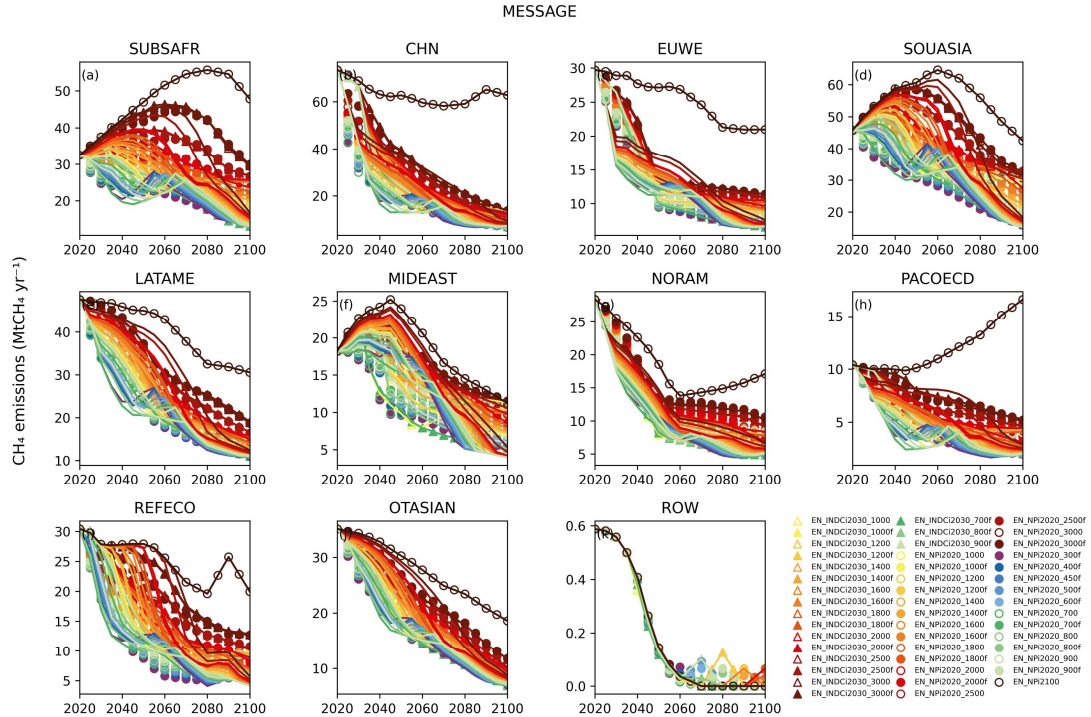


Figure S215. Test 4 - Regional MESSAGE total anthropogenic CH₄ validation result

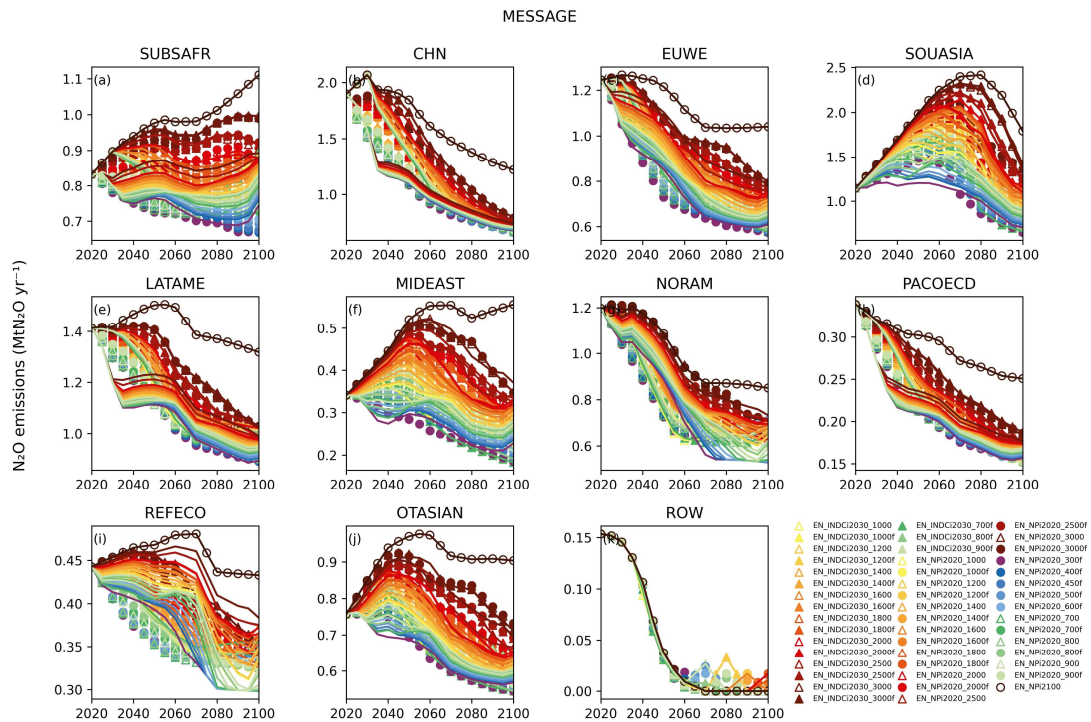


Figure S216. Test 4 - Regional MESSAGE total anthropogenic N₂O validation result

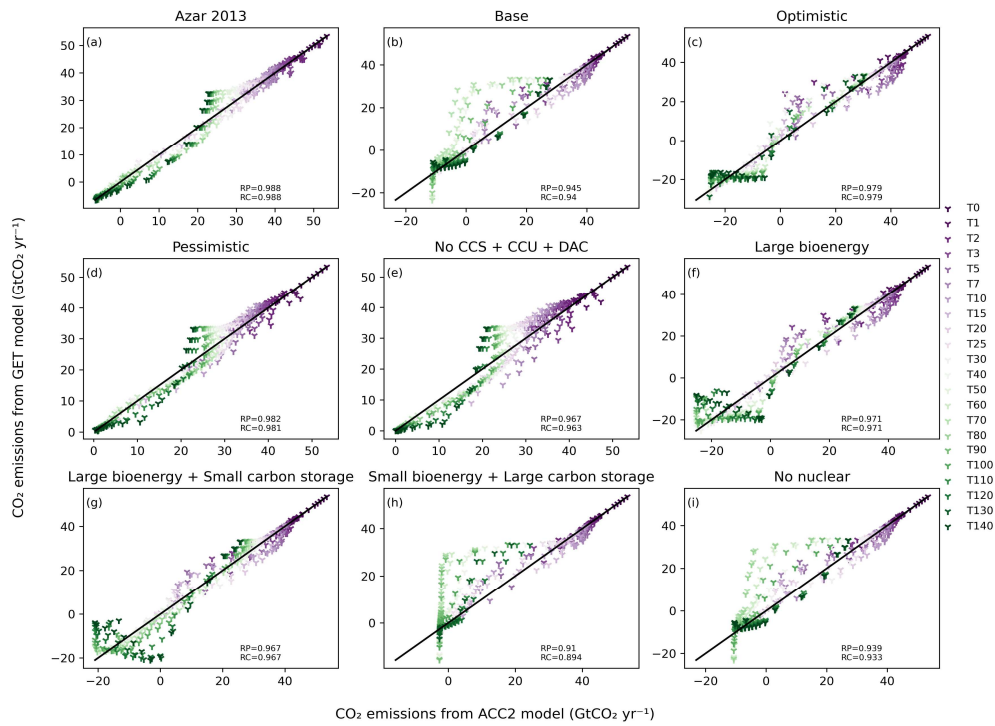


Figure S217. Test 4 - GET Reproducibility of energy-related CO₂

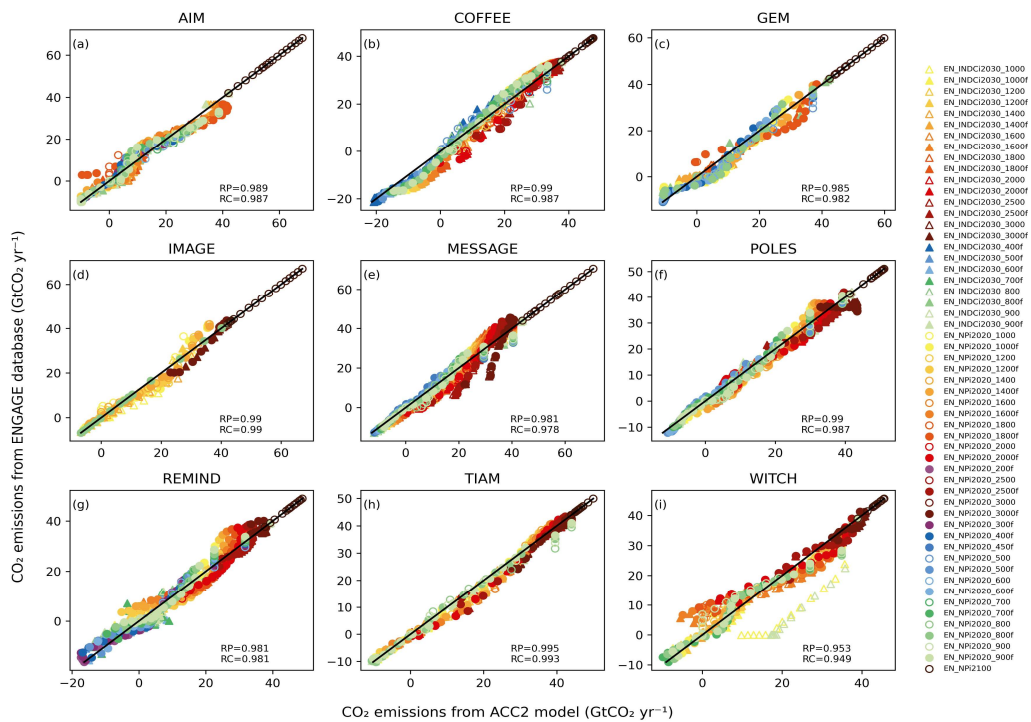


Figure S218. Test 4 - Global 9 models - Reproducibility of total anthropogenic CO₂

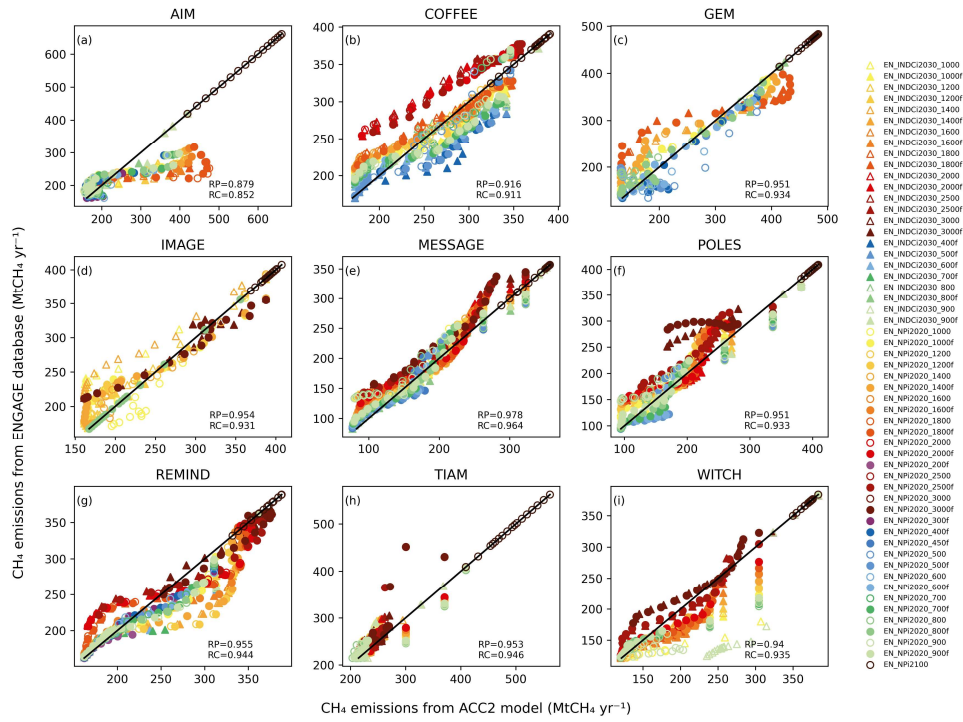


Figure S219. Test 4 - Global 9 models - Reproducibility of total anthropogenic CH₄

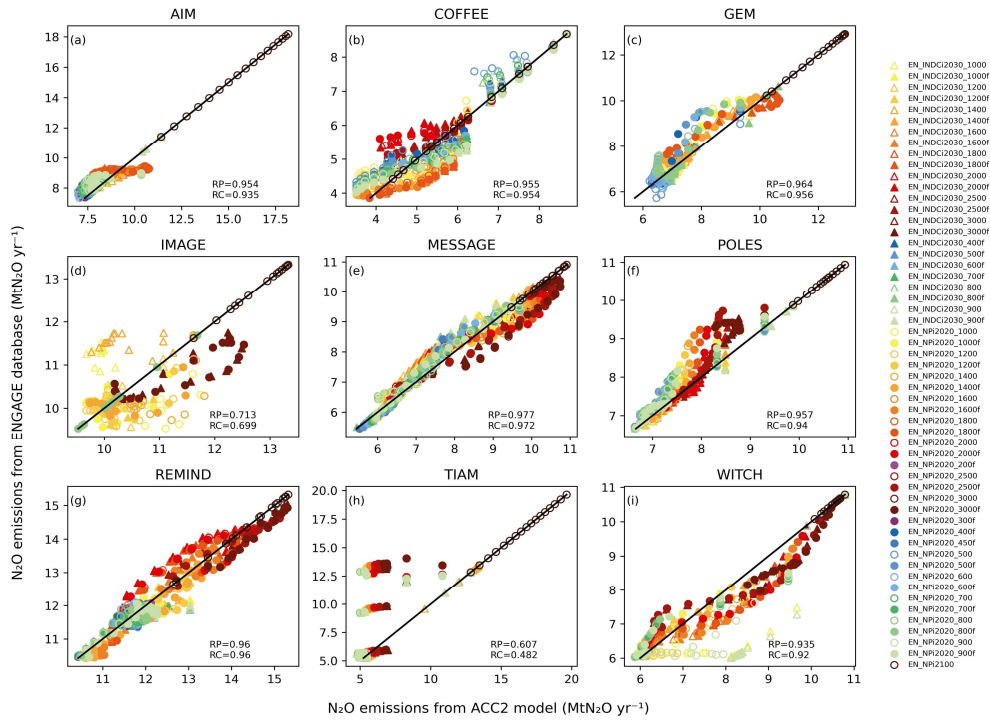


Figure S220. Test 4 - Global 9 models - Reproducibility of total anthropogenic N₂O

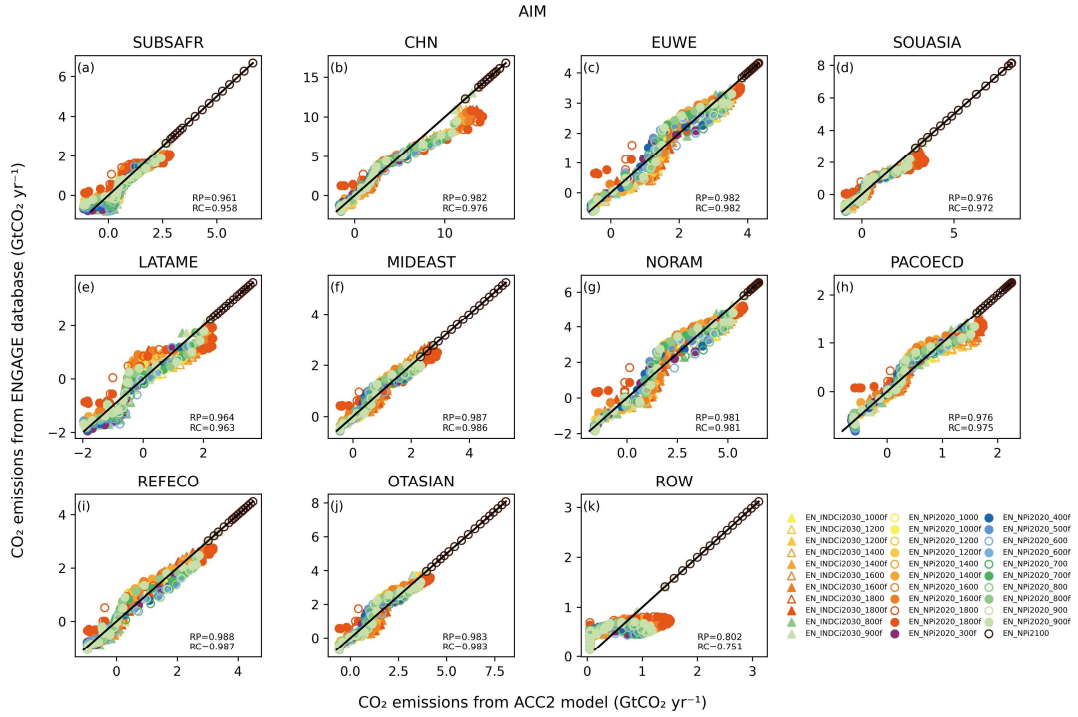


Figure S221. Test 4 - Regional AIM - Reproducibility of total anthropogenic CO₂

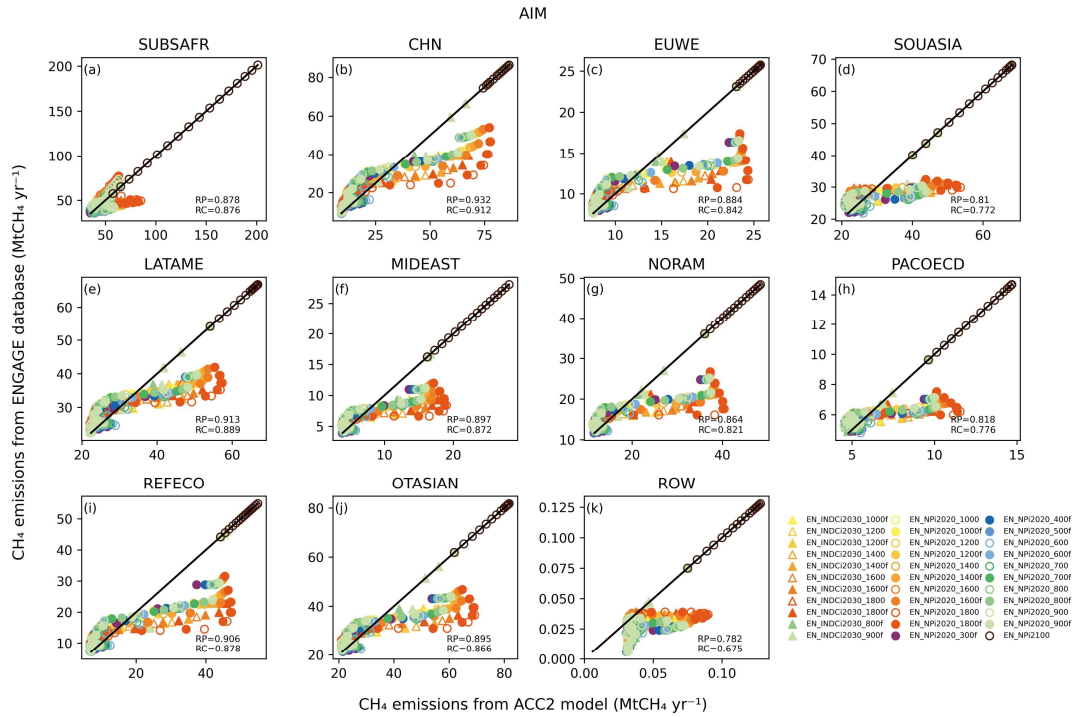


Figure S222. Test 4 - Regional AIM - Reproducibility of total anthropogenic CH₄

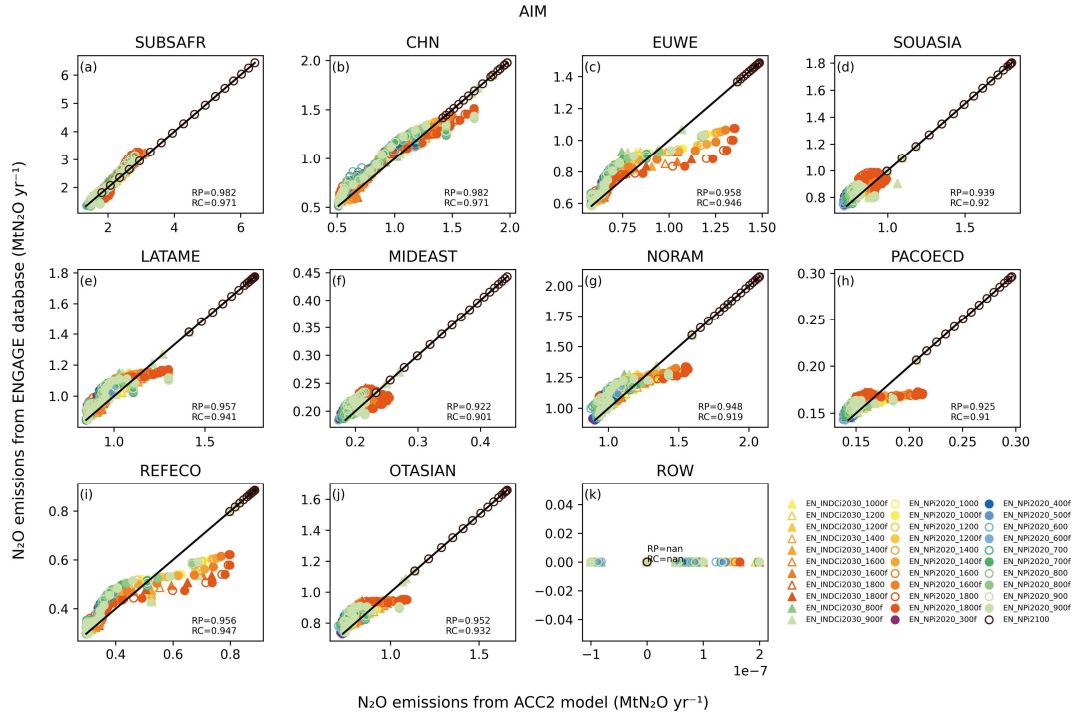


Figure S223. Test 4 - Regional AIM - Reproducibility of total anthropogenic N₂O

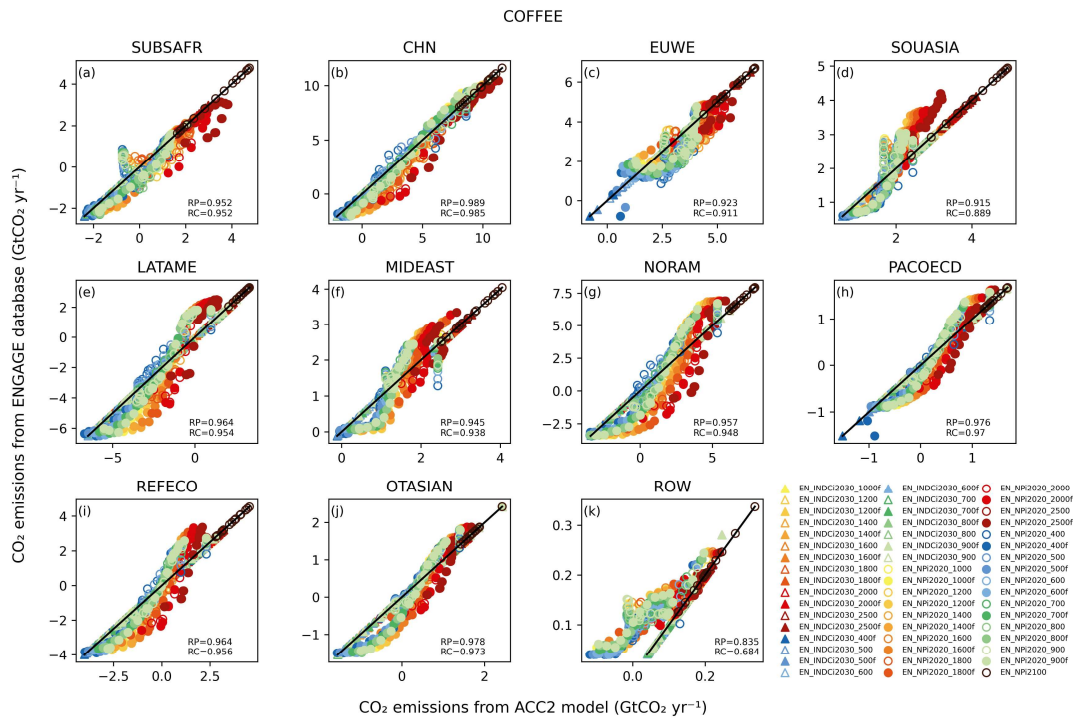


Figure S224. Test 4 - Regional COFFEE - Reproducibility of total anthropogenic CO₂

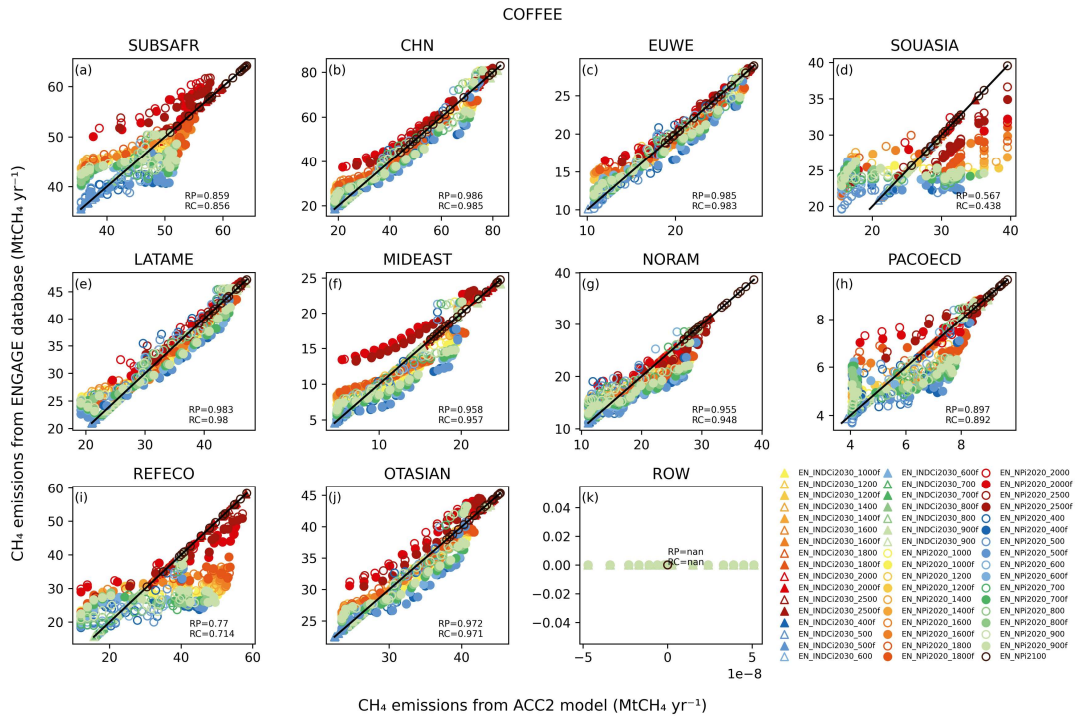


Figure S225. Test 4 - Regional COFFEE - Reproducibility of total anthropogenic CH₄

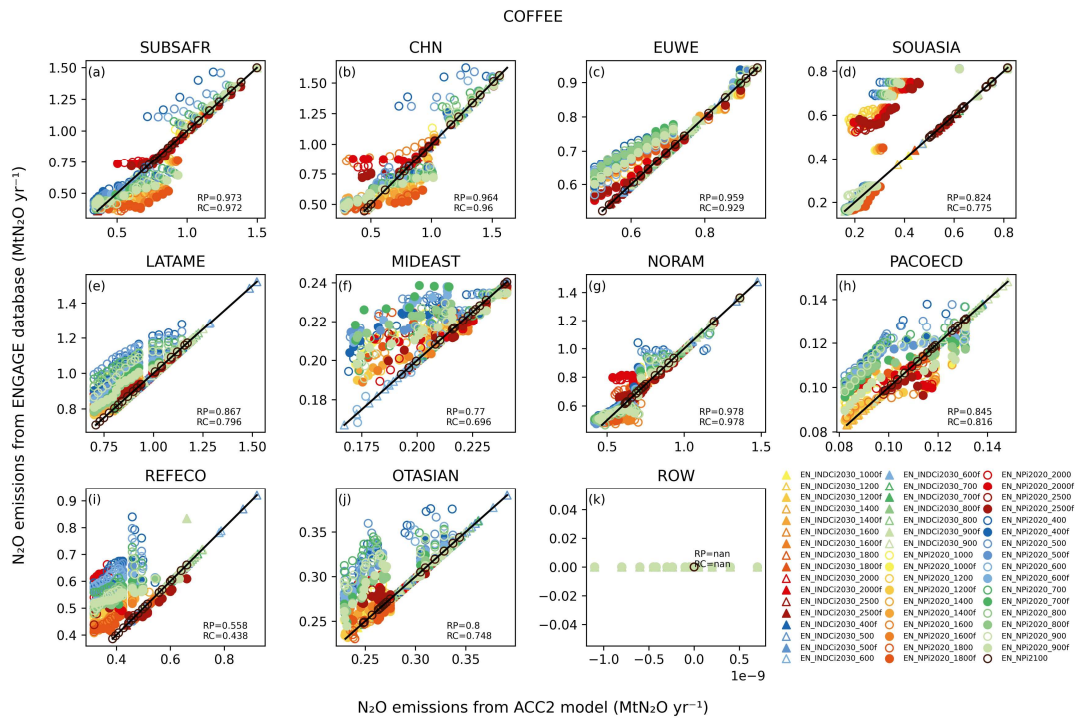


Figure S226. Test 4 - Regional COFFEE - Reproducibility of total anthropogenic N₂O

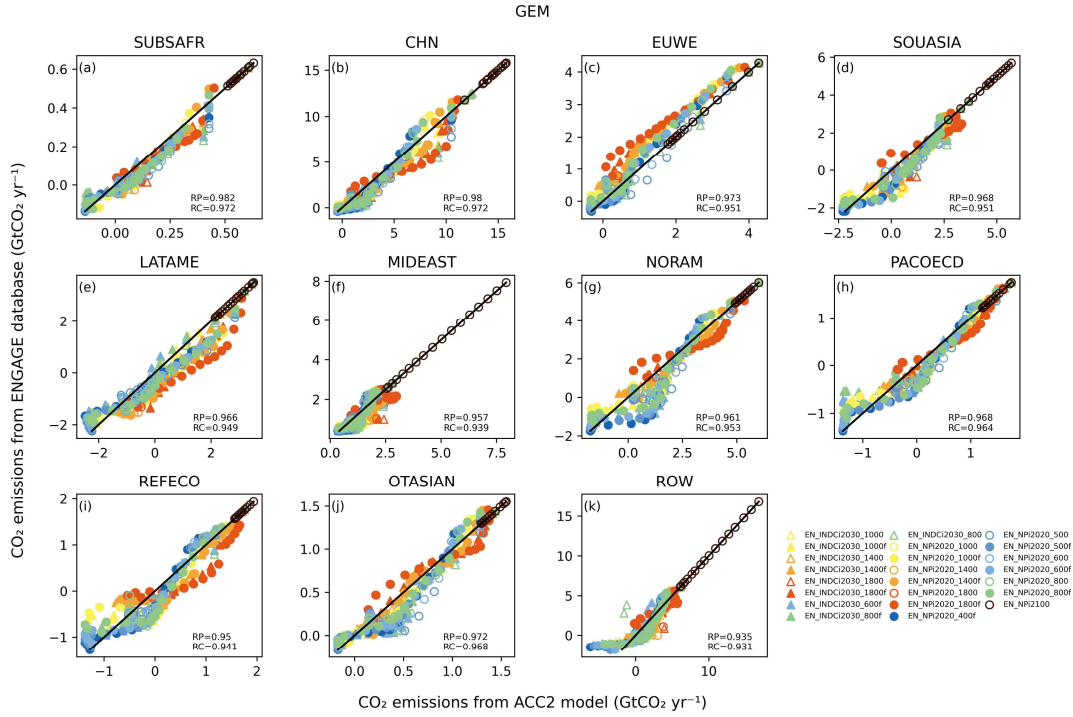


Figure S227. Test 4 - Regional GEM - Reproducibility of total anthropogenic CO₂

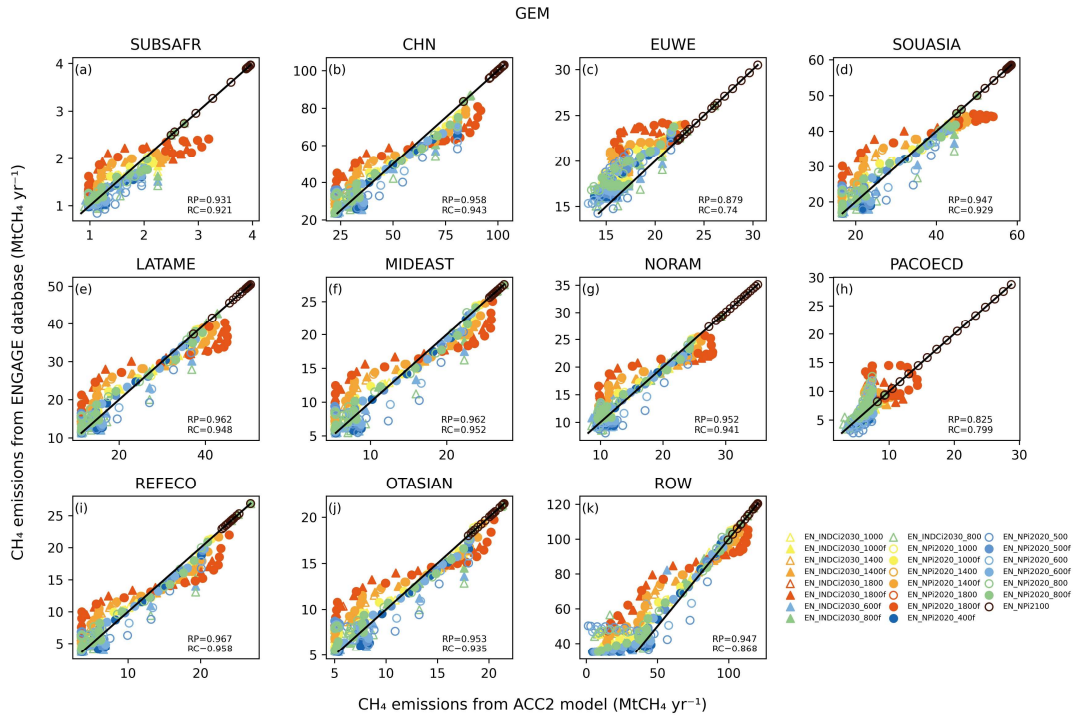


Figure S228. Test 4 - Regional GEM - Reproducibility of total anthropogenic CH₄

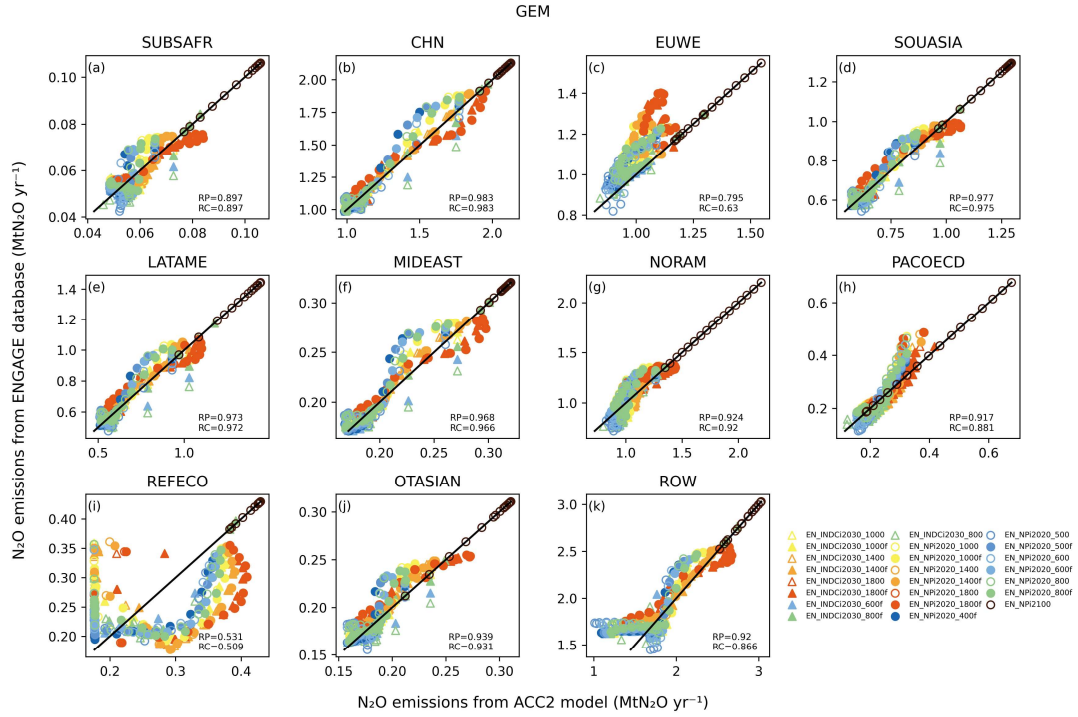


Figure S229. Test 4 - Regional GEM - Reproducibility of total anthropogenic N₂O

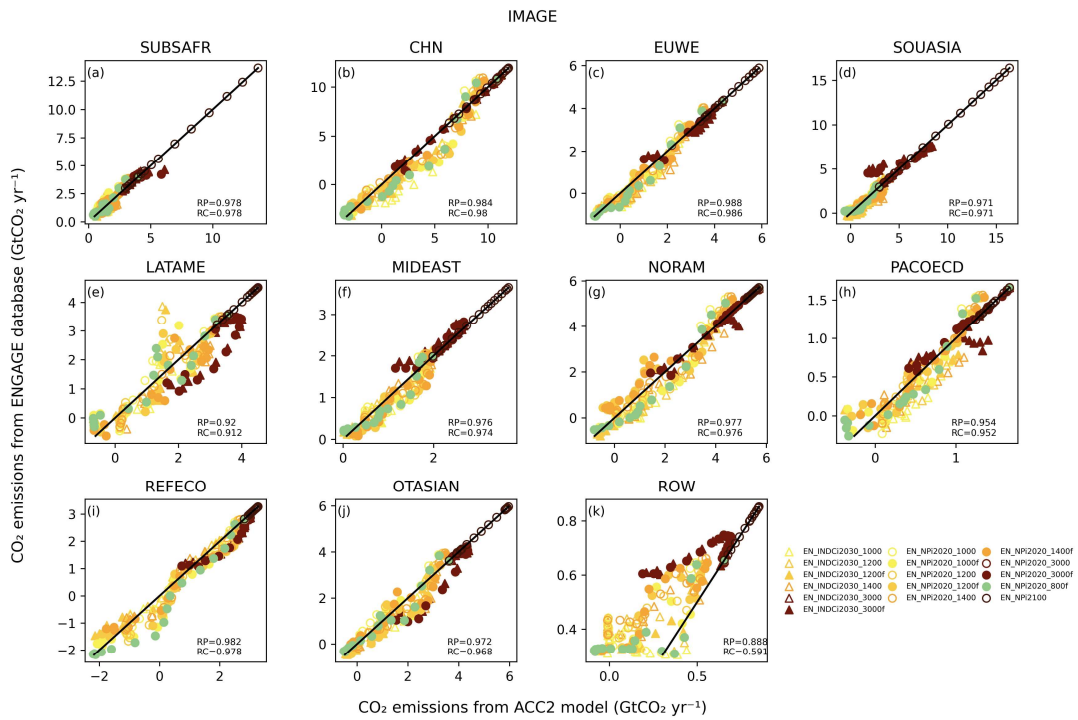


Figure S230. Test 4 - Regional IMAGE - Reproducibility of total anthropogenic CO₂

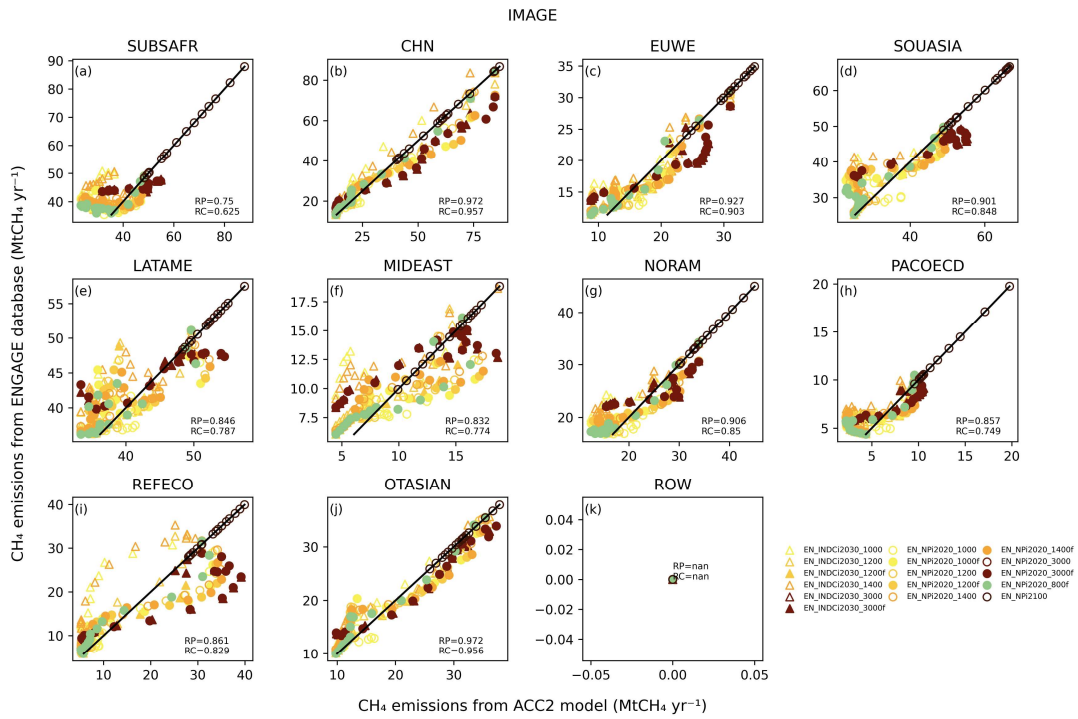


Figure S231. Test 4 - Regional IMAGE - Reproducibility of total anthropogenic CH₄

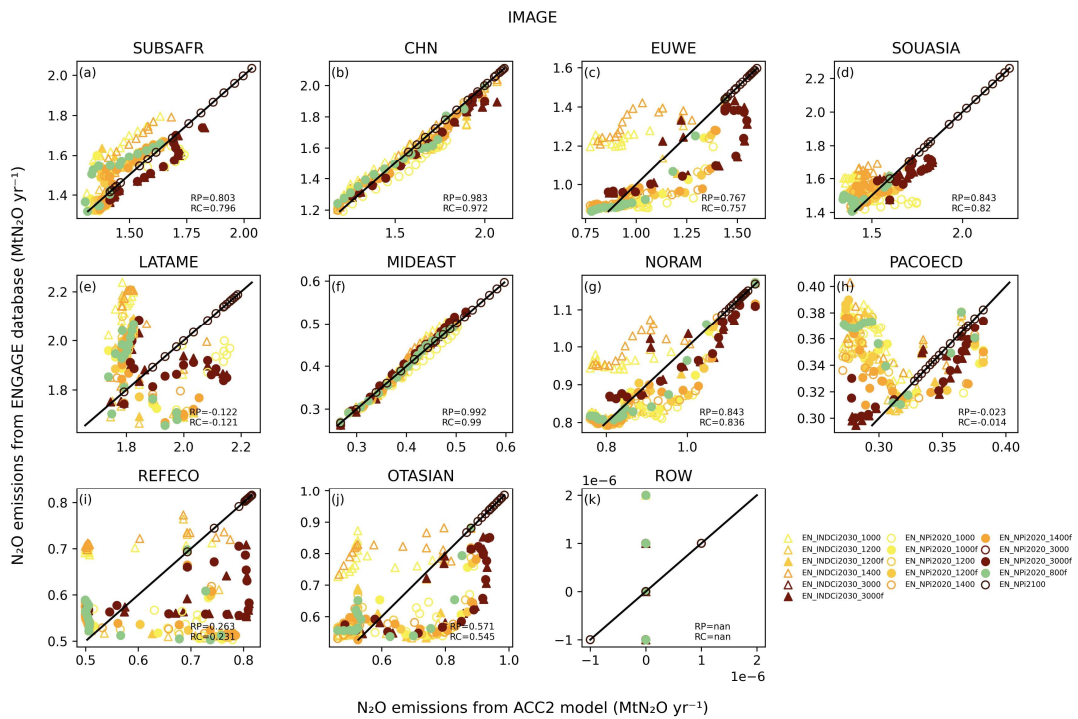


Figure S232. Test 4 - Regional IMAGE - Reproducibility of total anthropogenic N₂O

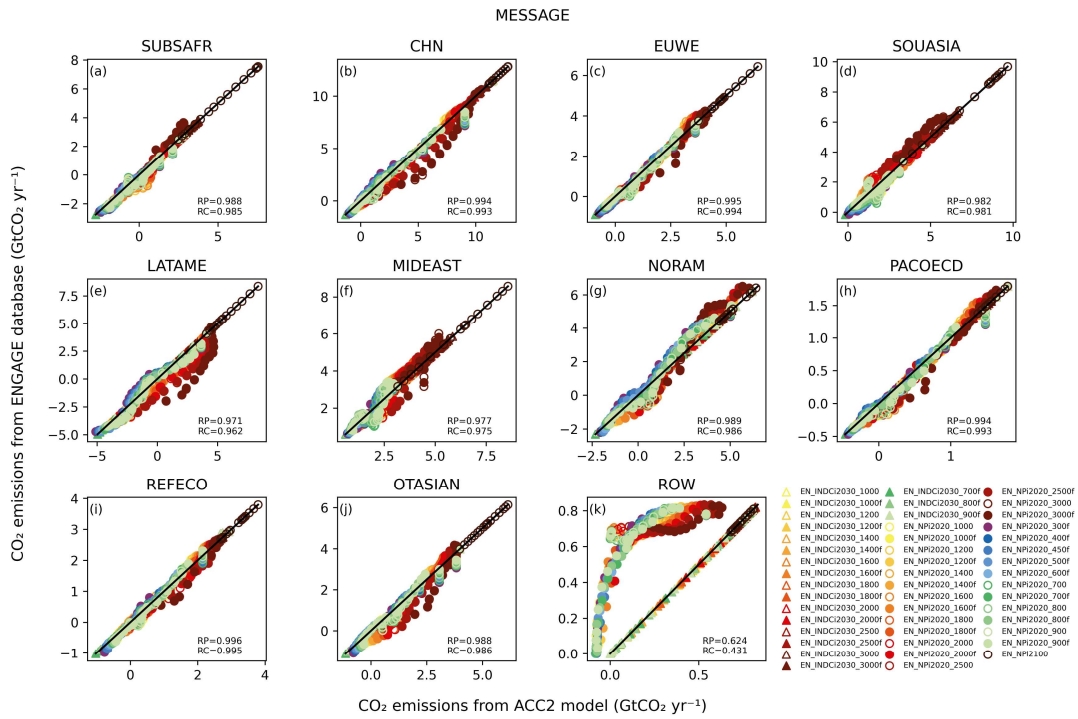


Figure S233. Test 4 - Regional MESSAGE - Reproducibility of total anthropogenic CO₂

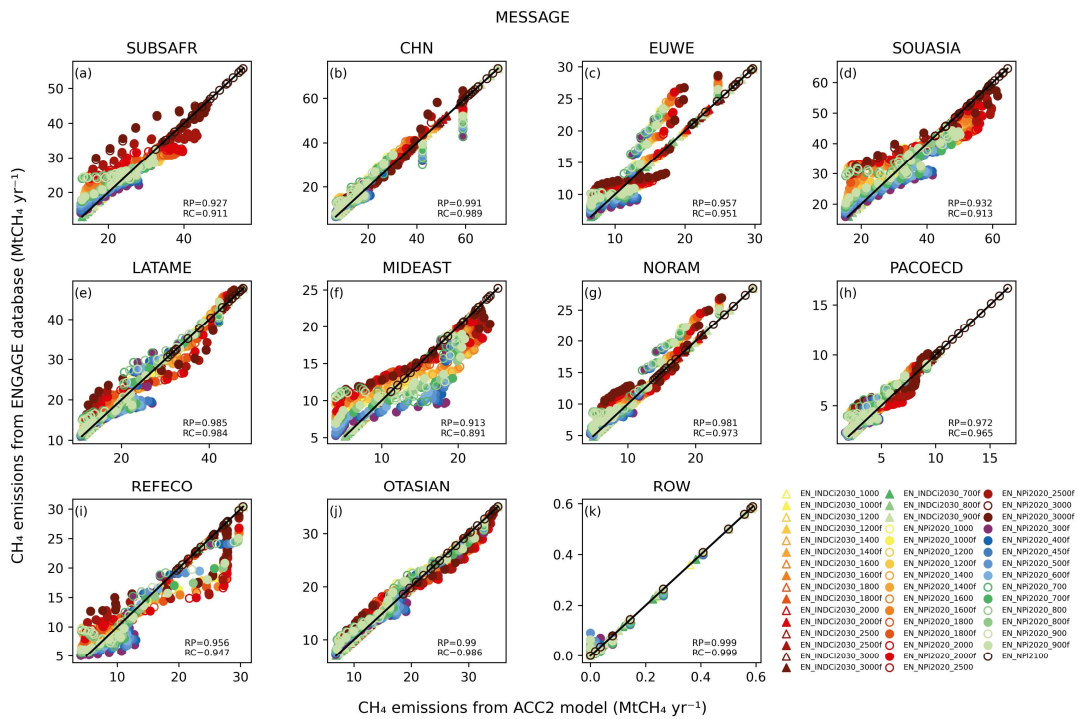


Figure S234. Test 4 - Regional MESSAGE - Reproducibility of total anthropogenic CH₄

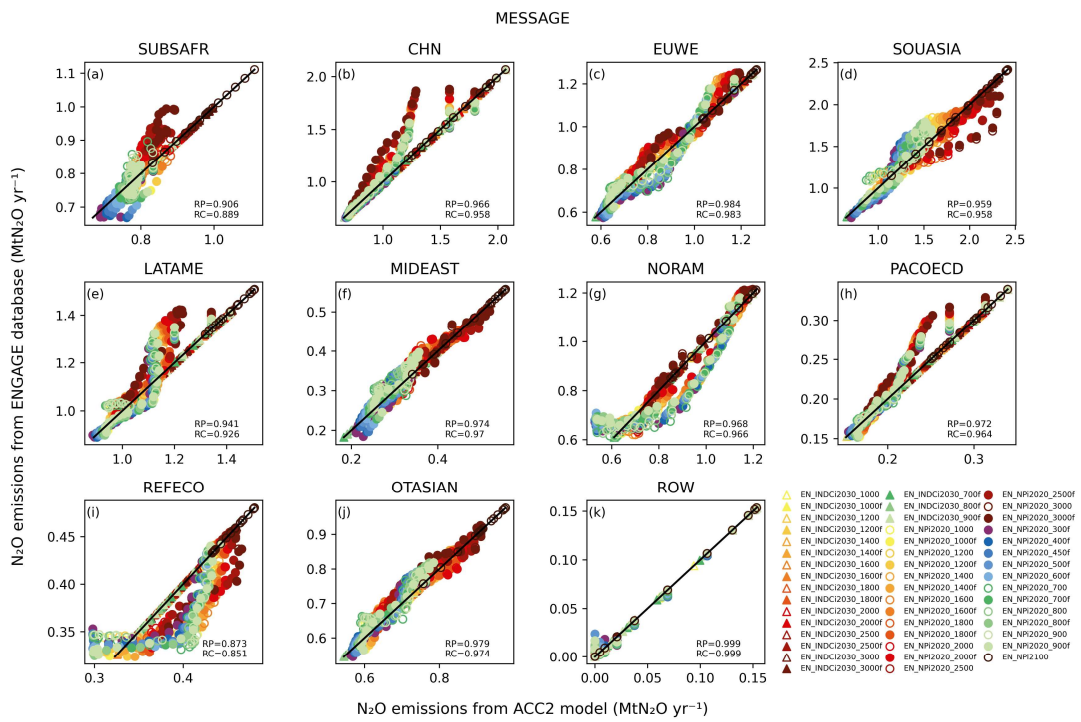


Figure S235. Test 4 - Regional MESSAGE - Reproducibility of total anthropogenic N₂O