Supplementary Information

Table S1. Regrouped region names and corresponding region names in each model.

Regrouped region name	IMAGE	EDGAR	QUANTIFY	IEA/SMP
North America	Canada, U. S.	Canada, U. S.	NAM	OECD North America
Latin America	Central America, South America	Mexico, Rest Central America, Brazil, Rest South America	LAM	Latin America
Africa	Northern Africa, Western Africa, Eastern Africa, Southern Africa	Northern Africa, Western Africa, Eastern Africa, Southern Africa	AFR	Africa
Europe	OECD Europe, Eastern Europe	OECD Europe, Central Europe	EU15, CEC	OECD Europe, Eastern Europe
Former USSR	Former USSR	Ukraine+, Asia-Stan, Russia+	CIS	FSU
Middle East	Middle East	Turkey, Middle East	MEA	Middle East
South Asia	South Asia	India+	SAS	India
East Asia	East Asia	Korea, China+	EAS	China
Southeast Asia	Southeast Asia	Southeastern Asia, Indonesia+	SEA	Other Asia
Pacific	Oceania, Japan	Oceania, Japan	OCN	OECD Pacific

Table S2. Key information, assumptions and major data sources for shipping fuel consumption.

Variable (unit)	Symbol[a]	Period	Data Source	Data Type	Flow/Product or Calculation
Marine distillate oil (MDO) by international marine bunkers (ktonne/year)	$FC_{IEA,MDO,int,k}(t)$	1971-2010	IEA[b]	raw	MARBUNK/GASDIES[e]
Marine distillate oil (MDO) by domestic navigation (ktonne/year)	$FC_{IEA,MDO,dom,k}(t)$	1971-2010	IEA[b]	raw	DOMESNAV/GASDIES[e]
Marine distillate oil (MDO)by fishing (ktonne/year)	$FC_{IEA,MDO,fishing,k}(t)$	1971-2010	IEA[b]	raw	FISHING/GASDIES[e]
Heavy (residual) fuel oil (HFO) by international marine bunkers (ktonne/year)	$FC_{IEA,HFO,int,k}(t)$	1971-2010	IEA[b]	raw	MARBUNK/RESFUEL+ other heavy fuel oil[e,]
Heavy (residual) fuel oil (HFO) by domestic navigation (ktonne/year)	$FC_{IEA,HFO,dom,k}(t)$	1971-2010	IEA[b]	raw	DOMESNAV/RESFUEL+ other heavy fuel oil[e]
Heavy (residual) fuel oil (HFO) by fishing (ktonne/year)	$FC_{IEA,HFO,fishing,k}(t)$	1971-2010	IEA[b]	raw	FISHING/RESFUEL+ other heavy fuel oil[e,f]
Global fuel consumption by shipping	$FC_{global,i}(t)$	2011-2050	IEA[b]; Eyring et al. (2005b)	calculated	$FC_{global,i}(t)=\begin{cases}\sum_l\sum_m\sum_k FC_{IEA,l,m,k}(t) & (t\le 2010)\\ FC_{global,i}(2010)\times\beta_i(t) & (t>2010)\end{cases}$ [f]
Regional fuel growth rate	$\alpha_{l,m,k,i}(t)$	2011-2050	IEA\SMP[c]; IMAGE[d]	calculated	$\alpha_{l,m,k,i}(t)=\left(\frac{GDP_{k,i}(t)}{GDP_{k,i}(t-1)}-1\right)^{\gamma_{k,m}}+1$ [g]
Regional fraction of fuel consumption	$f_{l,m,k,i(t)}$	2011-2050	-	calculated	$f_{l,m,k,i}(t)=\frac{f_{l,m,k}(2010)\times\alpha_{l,m,k,i}(t)}{\sum_l\sum_m\sum_k f_{l,m,k}(2010)\times\alpha_{l,m,k,i}(t)}$
Regional fuel consumption (ktonne/year)	$FC_{l,m,k,i}(t)$	2011-2050	-	calculated	$FC_{l,m,k,i}(t)=FC_{global,i}(t)\times f_{l,m,k,i}(t)$

[a] FC = Fuel Consumption; int = international marine bunker (MARBUNK), dom = domestic navigation (DOMESNAV); subscripts i, k, l, and m represent scenario (A1B, A2, B1, and B2), region (1-17), fuel type (MDO and HFO), and shipping category (int, dom, and fishing); variable t represents calendar year.
[b] IEA (2012a, b)
[c] Fulton and Eads (2004)
[d] RIVM (2001); MNP (2006)
[e] The integration is the same as Bond et al. (2004); GASDIES and RESFUEL represent gas/diesel and fuel oil.

[f] β is annual growth rate for global fuel consumption from Eyring et al. (2005); it is distinguished by scenario and calendar year. For years 2011-2020, β is 2.08%, 1.65%, 1.94%, and 1.85% per year for A1B, A2, B1, and B2, respectively; for years 2021-2050, the values are 1.93%, 1.14%, 1.59%, and 1.40% per year, respectively.

[g] GDP = Gross Domestic Product, from IMAGE (RIVM, 2001; MNP, 2006);γ, taken from IEA\SMP model (Fulton and Eads, 2004), is elasticity and represents the relative growth rate of fuel consumption to GDP

Table S3. Key information, assumptions and major data sources for aviation fuel consumption.

Variable (unit)	Symbol[a]	Period	Data Source	Data Type	Flow/Product or Calculation
Aviation fuel consumption (ktonne/year)	$FC_{IEA,air,k}(t)$	1971-2010	IEA[b]	raw	DOMESAIR+AVBUNK/AVGAS+JETGAS+JETKERO[e]
Global fuel consumption by aviation (ktonne/year)	$FC_{IEA,air,k,i}(t)$	2011-2050	-	calculated	$FC_{global,i}(t)=\begin{cases}\sum_k FC_{IEA,air,k}(t) & (t\le 2010)\\ FC_{global,i}(2010)\times\beta_i(t) & (t>2010)\end{cases}$ [f]
Regional fuel growth rate	$\alpha_{air,k,i(t)}$	2011-2050	IEA\SMP[c]; IMAGE[d]	calculated	$\alpha_{air,k,i}(t)=\left[\left(\frac{GDP_{k,i}(t)}{GDP_{k,i}(t-1)}-1\right)^{\gamma_k}+1\right]\times(1+\mu)$ [g]
regional fraction of fuel consumption	$f_{air,k,i(t)}$	2011-2050	-	calculated	$f_{air,k,i}(t)=\frac{f_{air,k}(2010)\times\alpha_{air,k,i}(t)}{\sum_k f_{air,k}(2010)\times\alpha_{air,k,i}(t)}$
Regional fuel consumption (ktonne/year)	$FC_{air,k,i}(t)$	2011-2050	-	calculated	$FC_{air,k,i}(t)=FC_{global,i}(t)\times f_{air,k,i}(t)$

[a] FC = Fuel Consumption; Air = Aviation, including domestic air (DOMESAIR) and international aviation bunkers (International aviation bunkers); subscripts *i* and *k* represent scenario (A1B, A2, B1, and B2) and region (1-17); variable t represents calendar year.
[b] IEA (2012a, b)
[c] Fulton and Eads (2004)
[d] RIVM (2001); MNP (2006)
[e] The integration is the same as Bond et al. (2004); AVGAS, JETGAS, and JETKERO represent aviation gasoline, gasoline type jet fuel, and kerosene type jet fuel, respectively.
[f] β is an annual growth rate for global fuel consumption from Owen et al. (2010); it is distinguished by scenario and calendar year. For years 2011-2020, β is 3.55% per year for all the four scenarios; for years 2021-2050, the values are 2.78%, 1.12%, 0.79%, and 0.86% per year, for A1B, A2, B1, and B2, respectively.
[g] GDP = Gross Domestic Product, from IMAGE (RIVM, 2001; MNP, 2006);γ, taken from IEA\SMP model (Fulton and Eads, 2004), is elasticity and represents the relative growth rate of revenue passenger kilometers (RPK) to GDP; μ is the improvement rate of energy intensity, it is also taken from IEA\SMP model (Fulton and Eads, 2004)

Table S4. Key information, assumptions and major data sources for rail fuel consumption.

Variable (unit)	Symbol[a]	Period	Data Source	Data Type	Flow/Product or Calculation
Rail oil consumption (ktonne/year)	$FC_{IEA,rail,Oil,k}(t)$	1971-2010	IEA[b]	raw	RAIL/GASDIES+RESFUEL+ other heavy fuel oil[e]
Rail coal consumption (ktonne/year)	$FC_{IEA,rail,Coal,k}(t)$	1971-2010	IEA[b]	raw	RAIL/ANTCOAL + COKCOAL+ other kinds of coal[e]
Regional energy growth rate	$\alpha_{rail,m,k,i}(t)$	2011-2050	IEA\SMP[c]; IMAGE[d]	calculated	$\alpha_{rail,m,k,i}(t)=\left[\left(\frac{GDP_{k,i}(t)}{GDP_{k,i}(t-1)}-1\right)^{\gamma_{m,k}}+1\right]\times\left(1+\mu_{m,k}\right)$ [f]
Regional oil consumption (except East Asia) (ktonne/year)	$FC_{rail,Oil,k,i}(t)$	2011-2050	IEA\SMP[c]	calculated	$FC_{rail,Oil,k,i}(t)=FC_{IEA,rail,Oil,k}(2010)\times\alpha_{rail,k,i}$ [g] $\left(\text{where } \alpha_{rail,k,i}=f_{frt,k}\times\alpha_{rail,frt,k,i}+f_{pass,k}\times\alpha_{rail,pass,k,i}\right)$
East Asia oil and coal consumption (ktonne/year)	$FC_{rail,l,EastAsia,i}(t)$	2011-2050	-	calculated	$FC_{rail,l,EastAsia,i}(t)=\frac{\left(\sum_{l=coal,oil}FC_{IEA,rail,l,East(2010)}\times Q_l\right)\times\alpha_{rail,EastAsia,i}\times X_l(t)}{Q_l}$ [h]

[a] FC = Fuel Consumption; subscripts *i*, *k*, and *m* represent scenario (A1B, A2, B1, and B2), region (1-17), subgroup of railway (freight and passenger rail transport); variable t represents calendar year.
[b] IEA (2012a, 2012b)
[c] Fulton and Eads (2004)
[d] RIVM (2001); MNP (2006)
[e] The integration is the same as Bond et al. (2004); GASDIES, RESFUEL, ANTCOAL, and COKCOAL represent gas/diesel, fuel oil, anthracite, and coking coal, respectively.
[f] GDP = Gross Domestic Product, from IMAGE (RIVM, 2001; MNP, 2006); γ, taken from IEA\SMP model (Fulton and Eads, 2004), is elasticity and represents the relative growth rate of total passenger-km of travel for passenger rail or total tonne-km of travel for freight rail to GDP; μ is an improvement rate of energy intensity, it is also taken from IEA\SMP model (Fulton and Eads, 2004)
[g] f is the fraction of energy by passenger and freight rail, coming from IEA\SMP model; frt = freight, pass = passenger; middle distillate and residual fuel are treated in the same way, so that the growth rate of energy is also the growth rate of oil consumption
[h] *l* represents coal or oil; Q_l is energy content of coal or oil; $X_l(t)$ is the fraction of coal or oil in calendar year t, and estimated by transition curve in Bond et al. (2004):

$X_{coal}(t)=\left(X_{coal,0}-X_{coal,f}\right)e^{\left[-(t-t_0)^2/2s^2\right]}+X_{coal,f}$, where X_0 and X_f are the initial and final values of the energy fraction by coal; t_0 is the time at which the transition begins, and *s* is the rate. Here $X_{coal,0}$ = 0.65, $X_{coal,f}$ = 0, t_0 = 2010, and s = 12 years. Then $X_{oil}(t)$ = 1- $X_{coal}(t)$.

Table S5. CO emission projections from different regions in years 2010, 2030, and 2050 (Unit: Tg/year).

Region	2010	2030				2050			
		A1B	A2	B1	B2	A1B	A2	B1	B2
Canada	1.84	1.68	1.52	1.38	1.30	1.66	1.59	1.18	1.00
U. S.	11.4	11.3	9.19	9.63	8.19	10.7	8.36	7.64	5.71
Central America	14.5	5.51	4.88	4.76	4.21	4.42	4.02	3.31	2.25
South America	11.0	5.67	5.17	4.86	4.43	5.15	4.97	4.06	2.98
Northern Africa	8.00	5.77	5.18	5.51	4.91	5.97	4.53	4.68	3.64
Western Africa	7.24	21.4	15.0	18.2	13.7	33.5	21.2	24.8	14.7
Eastern Africa	0.89	3.42	2.17	2.98	2.04	10.4	5.35	7.46	3.57
Southern Africa	6.38	4.08	3.18	3.55	3.12	2.93	1.81	2.07	1.47
OECD Europe	9.31	7.55	7.09	6.20	5.96	6.79	7.19	4.99	4.06
Eastern Europe	2.21	1.67	1.09	1.20	1.17	1.44	1.08	1.03	0.86
Former USSR	10.6	14.1	9.39	8.58	9.39	12.5	8.74	7.11	7.68
Middle East	11.5	6.73	6.24	5.72	5.30	8.26	8.43	5.57	5.53
South Asia	6.84	15.1	8.99	11.9	13.0	29.2	15.3	17.8	16.5
East Asia	20.5	20.7	12.9	17.6	17.5	22.2	11.0	15.3	16.7
Southeast Asia	11.0	10.0	6.67	7.78	7.77	10.7	7.14	7.24	6.49
Oceania	1.46	1.11	0.83	0.92	0.79	0.98	0.73	0.72	0.60
Japan	2.19	1.81	1.58	1.49	1.50	1.57	1.34	1.15	1.01
Total	137	138	101	112	104	168	113	116	95

Table S6. NO_x emission projections from different regions in years 2010, 2030, and 2050 (Unit: Tg/year).

Region	2010	2030				2050			
		A1B	A2	B1	B2	A1B	A2	B1	B2
Canada	0.80	0.52	0.47	0.46	0.46	0.58	0.46	0.43	0.41
U. S.	5.89	4.65	4.13	4.09	3.99	5.69	4.38	3.95	3.87
Central America	2.78	1.99	1.81	1.81	1.61	1.93	1.59	1.59	1.26
South America	4.45	3.21	3.01	2.92	2.77	3.39	2.82	2.78	2.31
Northern Africa	1.67	2.11	1.75	1.89	1.57	2.07	1.45	1.50	1.13
Western Africa	1.02	2.86	2.06	2.47	1.90	5.15	3.33	3.86	2.34
Eastern Africa	0.26	0.95	0.61	0.83	0.58	2.89	1.47	2.06	1.01
Southern Africa	1.22	1.63	1.26	1.44	1.21	1.48	0.96	1.13	0.90
OECD Europe	8.50	6.30	5.76	5.76	5.55	7.24	5.90	5.76	5.40
Eastern Europe	1.23	1.02	0.75	0.80	0.79	0.99	0.70	0.73	0.67
Former USSR	2.84	2.52	1.85	1.90	1.90	2.33	1.61	1.60	1.58
Middle East	5.49	4.86	4.59	4.48	4.15	5.78	5.03	4.60	4.09
South Asia	2.74	2.76	1.86	2.26	2.38	3.43	1.76	2.43	2.18
East Asia	8.71	9.81	7.41	8.46	8.81	12.3	7.59	9.24	9.48
Southeast Asia	6.31	6.82	5.56	5.97	6.25	8.23	5.85	6.59	6.69
Oceania	0.72	0.54	0.47	0.47	0.46	0.54	0.42	0.38	0.38
Japan	1.46	0.96	0.90	0.88	0.87	1.09	0.91	0.85	0.84
Total	56.1	53.5	44.2	46.9	45.2	65.1	46.2	49.5	44.5

Table S7. THC emission projections from different regions in years 2010, 2030, and 2050 (Unit: Tg/year).

Region	2010	2030				2050			
		A1B	A2	B1	B2	A1B	A2	B1	B2
Canada	0.19	0.16	0.14	0.13	0.13	0.17	0.14	0.12	0.11
U. S.	1.08	1.09	0.88	0.94	0.83	1.17	0.82	0.87	0.67
Central America	2.01	0.77	0.70	0.68	0.61	0.69	0.62	0.54	0.39
South America	1.64	0.85	0.78	0.74	0.69	0.83	0.76	0.67	0.51
Northern Africa	1.13	0.98	0.89	0.95	0.84	0.88	0.69	0.71	0.57
Western Africa	0.76	2.25	1.59	1.92	1.46	3.65	2.32	2.72	1.62
Eastern Africa	0.11	0.43	0.28	0.38	0.26	1.32	0.69	0.95	0.46
Southern Africa	0.72	0.58	0.45	0.51	0.45	0.44	0.28	0.33	0.24
OECD Europe	1.20	0.97	0.87	0.85	0.80	1.01	0.88	0.81	0.68
Eastern Europe	0.34	0.25	0.17	0.19	0.19	0.23	0.17	0.17	0.14
Former USSR	1.45	1.69	1.14	1.07	1.15	1.65	1.15	0.97	1.03
Middle East	1.77	1.10	1.03	0.97	0.91	1.37	1.32	0.98	0.94
South Asia	1.10	1.89	1.14	1.50	1.62	3.76	1.97	2.33	2.15
East Asia	3.09	3.18	2.12	2.72	2.76	3.64	1.96	2.62	2.79
Southeast Asia	1.75	1.63	1.18	1.33	1.35	1.92	1.31	1.40	1.31
Oceania	0.22	0.16	0.12	0.14	0.12	0.14	0.11	0.11	0.09
Japan	0.26	0.20	0.17	0.17	0.17	0.20	0.16	0.16	0.14
Total	18.8	18.2	13.6	15.2	14.3	23.1	15.3	16.5	13.8

Table S8. PM emission projections from different regions in years 2010, 2030, and 2050 (Unit: Tg/year).

Region	2010	2030				2050			
		A1B	A2	B1	B2	A1B	A2	B1	B2
Canada	0.06	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
U. S.	0.33	0.25	0.23	0.24	0.23	0.30	0.24	0.25	0.23
Central America	0.16	0.15	0.14	0.14	0.13	0.15	0.13	0.13	0.11
South America	0.35	0.25	0.24	0.24	0.23	0.25	0.22	0.22	0.18
Northern Africa	0.16	0.20	0.17	0.18	0.16	0.15	0.12	0.12	0.10
Western Africa	0.06	0.15	0.12	0.14	0.11	0.32	0.20	0.24	0.15
Eastern Africa	0.02	0.09	0.06	0.08	0.05	0.27	0.14	0.20	0.10
Southern Africa	0.09	0.14	0.11	0.13	0.11	0.12	0.08	0.09	0.08
OECD Europe	0.54	0.45	0.42	0.43	0.41	0.52	0.44	0.47	0.42
Eastern Europe	0.10	0.07	0.05	0.06	0.05	0.06	0.04	0.05	0.04
Former USSR	0.25	0.21	0.16	0.16	0.16	0.18	0.12	0.12	0.12
Middle East	0.44	0.40	0.38	0.38	0.35	0.43	0.37	0.37	0.32
South Asia	0.29	0.28	0.19	0.24	0.25	0.41	0.21	0.28	0.25
East Asia	0.82	0.96	0.71	0.85	0.87	0.91	0.57	0.73	0.74
Southeast Asia	0.55	0.61	0.51	0.55	0.57	0.73	0.52	0.62	0.62
Oceania	0.06	0.04	0.03	0.04	0.03	0.03	0.02	0.03	0.02
Japan	0.10	0.07	0.07	0.07	0.06	0.08	0.07	0.07	0.07
Total	4.37	4.36	3.62	3.93	3.80	4.94	3.53	4.02	3.58

Table S9. BC emission projections from different regions in years 2010, 2030, and 2050 (Unit: Gg/year).

Region	2010	2030				2050			
		A1B	A2	B1	B2	A1B	A2	B1	B2
Canada	23	10	8	9	8	9	7	7	6
U. S.	113	67	52	58	52	75	51	57	44
Central America	61	56	52	50	47	48	41	39	29
South America	152	100	95	90	88	84	72	67	55
Northern Africa	75	95	83	88	76	84	60	63	48
Western Africa	25	72	52	63	48	149	94	111	67
Eastern Africa	12	46	30	41	29	149	76	108	53
Southern Africa	38	62	49	55	48	51	31	37	30
OECD Europe	151	89	73	78	73	96	73	78	64
Eastern Europe	46	34	25	27	27	28	20	21	18
Former USSR	116	88	64	64	66	62	44	41	41
Middle East	170	140	134	127	121	133	123	100	93
South Asia	139	124	87	104	109	161	82	112	99
East Asia	265	283	208	244	253	179	114	129	135
Southeast Asia	171	154	125	132	138	146	101	110	107
Oceania	24	16	13	14	13	11	8	9	8
Japan	27	11	10	10	10	13	10	10	9
Total	1608	1447	1160	1254	1206	1478	1005	1100	906

Table S10. OC emission projections from different regions in years 2010, 2030, and 2050 (Unit: Gg/year).

Region	2010	2030				2050			
		A1B	A2	B1	B2	A1B	A2	B1	B2
Canada	17	8	7	7	7	7	6	6	5
U. S.	74	48	42	44	41	53	41	43	37
Central America	35	34	32	31	29	32	29	27	23
South America	74	59	57	54	52	51	46	43	35
Northern Africa	42	52	47	50	44	51	40	42	34
Western Africa	12	32	24	28	22	66	42	50	31
Eastern Africa	5	17	12	15	11	54	29	39	20
Southern Africa	17	28	22	25	22	27	16	20	17
OECD Europe	90	64	58	59	56	68	59	59	52
Eastern Europe	22	16	12	13	13	12	9	9	8
Former USSR	69	82	57	55	58	67	47	39	42
Middle East	83	76	73	71	67	72	66	59	53
South Asia	72	118	75	98	103	211	107	140	127
East Asia	160	259	178	227	233	188	104	143	151
Southeast Asia	97	110	87	96	98	118	83	93	91
Oceania	15	12	10	11	10	9	7	8	7
Japan	18	10	9	9	9	11	9	9	9
Total	902	1025	803	894	876	1097	740	830	740

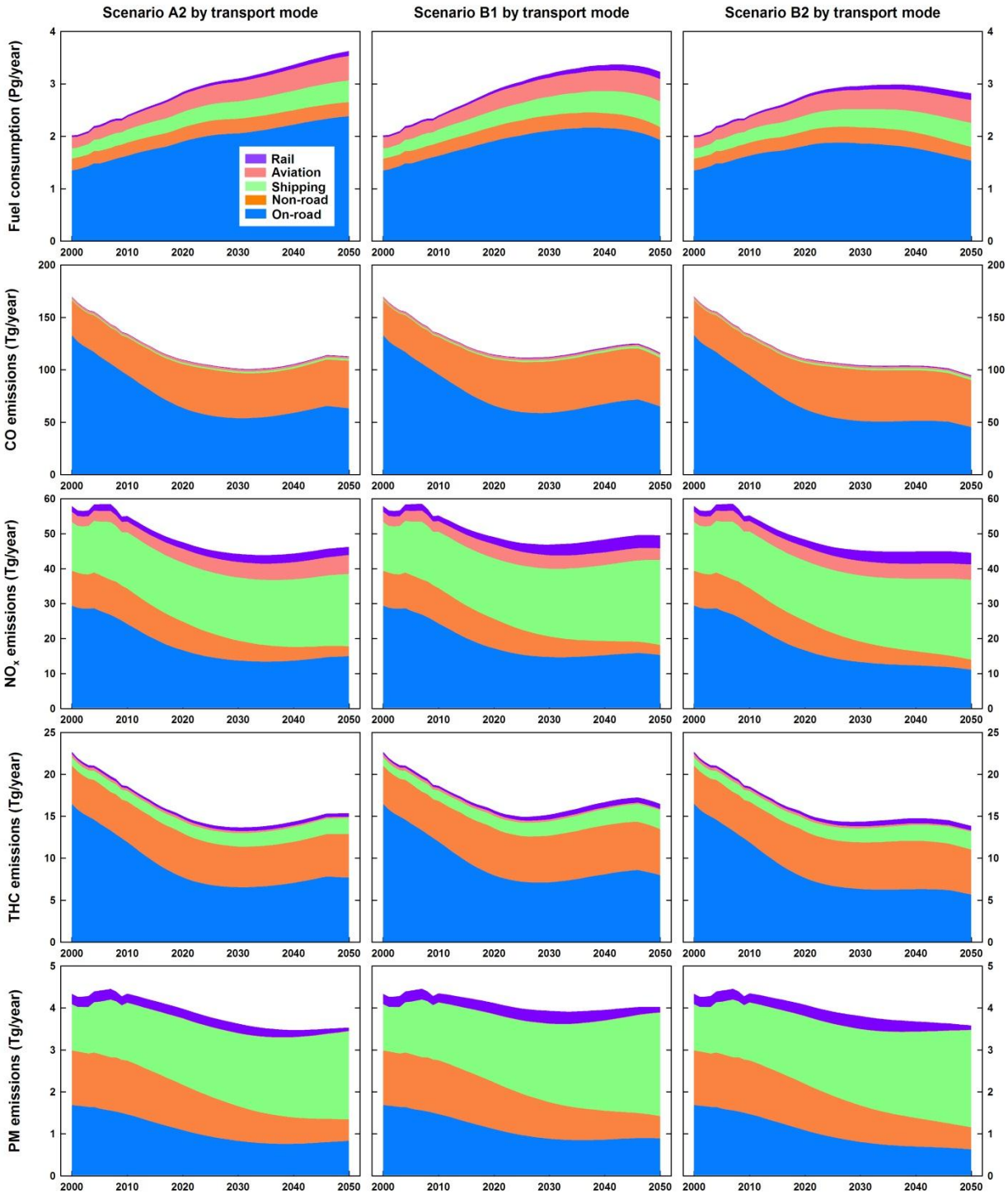
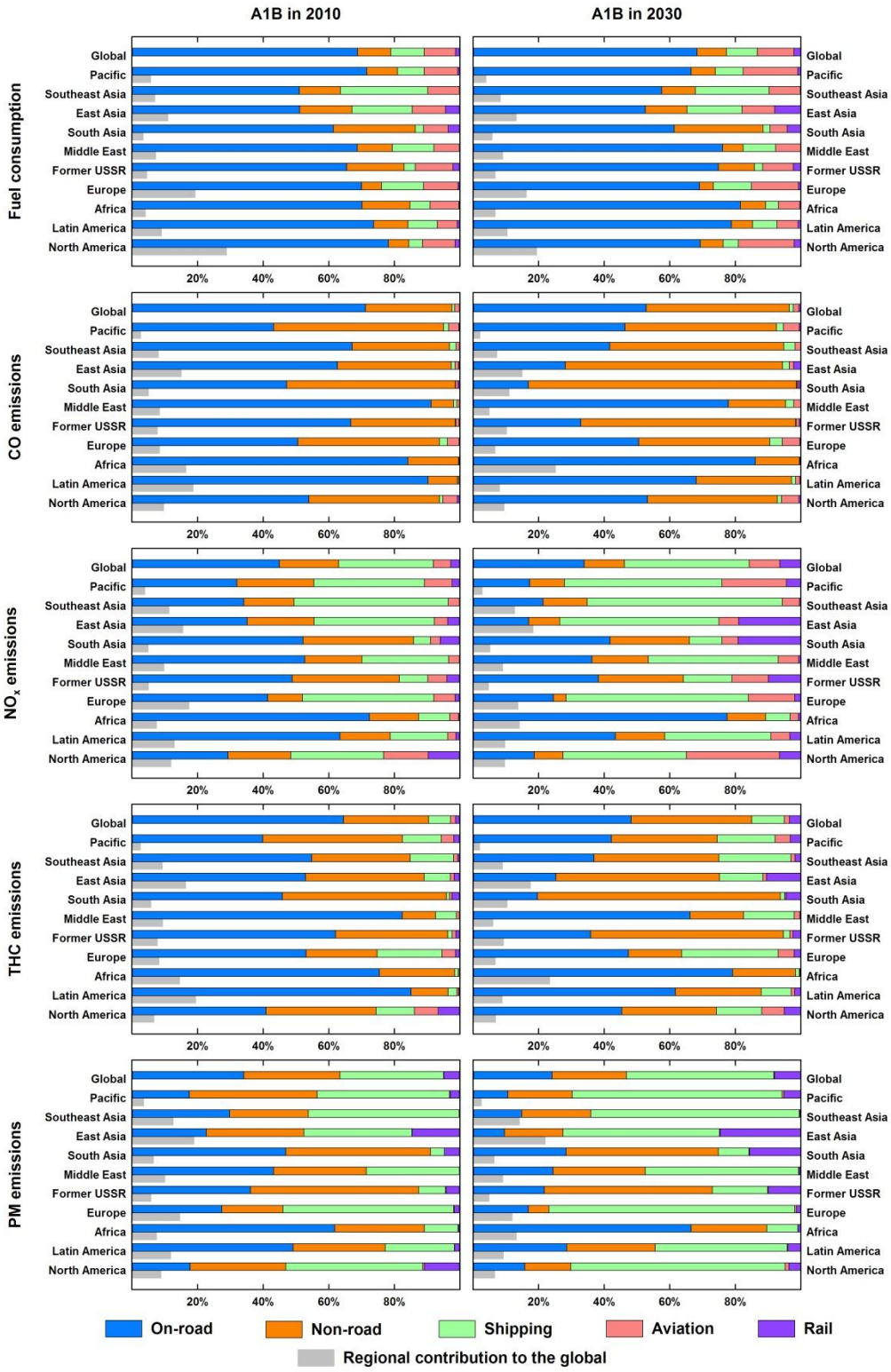


Fig. S1. Estimated global fuel consumption and emissions of CO, NOx, THC, and PM segregated by transport mode under scenarios A2 (left), B1 (middle), and B2 (right).


A1B in 2010
A1B in 2030
Fuel consumption
CO emissions
NOx emissions
THC emissions
PM emissions
Global
Pacific
Southeast Asia
East Asia
South Asia
Middle East
Former USSR
Europe
Africa
Latin America
North America
20%
40%
60%
80%
On-road
Non-road
Shipping
Aviation
Rail
Regional contribution to the global

63

Fig. S2. Transport mode contributions to fuel consumption and emissions of CO, NO_x, THC, and PM under scenario A1B in years 2010 (left) and 2030 (right). The grey bars represent the regional contributions to the global emissions.