Supplementary Information

S1. Detailed results of TM5-FASST

Health impacts of black carbon (BC), sulphur dioxide (SO_2), ammonia (NH_3) and organic carbon (OC) occur via fine particulate matter ($PM_{2.5}$); Non-Methane Volatile Organic Compound (NMVOC) emissions affect human health by acting as an ozone (O_3) precursor; NO_x health effects included are through second $PM_{2.5}$ and ozone formation. A minor indirect effect of SO_2 on ozone formation through hydroxyl radicals is also included. We assume equal toxicity for all components of fine particulate matter. Organic carbon is obtained through conversion of the impacts of particulate organic matter by multiplying with a conversion factor of 1.4. The average social cost per Gg air pollutant emissions used in this study can simply be deducted from the table above by multiplying with $2 million (2015) per premature death. $PM_{2.5}$-equivalent weights can easily be obtained from Table S1 by dividing the premature deaths per Gg for each pollutant by the corresponding number of primary $PM_{2.5}$. Primary $PM_{2.5}$ is the sum of black carbon and particulate organic matter. The TM5-FASST model was run including the urban increment option (see Van Dingenen et al., 2018b) and including H_2O in aerosol mass. For the sensitivity analysis in Section 3.4, total impacts from Table S2 are included. For methane, the number of premature deaths per Gg of CH_4 emissions is assumed to be unrelated to the source region of emissions, and equals 0.15 (0.50) premature deaths per Gg CH_4 in the year 2000 (2050). The description of the 56 regions is given in Table S3. To derive the number of premature deaths per Gg of emissions over time, we account for population growth and age structure (for ischemic heart disease and stroke), as well as the evolution of base mortality rates (up to 2040 and fixed thereafter) as in Stanaway et al. (2018).

Table S1 Premature deaths per Gg of emissions, including only within-region impacts. Source: Own calculations with the TM5-FASST model.

	2000							**2050**						
	Prim. $PM_{2.5}$	BC	POM	SO2	NH3	NOX	NMVOC	Prim. PM2.5	BC	POM	SO2	NH3	NOX	NMVOC
AUT	9.5	11.4	8.7	0.3	3.3	0.2	0.01	34.3	39.6	31.9	2.3	13.8	3.4	0.66
CHE	9.0	7.4	9.6	0.5	8.0	0.8	0.02	39.5	36.9	40.5	2.9	26.4	5.2	0.67
BLX	20.7	26.2	15.9	0.6	9.1	0.2	0.07	59.3	73.3	47.0	2.7	20.8	2.8	0.95
ESP	15.0	24.8	10.3	1.3	1.9	1.2	0.07	36.2	58.3	25.6	3.4	3.4	3.4	0.62
FIN	6.2	8.3	5.4	0.3	3.9	0.0	0.01	16.4	21.5	14.5	0.7	7.9	1.0	0.49
FRA	12.1	15.7	9.8	0.7	2.1	0.9	0.04	28.3	35.4	24.0	2.8	4.7	3.4	0.75
GBR	39.0	46.5	32.1	1.3	10.6	0.5	0.09	70.7	84.1	58.4	2.7	14.6	1.6	0.87
GRC	5.6	7.7	4.6	0.3	1.0	1.0	0.04	16.2	20.9	13.9	2.5	2.2	3.9	0.81
ITA	18.2	23.0	14.4	1.3	5.1	2.0	0.13	33.5	41.9	26.9	2.8	7.0	3.9	0.84
RFA	20.0	24.0	16.5	1.1	5.8	1.3	0.08	47.9	57.0	39.9	3.1	11.4	3.7	0.76
SWE	7.6	9.9	6.8	0.5	1.9	0.7	0.01	19.2	24.7	17.2	1.7	4.2	3.1	0.51
TUR	5.6	5.5	5.7	0.8	2.0	1.4	0.02	24.1	24.9	23.8	4.1	4.7	5.6	0.78
NOR	10.3	12.5	9.2	0.3	0.9	0.4	0.00	32.1	38.6	29.0	1.4	2.0	3.1	0.47
BGR	6.7	7.7	6.5	0.3	2.0	0.8	0.01	16.2	18.4	15.8	2.2	4.0	3.7	0.55
HUN	10.8	13.0	10.2	0.4	3.1	0.4	0.01	22.1	26.0	21.0	1.9	7.6	2.6	0.59
POL	10.2	12.6	9.5	0.6	5.7	0.4	0.03	19.5	23.7	18.3	1.7	8.1	2.0	0.65
RCEU	6.7	7.0	6.7	0.6	3.3	1.3	0.00	15.5	17.9	15.1	1.9	5.0	3.6	0.50
RCZ	7.4	8.4	7.0	0.3	3.5	0.3	0.02	24.6	28.1	23.3	1.8	10.5	2.5	0.63
ROM	11.2	11.8	11.1	0.7	2.7	1.2	0.01	22.0	24.2	21.6	2.5	4.8	3.8	0.60
MEME	7.9	7.1	8.1	0.5	1.5	0.3	0.03	36.7	34.4	37.5	3.9	4.2	2.9	0.69
NOA	5.6	5.1	5.8	0.7	0.4	0.4	0.03	19.7	19.1	19.9	2.9	0.7	2.9	0.44
EGY	42.5	49.2	38.9	1.2	7.7	0.6	0.16	94.0	108.7	86.3	3.5	12.5	3.4	1.12
GOLF	2.4	2.8	2.3	0.2	0.6	0.2	0.01	15.0	16.8	14.5	4.9	-1.8	4.1	0.51
WAF	3.8	4.7	3.7	1.6	0.2	0.7	0.02	3.6	4.3	3.5	0.9	-0.1	3.3	0.21
EAF	2.2	2.8	2.2	1.7	0.1	0.3	0.00	3.6	4.4	3.5	2.0	0.2	1.9	0.10
SAF	1.5	1.8	1.5	1.0	0.1	0.2	0.00	3.1	3.6	3.0	1.4	0.2	1.1	0.04
RSA	9.2	11.5	8.7	1.0	1.3	0.2	0.04	14.6	18.3	13.8	1.4	1.4	0.6	0.12
KAZ	1.2	1.6	1.2	0.1	0.5	0.2	0.00	5.7	7.0	5.5	1.0	1.7	3.4	0.45
RIS	15.2	15.4	15.2	0.6	3.8	0.5	0.01	30.8	31.7	30.7	2.5	4.3	3.4	0.60
RUS	22.1	29.0	20.9	1.1	5.3	1.0	0.03	23.7	30.6	22.5	1.1	4.2	2.3	0.58
RUE	1.6	3.8	1.5	0.4	0.6	0.5	0.00	3.7	5.8	3.5	1.1	0.9	4.2	0.36
UKR	20.9	22.2	20.7	1.3	4.5	1.8	0.02	28.1	30.4	27.7	2.2	4.4	3.2	0.62
COR	6.9	7.6	6.5	0.3	3.9	-0.8	0.34	26.8	27.8	26.3	3.4	12.3	1.0	3.69
JPN	20.2	21.8	19.1	2.0	7.3	0.6	0.08	25.0	26.9	23.6	1.9	6.2	1.9	0.79
AUS	0.5	1.4	0.4	0.1	0.1	0.0	0.00	2.1	5.0	1.7	0.5	0.2	0.5	0.04
NZL	0.3	0.3	0.3	0.0	0.0	0.0	0.00	1.1	1.3	0.9	0.1	0.1	0.1	0.02
PAC	0.3	0.3	0.3	0.1	0.3	0.1	0.00	1.5	1.4	1.6	0.5	0.9	1.3	0.04
MON	6.6	7.7	6.3	0.7	0.2	0.5	0.01	51.2	58.0	49.0	5.5	2.6	7.9	-0.42
CHN	15.6	12.4	16.6	2.7	4.9	5.4	0.45	50.9	40.9	54.2	6.4	11.3	17.6	1.89
TWN	8.0	8.4	7.7	0.8	2.0	0.0	0.09	47.6	49.6	46.5	5.4	10.6	7.8	1.44
RSAS	49.4	51.3	49.0	5.1	1.1	3.6	0.05	199.7	212.4	197.0	25.8	2.3	27.4	1.14
NDE	48.5	55.2	47.0	9.0	1.7	7.4	0.27	180.2	203.6	175.0	24.3	4.4	27.0	1.35
IDN	1.8	2.4	1.7	1.2	0.1	0.5	0.00	5.2	6.8	5.1	2.4	0.1	2.3	0.07
THA	4.9	5.8	4.6	1.2	0.2	0.5	0.00	11.3	12.5	10.9	2.9	0.4	6.7	0.22
MYS	1.8	2.6	1.7	0.5	0.1	0.1	0.00	5.2	7.4	4.8	1.7	0.2	2.8	0.12
PHL	12.0	12.3	12.0	1.1	1.4	0.4	0.02	35.8	36.6	35.6	2.5	3.0	3.8	0.37
VNM	8.5	7.6	8.7	1.7	0.5	0.2	-0.01	21.8	19.5	22.2	4.4	1.1	7.6	0.06
RSEA	4.0	4.0	3.9	1.7	0.1	1.2	-0.01	11.2	10.9	11.3	4.2	0.4	11.8	0.07
CAN	1.3	5.4	0.9	0.2	0.8	0.1	0.02	4.8	17.4	3.7	0.8	2.4	1.2	0.37
USA	12.1	18.3	9.9	1.0	3.3	0.3	0.15	22.4	33.7	18.3	1.3	4.4	0.9	0.61
BRA	2.5	6.4	2.0	1.5	0.2	0.3	0.01	6.6	16.4	5.3	2.8	0.4	0.9	0.04
MEX	4.3	6.6	4.0	0.7	0.7	0.5	0.02	13.0	20.0	12.0	1.6	1.5	2.5	0.29
RCAM	2.9	4.0	2.7	0.8	0.5	0.3	0.00	6.4	8.2	6.2	1.2	0.6	1.9	0.20
CHL	9.0	10.2	8.7	0.2	1.6	0.2	0.06	20.2	22.8	19.5	0.5	2.5	0.5	0.16
ARG	8.5	18.5	6.3	1.1	0.2	0.1	0.01	5.3	11.1	4.0	0.6	0.1	0.5	0.05
RSAM	2.0	3.6	1.8	1.6	0.3	0.1	0.00	6.1	10.8	5.5	3.4	0.7	0.9	0.05

Table S2 Premature deaths per Gg of emissions, including impacts within and outside of the source region. Source: Own calculations with the TM5-FASST model.

	2000							**2050**						
	Prim. $PM_{2.5}$	BC	POM	SO2	NH3	NOX	NMVOC	Prim. PM2.5	BC	POM	SO2	NH3	NOX	NMVOC
AUT	21.9	25.2	20.4	2.2	12.7	2.8	0.26	34.3	39.6	31.9	2.3	13.8	3.4	0.66
CHE	22.7	21.6	23.2	2.5	21.8	3.9	0.27	39.5	36.9	40.5	2.9	26.4	5.2	0.67
BLX	33.9	41.9	26.9	2.4	17.0	2.4	0.44	59.3	73.3	47.0	2.7	20.8	2.8	0.95
ESP	16.7	26.9	11.9	2.5	2.3	1.9	0.23	36.2	58.3	25.6	3.4	3.4	3.4	0.62
FIN	9.8	12.6	8.7	0.8	6.9	0.9	0.18	16.4	21.5	14.5	0.7	7.9	1.0	0.49
FRA	17.8	22.4	15.1	2.5	4.2	2.5	0.31	28.3	35.4	24.0	2.8	4.7	3.4	0.75
GBR	42.2	50.3	34.9	2.4	12.5	1.4	0.38	70.7	84.1	58.4	2.7	14.6	1.6	0.87
GRC	9.8	12.7	8.3	2.0	2.1	2.5	0.25	16.2	20.9	13.9	2.5	2.2	3.9	0.81
ITA	21.1	26.4	16.9	2.5	6.4	2.9	0.34	33.5	41.9	26.9	2.8	7.0	3.9	0.84
RFA	28.4	33.7	23.7	2.8	9.9	3.0	0.34	47.9	57.0	39.9	3.1	11.4	3.7	0.76
SWE	11.4	14.6	10.2	1.5	3.6	2.5	0.19	19.2	24.7	17.2	1.7	4.2	3.1	0.51
TUR	10.2	10.8	10.1	2.5	2.8	2.6	0.22	24.1	24.9	23.8	4.1	4.7	5.6	0.78
NOR	13.5	16.2	12.2	1.2	1.1	2.0	0.15	32.1	38.6	29.0	1.4	2.0	3.1	0.47
BGR	14.3	16.3	13.9	2.1	5.0	3.3	0.18	16.2	18.4	15.8	2.2	4.0	3.7	0.55
HUN	19.2	22.5	18.2	2.1	8.9	2.4	0.22	22.1	26.0	21.0	1.9	7.6	2.6	0.59
POL	16.5	19.9	15.5	2.0	9.6	1.9	0.25	19.5	23.7	18.3	1.7	8.1	2.0	0.65
RCEU	10.8	12.5	10.5	1.9	5.2	3.1	0.17	15.5	17.9	15.1	1.9	5.0	3.6	0.50
RCZ	19.4	21.9	18.5	2.0	11.6	2.3	0.25	24.6	28.1	23.3	1.8	10.5	2.5	0.63
ROM	21.5	23.5	21.1	2.8	6.4	3.9	0.21	22.0	24.2	21.6	2.5	4.8	3.8	0.60
MEME	11.3	10.8	11.5	2.0	1.7	0.9	0.18	36.7	34.4	37.5	3.9	4.2	2.9	0.69
NOA	7.8	7.7	7.8	2.0	0.4	1.2	0.15	19.7	19.1	19.9	2.9	0.7	2.9	0.44
EGY	44.5	51.4	40.8	2.6	8.0	1.1	0.30	94.0	108.7	86.3	3.5	12.5	3.4	1.12
GOLF	5.6	6.3	5.3	2.7	0.0	1.3	0.13	15.0	16.8	14.5	4.9	-1.8	4.1	0.51
WAF	4.1	5.0	4.0	1.7	0.0	0.9	0.05	3.6	4.3	3.5	0.9	-0.1	3.3	0.21
EAF	2.7	3.4	2.7	2.3	0.2	0.6	0.03	3.6	4.4	3.5	2.0	0.2	1.9	0.10
SAF	2.0	2.3	2.0	1.4	0.1	0.3	0.01	3.1	3.6	3.0	1.4	0.2	1.1	0.04
RSA	9.4	11.8	8.9	1.3	1.3	0.3	0.05	14.6	18.3	13.8	1.4	1.4	0.6	0.12
KAZ	4.2	5.2	4.0	0.8	2.0	1.9	0.14	5.7	7.0	5.5	1.0	1.7	3.4	0.45
RIS	18.2	18.8	18.1	1.7	4.1	1.1	0.17	30.8	31.7	30.7	2.5	4.3	3.4	0.60
RUS	24.5	31.8	23.2	1.7	6.4	1.8	0.19	23.7	30.6	22.5	1.1	4.2	2.3	0.58
RUE	2.4	4.6	2.3	0.9	0.9	1.9	0.11	3.7	5.8	3.5	1.1	0.9	4.2	0.36
UKR	26.5	28.8	26.1	2.6	6.3	3.4	0.22	28.1	30.4	27.7	2.2	4.4	3.2	0.62
COR	10.1	10.6	9.8	1.8	6.8	0.5	1.05	26.8	27.8	26.3	3.4	12.3	1.0	3.69
JPN	20.4	22.0	19.2	2.1	7.3	1.1	0.26	25.0	26.9	23.6	1.9	6.2	1.9	0.79
AUS	0.6	1.5	0.5	0.2	0.1	0.1	0.01	2.1	5.0	1.7	0.5	0.2	0.5	0.04
NZL	0.3	0.4	0.3	0.1	0.0	0.0	0.01	1.1	1.3	0.9	0.1	0.1	0.1	0.02
PAC	0.3	0.3	0.3	0.2	0.3	0.3	0.01	1.5	1.4	1.6	0.5	0.9	1.3	0.04
MON	10.3	11.4	9.9	2.0	1.1	2.6	-0.13	51.2	58.0	49.0	5.5	2.6	7.9	-0.42
CHN	16.1	13.0	17.2	3.0	5.1	5.9	0.52	50.9	40.9	54.2	6.4	11.3	17.6	1.89
TWN	8.9	9.2	8.8	2.0	3.9	2.0	0.40	47.6	49.6	46.5	5.4	10.6	7.8	1.44
RSAS	76.1	80.4	75.2	12.9	1.4	9.2	0.28	199.7	212.4	197.0	25.8	2.3	27.4	1.14
NDE	54.1	60.9	52.6	11.0	1.9	8.3	0.33	180.2	203.6	175.0	24.3	4.4	27.0	1.35
IDN	2.0	2.6	2.0	1.3	0.1	0.6	0.02	5.2	6.8	5.1	2.4	0.1	2.3	0.07
THA	6.3	7.0	6.1	2.2	0.3	1.8	0.06	11.3	12.5	10.9	2.9	0.4	6.7	0.22
MYS	2.4	3.5	2.3	1.1	0.1	0.6	0.03	5.2	7.4	4.8	1.7	0.2	2.8	0.12
PHL	12.1	12.4	12.0	1.2	1.4	0.8	0.08	35.8	36.6	35.6	2.5	3.0	3.8	0.37
VNM	10.0	8.9	10.2	3.0	0.7	1.9	0.02	21.8	19.5	22.2	4.4	1.1	7.6	0.06
RSEA	6.1	6.0	6.1	3.2	0.3	3.0	0.03	11.2	10.9	11.3	4.2	0.4	11.8	0.07
CAN	2.1	7.3	1.6	0.6	1.6	0.7	0.14	4.8	17.4	3.7	0.8	2.4	1.2	0.37
USA	12.5	18.9	10.2	1.0	3.5	0.5	0.27	22.4	33.7	18.3	1.3	4.4	0.9	0.61
BRA	2.7	6.6	2.1	1.7	0.2	0.4	0.01	6.6	16.4	5.3	2.8	0.4	0.9	0.04
MEX	4.6	7.1	4.3	0.9	0.8	0.9	0.09	13.0	20.0	12.0	1.6	1.5	2.5	0.29
RCAM	3.4	4.5	3.3	1.0	0.5	0.7	0.06	6.4	8.2	6.2	1.2	0.6	1.9	0.20
CHL	9.7	11.0	9.4	0.4	1.8	0.3	0.07	20.2	22.8	19.5	0.5	2.5	0.5	0.16
ARG	8.7	18.8	6.5	1.2	0.2	0.2	0.02	5.3	11.1	4.0	0.6	0.1	0.5	0.05
RSAM	2.3	3.9	2.0	1.7	0.4	0.3	0.01	6.1	10.8	5.5	3.4	0.7	0.9	0.05

Table S3 The 56 regions of the TM5-FASST model

Region description	Code	Region description	Code
Austria, Slovenia and Liechtenstein	AUT	Rest of former Soviet Union	RIS
Switzerland	CHE	Russia, Armenia, Georgia and Azerbeijan	RUS
Belgium, Luxemburg and Netherlands	BLX	Eastern part of Russia	RUE
Spain and Portugal	ESP	Ukraine, Belarus and Moldovia	UKR
Finland	FIN	South Korea	COR
France and Andorra	FRA	Japan	JPN
Great Britain and Ireland	GBR	Australia	AUS
Greece and Cyprus	GRC	New Zealand	NZL
Italy, Malta, San Marino and Monaco	ITA	Pacific Islands and Papua New Guinea	PAC
Germany	RFA	Mongolia and North Korea	MON
Sweden and Denmark	SWE	China, Hong Kong and Macao	CHN
Turkey	TUR	Taiwan	TWN
Norway, Iceland and Svalbard	NOR	Rest of South Asia	RSAS
Bulgaria	BGR	India, Maldives and Sri Lanka	NDE
Hungary	HUN	Indonesia and East Timor	IDN
Poland and Baltic states	POL	Thailand	THA
Serbia, Montenegro, Macedonia and Albania (Rest of Central Europe)	RCEU	Malaysia, Singapore and Brunei	MYS
Czech Republic and Slovakia	RCZ	Philippines	PHL
Romania	ROM	Vietnam	VNM
Israel, Jordan, Lebanon, Palestine Territories and Syria (Near East)	MEME	Cambodia, Laos and Myanmar	RSEA
Morocco, Tunisia, Libya and Algeria	NOA	Canada and Greenland	CAN
Egypt	EGY	United States	USA
Gulf states	GOLF	Brazil	BRA
West Africa	WAF	Mexico	MEX
Eastern Africa	EAF	Central America and Caribbean	RCAM
Southern Africa (ex RSA)	SAF	Chile	CHL
Republic of South Africa, Swaziland and Lesotho	RSA	Argentina, Falklands and Uruguay	ARG
Kazachstan	KAZ	Rest South America	RSAM

S2. Background on the POLES-JRC model

The POLES model (Prospective Outlook on Long-term Energy System) is a global energy system model covering final energy demand, transformation and electricity generation, primary energy supply, global trade of energy commodities and international fuel prices. Storage options are included and particular attention is paid to the modelling of the integration of intermittent renewables in the energy system (Després et al., 2017).

In addition, the model calculates the evolution of greenhouse gas and air pollutant emissions endogenously. The model covers all six Kyoto greenhouse gases and all major air pollutant emissions (SO_2, NO_x, NMVOCs, CO, BC, OC, $PM_{2.5}$, PM_{10}, and NH_3). Greenhouse gas emissions are calculated directly for emissions related to energy use, and by combining inputs from specialist models with the relevant drivers that are represented in the POLES model for non-combustion greenhouse gas emissions, as in agriculture and land use. The pollutant emissions are calculated as the product of activity and the pollutant-, sector- and fuel-specific emissions intensity factors based on IIASA (2015).

The POLES model-specific results presented in Section 3.2 were derived with the version of the POLES-JRC model that largely corresponds with the descriptions in Després et al. (2018) and Keramidas et al. (2018). Here, we provide more details on this version of the model, which includes updates compared to the version used to produce the scenarios that were submitted to the EMF-30 database (which is used in Section 3.3). Here, we focus the discussion on a subset of relevant updates, while referring to Després et al. (2018) for a more elaborate model description, including a detailed list of pollutant-, sector- and fuel- or process-specific activity indicators for greenhouse gas and air pollutant emissions.

First, we have introduced a distinction of buildings energy consumption by end-use. Space heating, space cooling, water heating, cooking and appliances are now represented separately. This development allows for a more detailed modelling of mitigation options, which in turn may improve the co-benefit estimate in the residential and services sector. Second, we have updated agriculture and land-use emissions and mitigation costs using more recent information from the GLOBIOM-G4M model (Havlík et al., 2014; Kindermann et al., 2008), and we now limit potential mitigation to the maximum carbon price point provided by GLOBIOM-G4M. For the EU Member States, we now base the relation between N_2O and NH_3 mitigation on the eCampa2 study with the CAPRI model (Pérez Domínguez et al., 2016). Taking on board the expertise embedded in agricultural models improves the co-benefit estimates for the agricultural sector. Third, we have refined our processing of air pollutant emission factors in general. An enhanced quality control process, combined with a shift towards a higher degree of automation in data processing has improved the implementation of air pollutant emissions in the POLES-JRC model. Further model updates include the use of more recent historical data, an update of expected learning for the cost of low-carbon technologies, an updated oil and gas supply module, and a revised modelling of carbon capture, including retrofit options for existing power plants and direct CO2 air capture.

The scenario set-up for the POLES-specific scenarios presented in Section 3.2 slightly differs from the one used in the scenarios in the EMF-30 database. The Reference takes into account an update of current and adopted climate and energy-related policies, as described in Keramidas et al. (2018), while the EMF-30 Reference includes no climate policy. The 2°C scenario in Section 3.2 builds on a differentiation of carbon prices across countries based on per capita income with a progressive convergence by 2050, as also described in Keramidas et al. (2018), while the EMF-30 climate policy scenarios model globally uniform carbon prices. Apart from these two differences, the Reference and 2°C scenario follow the same logic and roughly correspond to the Reference and ClimPolicy scenario in the EMF-30 database.

The supplementary Excel file presents pollutant-, region-, sector- and scenario-specific emissions for the years 2030 and 2050.

S3. Additional information on EMF-30

The 30th Energy Modeling Forum (EMF) was set up with the aim to provide insight into the role of short-lived climate forcers in climate policy. A consistent set of scenarios was designed, enabling an inter-comparison of results from various models. The EMF-30 database is particularly useful for the analysis in this paper, as it includes both greenhouse gas and air pollutant emissions on a sector-specific level. The results presented in Section 3.3 make use of scenario results of all models participating in EMF-30, so we are greatly indebted for the corresponding efforts of the respective modelling teams. To identify the sectors with relatively high air quality co-benefits, we have selected the scenarios with broad-based uniform carbon tax coverage only for all Kyoto greenhouse gases: ClimPolicy_V3, Slower-Action_V3 and Slower-to-faster_V3. These are compared to Reference_V3. These scenarios are described as follows:

Reference: No climate policy, default model improvements in methane emission factors, default long-term pollutant emission controls. (If an IAM group wishes to use SSPs, use SSP2.)

ClimPolicy: Global cumulative fossil CO_2 emissions constraint of 1,000 $GtCO_2$ from 2011-2100). This budget corresponds to the upper end of emission budgets of scenarios in the 430-480ppm category of likely 2°C scenarios, and is also used in the ADVANCE/IAMC community diagnostics exercise. Modelers should apply the same CO_2 price to land-use CO_2 and other GHG emissions. Models with a time horizon until 2050 should also apply a 2011-2050 budget of 1,000 $GtCO_2$, implicitly assuming carbon neutrality for the 2nd half of the century.

Slower-Action: Scenario with slower action on greenhouse gas reductions that replicates near-term developments consistent with the "intended nationally determined contributions" (INDC) currently negotiated under the UNFCCC. If available, modeling teams should submit a scenario with an explicit representation of the INDCs and their long-term extrapolation. As an alternative, they may construct a simplified Slower Action scenario with (a) 2030 CO_2 (incl. LULUCF) emissions of 39 $GtCO_2$ (tolerance range 37-41 $GtCO_2$), and cumulative 2011-2100 CO_2 (excl. LULUCF) emissions of 3,500 $GtCO_2$ (tolerance range 3,200 and 3,800 $GtCO_2$). Modelers should apply the same CO2e price to land-use CO_2 and other GHG emissions.

Slower-to-faster: Combination of Slower Action and Climate Policy scenarios. Pathways follow the Slower Action development until 2030. Thereafter, they still aim at limiting global cumulative fossil CO_2 emissions to 1,000 $GtCO_2$ from 2011-2100). After 2030, modelers should apply the same CO_2e price to land-use CO_2 and other GHG emissions.

In order to derive meaningful results, we have processed the database for the specific purposes of our analysis. Since NO_x emissions for energy demand by industry and residential sector not reported separately, we assume proportional reductions for both. We furthermore exclude NH_3 emissions from transport from one model because of a reporting issue. In addition, we apply a filter to look only at year-scenario-model-sector combinations that reduce CO_2 emissions by at least 2%. We do this to avoid a very small denominator in the calculation of co-benefits per tonne of greenhouse gases abated, which may be driven by other things than climate policy, and hence are not the focus of our study. Finally, we apply the following sector aggregation:

Table S4 Sector aggregation

EMF-30 database category	Aggregated sector
Energy Demand|Transportation	Transport
Energy Demand|Industry	Industry
Solvents	Industry
Energy Demand|Residential and Commercial	Residential
Energy Demand|Other Sector	Residential
Energy Supply	Energy
Land Use	AFOLU and waste
Waste	AFOLU and waste

The region definition in EMF-30 is the following:

REF = Countries from the **Reforming Economies** region (Albania, Armenia, Azerbaijan, Belarus, Bosnia and Herzegovina, Bulgaria, Croatia, Cyprus, Czech Republic, Estonia, Georgia, Hungary, Kazakhstan, Kyrgyzstan, Latvia, Lithuania, Malta, Poland, Republic of Moldova, Romania, Russian Federation, Slovakia, Slovenia, Tajikistan, TFYR Macedonia, Turkmenistan, Ukraine, Uzbekistan, rest of former Yugoslavia).

ASIA = The countries included in the regions China + (China, China Hong Kong SAR, China Macao SAR, Mongolia, Taiwan) , India + (Afghanistan, Bangladesh, Bhutan, India, Maldives, Nepal, Pakistan, Sri Lanka) and Rest of Asia (Brunei Darussalam, Cambodia, Democratic People's Republic of Korea, East Timor, Indonesia, Lao People's Democratic Republic, Malaysia, Myanmar, Papua New Guinea, Philippines, Republic of Korea, Singapore, Thailand, Viet Nam) are aggregated into this region.

MAF = This region includes the **Middle East** (Bahrain, Iran (Islamic Republic of), Iraq, Israel, Jordan, Kuwait, Lebanon, Oman, Qatar, Saudi Arabia, Syrian Arab Republic, United Arab Emirates, Yemen) **and African countries** (Algeria, Angola, Benin, Botswana, Burkina Faso, Burundi, Cote d'Ivoire, Cameroon, Cape Verde, Central African Republic, Chad, Comoros, Congo, Democratic Republic of the Congo, Djibouti, Egypt, Equatorial Guinea, Eritrea, Ethiopia, Gabon, Gambia, Ghana, Guinea, Guinea-Bissau, Kenya, Lesotho, Liberia, Libyan Arab Jamahiriya, Madagascar, Malawi, Mali, Mauritania, Mauritius, Morocco, Mozambique, Namibia, Niger, Nigeria, Reunion, Rwanda, Senegal, Sierra Leone, Somalia, South

Africa, Sudan, Swaziland, Togo, Tunisia, Uganda, United Republic of Tanzania, Western Sahara, Zambia, Zimbabwe).

LAM = This region includes the **Latin American countries** (Argentina, Bahamas, Barbados, Belize, Bolivia, Brazil, Chile, Colombia, Costa Rica, Cuba, Dominican Republic, Ecuador, El Salvador, Guadeloupe, Guatemala, Guyana, Haiti, Honduras, Jamaica, Martinique, Mexico, Netherlands Antilles, Nicaragua, Panama, Paraguay, Peru, Puerto Rico, Suriname, Trinidad and Tobago, Uruguay, Venezuela).

Table S5 Number of models in the EMF-30 database by region and scenario

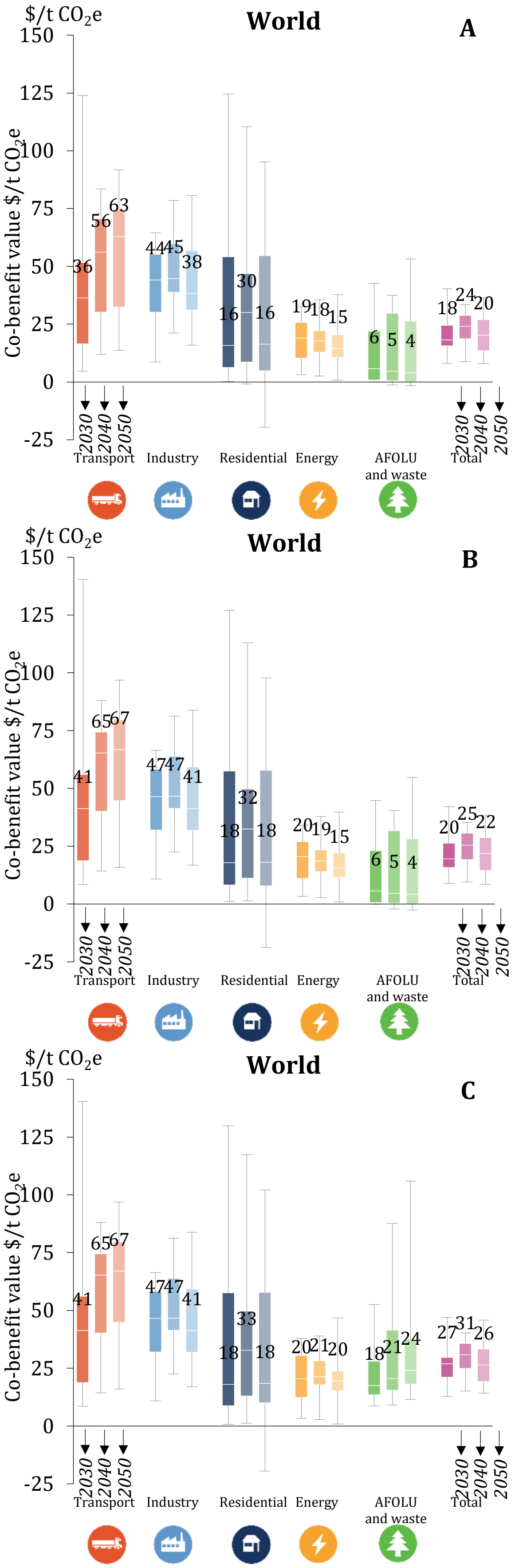
	Scenarios			
Regions	Reference_V3	ClimPolicy_V3	Slower-Action_V3	Slower-to-faster_V3
World	10	10	8	7
ASIA	10	10	8	7
LAM	9	9	8	7
MAF	9	9	8	7
OECD90	10	10	8	7
REF	9	9	7	6
ROWO	3	3	1	1
Brazil	6	6	5	4
China	10	10	8	7
EU	9	9	7	6
India	10	10	8	7
Japan	8	8	6	5
Russia	6	6	5	4
USA	10	10	8	7

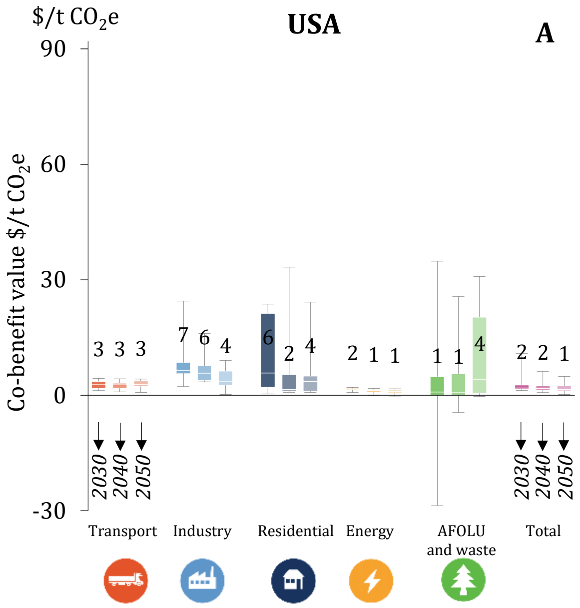
S4. Additional results

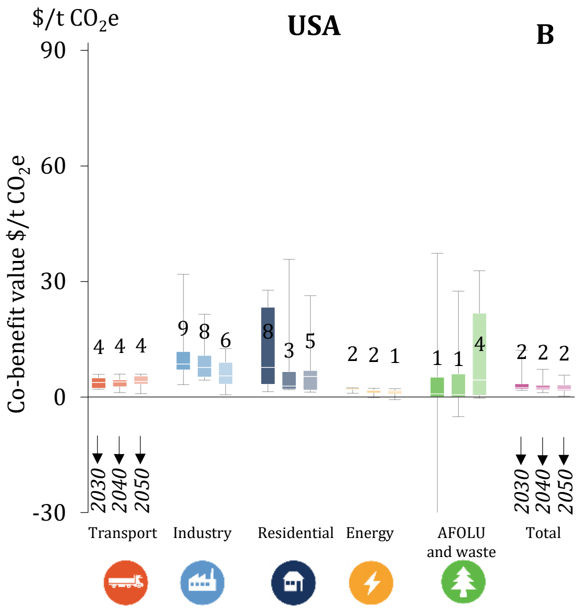
Table S6 Results of Figure 3 in tabulated format for the year 2030. Source: Own calculations based on the EMF-30 database composed of scenario results from 10 integrated assessment models.

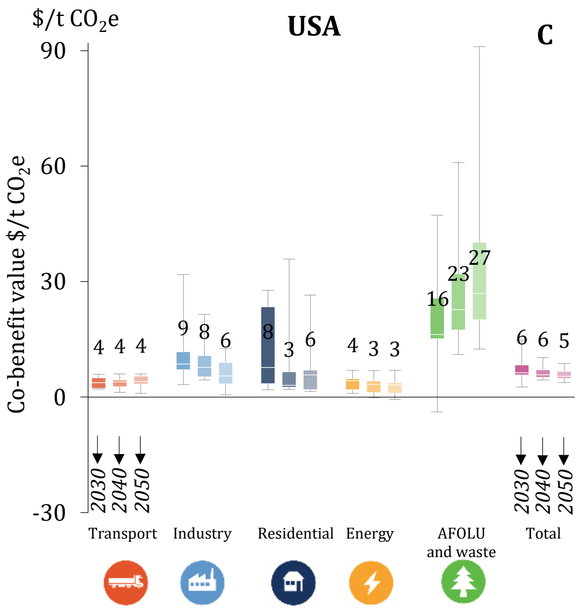
2030 Sector					Region				
Transport	World	EU	USA	India	China	ASIA	REF	LAM	MAF
Min	4.7	7.1	1.3	139	41	77	6.9	1.8	6.2
25pct	17	11	1.8	188	133	106	10	10	7.4
Med	36	13	2.7	242	139	131	12	10	12
75 pct	52	19	3.6	359	212	173	24	20	13
Max	124	23	4.3	514	280	244	38	23	21
Industry									
Min	8.6	11	2.3	169	43	55	-0.7	7.3	5.7
25pct	30	15	5.7	181	59	67	6.0	12	6.9
Med	44	18	6.5	218	69	77	10	16	10
75 pct	55	19	8.5	250	75	82	11	23	12
Max	65	54	24	273	80	118	17	33	19
Residential									
Min	0.2	4.9	0.3	-153	37	27	5.0	-6.2	-86
25pct	6.3	11	2.0	413	67	113	6.4	0.7	-8.6
Med	16	19	5.8	538	130	164	18	3.5	3.4
75 pct	54	25	21	680	196	227	21	5.3	8.2
Max	125	39	24	790	228	278	35	10	28
Energy									
Min	3.2	-25	0.8	31	1.3	3.9	1.1	0.2	-1.6
25pct	10	5.0	1.4	125	6.0	17	2.8	2.8	2.1
Med	19	6.6	1.6	150	11	39	4.6	4.5	3.9
75 pct	26	7.5	1.8	183	14	46	6.2	9.4	6.5
Max	33	12	2.0	474	36	71	25	15	12
AFOLU & waste									
Min	0.1	-4.1	-29	-149	-1.6	0.4	-0.7	-1.1	-7.8
25pct	0.9	1.3	-0.2	-2.1	0.0	3.2	-0.1	-0.1	-0.2
Med	5.8	8.6	0.9	2.4	1.3	14	3.5	1.5	0.5
75 pct	22	24	4.8	5.4	18	93	17	9.1	7.8
Max	43	62	35	135	76	176	164	28	27
Total									
Min	8.1	-0.9	1.3	4.7	4.5	16	2.8	-1.9	-19
25pct	16	7.1	1.6	109	11	32	4.9	3.2	0.0
Med	18	9.4	1.9	126	28	42	5.5	5.2	3.6
75 pct	25	13	2.7	165	38	52	7.9	7.8	7.5
Max	40	25	11	509	47	84	29	17	15

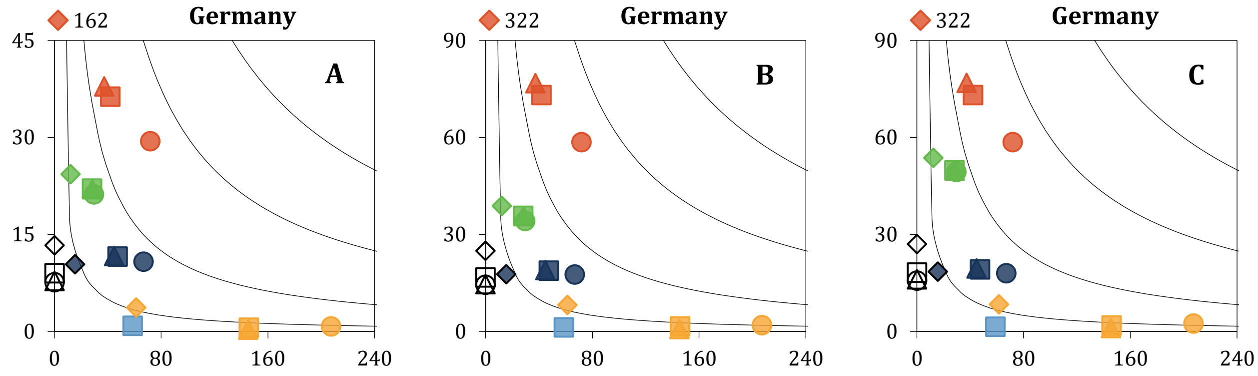
Figure S3 Co-benefits for the world, the USA and Germany including within-region impacts (A), all impacts (B) plus CH_4 (C). Source: EMF-30 database based on multi-model ensemble (World and USA) and POLES-JRC (Germany)




$/t CO2e
USA
A
90
60
30
0
-30
Co-benefit value $/t CO2e
3 3 3
7 6 4
6 2 4
2 1 1
1 1 4
2 2 1
2030
2040
2050
2030
2040
2050
Transport
Industry
Residential
Energy
AFOLU and waste
Total


$/t CO2e
USA
B
90
60
30
0
-30
Co-benefit value $/t CO2e
4 4 4
9 8 6
8 3 5
2 2 1
1 1 4
2 2 2
2030
2040
2050
2030
2040
2050
Transport
Industry
Residential
Energy
AFOLU and waste
Total


$/t CO2e
USA
C
90
60
30
0
-30
Co-benefit value $/t CO2e
4 4 4
9 8 6
8 3 6
4 3 3
16 23 27
6 6 5
2030
2040
2050
2030
2040
2050
Transport
Industry
Residential
Energy
AFOLU and waste
Total



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