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Future mercury levels in fish: model vs. observational predictions under different policy scenarios

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Section S1. Percentage annual change for each variable (X = Hg emissions, Hg deposition, or fish MeHg) was calculated as:

$$\%\ annual\ change\ in\ X = \frac{\left(\frac{X_{2050,\,scenario}}{X_{base\ year,\,scenario}} - 1\right)}{n} * 100$$

Where:

$X_{2050,\,scenario} = modeled\ value\ under\ a\ given\ scenario\ in\ 2050$

$X_{base\ year,\,scenario} = modeled\ value\ in\ the\ base\ year\ used\ in\ that\ study$

$n = number\ of\ years\ between\ the\ base\ year\ and\ future\ year$

Table S1. Anthropogenic and natural mercury emission inventories applied in atmospheric Models.

References (models) ⬇ **Scenarios**	**Anthropogenic**	**Natural**
(Corbitt et al. 2011) (Geos-Chem) A1B, A2, B1, and B2	(Pacyna et al. 2010) – base year emissions (Streets et al. 2009) – future emission scenarios	GEOS-Chem parameterization – geogenic/ legacy emissions
(Lei et al. 2014) (CAM-Chem/Hg) A1B, B1, and A1F1	(Pacyna et al. 2006) – base year emissions (Streets et al. 2009) – future emission scenarios	(Lei et al. 2013) – natural/legacy emissions (Witt et al. 2008; Aiuppa et al. 2007) – volcanic emissions (IPCC 2001) – forest & grassland burning (Smith-Downey et al. 2010) – terrestrial Hg storage
(Vijayaraghavan et al. 2014) (CTM) A2 and B2	(EPRI 2006) – base year emissions (Streets et al. 2009) – future emission scenarios	(Seigneur et al. 2004) – natural/legacy re-emissions
(Giang and Selin 2016) (Geos-Chem) No policy and Minamata	(Pacyna et al. 2006) – base year emissions (Streets et al. 2009) – future emissions	GEOS-Chem parameterization
(Pacyna et al. 2016) (GLEMOS and ECHMERIT) CPS, NPS, and MFR	(AMAP/UNEP, 2013) – baseline emissions (Streets et al. 2009; 2011; 2017) – historical and future scenario emissions (Pacyna et al. 2006; 2010) – earlier global anthropogenic inventories	(Pirrone et al. 2010) – volcanic / geogenic emissions (Smith-Downey et al. 2010) – terrestrial storage and natural re-emissions
(Angot et al. 2018) (Geos-Chem) NPS and MFR	(AMAP/UNEP, 2013) – base year emissions (Streets et al. 2011) – historical emissions (2000 BCE–2008 CE) (Pacyna et al. 2016) – future scenarios	(Pirrone et al. 2010; Bagnato et al. 2011) – geogenic emissions
(Perlinger et al. 2018) (Geos-Chem) Minimal regulation, Policy-in-action, and aspirational scenario	(AMAP/UNEP, 2013) – baseline emissions (Streets et al. 2009; 2011; 2017) – historical and future scenario emissions	(Pirrone et al. 2010; Bagnato et al. 2011) – geogenic GEOS-Chem parameterization – natural/legacy emissions

(Chen et al. 2018) (Geos-Chem) A1B, constant emissions, Hg control, and zero emissions	(Streets et al. 2011) – emissions (2000 BCE–2008 CE) (Horowitz et al. 2014) – commercial-product emissions (1850–2008) AMAP/UNEP (2018) – baseline emissions (Streets et al. 2011) – emissions (1850–1970) by region (Streets et al. 2009; Amos et al. 2013) – future scenario emissions	(Pirrone et al. 2010; Bagnato et al. 2011) – geogenic emissions
(Y. Zhang et al. 2021) (Geos-Chem) A1B, NPS-delayed, and MFR	AMAP/UNEP (2013) – base year emissions (Streets et al. 2009; Pacyna et al. 2016) – future scenario emissions	Default GEOS-Chem datasets
(H. Zhang et al. 2021) (Geos-Chem) A1B, B1	(Pacyna et al. 2010; Zhang et al. 2012) – base year emissions (Streets et al. 2009; Corbitt et al. 2011) – future scenario emissions	(Mason 2009; Bagnato et al. 2011) – geogenic emissions (Holmes et al. 2010) – biomass burning and soil evasion (Selin et al. 2008) – prompt terrestrial re-emission (Holmes et al. 2010; Zhang et al. 2016) – ocean evasion

Table S2. Acronyms and descriptions for climate-oriented and hybrid mercury emission scenarios.

Scenarios	Descriptions
BAS (Baseline)	Assumes continuation of air-quality and climate policies in force up to 2012, without introducing additional mercury or emission-control measures beyond 2030.
CLIM (Climate Mitigation)	Incorporates a 2 °C global climate policy, achieving substantial reductions in fossil-fuel use and associated mercury emissions by 2050.
CLIM+MFR	Climate mitigation scenario with maximum feasible mercury reduction measures, representing the lowest achievable global Hg emissions.
Net-Zero	Net-zero energy pathway (< 1.5 °C by 2100) combined with current-legislation Hg and air-quality policies.
Net-Zero + Hg MFR	Combines net-zero climate policy with maximum Hg-specific controls, yielding the lowest feasible Hg emissions by 2050.
SSP1-2.6	A lower-bound emissions scenario reflecting strong emphasis on sustainability and intensive control of climate-forcing agents.
SSP2-4.5	A middle-of-the-road scenario reflecting moderate socioeconomic development and continuation of current trends without strong climate mitigation.
SSP5-3.4	An overshoot scenario characterized by short-term growth in fossil fuel use and minimal consideration of climate control measures until 2040 followed by aggressive mitigation after mid-century.
SSP5-8.5	An upper-bound emissions scenario in which fossil-fuel use continues with little consideration of climate mitigation or transition to clean technologies.

Table S3. Full forms of abbreviations used for meteorological datasets and drivers in atmospheric Hg models.

Acronym / Model	**Descriptions**
GEOS	Goddard Earth Observing System
ECHAM5	The fifth-generation atmospheric general circulation model developed at the Max Planck Institute for Meteorology in Hamburg, based on the operational forecast model framework from ECMWF.
WRF	Weather Research and Forecasting
ECMWF	European Centre for Medium-Range Weather Forecasts
NCEP	National Centers for Environmental Prediction
NCAR	National Center for Atmospheric Research
ECCC	Environment and Climate Change Canada's
GEM	Global Environmental Multiscale
GCM	General circulation model
CCSM	Community Climate System Model
NCAR-MM	National Center for Atmospheric Research - Mesoscale Model
NOAA	National Oceanic and Atmospheric Administration
NCDC	National Climatic Data Center
MERRA-2	Modern-Era Retrospective analysis for Research and Applications, Version 2 by NASA's Global Modeling and Assimilation Office (GMAO)
GISS-GCM	Goddard Institute for Space Studies - general circulation model

Table S4. Summary of variables used in PCA and MLRM analyses.

Scenarios	**Change in fish MeHg (% yr^{-1})**	**Change of Hg deposition (% yr^{-1})**	**Watershed (km^2)**	**Lake Area (km^2)**	**Wetland (%)**	**Average depth (m)**	**Waterbodies**
SRES A2	0.114	0.264	17.040	1.070	4.030	6.400	Mendums Pond, NH
SRES B2	-0.318	-0.346	17.040	1.070	4.030	6.400	Mendums Pond, NH
NPS	-0.275	-0.383	183.100	7.148	14.285	5.570	Lakes in Maine, ME
MFR	-0.550	-0.645	183.100	7.148	14.285	5.570	Lakes in Maine, ME
Policy-in-action	-0.250	-0.341	190.000	9.700	14.210	15.000	Lakes in Michigan's UP, MI

Aspirational	-1.477	-1.477	190.000	9.700	14.210	15.000	Lakes in Michigan's UP, MI
Policy-in-action	0.438	0.277	190.000	9.700	14.210	15.000	Lake in Michigan's UP with Adirondack's deposition
Policy-in-action	-0.857	0.277	190.000	9.700	8.800	15.000	Lake in Michigan's UP with Adirondack's deposition and watershed features
Reduction in deposition, 50 %	-0.633	-1.020	4.200	0.200	1.000	2.000	Eagle Butte Lake, SD
Reduction in deposition, 50 %	-1.041	-1.020	0.810	0.120	-	4.800	Lake Barco, FL
Reduction in deposition, 50 %	-1.163	-1.020	50.000	3.600	4.000	5.000	Pawtuckaway Lake, NH
Reduction in deposition, 50 %	-1.571	-1.020	220.000	35.000	25.000	2.300	Lake Waccamaw, NC
Reduction in deposition, 50 %	-1.510	-1.020	2190.000	9.900	8.000	0.250	Brier Creek, GA

Note: For NPS and MFR, “Lakes in Maine” reflect the averaged characteristics of 20 modeled lakes.

Table S5. MLRM results testing whether lake characteristics alone predict changes in fish MeHg by 2050 in the model world.

	Coef	**std err**	**t**	**P>|t|**	**[0.025**	**0.975]**
const	-0.6521	0.432	-1.509	0.175	-1.674	0.370
Watershed	-0.0003	0.000	-0.924	0.386	-0.001	0.000
LakeArea	-0.0687	0.045	-1.526	0.171	-0.175	0.038
Wetland	0.0582	0.061	0.947	0.375	-0.087	0.203
AverageDepth	0.0072	0.039	0.187	0.857	-0.084	0.099

Table S6. MLRM results testing lake characteristics together with scenario-specific Hg deposition as predictors of changes in fish MeHg by 2050 in the model world.

	Coef	std err	t	P>|t|	[0.025	0.975]
const	−0.1249	0.275	−0.454	0.666	−0.799	0.549
Watershed	−0.0002	0.000	−1.219	0.269	−0.001	0.000
LakeArea	−0.0656	0.025	−2.599	0.041	−0.127	−0.004
Wetland	0.0685	0.035	1.982	0.095	−0.016	0.153
AverageDepth	−0.0264	0.023	−1.136	0.299	−0.083	0.030
Deposition	0.7864	0.195	4.032	0.007	0.309	1.264

Table S7. Characteristics of atmospheric Hg models, including resolution, primary oxidation pathways, and meteorological drivers.

Model	Spatial resolution	Vertical resolution	Primary Hg^0 oxidation pathways	Meteorological data sources (type)	References
GEOS-Chem	4°×5°	47 levels	Br	GEOS-5 assimilated meteorology (Offline)	(Corbitt et al. 2011; Giang and Selin 2016; Chen et al. 2018)
	2°×2.5°	40 levels	Br (1^{st} - stage)	MERRA-2 by NASA's GMAO (Offline);	(Angot et al. 2018; Y. Zhang et al. 2021; H. Zhang et al. 2021)
			NO_2 and HO_2 (2^{nd} - stage)	NASA GISS GCM ModelE2 (Online)	
GLEMOS	1°×1°	20 levels	O_3 and OH	WRF modelling system, based on ECMWF (Offline)	(Pacyna et al. 2016; De Simone et al. 2017; Travnikov et al. 2017)
			Br (Polar regions)		
ECHMERIT	2.8°×2.8°	19 levels	O_3 and OH	ECHAM5 based on ECMWF (Online)	
HYSPLIT-Hg	2.5°×2.5°	17 levels	O_3 and OH	NCEP/NCAR reanalysis model (Offline)	(Cohen et al. 2016)

GEM-MACH-Hg	1°×1°	58 levels	OH Br (Polar regions)	GEM model, based on ECCC weather prediction model (Online)	(Travnikov et al. 2017)
CAM-Chem/Hg	1.9°×2.5°	26 levels	O_3 and OH	CCSM, V3 (Offline)	(Lei et al. 2014)
CTM-Hg	8°×10°	9 levels	O_3 and OH	GCM (Offline)	(Bullock Jr. et al. 2009; Vijayaraghavan et al. 2014)
TEAM	10–20 km	6 layers	O_3 and OH	NCAR-MM5 (Offline)	
AEROMOD	1 km	-	O_3 and OH	NOAA and NCDC (Offline)	

Full forms of meteorological abbreviations used in this table are provided in Table S3.

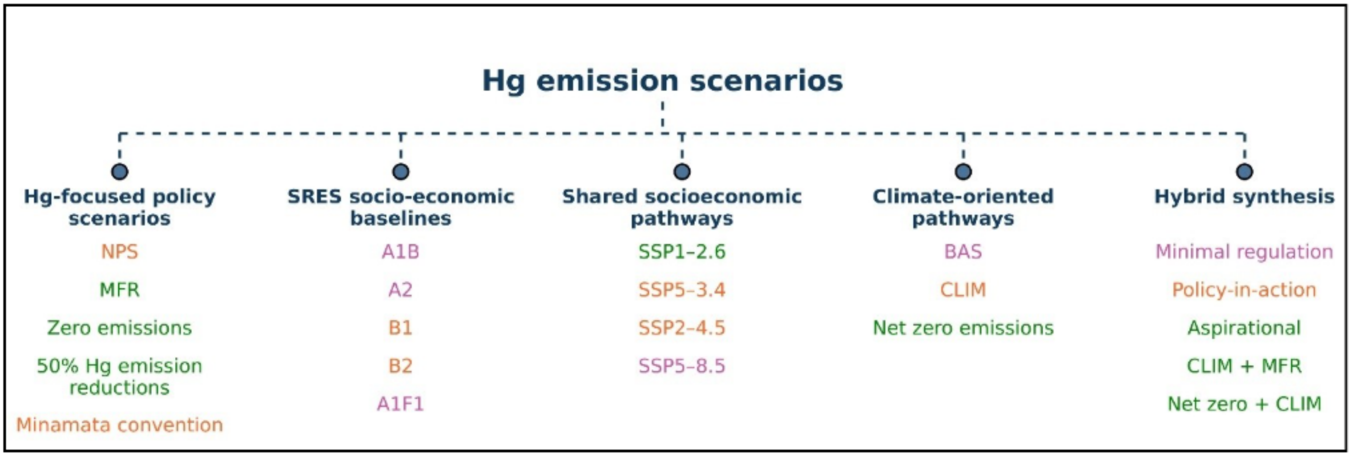

Figure S1: Classification of future Hg emission scenarios by policy focus and emission level. Emission levels are categorized as high (pink), medium (orange), and low (green).

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