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Supplement of

Projections of shipping emissions and the related impact on air pollution and human health in the Nordic region

Camilla Geels et al.

Correspondence to: Camilla Geels (cag@envs.au.dk)

Supplement

1 Details on shipping emissions

The applied fuel related emission factors for 2015 and the forecast years 2020, 2030 and 2050 are shown in Figure S1. They are aggregated from ship type, engine type, fuel type and engine production year. Details on the full set of basis emission factors can be found in Winther et al. (2017).

The shipping emissions for the d03 domain and the polar diversion routes are given in table 1 and 2. To summarize and show the total with a without the diversion emission contribution these are plotted together in Figure S2.

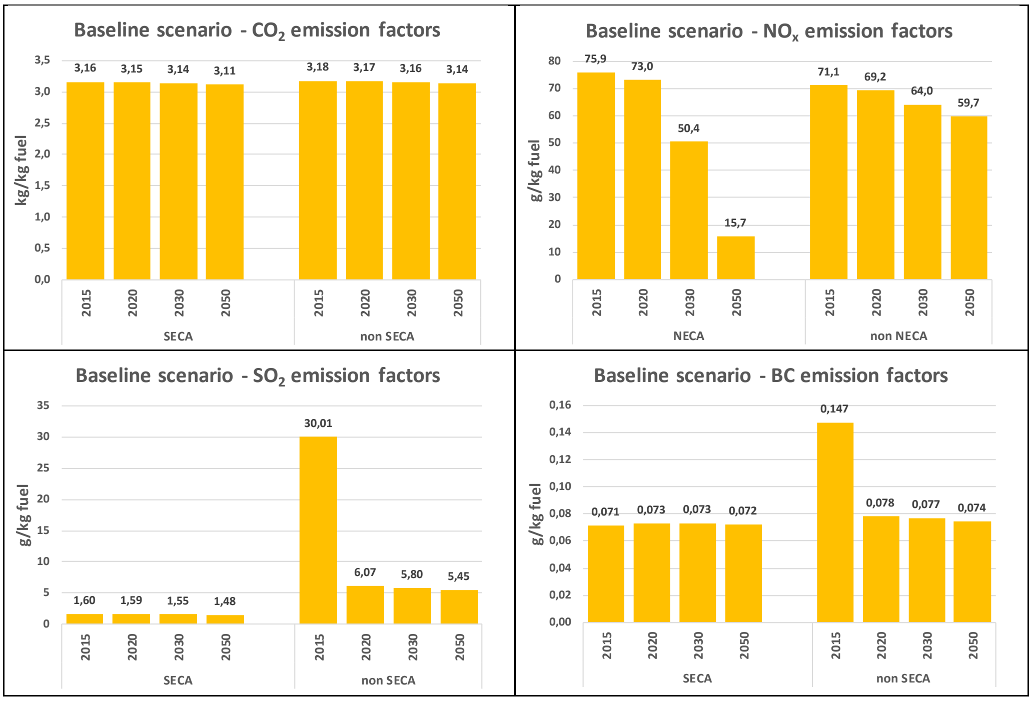

Figure S1: Fuel related emission factors of CO_2, NO_x, SO_2 and BC for 2015, 2020, 2030 and 2050 split into SECA and non SECA.

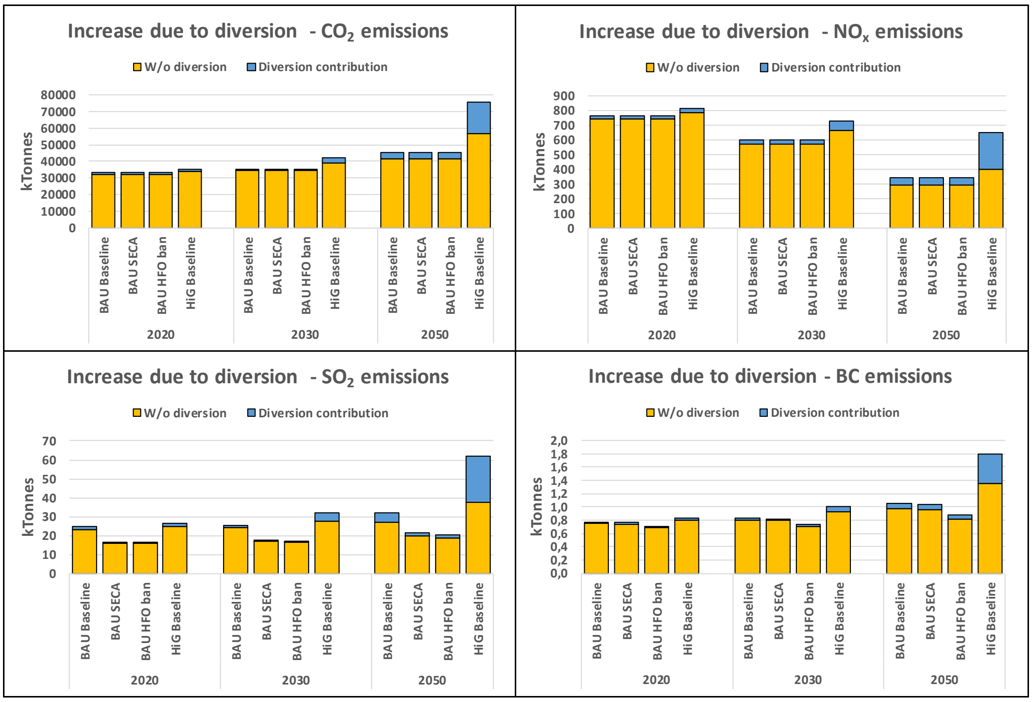

Figure S2: Estimated emissions of CO_2, SO_2, NO_x and BC in domain d03 without polar diversion traffic and for polar diversion traffic for the scenarios in 2020, 2030 and 2050.

2 Trend in emissions and overview of model setup

Table S1: Development in land based ECLIPSE V5a emissions as a %-change in the total emissions in the three DEHM domains.

	% change 2015 to 2030	% change 2015 to 2050
d01/Northern Hemisphere		
SO_x	-3	16
NO_x	-5	19
NH_3	17	34
$PPM_{2.5}$	-2	11
d02/Europe		
SO_x	-12	-5
NO_x	-28	-33
NH_3	2	5
$PPM_{2.5}$	12	29
d03/Nordic area		
SO_x	-3	7
NO_x	-25	-23
NH_3	0	3
$PPM_{2.5}$	13	24

Table S2: Overview of the emissions included in the different model runs carried out with the DEHM model. The MATCH model has been run for a subset.

Year	Emissions - land	Emissions - shipping	Run name
2015	**ECLIPSEV5a CLE**	**BAU**	**2015BAU**
2015	**ECLIPSEV5a CLE**	**As above and reduced shipping**	**2015BAU_70%**
2030	ECLIPSEV5a CLE	BAU	2030BAU
2030	ECLIPSEV5a CLE	As above and reduced shipping	2030BAU_70%
2030	ECLIPSEV5a CLE	BAU incl. Arctic div. routes	2030BAU_PolarDiv
2030	ECLIPSEV5a CLE	As above and reduced shipping	2030BAU_PolarDiv_70%
2030	ECLIPSEV5a CLE	SECA incl. Arctic div. routes	2030BAU_SECA_PolarDiv
2030	ECLIPSEV5a CLE	As above and reduced shipping	2030BAU_SECA_PolarDiv_70%
2030	ECLIPSEV5a CLE	HFO ban incl. Arctic div. routes	2030BAU_HFO_Ban_PolarDiv
2030	ECLIPSEV5a CLE	As above and reduced shipping	2030BAU_HFO_Ban_PolarDiv_70%
2030	ECLIPSEV5a CLE	HiG traffic incl. Arctic div. routes	2030HiG_PolarDiv
2030	ECLIPSEV5a CLE	As above and reduced shipping	2030HiG_PolarDiv_70%
2050	**ECLIPSEV5a CLE**	**BAU**	**2050BAU**
2050	**ECLIPSEV5a CLE**	**As above and reduced shipping**	**2050BAU_70%**
2050	**ECLIPSEV5a CLE**	**BAU incl. Arctic div. routes**	**2050BAU_PolarDiv**
2050	**ECLIPSEV5a CLE**	**As above and reduced shipping**	**2050BAU_PolarDiv_70%**
2050	**ECLIPSEV5a CLE**	**SECA incl. Arctic div. routes**	**2050BAU_SECA_PolarDiv**
2050	**ECLIPSEV5a CLE**	**As above and reduced shipping**	**2050BAU_SECA_PolarDiv_70%**
2050	**ECLIPSEV5a CLE**	**HFO ban incl. Arctic div. routes**	**2050BAU_HFO_Ban_PolarDiv**
2050	**ECLIPSEV5a CLE**	**As above and reduced shipping**	**2050BAU_HFO_Ban_PolarDiv_70%**
2050	**ECLIPSEV5a CLE**	**HiG traffic incl. Arctic div. routes**	**2050HiG_PolarDiv**
2050	**ECLIPSEV5a CLE**	**As above and reduced shipping**	**2050HiG_PolarDiv_70%**

3 Evaluation of the DEHM model

The DEHM model is continuously evaluated against observations from international monitoring networks. In Fig. S3 and S4 an overall evaluation of DEHM against observations from the EMEP network within Europe is given as an average over all the available data for 2015. The comparison between model and observations are shown for the components that are included in the health assessment ($PM_{2.5}$, NO_2, and O_3).

The total $PM_{2.5}$ in the model is calculated as the sum of the species: primary emitted mineral dust, black carbon (fresh and aged), organic carbon, sea salt, and the secondary formed particles and secondary formed organic aerosols. The overall variability of $PM_{2.5}$ is seen to be captured by the model, with a correlation coefficient of 0.79. The model tends to underestimate the level during the summer months and the overall fractional bias is slightly negative. For NO_2 the seasonal pattern with lower values in the summer is reproduced by the model (with a correlation of 0.73), but the model over predicts some of the peaks, which leads to a slightly positive bias (FB of 0.03). For O_3 the comparison is made for daily, hourly as well as daily maximum values, as these maximum values are relevant for the health impacts. They all show a pronounced seasonal variation with highest values in the warmer months. This is replicated by the model and correlations above 0.90 are seen for all three components. The DEHM models is seen to underestimate the daily maximum slightly, while a small overestimation is seen for the daily and hourly mean values.

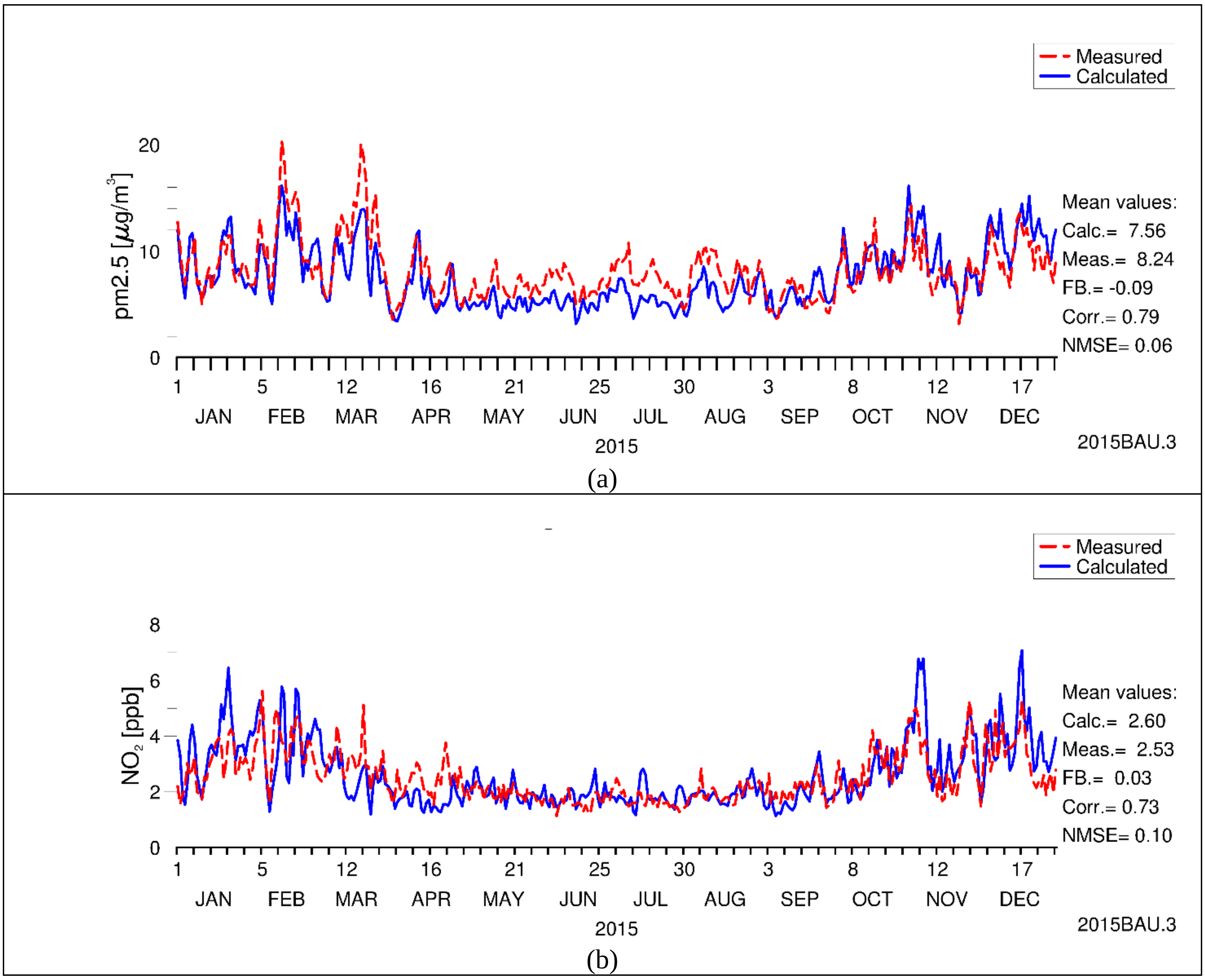

Figure S3: A comparison between DEHM results and observations as daily mean values for the year 2015. Shown as average values in space over all the available observations from the EMEP network. Here for the total $PM_{2.5}$ and NO_2 in µg/m^3. Standard statistical values are given to the right: the mean values, the Fractional Bias (FB), the correlation coefficient (Corr) and the Normalised Mean Square Error (NMSE).

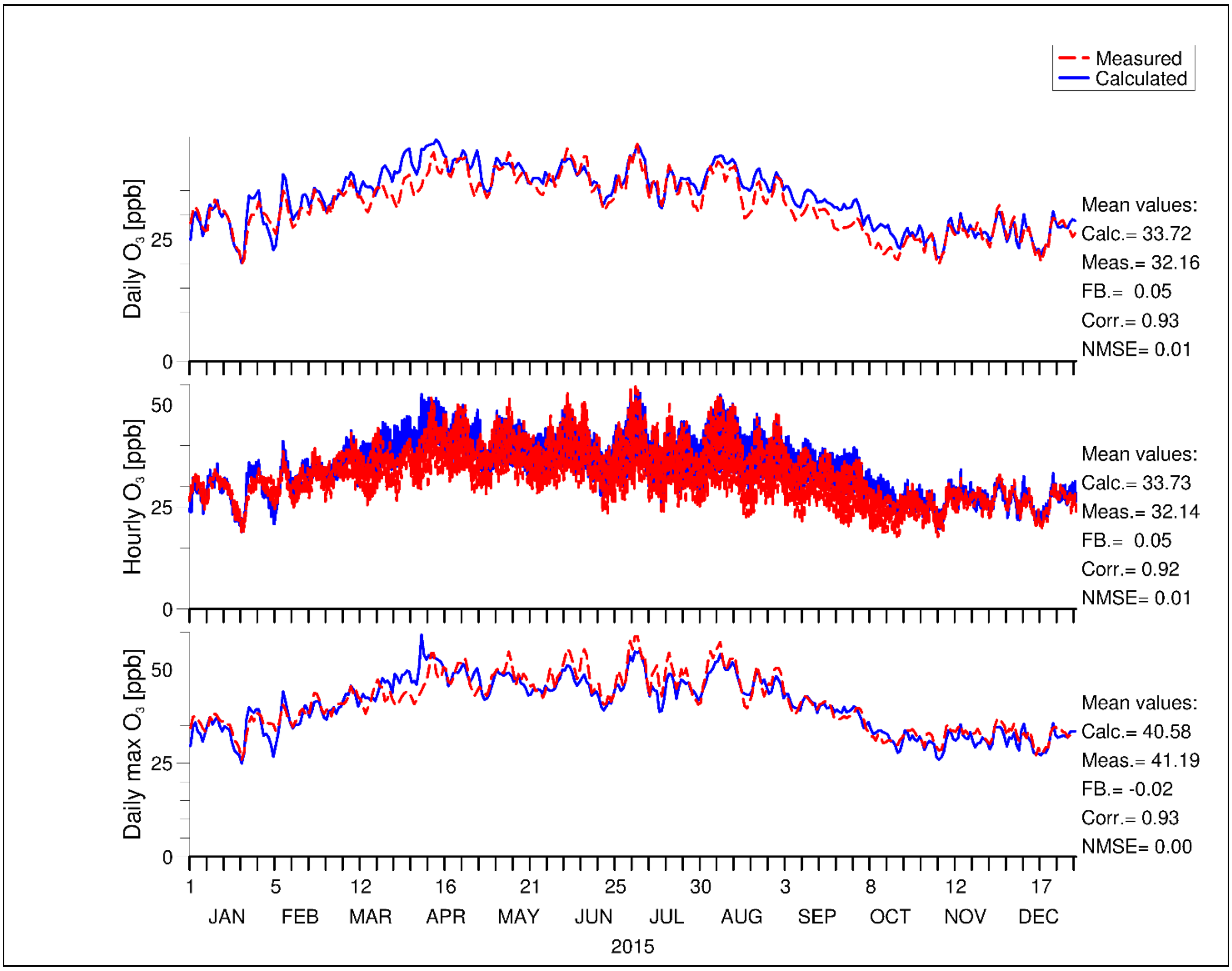

Figure S4: A comparison between DEHM results and observations for the year 2015. Shown as average values in space over all the available observations from the EMEP network. Here for O_3 as both daily and hourly mean values as well as daily maximum in ppb. Standard statistical values are given to the right: the mean values, the Fractional Bias (FB), the correlation coefficient (Corr) and the Normalised Mean Square Error (NMSE).

4 Evaluation of the MATCH model

The MATCH model is a model used for various applications, including operational air quality forecasting and is a member of the CAMS forecasting ensemble, mapping of historical exposure to air pollution including measurement model fusion methodologies, scenario simulations, dispersion of volcanic ashes and nuclear emergency preparedness. It is has been evaluated against observations from international monitoring networks for all applications and typically perform among the best Eulerian chemistry and transport models in Europe (e.g. Otero et al., 2017; Theobald et al, 2019). The current model configuration was evaluated in the EURODELTA trends exercise as described in the main paper. Evaluation scores of ozone and NO2 concentrations, and nitrogen and sulphur particle species for this model version over Europe are included in Table S3 for the year 2011. For PM10 and PM2.5 over the whole Europe, mean annual bias of MATCH span -5% - -18% (mean: -11%) and -3% - -21% (mean: -13%) respectively, and spatial correlations span between 0.34-0.78 (mean: 0.59) and 0.55-0.73 (mean: 0.67) respectively (Tsyro et al., 2021, manuscript).

We also present an evaluation for the smaller grid used in this study, for the BAU2015 simulation. Hourly observations for 2015 from Norway, Sweden and Denmark were extracted from the EMEP web page and were used to evaluate the model performance at the sites. The site-specific evaluation statistics were averaged and is presented in Table S3.

Table S3: Evaluation of the MATCH version used in this study based on measured daily concentrations at EMEP sites in Europe 2011 and evaluation of the MATCH BAU2015 simulation based on measured hourly ozone at EMEP sites in Scandinavia in 2015 (Extracted from https://projects.nilu.no//ccc/emepdata.html, Mars 2019).

		Obs (ppbv)	Mod (ppbv)	%bias	r	# stns	# values
Europe	Hourly ozone	30.9	30.4	1.6	0.66	102	842825
	Daily mean ozone	30.9	30.4	1.6	0.70	102	35934
	daily maximum ozone	39.9	39.3	1.5	0.77	102	35934
	Daily mean NO2	1.53	1.44	-5.9	0.58	37	12853
	Daily mean TNHx	1.507	1.266	-16	0.66	42	14181
	Daily mean TNO3	0.564	0.649	15	0.65	43	14723
	Daily mean SO42-	0.672	0.484	-28	0.61	54	16377
Scandinavia	hourly ozone	29.9	31.7	5.8	0.71	16	133817
	daily mean	29.9	31.7	5.8	0.80	16	5718
	daily maximum ozone	37.1	37.2	0.16	0.78	16	5718

5 Population data

Population data used in the EVA system are based on data from EuroStat. The population distribution from 2011 have been scaled with national totals for 2015 (see table S4) within the applied 16.67 km 16.67 km grid. The Faroe Islands is not included in the Eurostat data, but the population has here been added to the grid covering the Faroe Islands. The final population distribution can be seen in Figure S5.

Table S4: The total population in the Nordic countries for year 2015.

Country	Total population
Denmark	5645766
Norway	5151500
Sweden	9922787
Finland	5447248
Iceland	328261
Faroe Islands	49000

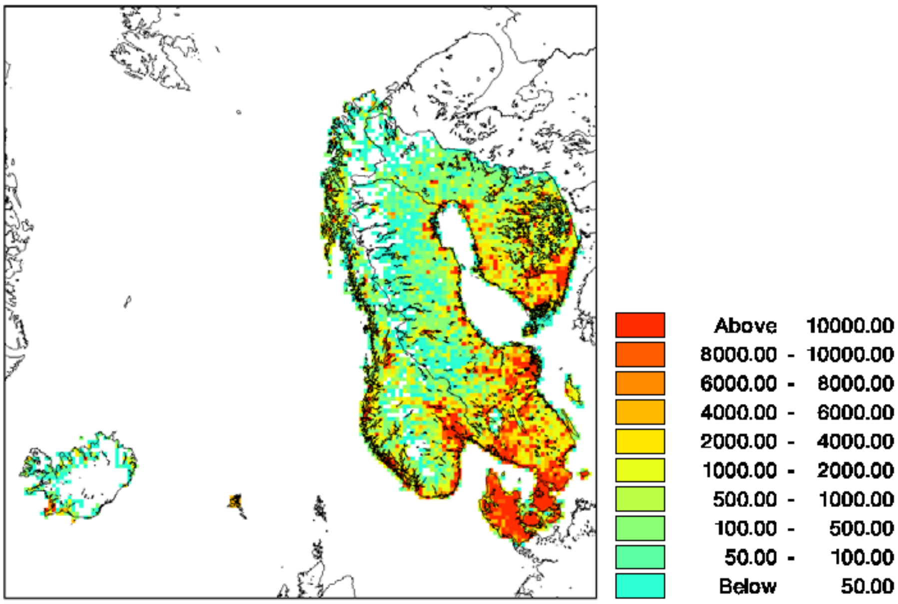

Figure S5: The population distribution in the 16.67 km x 16.67 km grid used for the health assessment.

6 Impact from shipping

The estimated number of premature deaths attributable to shipping is in Figure S6 given for all the scenarios and for each of the four countries (Norway, Finland, Denmark and Sweden). The numbers are given as the mean of the DEHM-EVA and MATCH-EVA estimates. The span between the models vary, but is in-between ±17% and ±42%.

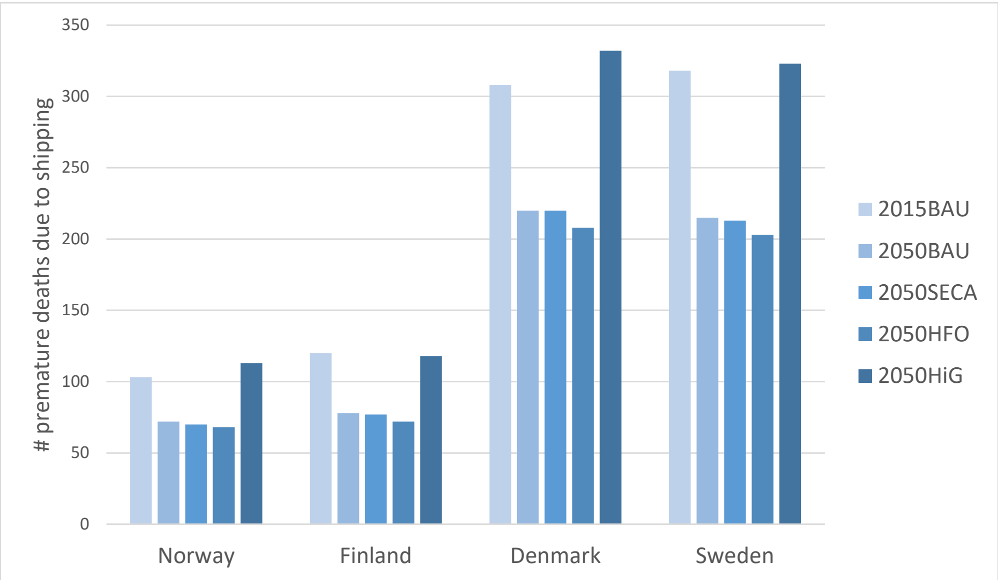

Figure S6: The estimated number of premature deaths attributable to shipping for each country and for each scenario. The numbers is a mean of the estimates by the two models. (Note that the 2050BAU and the SECA, HFO and HiG scenarios also includes the polar diversion routes).