

Health effects of atmospheric particles in the Nordic and Arctic regions



Nordic Council
of Ministers

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Particulate matter?

Particulate matter is the mixture of all solid and liquid particles suspended in air. This complex mixture includes both primarily emitted particles and secondary particles, formed from emissions of gases by atmospheric chemistry. Secondary formed particles are divided into organic and inorganic particles (sulfate, nitrate and ammonium). Primarily emitted particles can be mineral dust, soot, pollen, and sea salt. Particles vary greatly in size, composition, and origin. The sources can be both natural (e.g., sea salt and pollen) and anthropogenic (e.g. soot from combustion processes, residential combustion and traffic).

Atmospheric particles also play an important role in modifying the atmospheric radiative balance, and therefore climate, either directly by interacting with radiation through scattering (e.g. sulfate) or absorbing (e.g. soot) radiation, or indirectly by changing the cloud optical properties and droplet size. In general, particles cool the Earth's surface, masking the warming from greenhouse gases. This means that removing the particles would have a warming effect on the climate.

Particulate matter smaller than 2.5 μm in diameter ($\text{PM}_{2.5}$) is associated with negative health impacts for humans, such as increased mortality due to cardiovascular and respiratory diseases. Therefore, mitigating the $\text{PM}_{2.5}$ emissions would be beneficial in reducing the adverse health impacts. On the other hand, reducing their emissions would also mean a reduction in their cooling impact on climate.

Key messages

- Ambient particulate matter smaller than 2.5 μm ($\text{PM}_{2.5}$) is associated with negative health impacts for humans, such as increased mortality and morbidity due to cardiovascular and respiratory diseases.
- More than 80% of the $\text{PM}_{2.5}$ mass in 2015 is attributed to atmospheric transport from outside the Nordic region¹, implying an effort outside the Nordic region is necessary in order to efficiently decrease the pollutant levels over the area.
- The leading anthropogenic emission sector in the Nordic region is residential wood combustion, contributing by more than 60% to the $\text{PM}_{2.5}$ mass in 2015 originating from the region itself.
- In the Nordic countries, residential combustion is the main sectors to be targeted to reduce the negative impacts of air pollution, followed by traffic and agriculture/waste management sectors, in order to reduce the adverse impacts of air pollution and their associated costs.
- Today ambient anthropogenic $\text{PM}_{2.5}$ causes ca. 5,000 – 9,000 premature deaths every year in the Nordic countries, and ca. 3,500 – 4,500 premature deaths in the Arctic region².
- Current global commitments on emission reductions, addressing medium-level mitigation scenarios, lead to decreases in $\text{PM}_{2.5}$ -related premature mortality of up to 27% and 23% in 2030, and by up to 35% and 26% in year 2050, in the Nordic and the Arctic region, respectively.
- High-level mitigation scenarios with more ambitious emission reductions lead to decreases of $\text{PM}_{2.5}$ -related premature mortality in the Nordic regions by up to 35% and 50% in 2030 and 2050, respectively, while in the Arctic, reductions are up to 27% and 46% in 2030 and 2050, respectively.
- A low-level mitigation scenario, where the global commitments are not achieved, leads to reductions in $\text{PM}_{2.5}$ -mortality of up to 18% in 2030 and 31% in 2050 in the Nordic countries. On the other hand, some models also show an increase in $\text{PM}_{2.5}$ -related mortality in 2030 by up to 7% in the Nordic countries under this scenario. In the Arctic, either reductions of up to 7% and 22%, or increases of 15% are calculated in 2030 and 2050, respectively.
- Overall, the $\text{PM}_{2.5}$ concentrations and the related premature mortality in the different climate scenarios, addressing medium to high level of mitigation, follow the emission changes in these scenarios.
- In the low-level mitigation scenario, on the other hand, some models calculate an increase in the concentrations and the related premature mortality, while other models show a decrease. This suggests an uncertainty in the representation and complexity in chemical and physical processes in the different models and the resulting response to relatively smaller changes in emissions.

1. The Nordic countries considered in the FREYA project are Denmark, Finland, Norway and Sweden.

2. The Arctic region is defined as the area above 60°N.

Premature mortality?

Premature mortality/death due to air pollution refers to deaths where the person would die earlier ("premature") than the person would have died from other causes if the person was not exposed to air pollution. Premature mortality can be due to either short-term ("acute") or long-term ("chronic") exposure to air pollution over a year or more. Exposure to particulate matter is especially attributed to long-term exposure in the assessment of premature mortality. Particulate matter can lead to premature mortality mainly due to lower respiratory infections, stroke, chronic obstructive pulmonary disease, lung cancer, and ischemic heart disease.

Recommendations

- In order to reduce the negative health impacts of PM_{2.5} in the Nordic countries, residential combustion, in particular wood combustion, is the main sector to be targeted.
- Traffic and agriculture/waste management sectors should also be targeted to reduce the adverse impacts of air pollution.
- As more than 80 % of the PM_{2.5}-related premature deaths are caused by sources outside the continental Nordic area, an international emission mitigation effort is needed to reduce the negative health impacts of air pollutants in the Nordic region.
- Commitments on mitigating the anthropogenic emissions on the Nordic as well as European and global scale should be fulfilled in order to reduce the negative impacts of air pollution in the future.
- The contributions of the Nordic countries to the PM_{2.5} levels and associated mortality in the Arctic is very limited, therefore further emission reductions are required in the mid-latitudes in order to mitigate the negative health impacts in the Arctic region.

Introduction

The main objectives of the “Effects of short-lived climate pollutants on atmospheric chemistry, health and climate in the Nordic and the Arctic region” (FREYA³) project have been to assess:

- the contributions of anthropogenic emission sources in the Nordic countries to the air pollution levels in each country and their neighboring Nordic countries
- the contributions of local versus long-range transported air pollution on surface pollutant levels over the Nordic region
- the contributions of Nordic sources on the premature deaths in the region and identify the major emission sectors for mitigation of adverse health impacts due to air pollution
- how the premature mortality will change in the future under different emission scenarios.

In order to address these objectives, an integrated assessment model, which has been coupled to a regional chemistry and transport model and three fully-coupled Earth system models, has been used to estimate the present-day (2015) and future (2015–2050) surface PM_{2.5} concentrations and associated premature mortality in the Nordic region under various emission scenarios of low to high mitigation of anthropogenic emissions.

For more information: The main results of the FREYA project with regards to sectoral contributions of the individual Nordic countries on the air pollution levels and associated premature mortality in the region are published in the scientific paper “Contributions of Nordic anthropogenic emissions on air pollution and premature mortality over the Nordic region and the Arctic” in the journal Atmospheric Chemistry and Physics (Im et al., 2019). The integrated assessment model is further described in Im et al. (2018).

3. The FREYA project was funded by the Nordic Working Group for Climate and Air (NKL) under the auspices of the Nordic Council of Ministers. However, the content does not necessarily reflect the Nordic Council of Ministers' views, opinions, attitudes or recommendations.

Background

Air pollution is the world's largest single environmental health risk (WHO, 2014). A large number of studies made assessments for the Nordic countries with estimates ranging from 6,500 to 9,500 for the year 2000 (Brandt et al., 2013; Geels et al., 2015; Watkiss et al., 2005, Karvosenoja et al., 2010). Forsberg et al. (2015) and Kukkonen et al. (2018) suggested that long-range transported fine particulate matter dominates the health effects in the Nordic countries.

Air pollution is a transboundary problem covering global, regional, national and local sources, leading to large spatial variability and therefore to large differences in the geographical distribution of human exposure to air pollution (Im et al., 2018). In the Nordic countries, there are large spatial differences in air pollution levels because of long-range transported air pollution, especially from the south and east as well as due to the degree of urbanization. Furthermore, the widespread use of domestic wood stoves in the Nordic countries represents a special challenge for exposure to air pollution (Kukkonen et al., 2019). The Nordic countries are generally characterized among the EU countries with low air pollution levels (EEA, 2018).

Previous studies (e.g. Geels et al., 2015) showed that climate change alone can only lead to a small increase in the air pollution-related premature mortality in the Nordic region by up to 9%. The increase is mainly associated to the increase in the natural precursors of ozone due to a warmer climate. The change in the PM_{2.5}-related mortality was projected to change by less than ±5% due to climate change alone. On the other hand, the decrease in anthropogenic emissions can have a huge impact on the air pollution levels and the associated premature mortality. Geels et al. (2015) showed that combined climate and emissions changes towards the 2050s can lead to a 40%–60% decrease in ozone-related mortality and a ca. 65% decrease in PM_{2.5}-related mortality in the Nordic region.

The assessment system

FREYA uses the Danish Economic Valuation of Air pollution model system (EVA: Brandt et al., 2013; Geels et al., 2015; Im et al., 2018, 2019), which can calculate all-cause acute and chronic mortality and morbidity based on linear exposure-response functions, along with cause-specific mortality based on non-linear functions following Burnett et al. (2018). The linear model estimates PM_{2.5}-related premature mortality due to acute and chronic exposure PM_{2.5}, using risk ratios recommended by the WHO (2013), which are applied on the Danish population in order to derive exposure-response functions (ERFs). Previous studies showed non-linear relationships, being steeper at lower than at higher concentrations (e.g. Samoli et al., 2005; Burnett et al., 2018), potentially overestimating health impacts over highly polluted areas. Therefore, using linear ERFs in EVA is a reasonable approximation for the Nordic region.

Assessments have been made for the present-day (2015) and the future until 2050. The source contributions in the present day have been calculated using an extensive set of simulations conducted by the Danish Eulerian Hemispheric Model (DEHM), where each anthropogenic emission sector is perturbed in each of the four Nordic countries separately (Im et al., 2019).

Based on climate and air pollution simulations by three global climate models, the number of anthropogenic PM_{2.5}-related premature mortality cases in the Nordic countries in 2015 is estimated to be between 5,000 and 9,000 in 2015, while in the Arctic, the number of premature deaths is estimated to be 3,500–4,500.

Future climate scenarios

Future climate projections are simulated using emission projections taken from the ongoing Intergovernmental Panel for Climate Change (IPCC) Assessment Report 6 (AR6) scenarios developed on the Coupled Model Intercomparison Project Phase 6 (CMIP6). These projections include the following levels of socioeconomic challenges:

High (SSP1-2.6): Ambitious reductions are implemented than what is already committed by current legislations. All current and emerging technologies will be implemented to reduce emissions.

Medium (SSP2-4.5): The existing commitments on emissions reductions in different countries are fulfilled.

Low (SSP3-7.0): Limited reductions are implemented and the current commitments are not fulfilled.

Medium-low (SSP3-7.0-lowNTCF): As in SSP3-7.0, but with reduced near-term emissions.

Contribution of Nordic emission sources to PM_{2.5} and associated premature mortality in the Nordic countries

According to the DEHM model calculations with country- and sector-specific emission perturbations, the Nordic countries are responsible for up to 20% of the regional background surface PM_{2.5} concentrations in the countries itself. The non-industrial combustion, which is dominated by the residential wood combustion, is responsible for 50% to 80% of the country's own contribution to surface PM_{2.5} in Denmark, Finland and Norway. In Sweden, 25% and 30% originates from residential combustion and industrial activities, respectively.

The total number of premature mortality cases due to exposure to surface PM_{2.5} in 2015 are calculated to be ~3,500 in Denmark and Sweden and ~1,500 in Finland and Norway, summing up to ~10,000 premature deaths in the four Nordic countries. On the other hand, Danish sources were responsible for ~400 premature deaths in Denmark, Norwegian sources for ~200 deaths in Norway, Finnish sources for ~270 deaths in Finland, and Swedish sources for ~330 deaths in Sweden. The contributions of the different emission sectors to premature mortality in each of the Nordic countries also vary. In Denmark, residential combustion and agriculture emissions contributed similarly by 33% to the ~400 premature mortality cases in 2015. In Norway, residential combustion was responsible for 48% of the ~200 premature deaths in Norway. In Finland, residential combustion and traffic were responsible for more than half of the ~270 premature deaths in Finland. Finally, in Sweden, traffic and waste management/agriculture were responsible for 50% of the ~330 total premature deaths in Sweden.

These results suggest that in Denmark, Finland and Norway, residential combustion is the main sector to be targeted to reduce the negative impacts of air pollution, while in Sweden, traffic and agriculture/waste management sectors should be targeted to reduce the adverse impacts of air pollution. Overall, Nordic countries contribute to low premature death cases in their Nordic neighbors (≤ 50). It is important to note that more than 80 % of the PM_{2.5}-related premature deaths are caused by sources outside the Nordic area.

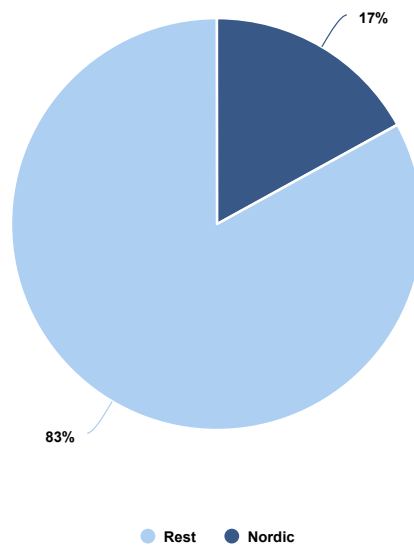


Fig. 1a. Share of Nordic and outside-Nordic emission sources to PM_{2.5}-related premature deaths in the Nordic countries.

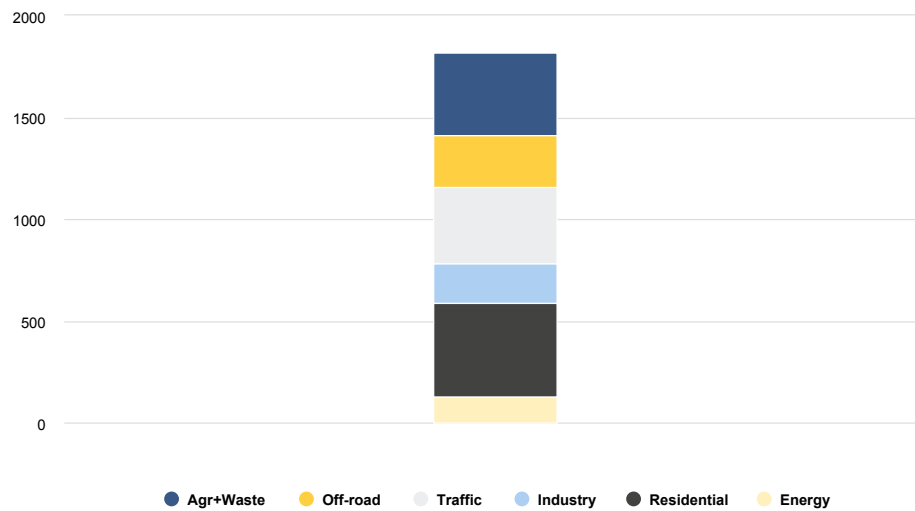


Fig. 1b. The contributions of individual anthropogenic sources to the Nordic-caused premature deaths.

Future premature mortality in the Nordic region under different emission projections

Future simulations conducted with three fully-coupled Earth system models (ESMs) using projected anthropogenic emissions for the 2015–2050 period under different mitigation scenarios from the Coupled Model Intercomparison Project Phase 6 (CMIP6: Eyring et al., 2016), which serves to the ongoing IPCC Assessment Report 6 (AR6), showed large reductions in PM_{2.5}-caused premature deaths in the Nordic region. However, it should be noted that FREYA focused on impacts of climate mitigation scenarios, where additional measures to mitigate individual sectors such as the wood combustion are outside the scope of these climate mitigation scenarios.

Mitigation of anthropogenic emissions under existing commitments (SSP2-4.5) leads to a reduction of up to 28% and 35% in the PM_{2.5}-caused premature mortality in the Nordic region by 2030 and 2050, respectively. More ambitious emission mitigations (SSP1-2.6) lead to larger reductions in premature mortality in 2030 (13% to 36%) and in 2050 (19% to 49%). A business as usual scenario (SSP3-7.0) also leads to reductions in premature mortality (up to 19% in 2030 and 31% in 2050). SSP3-7.0 can, however, lead to increases in premature mortality by up to 7% in 2030. Finally, an intermediate scenario (SSP3-7.0-lowNTCF) between (SSP2-4.5 and SSP3-7.0) leads to reduction of up to 43% in 2030 and 58% in 2050.

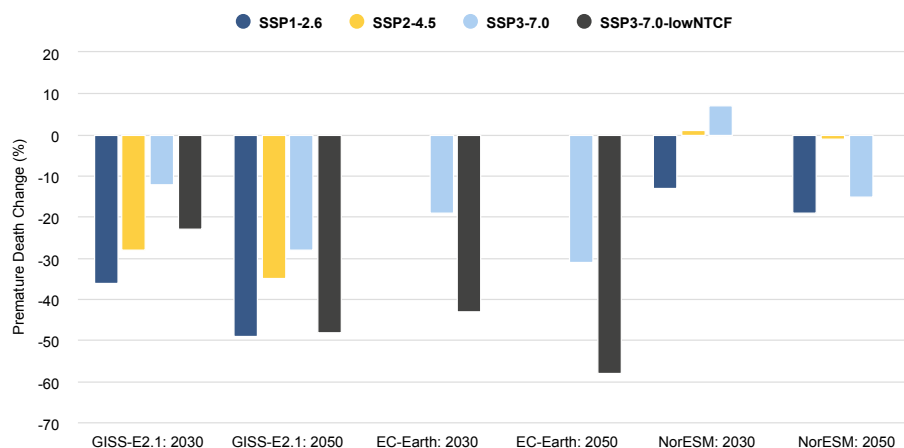


Fig. 2. Change in PM_{2.5}-related premature deaths in the Nordic region in 2030 and 2050 with respect to 2015, as simulated by the suit of three ESMs under various future emission and climate change projections.

Present and future premature mortality in the Arctic region

Residential combustion in the Nordic countries is also the largest contributor to Arctic (>60 °N) BC and OC levels, followed by industry. The outflow from Finland, Norway and Sweden can reach to the central Arctic Ocean over to the northern parts of Greenland, contributing to the PM_{2.5} levels by around 1% – 2%.

The number of premature deaths in the Arctic region associated with exposure to PM_{2.5} in 2015 is estimated to be 3,500 to 4,700. However, reduction of anthropogenic emissions under existing commitments (SSP2-4.5) leads to a reduction of up to 25% in the PM_{2.5}-caused premature mortality in the Arctic region by 2030 and 2050, while more ambitious emission reductions (SSP1-2.6) can lead to further reductions in premature mortality in 2030 (up to 27%) and in 2050 (up to 46%). The businesses usual scenario (SSP3-7.0) also leads to reductions in premature mortality (up to 7% in 2030 and 22% in 2050), while in the short-term (2030), it can also lead to increases in premature mortality by up to 15%. Finally, the intermediate scenario (SSP3-7.0-lowNTCF) leads to reduction of up to 33% in 2030 and 50% in 2050.

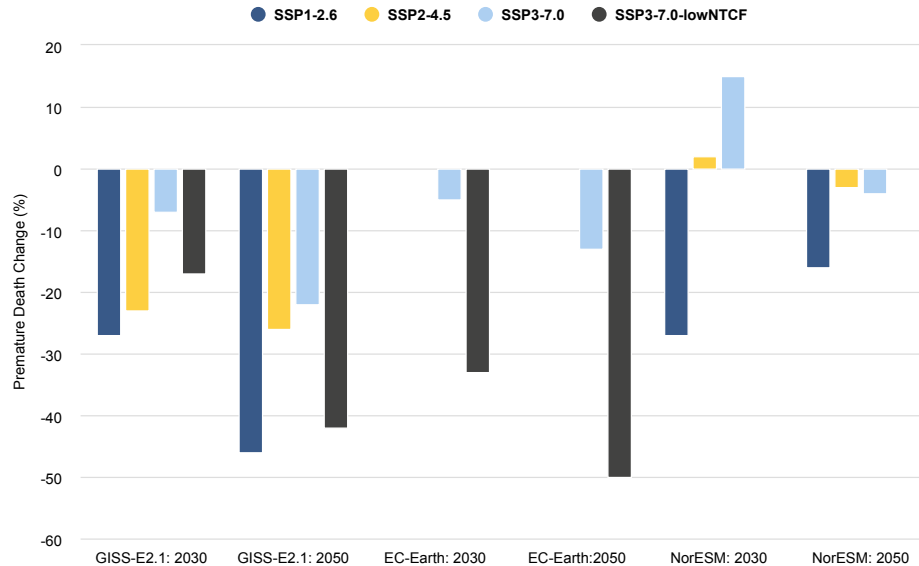


Fig. 3. Change in PM_{2.5}-related premature deaths in the Arctic region in 2030 and 2050 with respect to 2015, as simulated by the suit of three ESMs under various future emission and climate change projections.

Unknowns and needs for improved assessments

Health impact assessments are subject to uncertainty in the different input parameters such as the concentrations, disease rates and exposure-response relationships. The simulated future PM_{2.5} concentrations by the Earth system models have coarse spatial resolutions to capture co-location of pollution levels and population at smaller spatial scales, such in the Nordic countries, which can lead to underestimate PM_{2.5}-caused premature mortality (Punger and West, 2013).

An important and uncertain assumption is that the exposure-response relationships are derived based on total PM_{2.5} mass, instead of individual PM_{2.5} components, such as BC. There are some studies that suggest BC being more strongly associated with negative health effects compared to total PM_{2.5} mass. This implies an additional underestimation of PM_{2.5}-caused premature mortality due to BC emission reductions achieved by the mitigation of BC emissions.

On top of the above uncertainties, the exposure-response relationships used in our analysis originate from epidemiological studies largely conducted outside of the Arctic region, which may not be optimal to apply to the Arctic communities.

A final unknown in relation to the future mortality estimations is the synergistic effect of simultaneous exposure to extreme temperatures (e.g. heat waves or cold spells) due to climate change and increased air pollution concentrations, which was not considered in this study and is an emerging research field (e.g. the H2020 EXHAUSTION project).

Despite the above unknowns and uncertainties, results from the FREYA project supports the necessity to mitigate the anthropogenic emissions in order to reduce the adverse health impacts of air pollution, in particular fine particulate matter. These findings also support the findings from the 2021 AMAP assessment for short-lived climate forcers (AMAP, 2021). Further, the study pinpoints important emission sectors in the different Nordic countries that should be targeted for further reductions of air pollutants in the region, that are contributing to the health burden.

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About this publication

Health effects of atmospheric particles in the Nordic and Arctic regions

Sectoral contributions and impacts of future changes in anthropogenic emissions and climate

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