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ENVIRONMENTAL EFFECTS OF NORDIC TRANSPORT PATHWAYS TOWARDS CLIMATE NEUTRALITY

Transforming transport is a key energy challenge in the Nordic region to achieve the ambitious climate targets set by the Nordic governments. There are several strategies for reducing the greenhouse gas (GHG) emissions in the transport sector including increased efficiency, reduced transport demand, and shifting to various fuels with low or zero GHG emissions (including e.g., biofuels, electricity, hydrogen and other so-called electrofuels produced primarily from electricity, water, and carbon). Thus, transport and energy systems will interact more with each other in the future. The influence of transition strategies for the Nordic transport sector on other environmental impacts such as emissions of air pollution need to be assessed for policy makers, industry, and researchers to better understand the sustainability of different pathways. Increased knowledge is thus needed in terms of environmental impact of e.g., fuel switch and increased electrification for transport.

Electrification of vehicles, promoted as a key strategy in several Nordic countries, helps to improve energy efficiency and reduces local air pollution. However, it takes time to transform the existing vehicle fleet (particularly when also considering ocean and air transport), both due to the long lifetime of vehicles and that it may be difficult to rapidly scale up battery production. Thus, carbon-based transportation fuels may remain important in the coming decades for some trans-

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port modes. By increasing the use of biofuels in parallel with direct and indirect electrification (including hydrogen and electrofuels) as well as energy efficiency improvements, more rapid reductions in fossil fuel use in the Nordic transport sector may be achieved. However, the impact on other emissions to air of these changes are not clearly known.

The overall goal of the assessment summarized here is to contribute to increased knowledge and understanding of the environmental effects of decarbonization strategies for the Nordic transport sector. The assessment is partly presented in Wolfgang et al. (2023) but with environmental impacts from electricity production added in this publication to make it more comprehensive and more relevant from a broader energy system perspective. Results for Sweden and Norway are presented here (but are available also for Denmark).

More specifically, an initial assessment of the potential impact of decarbonization scenarios for the Nordic transport sectors (including road transport, shipping, and aviation) on the most common emissions of air pollution including nitrogen oxides (NOx) and particulate matter (PM) are performed. Several scenarios with varying levels of different key options and measures e.g., electrification, biofuels, hydrogen, and transport demand based on the Open Nordic TIMES model (ON-TIMES) model is used. For the assessment, a modelling tool for linking and transferring data between the ON-TIMES model and the Greenhouse Gas and Air Pollution Interactions and Synergies (GAINS) model is developed and tested. The focus is on exhaust emissions, i.e., emissions linked to the fuel use, but emissions linked to production of the direct electricity needed for the transport sector is also included. Emissions from for example tire wear etc. is however not included. To also include the electricity demand for indirect electrification is a topic for further research.

The **ON-TIMES model** is a bottom-up, optimization (cost minimization) energy system model with comprehensive coverage of the national energy system including the transport sector, power and heat, industry, service sector, and residential sector (2015-2050). It covers Sweden, Norway, Denmark, Finland, and Iceland. Each country is modelled individually and is geographically aggregated into different regions that are interconnected through the representation of transmission lines, allowing e.g., electricity trade. The model is used for producing scenarios showing pathways to Nordic carbon neutrality.

The **GAINS model** developed by International Institute for Applied Systems Analysis (IIASA) estimates emissions to air and abatement costs as well as environmental and health impact of emissions until 2050. The model explores cost-effective emission to air control strategies that simultaneously tackle local air quality and climate gases to maximize economic and environmental benefits. The model covers in total emissions of ten air pollutants and six climate gases.

Low-carbon scenarios

The scenarios explored are based on the scenarios developed in the Nordic Clean Energy Scenarios project [1]. The Carbon Neutral Nordic (**CNN**) scenario seeks the least-cost pathway for meeting the Nordic carbon neutrality target considering current national plans, strategies, and targets. The CNN+less electrification scenario (in short **CNN ELC**) has a lower electrification rate for transport than the CNN scenario. In the **CNN HOPE** scenario, the difference is that most of the shipping related data has been updated. The Nordic Powerhouse (**NPH**) scenario represents a scenario where the Nordics provide more clean electricity, clean fuels, and carbon storage for Europe. The national transport fuel use in the included scenarios is illustrated for Sweden in Figure 1.

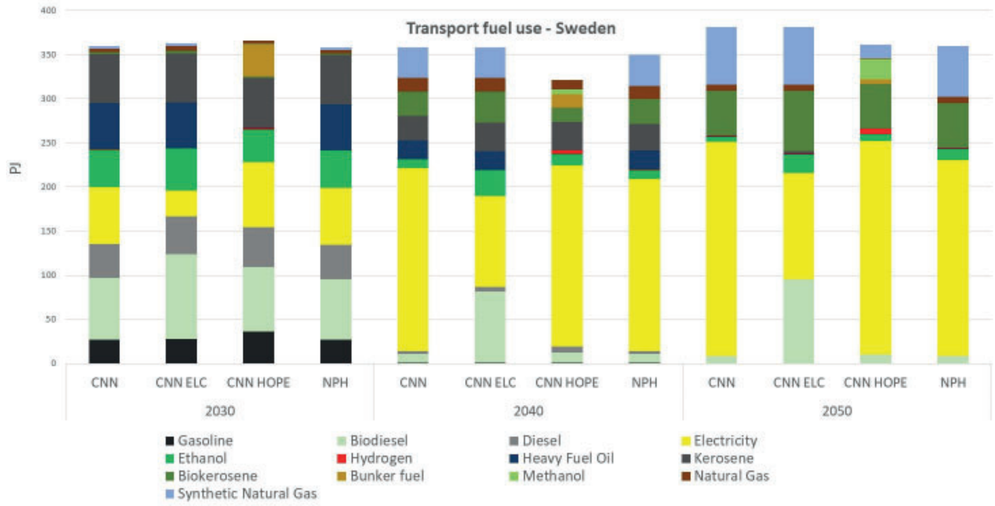

Figure 1. *Cost-effective fuel choices in the Swedish transport sector in the assessed scenarios when using the ON-TIMES model. For scenario descriptions see the text. Synthetic natural gas (methane) is based on hydrogen or bioenergy, sometimes combined with carbon capture and storage.*

CNN is represented by strong electrification in the road transport sector. There is also an increase in synthetic natural gas (representing methane based on hydrogen or bioenergy, sometimes combined with carbon capture and storage) and introduction of biomass-based kerosene for the aviation sector. Which transport fuels that increase to compensate for the somewhat lower electrification for road transport in the CNN ELC scenario varies somewhat between the countries and include biodiesel (all countries), biomass-based kerosene (Denmark and Sweden), natural gas (Denmark and Norway), synthetic natural gas (Denmark and Norway), and hydrogen (Denmark and Norway). In the CNN HOPE scenario there is a higher level of hydrogen and methanol for shipping. The NPH scenario does not differ that much from the CNN scenario but contains a slightly lower use of electricity (but higher than the CNN ELC scenario). Across all scenarios, fossil ke-

1) https://pub.norden.org/nordicenergyresearch2021-01/#

rosene is gradually being phased out from 2030; replaced mainly with biokerosene. Meanwhile, natural gas is being reduced incrementally following 2030 and is swapped for synthetic natural gas. In terms of electricity production wind power increases the most in Norway. In Sweden, both wind and solar power increases considerably until 2050. However, for the electricity used for transportation the GHG emissions for the national electricity mix is used.

The potential impact on air pollution in the form of NOx and particulate matter

The development of air pollution in the form of NOx emissions in the assessed scenarios for aviation, shipping, and road (including rail) as well as for electricity production for direct use in the transport sector are illustrated for Sweden and Norway in Figures 2-3.

Figure 2. *The modelled development of NOx emissions (in kton) for aviation, road transport including rail, and shipping as well as from electricity production for direct us in the transport sector in Sweden in the assessed scenarios. For scenario descriptions see the text. The brighter color for the 2020 bar indicates that the outcome has not been validated against the actual outcome and is also modelled (valid also for the coming figures).*

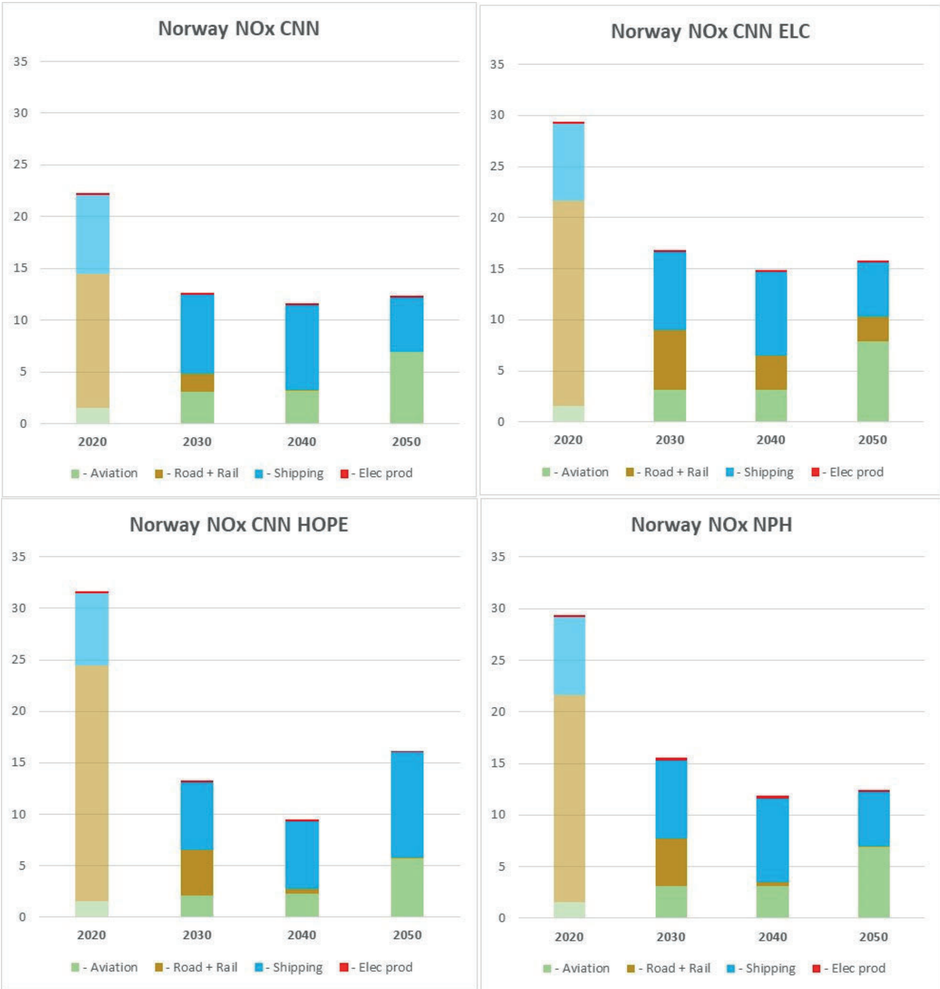

Figure 3. *The modelled development of NOx emissions (in kton) for aviation, road transport including rail, and shipping as well as from electricity production for direct us in the transport sector in Norway in the assessed scenarios. For scenario descriptions see the text.*

The rapid electrification in the road transport sector in the CNN, CNN HOPE and NPH scenario leads to lower NOx emissions compared to 2020 in these scenarios but also compared to the CNN ELC scenario with a lower electrification rate (for 2040 and 2050). However, as the road transport sector is electrified to some extent also in the latter scenario the NOx emissions are reduced but to a lower extent. On the other hand, varying levels of biofuels will not influence air pollution in the assessed Nordic countries to a major extent as they mainly replace fossil fuels which has similar emissions of NOx. Increased use of hydrogen will lead to reductions in terms of NOx emissions. The reason for the increase in NOx emissions in 2050 in Norway and Sweden in the CNN HOPE scenario compared to the CNN scenario is due to the assumed increase demand for shipping and thereby fuel use in 2050 in the former scenario.

The development of air pollution in the form of emissions of particulate matter (PM2.5) in the assessed scenarios for aviation, shipping, and road including rail as well as for electricity production for transport are presented for Sweden and Norway in Figures 4-5.

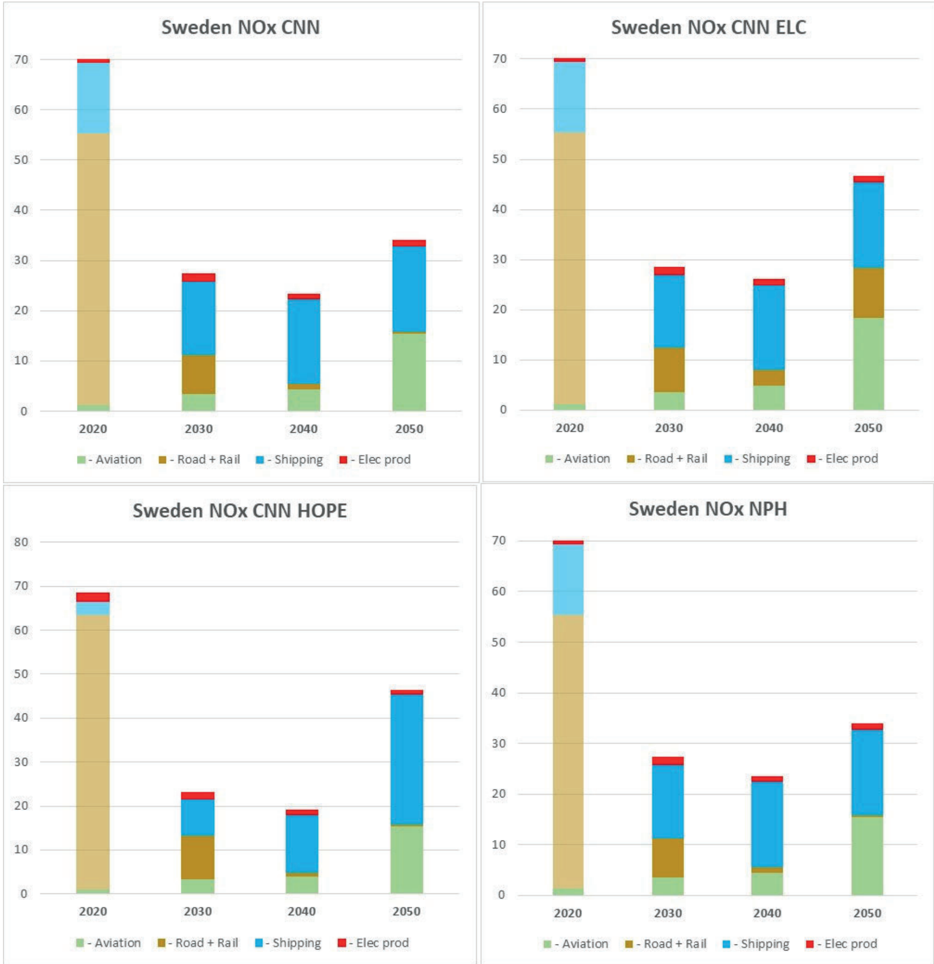

Figure 4. *The modelled development of particles (PM2.5, in kton) for aviation, road transport including rail, and shipping as well as from electricity production for direct us in the transport sector in Sweden in the assessed scenarios. For scenario descriptions see the text.*

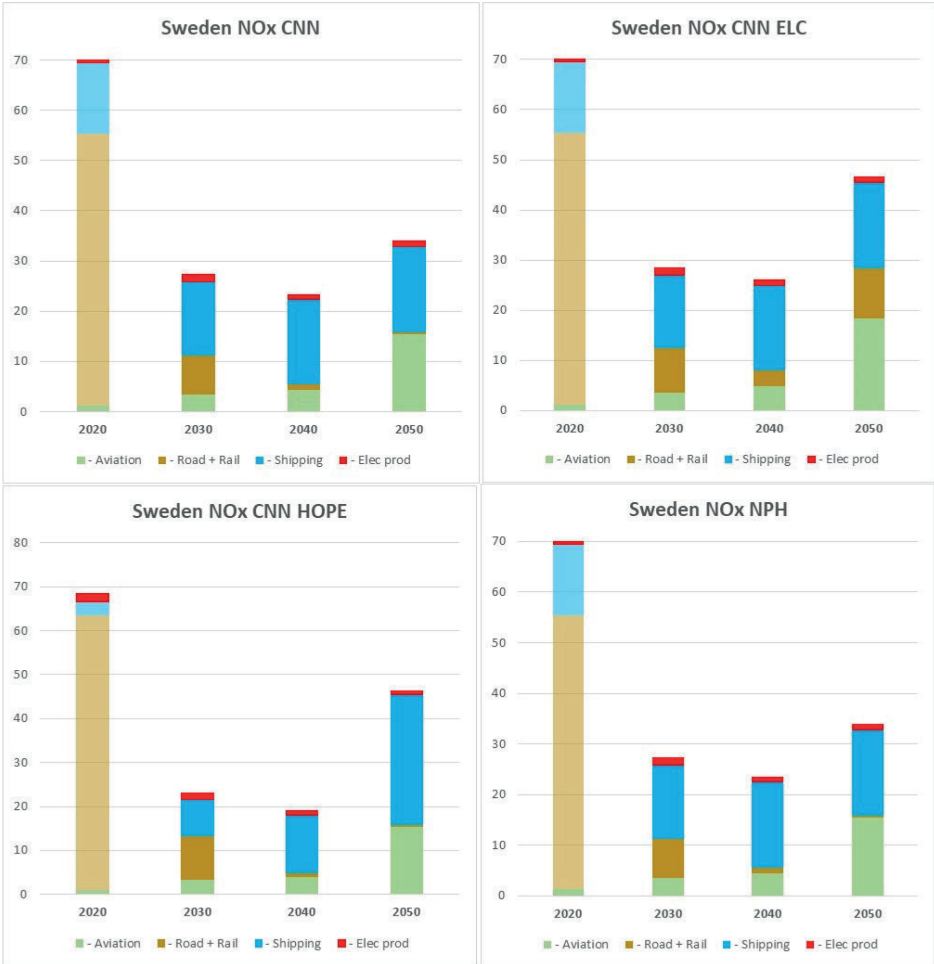

Figure 5. *The modelled development of particles (PM2.5, in kton) for aviation, road transport including rail, and shipping as well as from electricity production for direct us in the transport sector in Norway in the assessed scenarios. For scenario descriptions see the text.*

The rapid electrification in the road transport sector also leads to lower particle emissions (in the form of PM2.5) with time for all scenarios but also compared to the scenarios with a lower electrification rate (mainly CNN ELC scenario). The impact of the electrification rate is particularly evident in the Norwegian case. As expected, reductions in energy transport demand leads to lower emissions of NOx and PM. The increase in particles in the CNN HOPE scenario remains to be confirmed in further studies, but the increase in 2050 compared to 2040 is due to the assumed increase in shipping fuel demand in this case.

The NOx emissions in Sweden for the road sector in 2020 found in the modelling match relatively well with the reported emissions of NOx from road transport in Sweden. Also, the modelled levels of NOx emissions for aviation and shipping for Sweden seem reasonable when compared to reported emissions. Emissions of particles are much more difficult to compare with national statistics due to definition and delimitation issues.

Main findings

This study provides an example of how the impact of air pollution linked to various scenarios for transformation of the Nordic transport sector produced by energy systems modelling can be assessed. Below, the main findings are summarized.

- It is interesting to address emissions of air pollution linked to Nordic energy system model assessments to obtain a broader picture of the sustainability of various scenarios and strategies. This is a topic to be explored further.
- The environmental effects of various strategies for decarbonization of Nordic transport modes can be assessed by soft-linking the ON-TIMES model and the GAINS model via a modelling data transfer tool. This study focused on the transport sector, but the assessment could also be expanded to include other energy sectors to further explore the environmental effects of Nordic decarbonization.
- Electrification of transport will reduce the emissions of NOx (and this will be the case for all transport modes as well as in all assessed Nordic countries).
- A shift to biofuels (from fossil fuels) will not influence air pollution in the Nordic region to a major extent.
- Reduced energy transport demand will in total lead to lower emissions of air pollution due to that less fuels emitting air pollution are used in such scenarios.
- There is a considerable potential for emission reductions both in terms of CO_2, NOx and particles linked to the potential increased use of hydrogen for shipping as well as other transport modes.
- The production of electricity for direct use of electricity in the transport sector does not contribute considerably to emissions of NOx and PM in the assessed scenarios.

More detailed and comprehensive assessments of the impact of air pollution of different decarbonization strategies than were possible within the scope of this project is called for as it is important to be able to assess carbon abatement and abatement of other air pollution at simultaneously. For example, a larger share of the energy system should be included to assess the energy needed, for example for production of fuels (e.g., hydrogen and electrofuels) for the transport sector (as well as other sectors). For the transport sector specifically, all transport related emissions should be explored and acknowledged to better understand how to improve the sustainability of transport and related energy demand.

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FURTHER READING:

This brief mainly summarizes the findings from the project "Kostnader för att reducera utsläpp av växthusgaser från väg- och flygtransporter medbiodrivmedel och elektrobränslen" financed by the Swedish Energy Agency [Project no. P2021-00091 carried out within the Bio+ program (https://bioplusportalen.se/en/).

Hansson, J., et al., 2023. Costs for reducing GHG emissions from road and air transport with biofuels and electrofuels. Report C770, IVL Swedish Environmental Research Institute. ISBN 978-91-7883-511-9. https://www.diva-portal.org/smash/record.jsf?pid=diva2%3A1776832&dswid=8981

NORTH EUROPEAN ENERGY PERSPECTIVES, Nepp

North European Energy Perspectives, Nepp, is a multidisciplinary research programme. The purpose of Nepp is to show how the energy systems in Sweden, the Nordics, and Northern Europe, can achieve balanced and sustainable development paths and contribute to the green transition of society as a whole. The programme functions as a research cluster, where researchers from different organisations and universities conduct studies, that takes as starting point the challenges facing society in achieving the transition. Also, Nepp is an arena for dialogue, co-creation, and a holistic approach for the energy sector and energy research.

The research company Energiforsk is the host of Nepp and responsible for the programme's overall direction. Project leader is the consultancy and research company Profu.