How ammonia can play a role in climate change, air quality, and N deposition by being a carbon-free fuel?

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Summary

The transition to carbon-free fuels like NH_3 holds promise for reducing greenhouse gas emissions and mitigating climate change impacts. However, its adoption raises concerns about increased nitrogen oxide and NH_3 emissions, affecting air quality and nitrogen deposition. Utilizing the AIM-Hub coupling with GEOS-Chem model shown significant GHGs emission reductions but also potential air quality and N deposition issues. Moreover, weak air quality control policies alongside ammonia use could exacerbate $PM_{2.5}$ and ozone, especially in Asia and South America.

INTRODUCTION

- Ammonia is increasingly recognized as a carbon-free fuel capable of aiding the transition to net-zero emissions, especially in hard-to-electrify sectors like maritime shipping and heavy industry (IPCC, 2023)
- Ammonia combustion can produce significant air pollutants if not properly managed. This study aims to comprehensively evaluate the influence of ammonia fuel on climate change, air quality, and nitrogen deposition.
- Our study will explore ammonia's potential across all sectors globally.

METHODOLOGY

- AIM-Hub model developed by Fujimori et al. (2018) used to estimate the position of ammonia fueled based under climate change mitigation policy by simulating based on four scenarios as shown in Table.

Identifier	Description	Reference pathway
Baseline	Baseline	SSP2 baseline with high greenhouse gas emissions and business as usual practices
1p5c_wo/nh3	Climate change mitigation (1.5 degree) with-out ammonia fuel	Maintain cumulative CO_2 emissions below 600 Gt after 2020 for a 50% chance of remaining within 1.5°C warming without using ammonia fuel
1p5c_w/nh3	Climate change mitigation (1.5 degree) with ammonia fuel	Maintain cumulative CO_2 emissions below 600 Gt after 2020 for a 50% chance of remaining within 1.5°C warming by using ammonia fuel
1p5c_w/nh3_LoAQC	Climate change mitigation (1.5 degree) with ammonia fuel + Low air quality control	Maintain cumulative CO2 emissions below 600 Gt after 2020 for a 50% chance of remaining within 1.5°C warming by using ammonia fuel under the “Weak Air Pollution Control Policy”.

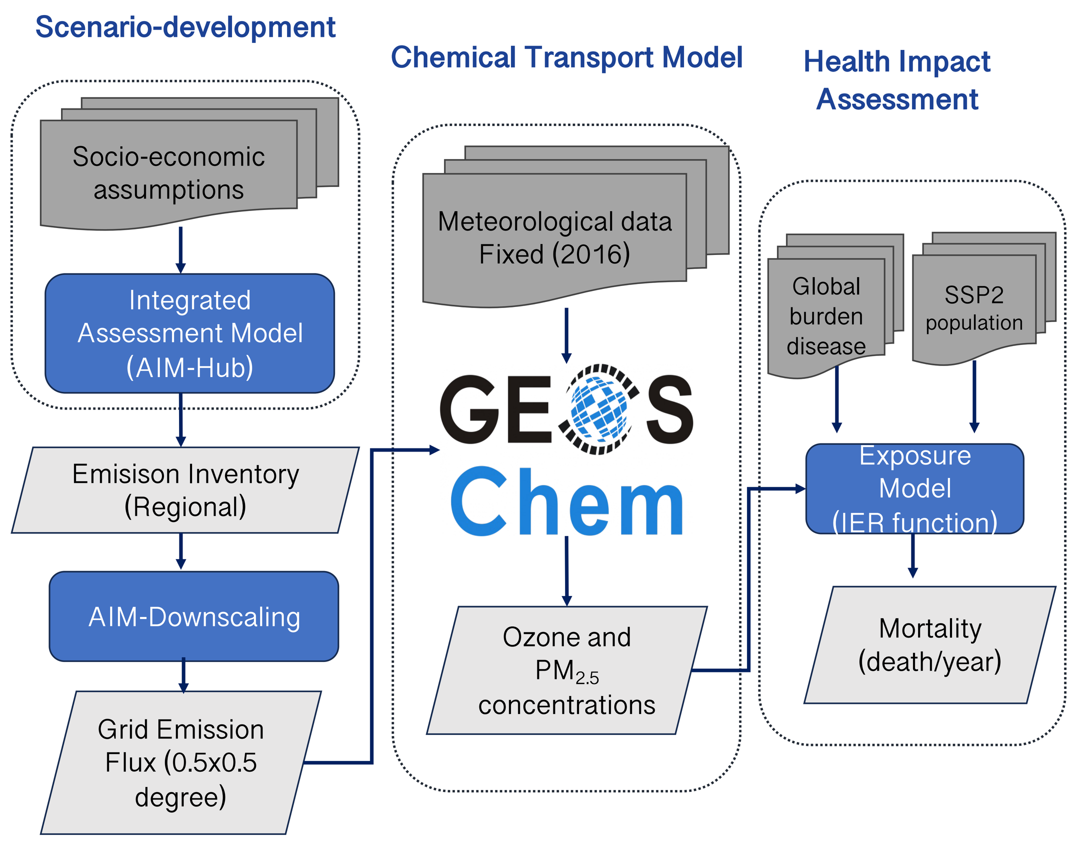

Fig.1 Overall research framework

- All scenarios in this study is based on SSP2 assumptions. We simulated for 2015, 2030, 2050, and 2100 which allowed observation of immediate and long-term effects, providing insights into policy interventions.
- We also explore the impact of ammonia fuel on future air quality and nitrogen deposition which has not been explored in the previous by using a chemical transport model (CTM) called GEOS-Chem model
- the impact on health, based on the Integrated Exposure Response (IER) function were estimate using $PM_{2.5}$ and O_3 concentration outcome from CTM.

RESULT

- Conversely, in a scenario utilizing ammonia-fuel-based options (1p5c_w/nh3), the final energy derived from hydrogen and ammonia surpasses that without using ammonia especially in transportation and industrial sector (Fig.2a and 2b). This is due to the greater flexibility in logistics and low operation cost provided by ammonia fuel.

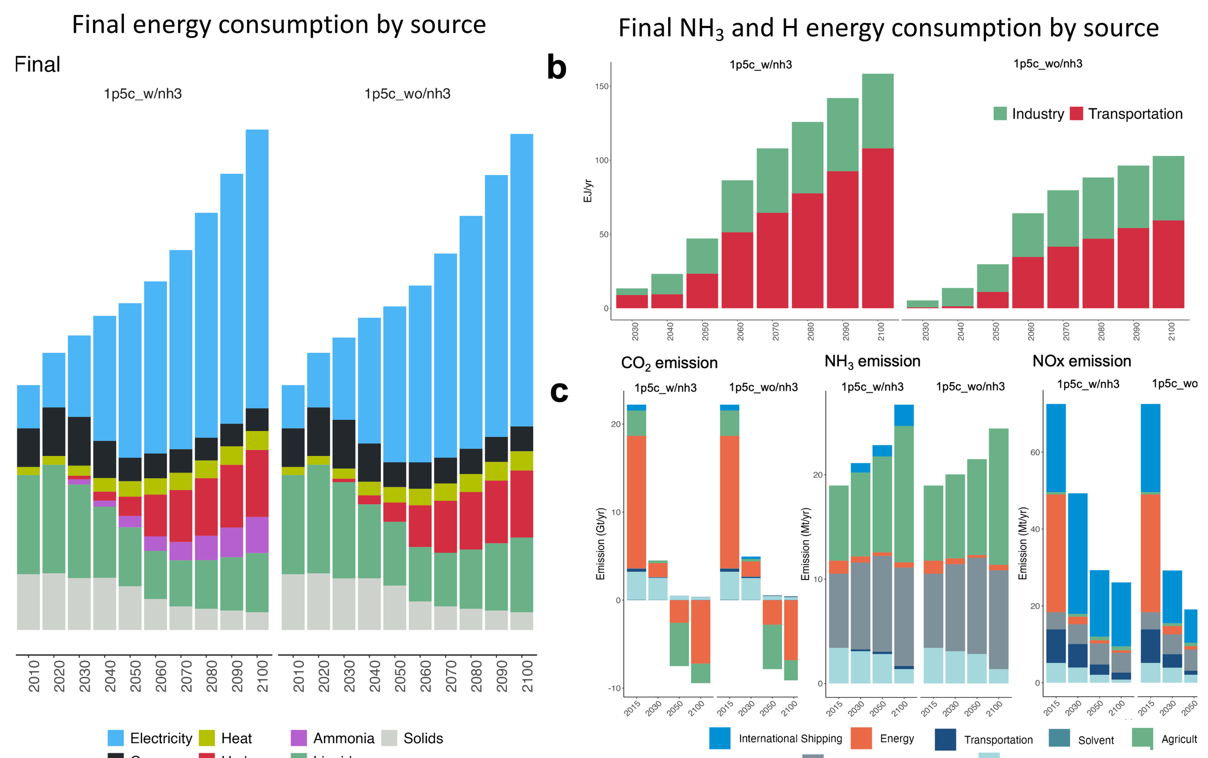

Fig.2

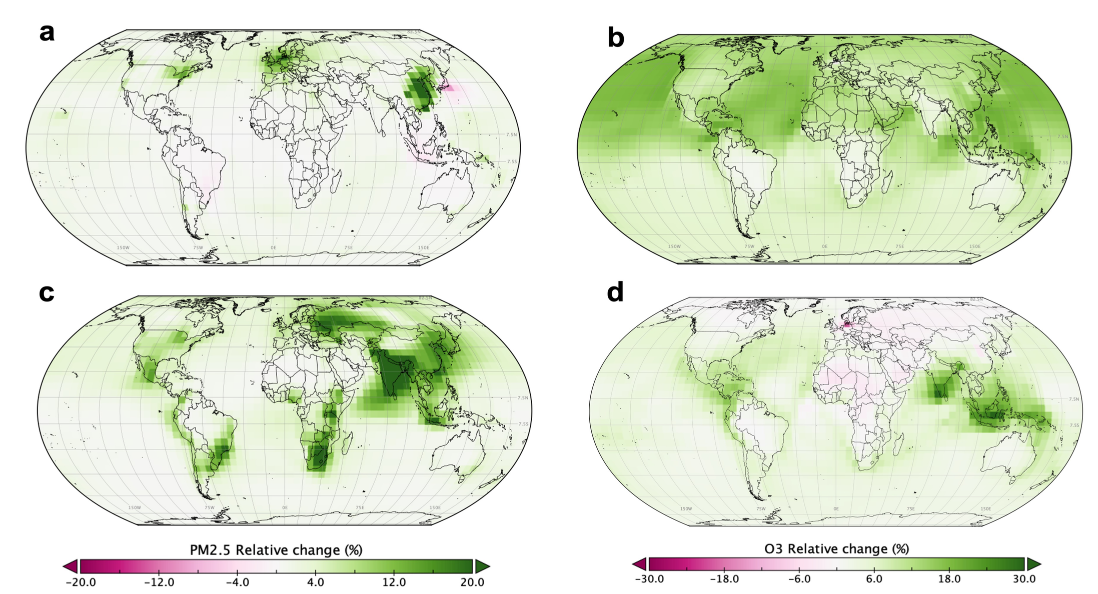

Fig. 3 The relative percentage change of PM2.5 (a) and O3 (b) comparing between without- and with ammonia fuel scenario for 2050 and without- and with proper air quality management for ammonia fuel scenario for 2050 for PM2.5 (c) and O3 (d)

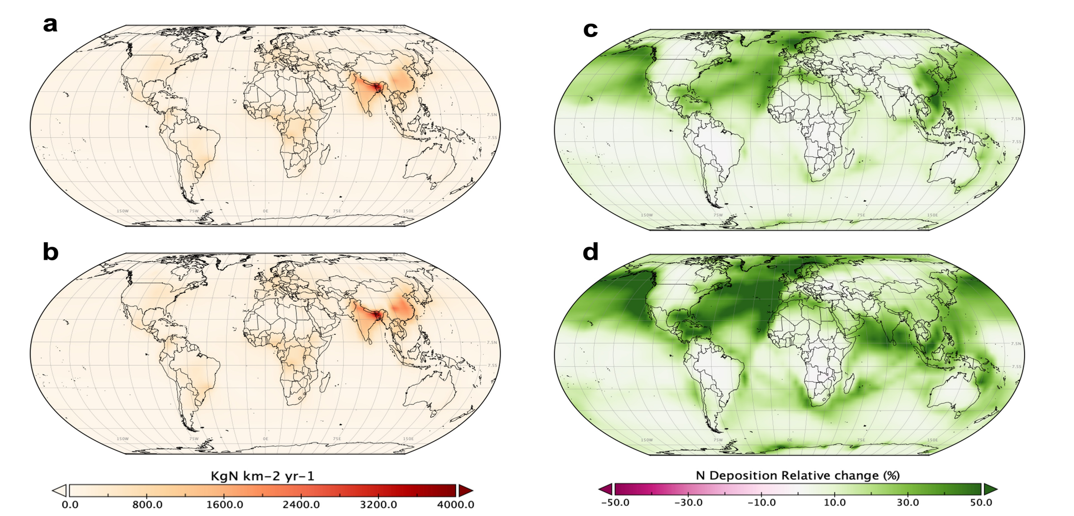

Fig. 4 Spatial distribution of total nitrogen deposition flux in Kg N km-2 yr-1 for 2050 in (a) 1p5c_wo/nh3 (b) 1p5c_w/nh3; Nitrogen deposition percentage change (%) between (c) with and without using ammonia fuel and (d) ammonia fuel with and without proper air quality management

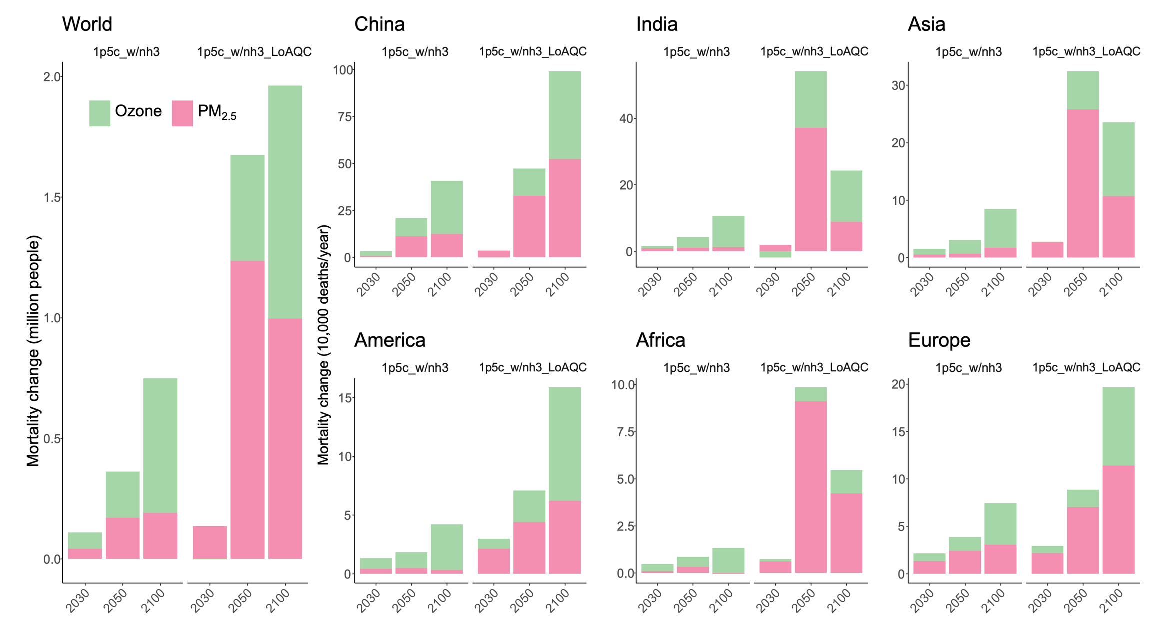

Fig. 5 $PM_{2.5}$ and O_3 premature mortality change

- Using ammonia as a fuel could lead to a significant increase in health burdens worldwide. As depicted in Fig. 5. Approximately 800,000 additional deaths could occur compared to scenarios where ammonia is not used as a fuel
- Ammonia fuel could have a greater benefit in reducing GHGs from the international ship transportation sector as shown in Fig. 2c. However, it may influence NOx and NH3 levels leading to increasing in $PM_{2.5}$, O_3, and N deposition as shown in Fig 3 and 4.

DISCUSSION AND CONCLUSION

- The adoption of ammonia fuel as a carbon-free alternative to fossil fuels holds significant potential for reducing greenhouse gas emissions.
- While the reduction in greenhouse gas emissions is a substantial environmental benefit, it is imperative to address the potential increase in NOx and NH_3 emissions. This increase can exacerbate ambient air quality issues, particularly with respect to $PM_{2.5}$ and O_3. The increase in these pollutants can have significant health and environmental impacts.
- Transitioning from traditional fossil fuels to carbon-free alternatives like ammonia requires more than just the fuel switch itself; it necessitates the stringent implementation of air quality control policies.

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