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State Key Laboratory of Earth Surface Processes and Resource Ecology

LCS·R Net

LCS-RNet 14th Annual Meeting

Global forests as a carbon sink in response to anthropogenic nitrogen deposition

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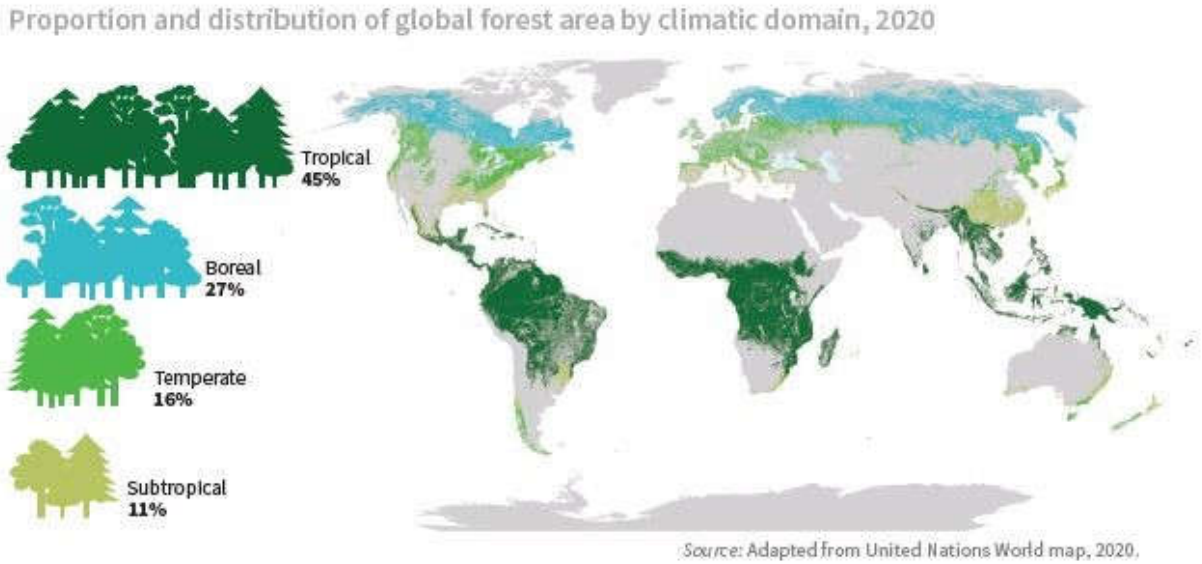
Dec 18, 2023

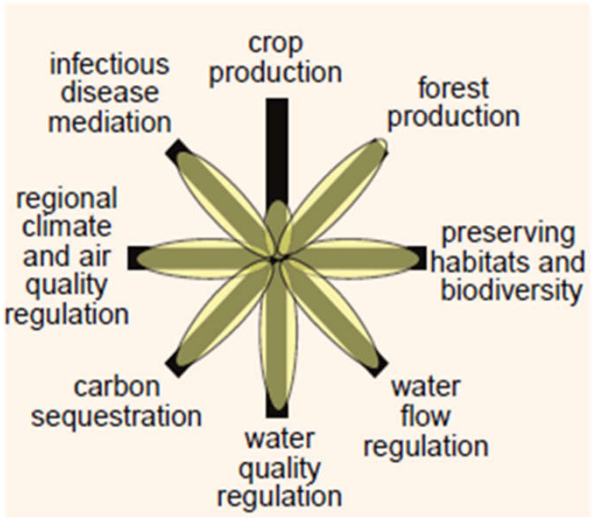
1. Background and question

Forests cover 31% of global land area and provide essential ecosystem services

Distribution of global forests (4060 M ha)



Ecosystem services of natural forests

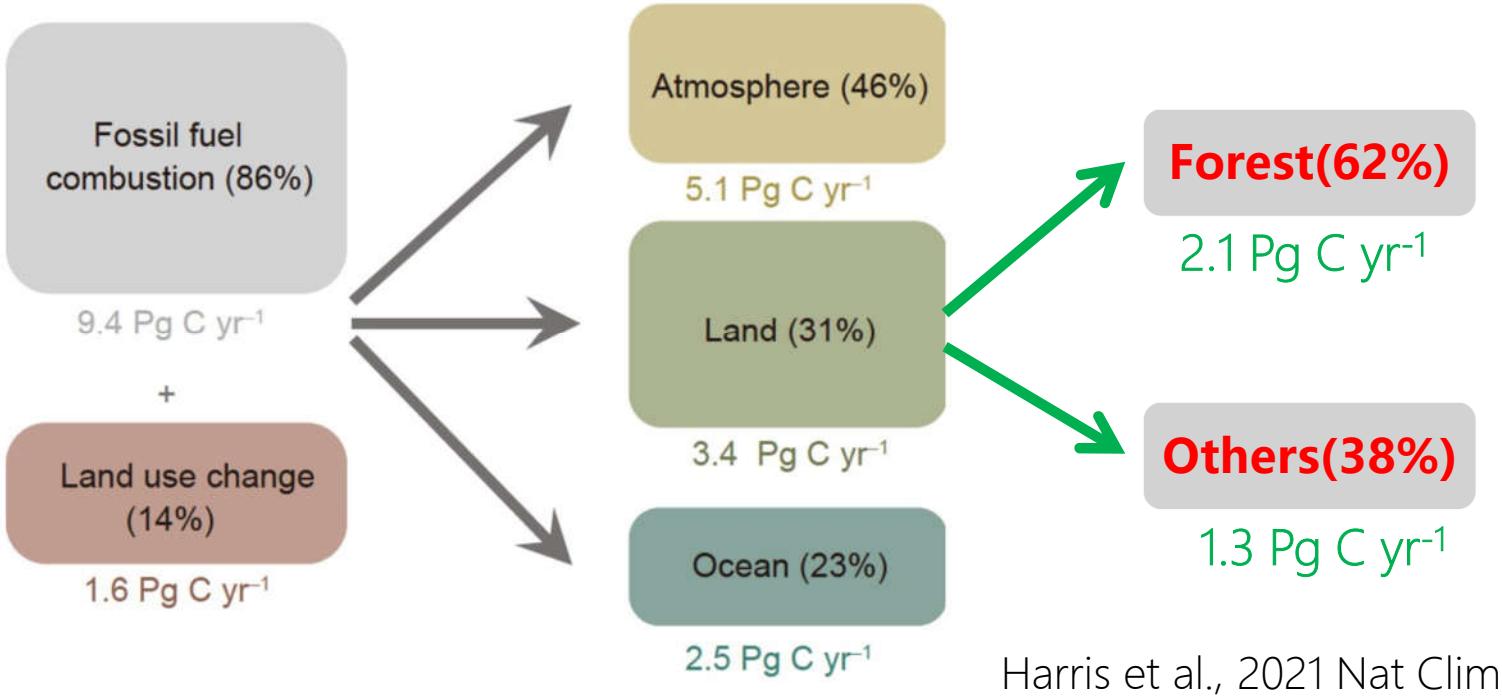


Foley et al., 2005 Science

1. Background and question

Forests dominate the carbon sinks in global terrestrial biomes (>60%)

Global carbon budget (2019)

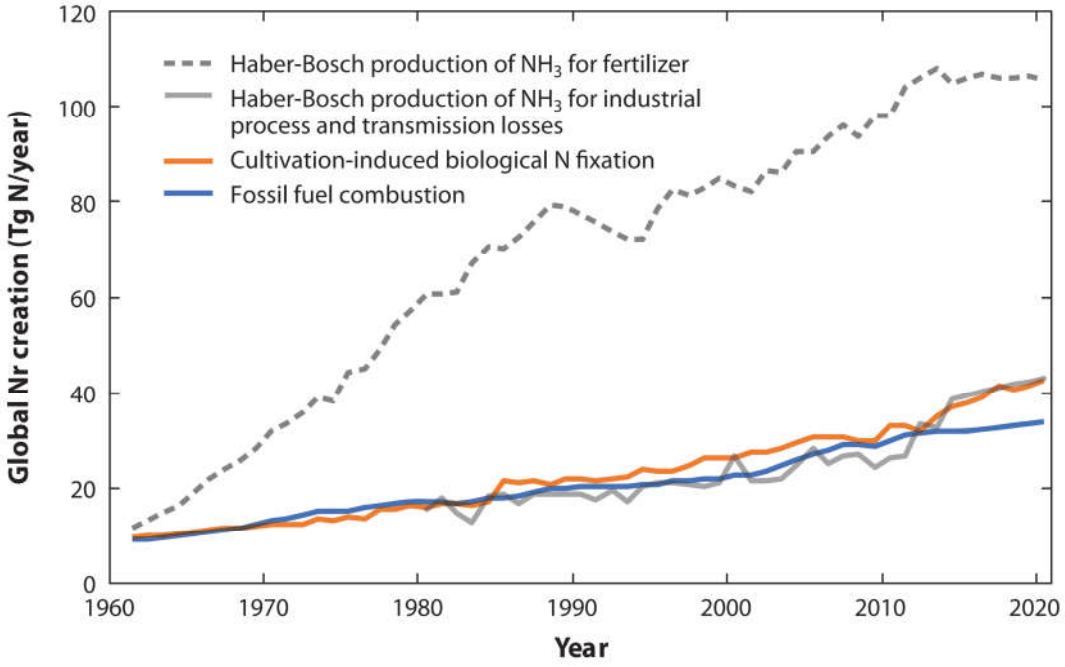


Harris et al., 2021 Nat Clim Chang

1. Background and question

Great acceleration of global N cycling: food production & population growth

Global creation of reactive nitrogen(Nr)



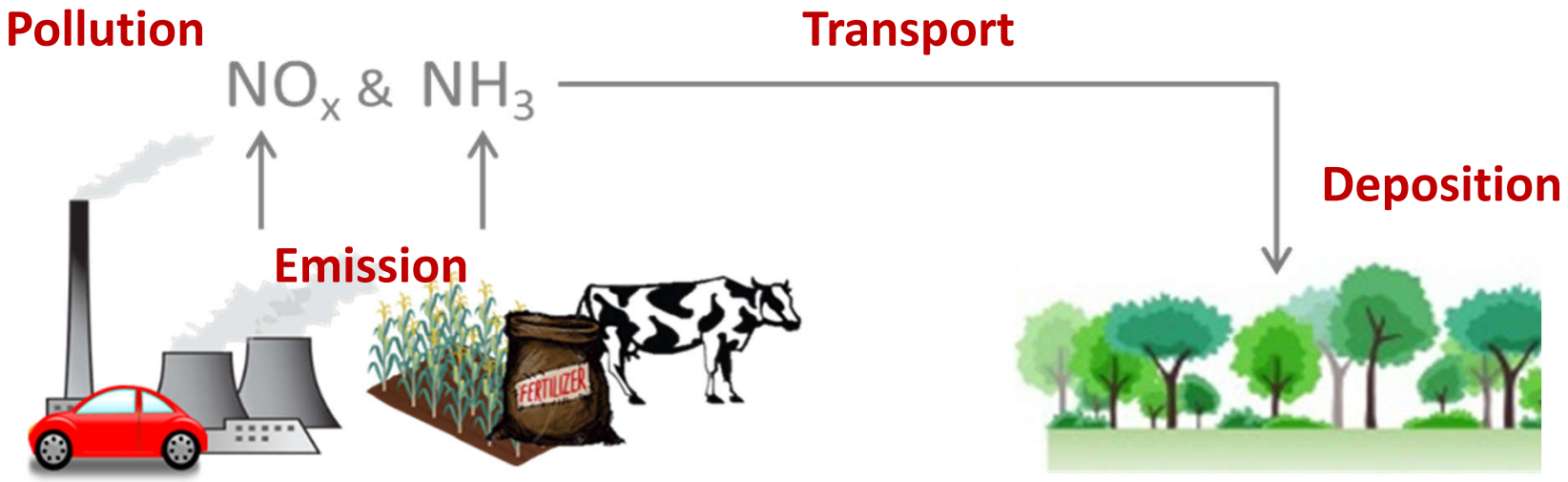
Galloway et al., 2021. Annu. Rev. Environ. Resour.

Growth of global population (>8 billion)

1. Background and question

Too much of a good thing

Curbing nitrogen emissions is a central environmental challenge for the twenty-first century, argue **Mark Sutton** and his colleagues.

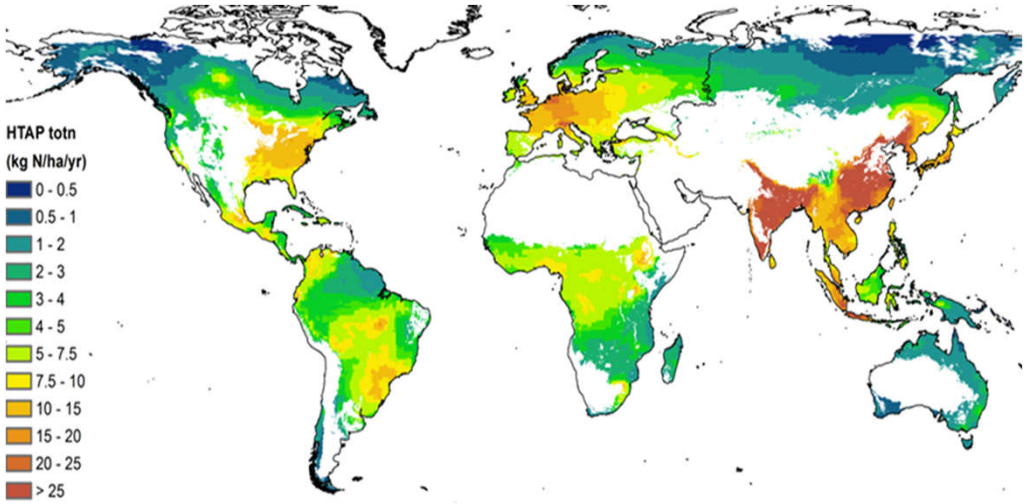


De Vries, Du, Butterbach-Bahl, Schulte-Uebbing, & Dentener, 2017. In Oxford Research Encyclopedia of Environmental Science.

1. Background and question

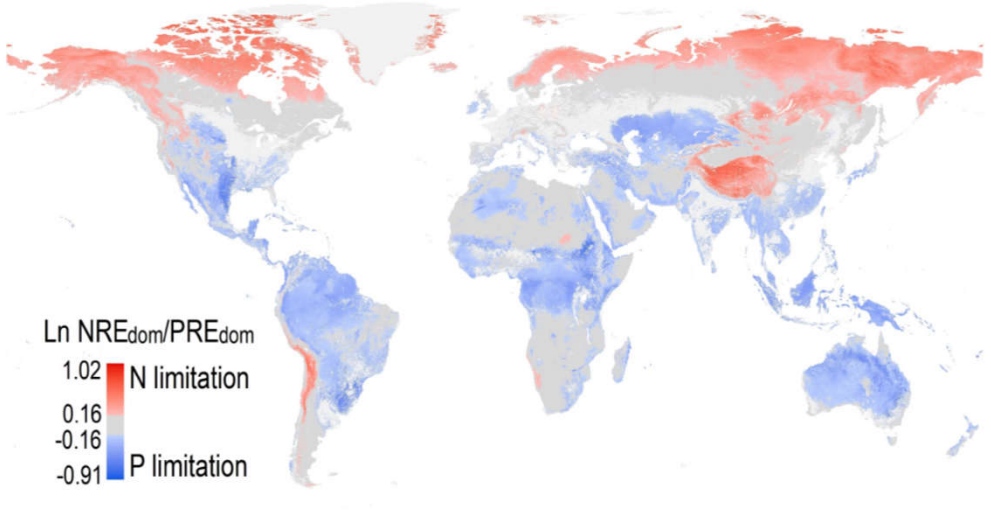
Large forested areas receive enhanced N deposition

N deposition to global forested areas (2010)



Schwede…**Du**… et al., 2018. Environmental Pollution

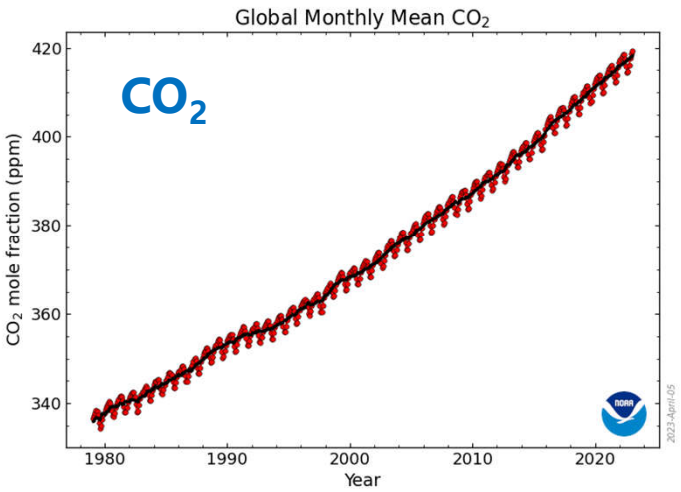
Nutrient limitation to global forests

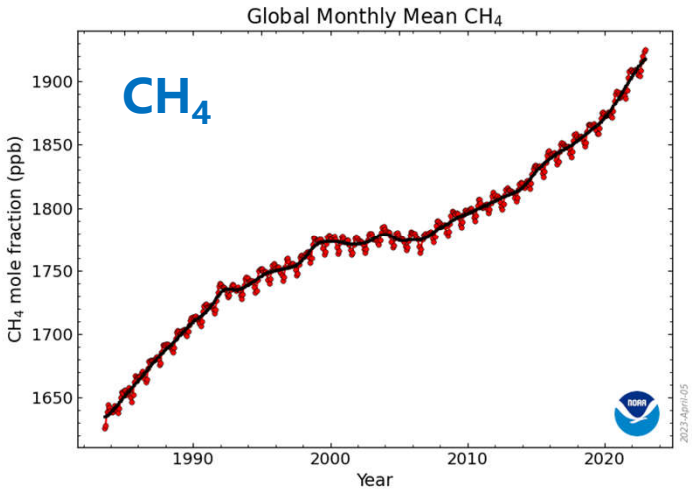


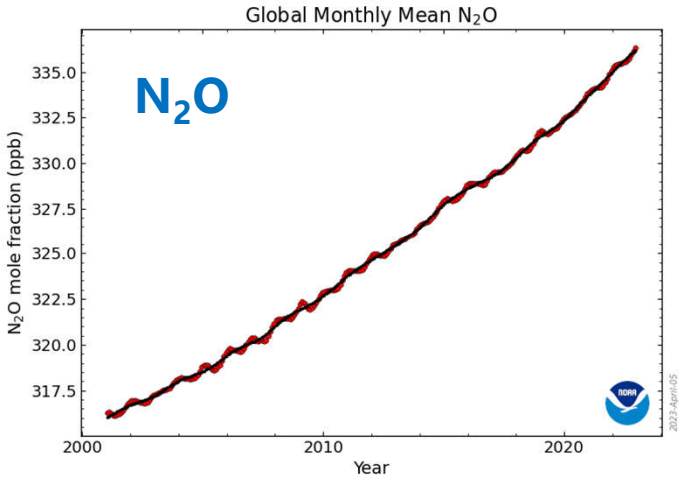
Du et al., 2020, Nature Geoscience

1. Background and question

Rising air concentrations of greenhouse gases (GHGs)



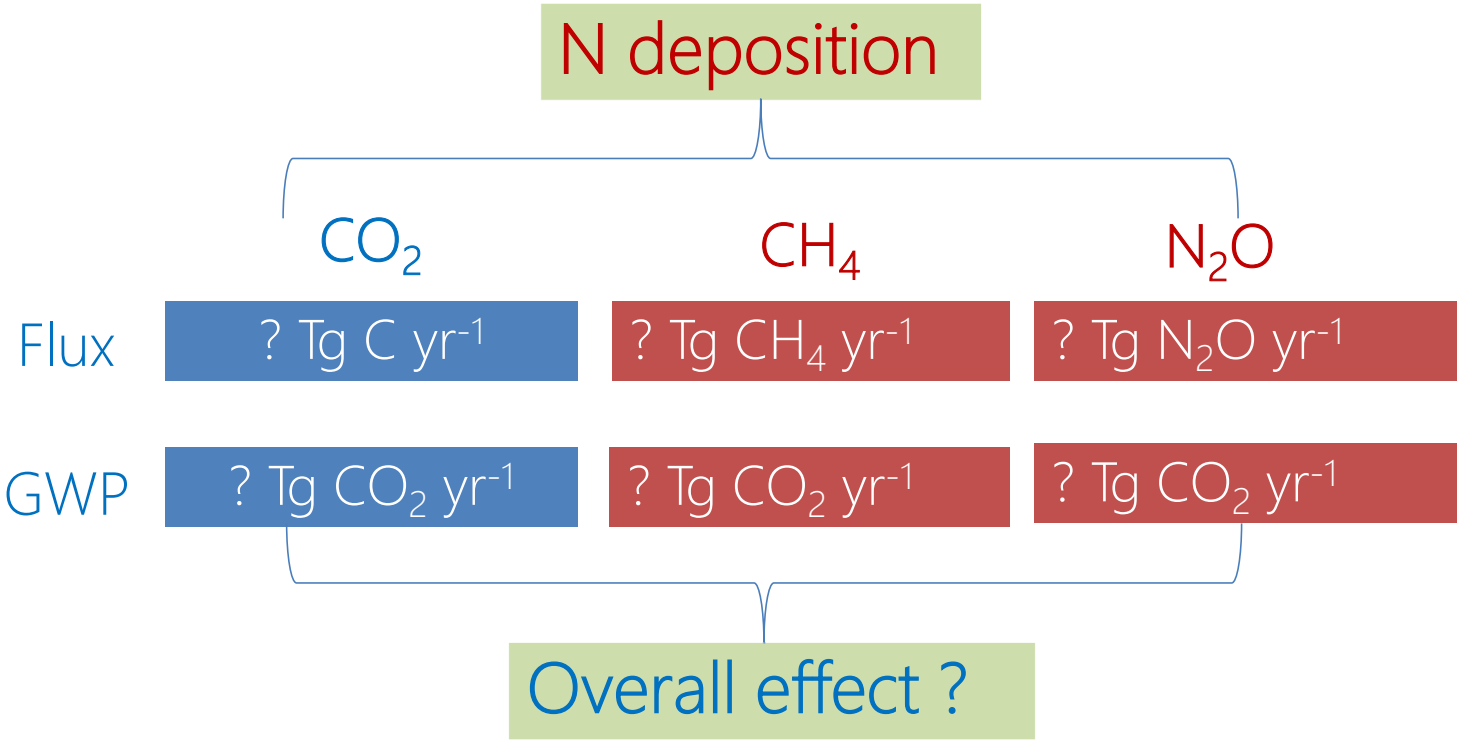




https://gml.noaa.gov/ccgg/trends/

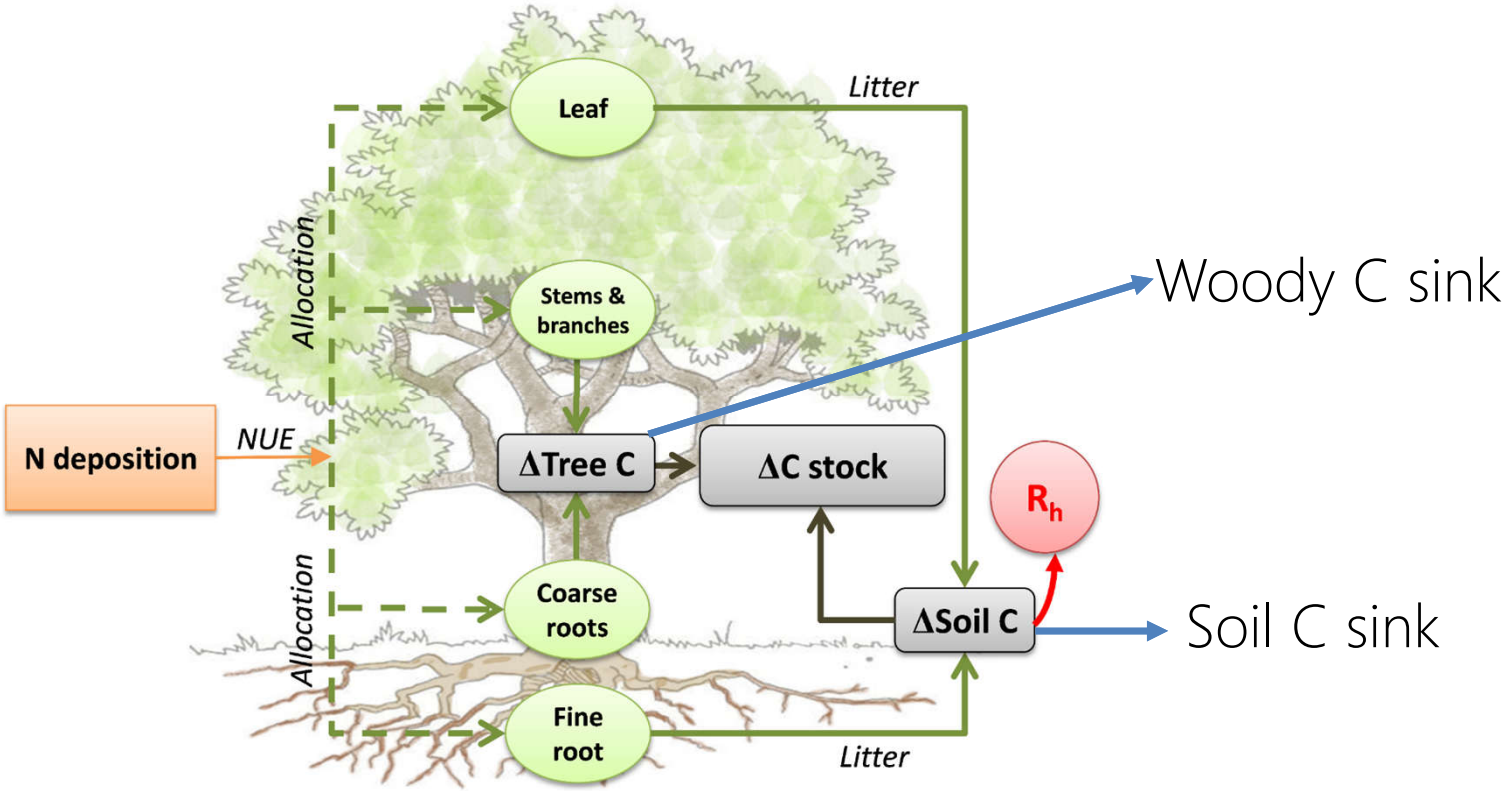
1. Background and question

Q: What's the overall effect of N deposition on GHGs in global forests?



2. Effects of nitrogen deposition on forest GHGs—CO_2

Nitrogen deposition and forest C sequestration



Du and De Vries, 2018. Environmental Pollution

2. Effects of nitrogen deposition on forest GHGs—CO_2

Stoichiometric upscaling approach

N-induced new productivity

$$NPP_{new} = \left(NSBNF \times NUE_{NSBNF} + SBNF \times NUE_{SBNF} + N_{dep} \times NUE_{Ndep}\right) \times R_{C-N}$$

$$R_{C-N} = \sum Frac_N \times C{:}N_{ratio}$$

N-induced C sink

$$C\ sink = \left(NSBNF \times NUE_{NSBNF} + SBNF \times NUE_{SBNF} + N_{dep} \times NUE_{Ndep}\right) \times R_{C\ sink-N}$$

$$\mathrm{R}_{C\ sink-N} = R_{C-N\ wood} + R_{C-N\ non-wood} \times Frac_{res}$$

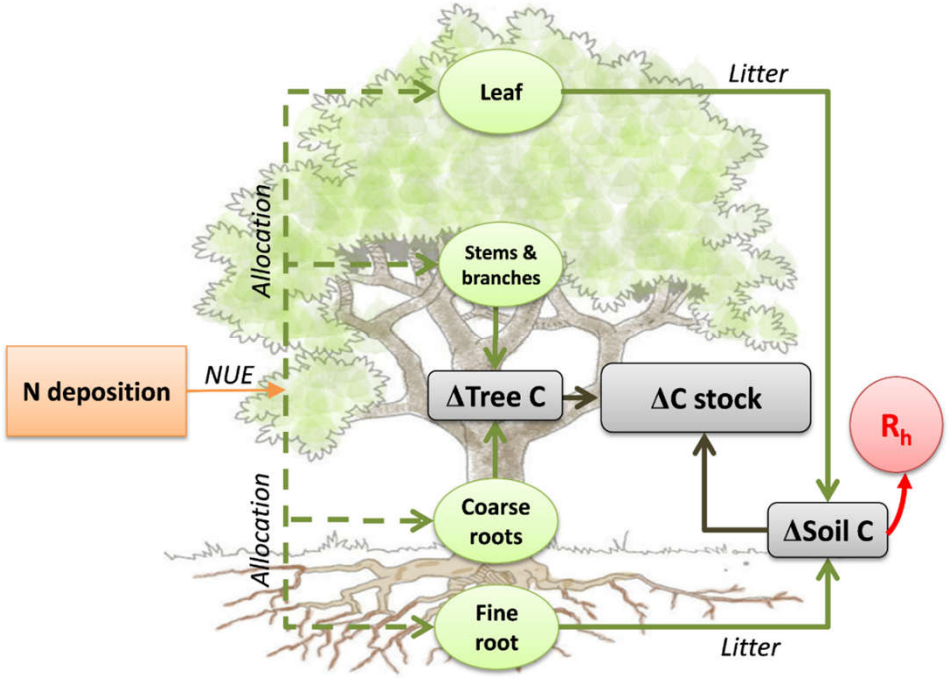
$$C\ sink_{wood} = \left(NSBNF \times NUE_{NSBNF} + SBNF \times NUE_{SBNF} + N_{dep} \times NUE_{Ndep}\right) \times R_{C-N\ wood}$$

$$C\ sink_{soil} = \left(NSBNF \times NUE_{NSBNF} + SBNF \times NUE_{SBNF} + N_{dep} \times NUE_{Ndep}\right) \times R_{C-N\ non-wood} \times Frac_{res}$$

Du and De Vries, 2018. Environmental Pollution

2. Effects of nitrogen deposition on forest GHGs—CO_2

Contribution of N deposition to global forest C sequestration (0.25 Pg C yr^{-1})



Woody C $Sink_{Ndep}$

0.19 Pg C yr^{-1}

+

Soil C $Sink_{Ndep}$

0.06 Pg C yr^{-1}

=

C $Sink_{Ndep}$

0.25 Pg C yr^{-1}

Du and De Vries, 2018. Environmental Pollution

2. Effects of nitrogen deposition on forest GHGs—CO_2

Contribution of N deposition to C sink in global forests

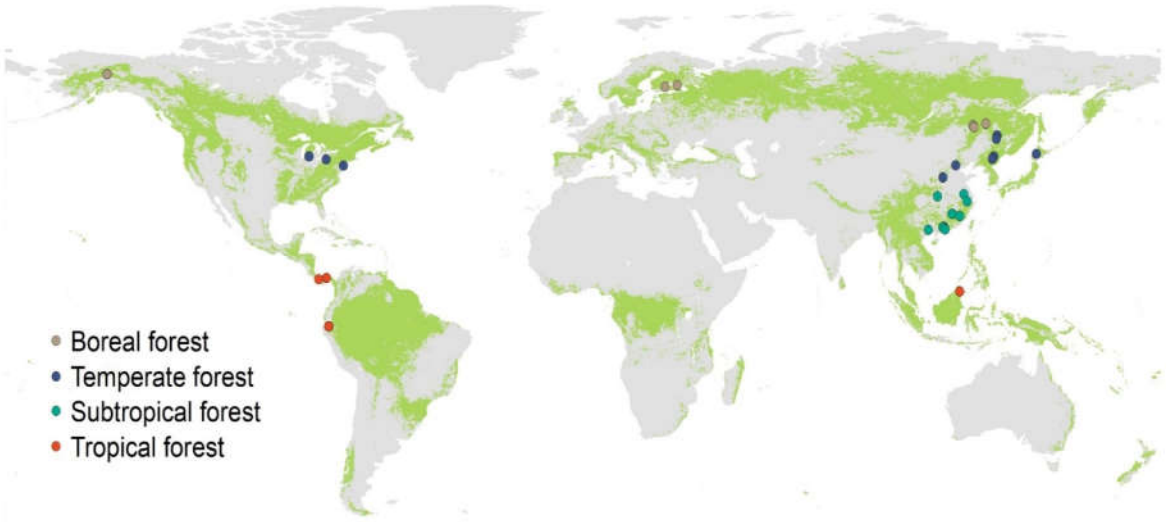
Study	Period/year	Boreal forest			Temperate forest			Tropical forest			Global		
		Area	Ndep	Csink	Area	Ndep	Csink	Area	Ndep	Csink	Area	Ndep	Csink
Woody biomass C sink													
Du and de Vries (2018)	2001	12.2	1.9	0.04	9.7	9.0	0.08	18.7	10.2	0.07	40.6	21.1	0.19
Schulte-Uebbing & de Vries (2018)	2000	12.1	2.2	0.04	10.2	8.0	0.12	17.9	11.4	0.02	40.2	21.6	0.18
Soil C sink													
Du and de Vries (2018)		12.2	1.9	0.02	9.7	9.0	0.03	18.7	10.2	0.01	40.6	21.1	0.06
Total C sink													
De Vries et al. (2014)	1993	7.8	1.3	0.03	8.6	7.1	0.13	16.2	6.9	0.11	32.6	15.3	0.27
Du and de Vries (2018)	2001	12.2	1.9	0.06	9.7	9.0	0.11	18.7	10.2	0.08	40.6	21.1	0.25
Wang et al. (2017)	2010	7.2	1.7	0.08	7.2	6.6	0.20	11.5	7.9	0.10	25.9	16.2	0.38
Gurmesa et al. (2022)	2010	12	3.7	0.17	7	8	0.24	23	13.1	0.31	42	24.8	0.72
Fleischer et al. (2015)	2000s	11.4	4.1	0.07	7.7	4.8	0.11	19.5	10.3	0.27	38.6	19.2	0.46

Du and De Vries, 2023. Academic Press

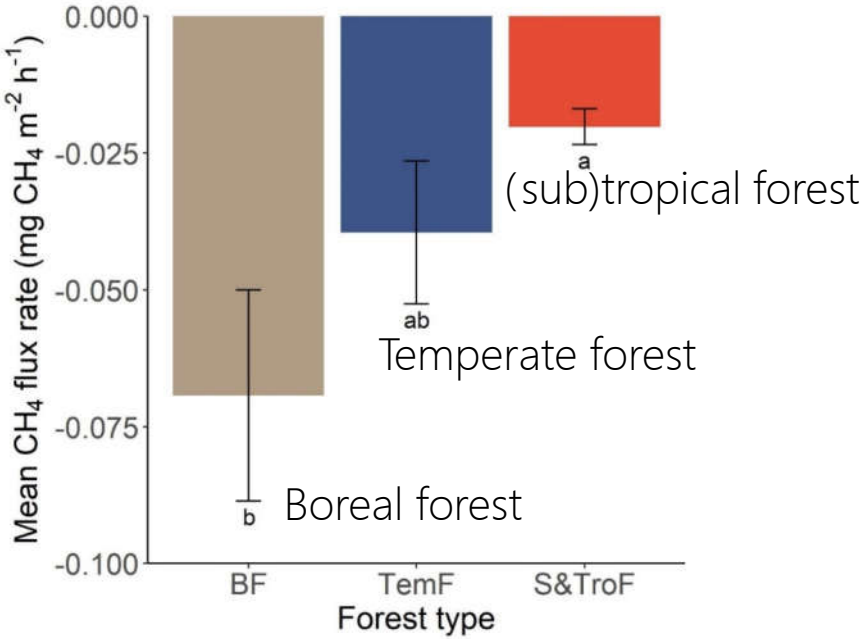
2. Effects of nitrogen deposition on forest GHGs—CH_4

Forest soils are sinks of atmospheric CH_4

Meta-analysis of N addition experiments



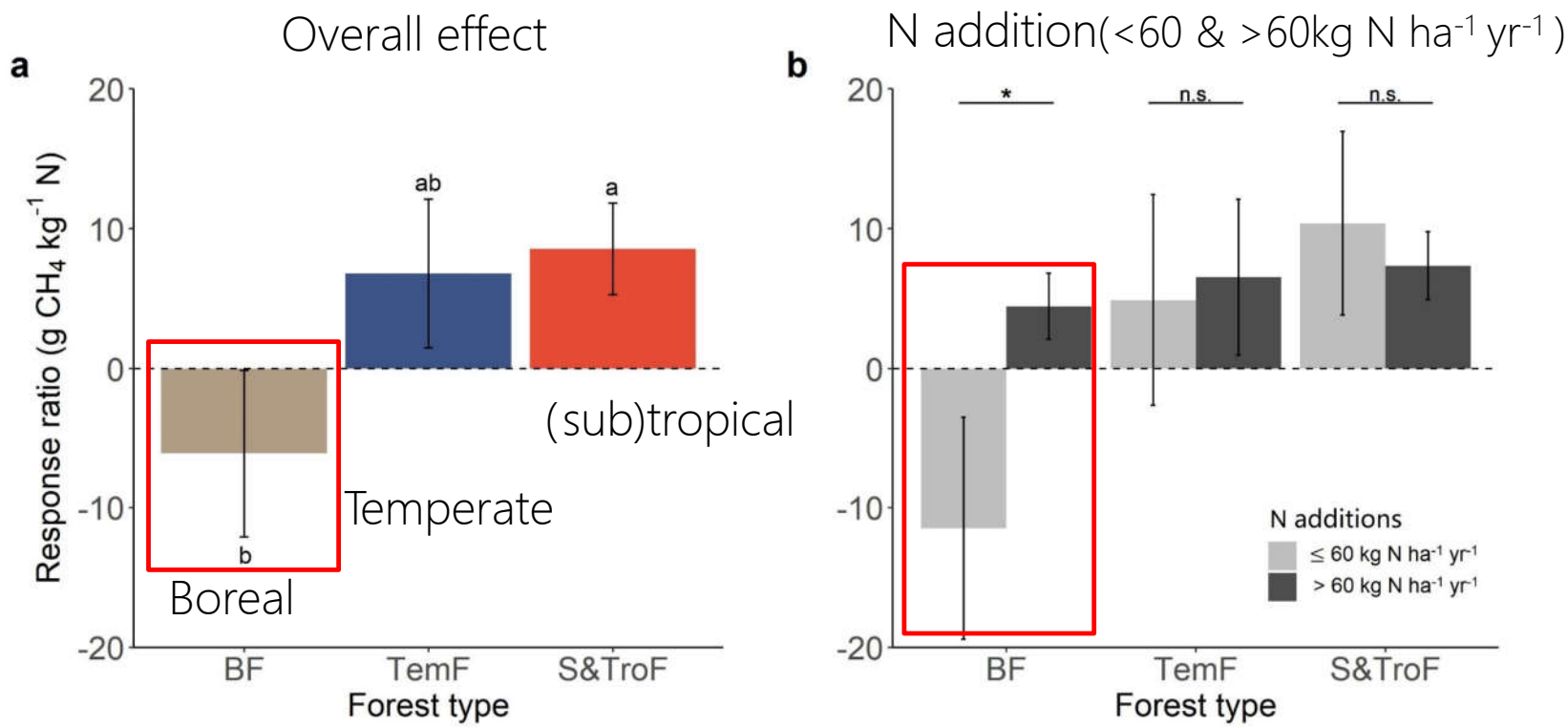
Soil CH_4 uptake in forest biomes



Xia, Du*, et al., 2020 Environmental Pollution; Xia, Du*, et al., 2023 Academic Press

2. Effects of nitrogen deposition on forest GHGs—CH_4

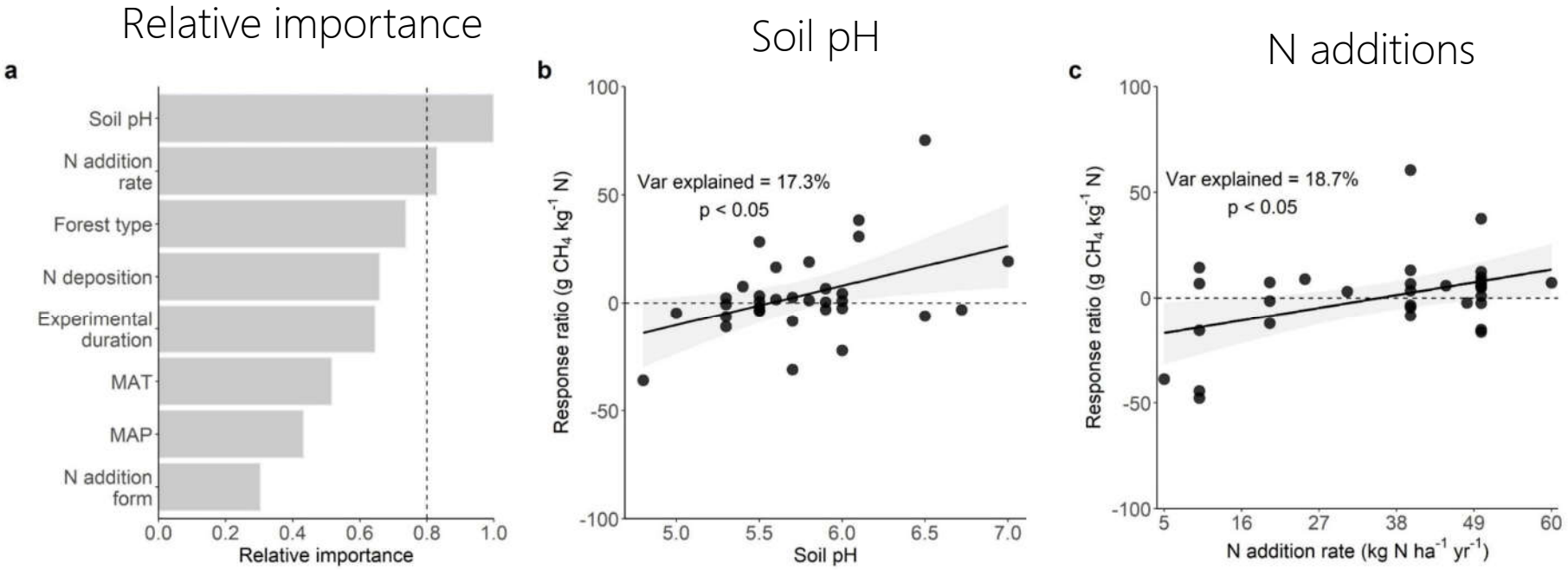
Effects of N deposition on soil CH_4 uptake in forest biomes



Xia, Du*, et al., 2020 Environmental Pollution; Xia, Du*, et al., 2023 Academic Press

2. Effects of nitrogen deposition on forest GHGs—CH_4

Factors regulating effects of N deposition on soil CH_4 uptake



Xia, Du*, et al., 2020 Environmental Pollution; Xia, Du*, et al., 2023 Academic Press

2. Effects of nitrogen deposition on forest GHGs—CH_4

Overall effects of N deposition on soil CH_4 uptake in global forests (0.18 Tg CH_4 yr^{-1})

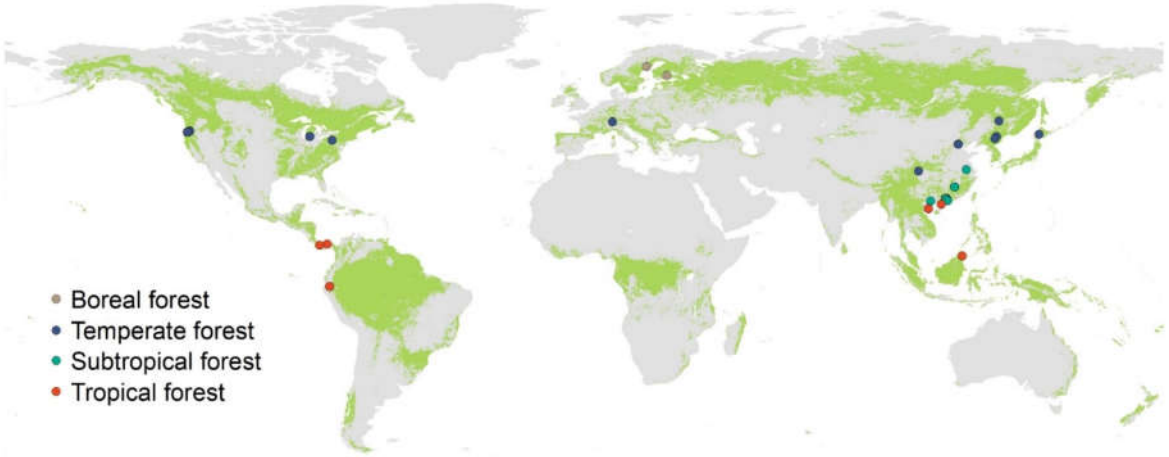
Forest biome	Area (Million ha)	Soil CH_4 flux rate (mg CH_4 m^{-2} h^{-1})	Biome CH_4 flux (Tg CH_4 yr^{-1})	Mean N deposition (kg N ha^{-1} yr^{-1})	Response ratio (g CH_4 kg^{-1} N)	Biome effect (Tg CH_4 yr^{-1})
Boreal	1225	-0.07 ± 0.02^{b}	-2.47 ± 0.68	1.2	-11.49 ± 7.94^{b}	-0.02 ± 0.01
Temperate	673	-0.04 ± 0.01^{ab}	-1.38 ± 0.45	7.3	4.89 ± 7.57^{ab}	0.02 ± 0.04
Subtropical & Tropical	2118	-0.02 ± 0.00^{a}	-3.71 ± 0.56	8.3	10.39 ± 6.57^{a}	0.18 ± 0.12
Total	4016	-	-7.55 ± 1.68	-	-	0.18 ± 0.17

Xia, Du*, et al., 2020 Environmental Pollution; Xia, Du*, et al., 2023 Academic Press

2. Effects of nitrogen deposition on forest GHGs—N_2O

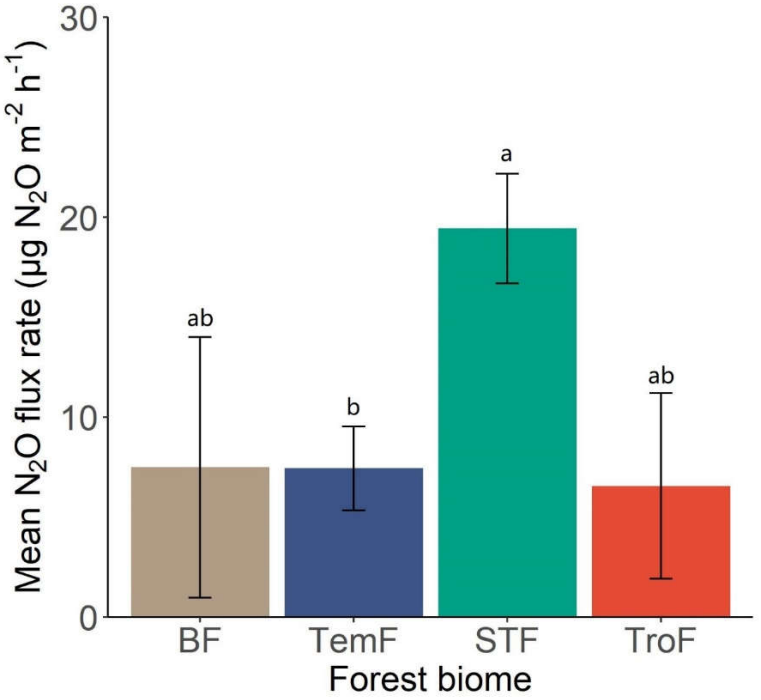
Forest soils are sources of atmospheric N_2O

Meta-analysis of N addition experiments



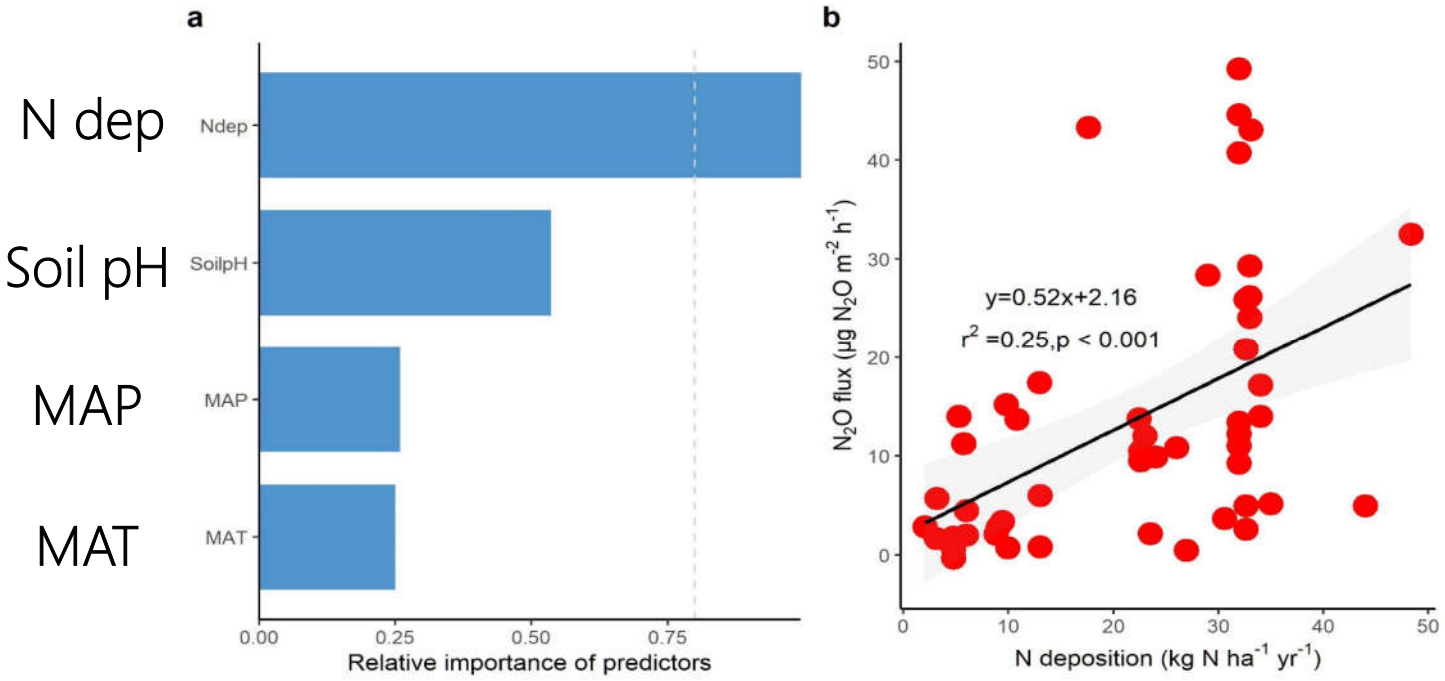
Du, et al., 2023 Academic Press

Soil N_2O emissions in forest biomes



2. Effects of nitrogen deposition on forest GHGs—N_2O

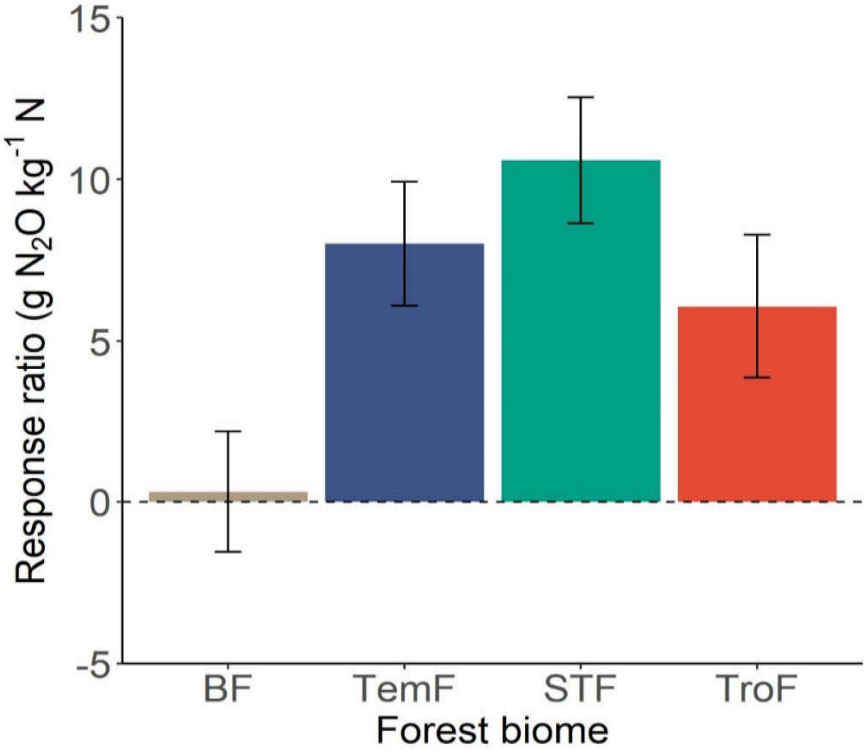
N deposition drives spatial variation in soil N_2O emissions



Du, et al., 2023 Academic Press

2. Effects of nitrogen deposition on forest GHGs—N_2O

Effects of N deposition on soil N_2O emissions in forest biomes



Du, et al., 2023 Academic Press

2. Effects of nitrogen deposition on forest GHGs—N_2O

Overall effect of N deposition on soil N_2O emissions in global forests(0.17 Tg N_2O yr^{-1})

Forest biome	Area (Million ha)	Soil N_2O emission rate (μg N_2O m^{-2} h^{-1})	Biome N_2O emission (Tg N_2O yr^{-1})	Mean N deposition (kg N ha^{-1} yr^{-1})	Emission factor (‰)	$Emission_{Ndep}$ (Tg N_2O yr^{-1})
Boreal forest	1225	7.5±6.5	0.27±0.23	1.2	0.2±1.2	0.001±0.003
Temperate forest	673	7.4±2.1	0.26±0.07	7.3	5.1±1.2	0.039±0.009
Subtropical forest	320	19.4±2.7	0.54±0.08	14.6	6.7±1.2	0.049±0.009
Tropical forest	1798	6.6±4.6	1.03±0.73	7.2	3.9±1.4	0.079±0.029
Total	4016	-	2.10±1.11	-	-	0.168±0.050

Du, et al., 2023 Academic Press

2. Effects of nitrogen deposition on forest GHGs—Overall effect

A: Overall effect of N deposition on GHGs

	CO_2	CH_4	N_2O
Flux	-250 Tg C yr^{-1}	0.18 Tg CH_4 yr^{-1}	0.17 Tg N_2O yr^{-1}
GWP	-917 Tg CO_2 yr^{-1}	4.5 Tg CO_2 yr^{-1}	50.7 Tg CO_2 yr^{-1}

GWP: -862 Tg CO_2 yr^{-1}

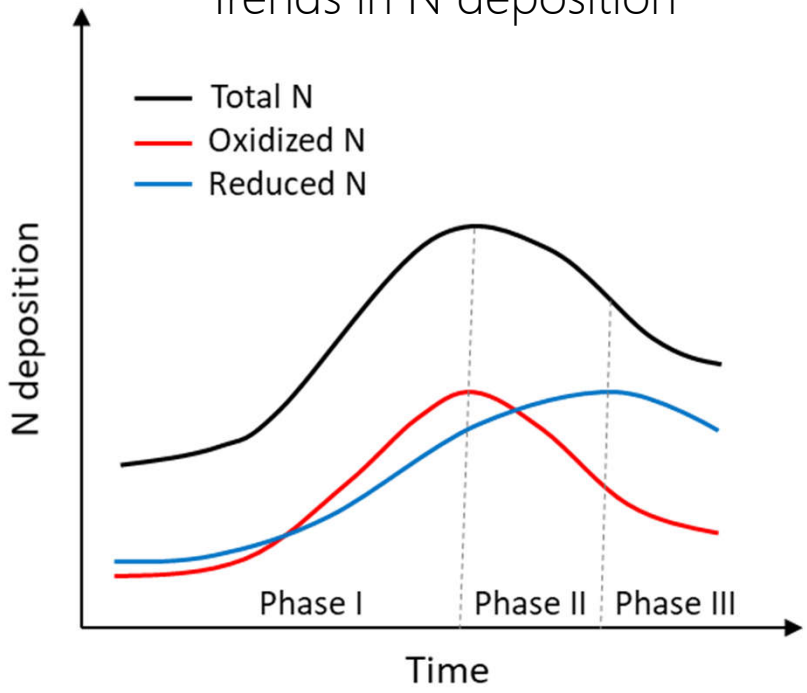
GHG	100-yr GWP
CO_2	1
CH_4	25
N_2O	298

Du & de Vries, 2023 Academic Press

3. Implications and outlook

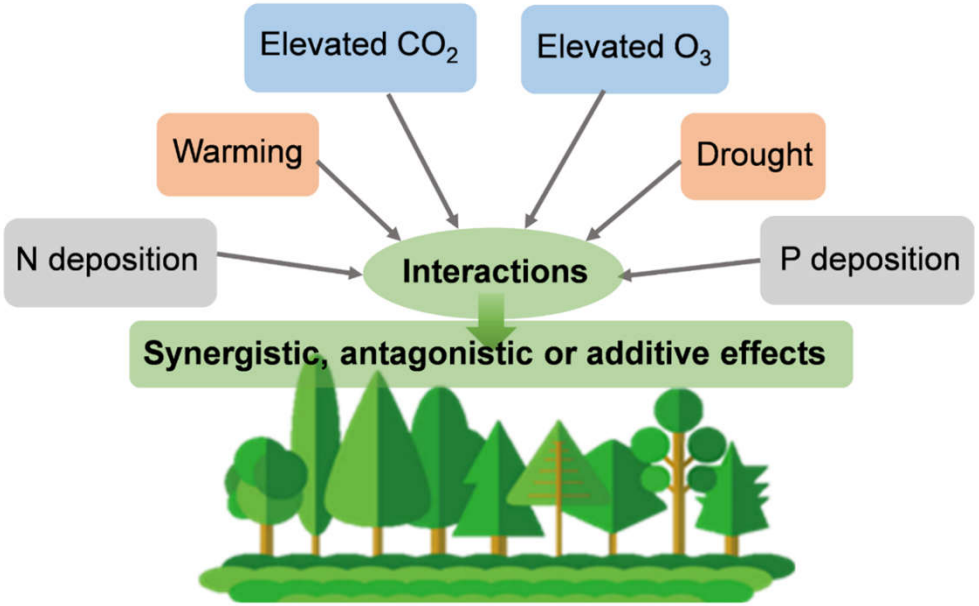
Future decline in N deposition and ecosystem responses

Trends in N deposition



Du, 2023 Springer

Interactions with other global change drivers

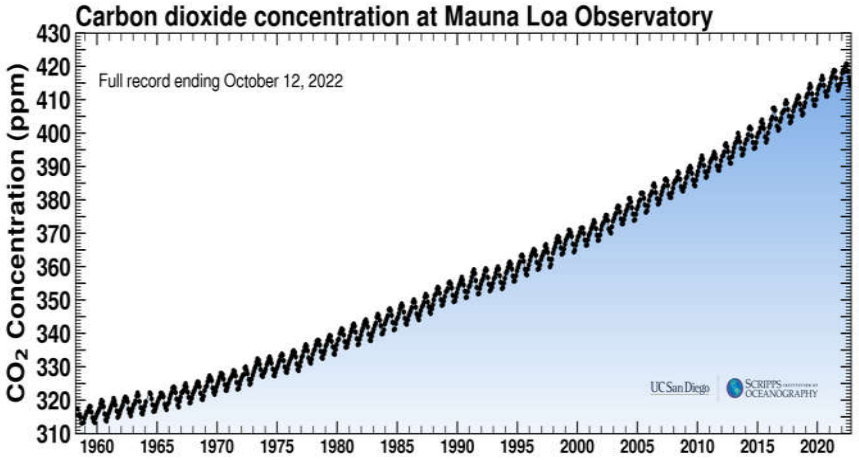


Du & de Vries 2023 Academic Press

3. Implications and outlook

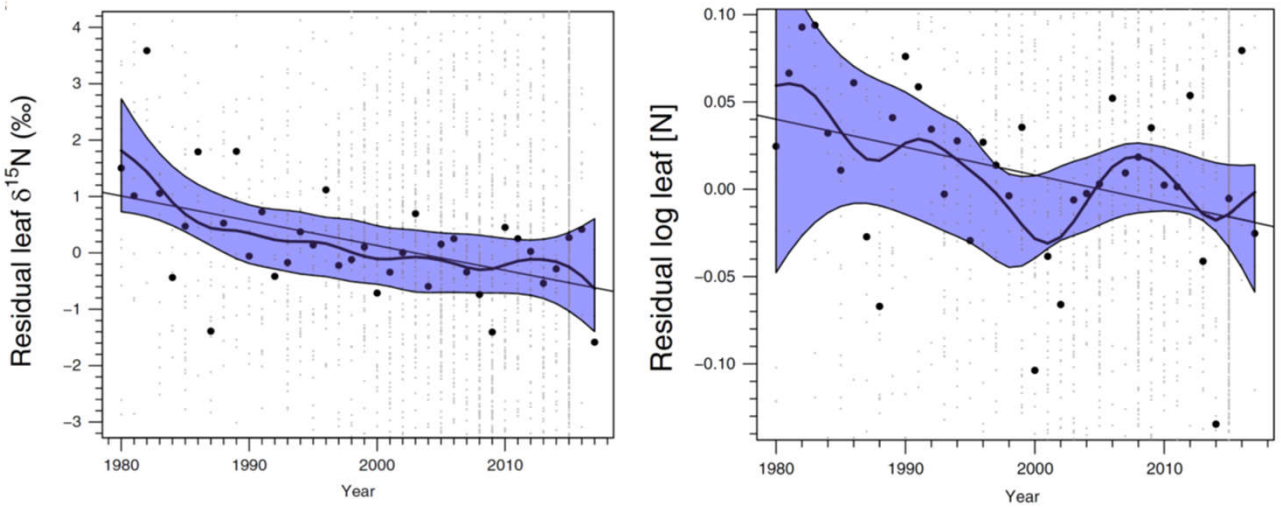
Feedbacks between CO_2 fertilization and declining N deposition

Rising CO_2 concentrations(Keeling Curve)



https://keelingcurve.ucsd.edu/

Nitrogen oligotrophication of terrestrial ecosystems (1980-2017)



Craine et al., 2018 Nature Ecology & Evolution

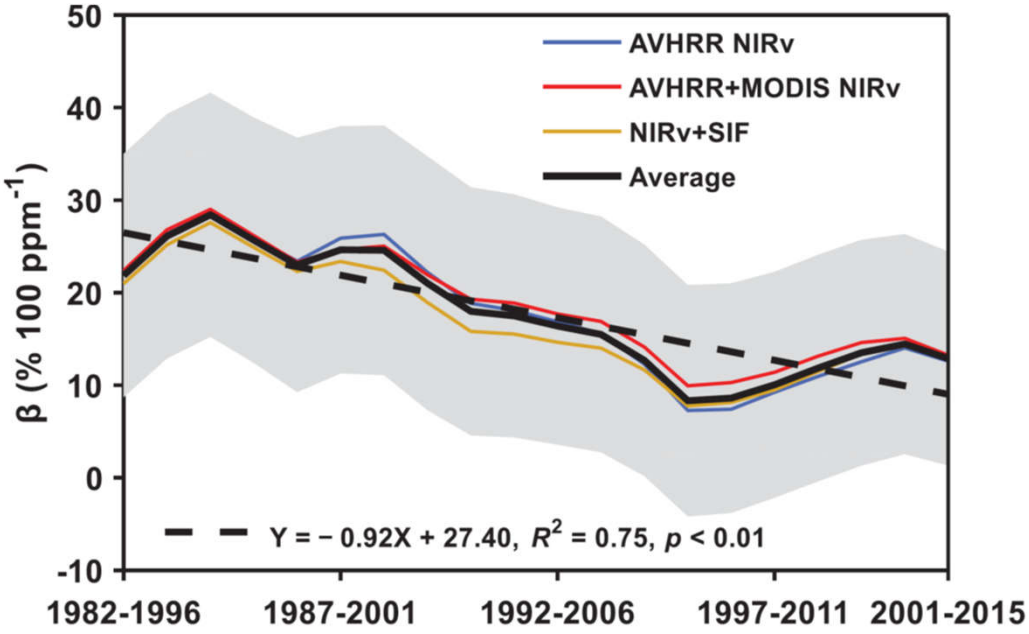
3. Implications and outlook

Declining strength of CO_2 fertilization in past four decades

Satellite data analysis:

$$\beta = \frac{\partial GPP}{\partial C_a}$$

the relative increase in GPP in response to a 100-ppm increase in atmospheric CO_2 concentration

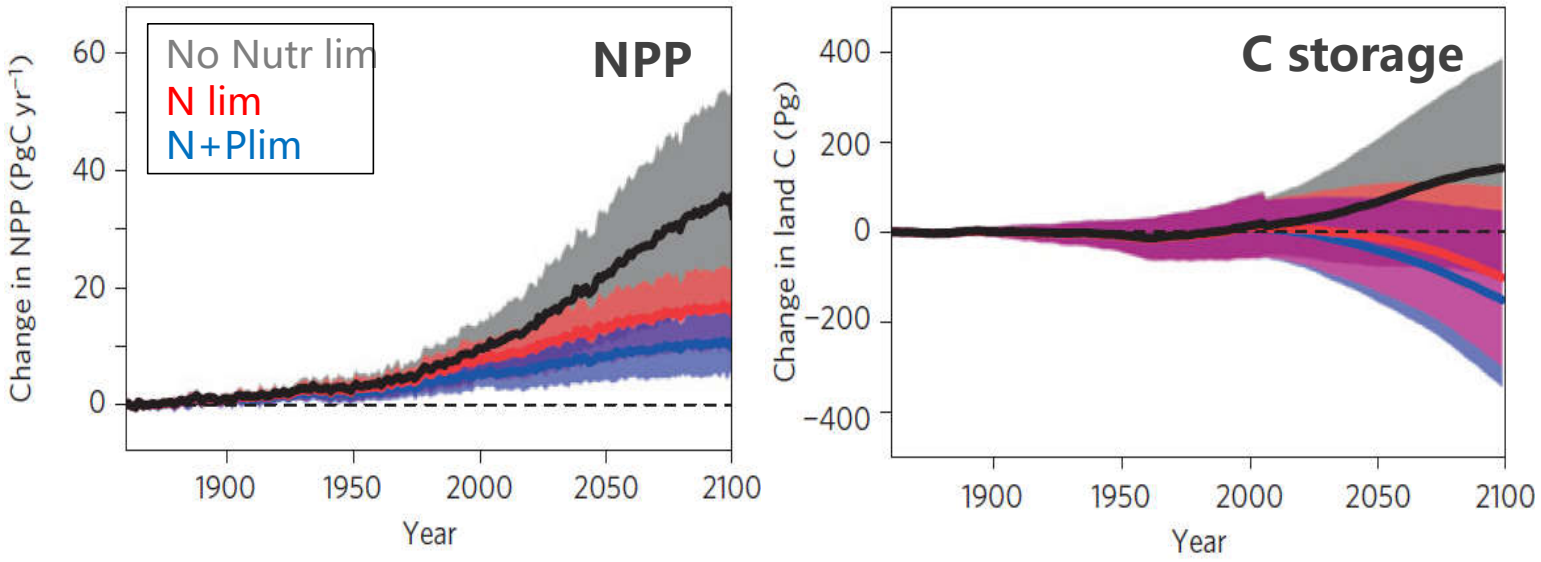


Wang et al., Science 370, 1295–1300 (2020)

3. Implications and outlook

Future nutrient limitation of CO_2 fertilization on forest growth and C sinks

Model projection of future land C sinks

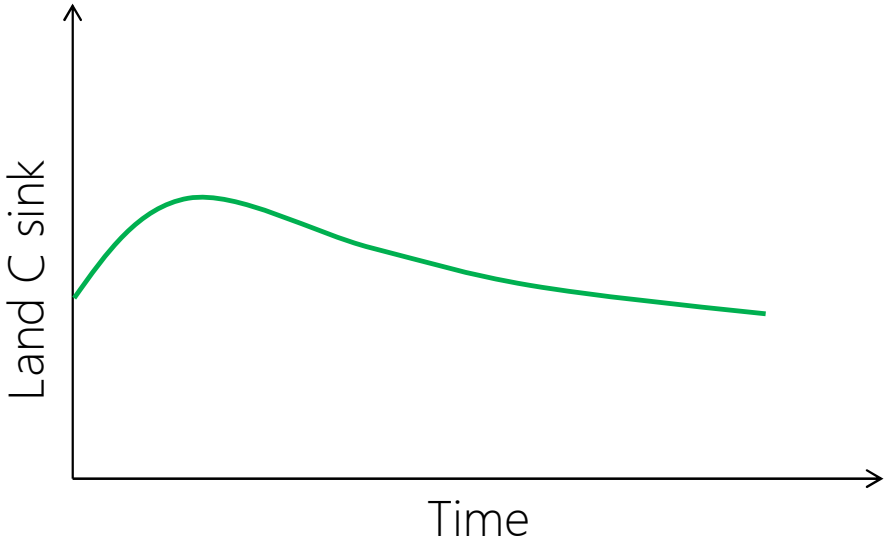


Wieder et al., 2015 Nature Geoscience

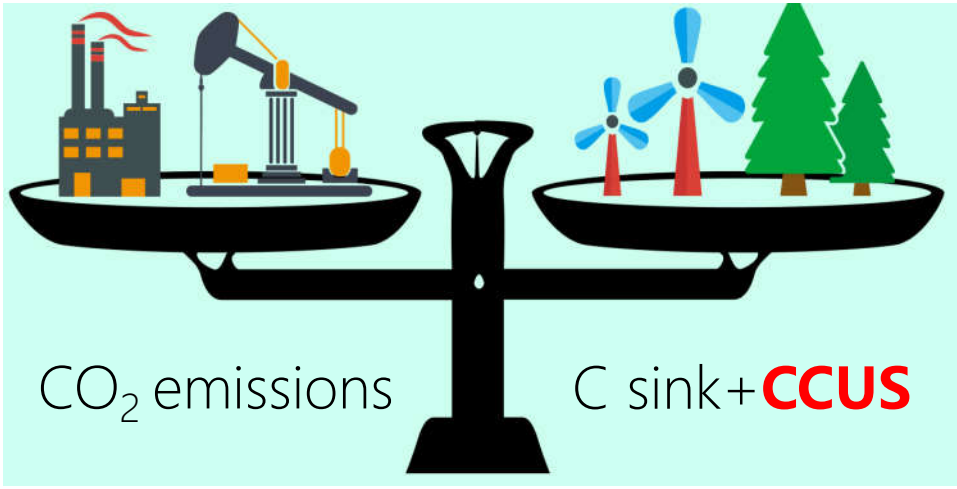
3. Implications and outlook

Future great challenge of carbon neutrality

Trend of future land C sink



The way to C neutrality



Thanks!