Increasing the cost-effectiveness of nutrient reduction targets using different spatial scales

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SCIENCE FOR A BETTER FUTURE OF THE BALTIC SEA REGION

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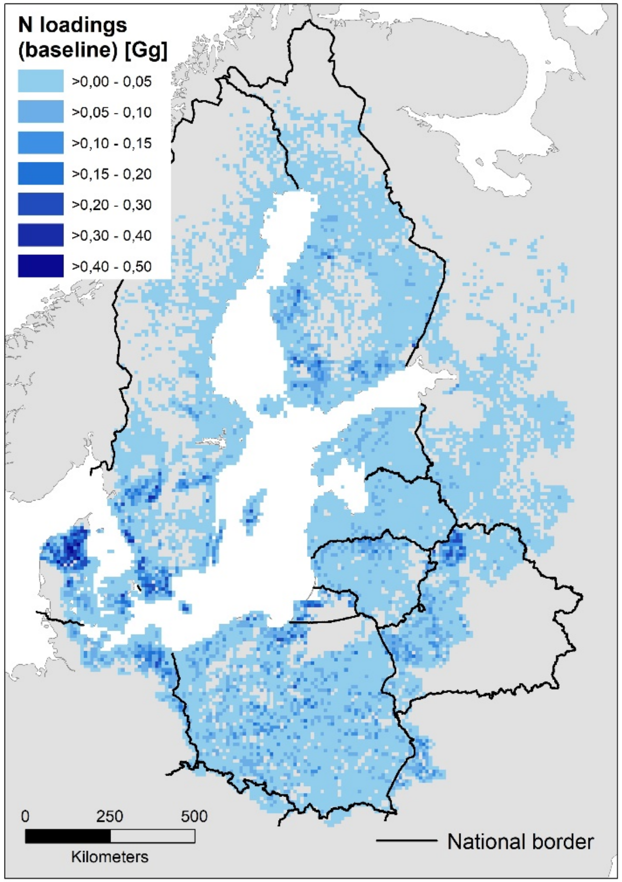
What is the problem?

- General issue: what is the best spatial scale to tackle environmental problems at?
- More specifically: when we think about shared water bodies (rivers, seas) which cover the jurisdictions of multiple countries, how best to implement reductions in pollution?
- Context: non-point nutrient pollution of coastal waters by agriculture
- Economic insight: given variations in marginal abatement costs, and variations in the physical relationship between land management actions and pollution outputs (varying marginal damage costs), a scheme which allows greater flexibility in WHERE and WHAT emission reductions are made will be lower cost than a scheme with less flexibility
- Implication: control burden – and benefits of control – will vary between countries in the most efficient solution

Case Study

- Nutrient inputs (pollution) in Baltic Sea
- Agriculture recognized as the main source of these inputs
- Non-point (diffuse source) pollution
- Multiple negative impacts of resulting eutrophication on marine life and recreational opportunities

Current N loadings



Aim of the study

- Ambitious targets to reduce nutrient loadings to the Baltic Sea
- A policy, which sets a target reduction at the largest area of spatial aggregation (the entire Baltic Sea) is more cost-effective than a policy, which imposes targets at lower levels of spatial disaggregation (e.g., sea basins, countries, watersheds, farms)
  - Potential to take advantage of options in areas where loading reductions from agriculture into the Baltic can be achieved at a relatively low cost (*hot-spots*)
  - Large spatial variations of the marginal “abatement” costs for reducing N loadings entering the Baltic Sea
    - The efficiency (profitability) of using mineral fertilizers / manure (livestock herds)
    - The relationship between N fertilizer/ manure use and N concentrations in the root zone
    - The extent and speed with which N in the root zone is transported to the Baltic as increased loading
- How much more effective are larger area targets?
- Where are the cost-effectiveness hot-spots located?

Policy Dilemma

- A policy which sets a reduction target at the largest area of spatial aggregation – in this case, the drainage basin for the entire Baltic Sea – would be more cost-effective than a policy which imposes targets at lower levels of spatial disaggregation, since this would provide greater opportunities to take advantage of potential measures where agricultural nutrient loading into the Baltic can be reduced at a relatively low cost.
- Yet policy instruments are often uniformly applied at country or regional level, which limits the possibilities to make use of the most cost-effective mitigation strategies across the Baltic Sea catchment.
- This may be due to a desire for a "fair allocation" of control targets across countries/regions, linked to the difficulty of securing multi-country agreements on regional pollution control
- Applies to many other regional pollution problems as well

Headline result

- The main result which emerges is that there is a large variation in the total cost of the programme depending on the spatial scale of targeting
- For example, for a 40% reduction in loads, the costs of a Baltic Sea-wide target is nearly three times lower than targets set at the smallest level of spatial scale (grid square).

Policy setting

The costs of achieving loading reductions are compared across five levels of spatial scale, namely:

- the entire Baltic Sea;
- the marine basin level;
- the country level;
- the watershed level;
- and the grid square level.

We compare targets set at these 5 levels in terms of (i) ecological impacts (ii) economic costs.

Previous studies: Baltic sea

- Studies carrying out ex-post evaluations of eutrophication policies in the Baltic Sea region confirm that these policies have failed to achieve cost-effective outcomes both within (European Environment Agency 2005, Elofsson 2012, Lankoski and Ollikainen 2013) and across (Häggmark Svensson and Elofsson 2019) countries.
- Reasons include an inefficient allocation of abatement across space (Elofsson 2012, Häggmark Svensson and Elofsson 2019) and emitting sectors (Elofsson 2012), inefficient design of policy instruments (Lankoski and Ollikainen 2013) and inability to efficiently allocate the abatement burden for internationally common targets among the participating countries (Häggmark Svensson and Elofsson 2019).

Our model: a bottom up approach linking agricultural profits, changes in root zone N concentrations and transport to the Baltic Sea

- 19,023 10x10 km grid cells
  - 117 watersheds
  - 10 countries
  - 14 sea basins
- 11 crop types + 3 livestock types
- Grid-cell specific data on environmental and economic conditions (e.g., soil type) and current agricultural practices (what crops, how managed)

Key considerations

- Show full degree of variability in MACs across farms in Baltic catchment
- Show full degree of variability in functions linking land use to run-off and leakage to Baltic
- Key Result we seek: How big an increase in total abatement costs do we incur by giving up on allowing the target to be set at the largest spatial scale?

(what is the penalty from not spatially differentiating control activities?)

Model set-up (1)

- Grid-cell specific root-zone N leaching
  - Modelled using DAISY – a separate soil-vegetation-atmosphere model (Abrahamsen and Hansen, 2000; Andersen et al., 2016)
- Grid-cell specific retention
  - Surface water nitrogen retention (117 watersheds) provided by the MESAW model (Grimvall and StÅLnacke, 1996)
  - Groundwater retention (each grid cell) estimated as the difference between cumulated watershed rootzone nitrogen leaching and the total riverine nitrogen loss from the watershed corrected for surface water retention (Andersen et al., 2016)
- Grid-cell specific profit functions
  - Experimental yield functions (Pedersen, 2009) adapted to all the grid cells by applying a horizontal-scaling calibration procedure (c.f. Brady, 2003)
  - Livestock profitability calculated using the Standard Gross Margin approach (weighted average for each of the NUTS 2 regions based on FADN (SGM for all animals groups) and Eurostat data (structure of the heard), averaged over 3 successive years for each region (to smooth out temporal fluctuations)

Model set up (2)

- The model considers three aspects of the problem simultaneously: the effectiveness of applying a particular measure in a particular grid square in terms of reduced leaching; the retention coefficient for each grid square (the proportion of nutrients leached from each grid square that does not reach the Baltic Sea); and the cost of applying the measures in each grid square.
- Each of these components is specified using non-linear relationships between the scale of application of the measure and its effect on the coastal load, and grid square-specific parameters.
- The model takes into account grid square-level interactions between the reductions of mineral fertilizer and manure application for each of 10 crop types
- For each grid square, evaluate the effects on farm income, nutrient leakage and run-off for a set of management measures. Costs are the difference in profit between farming in the square with versus without the control measure in place.
- Then used MATLAB (or GAMS for cross-check) to minimise these costs at s specific spatial scale subject to meeting a constraint on
- Every scenario was evaluated for decreases of between 5 and 50% (with 5 percentage point increments) of the maximum *potential* decrease from current N loads

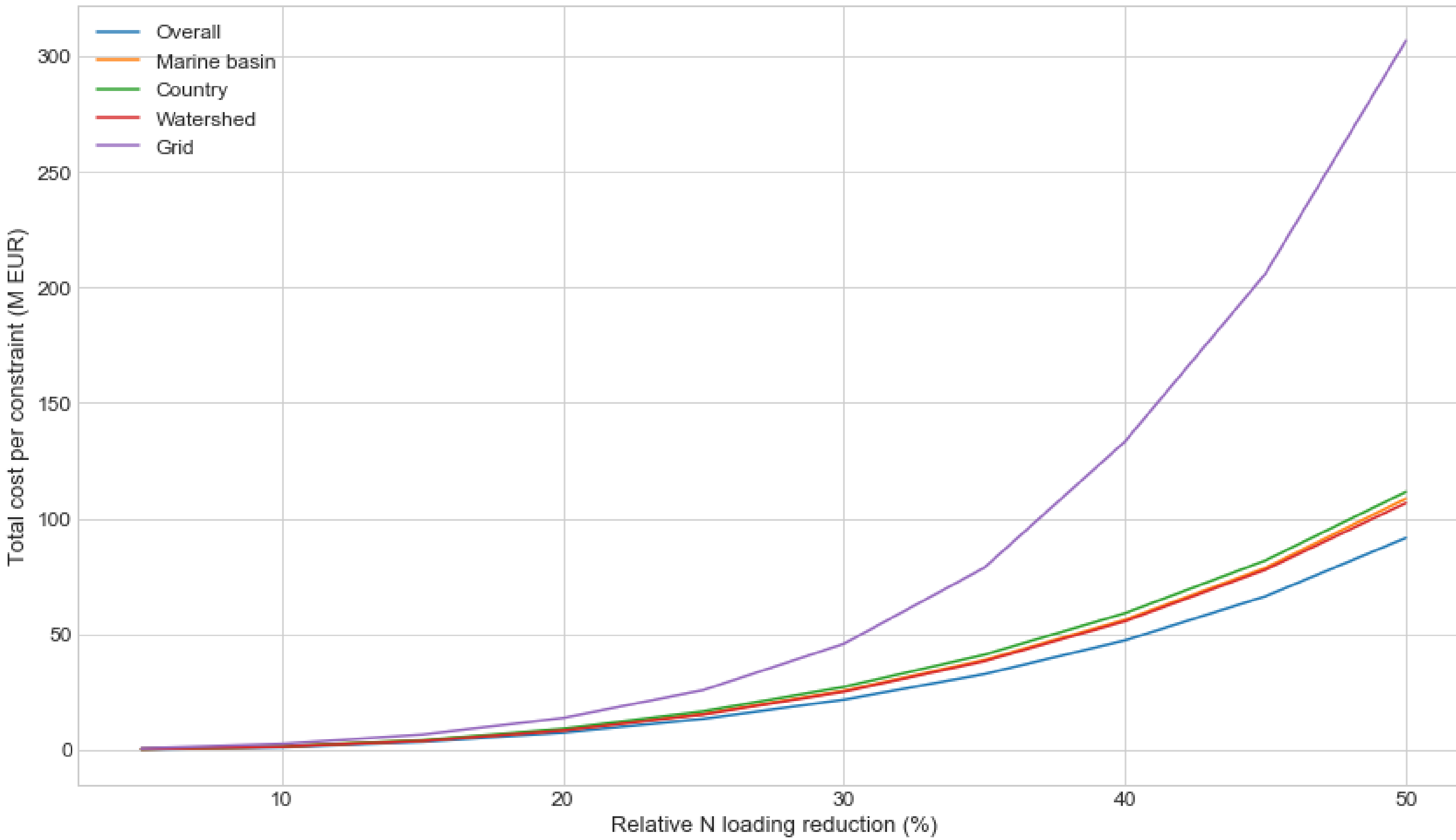
Scenarios compared

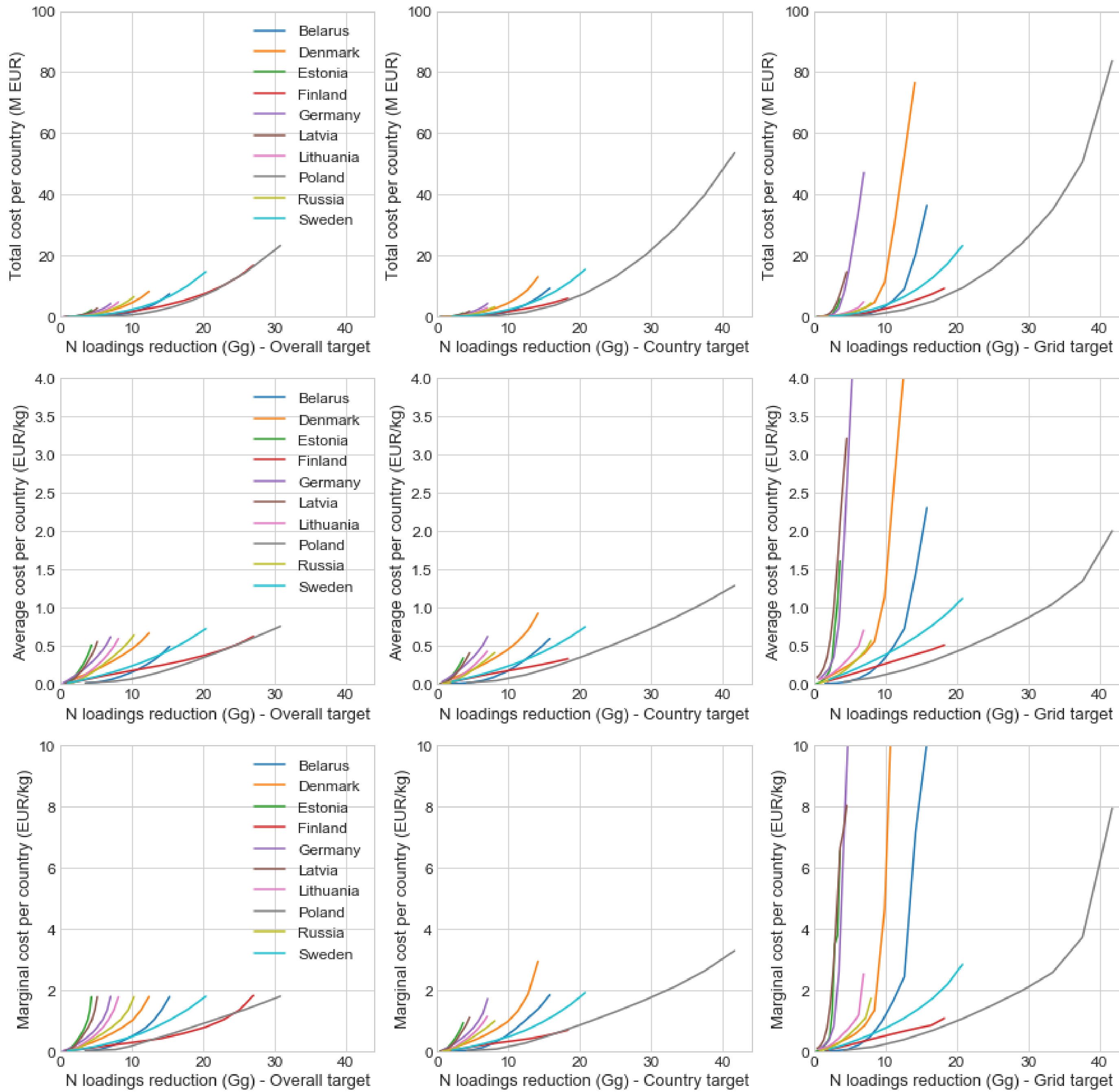
- Targets corresponding to relative reductions of 5%, 10%, … , 50% (of what is theoretically possible to reduce) allocated to:
  - The entire Baltic Sea (ALL)
  - 14 sea basins (BASIN)
  - 10 countries (CTR)
  - 117 watersheds (WTS)
  - 19,023 grid cells (GRID)

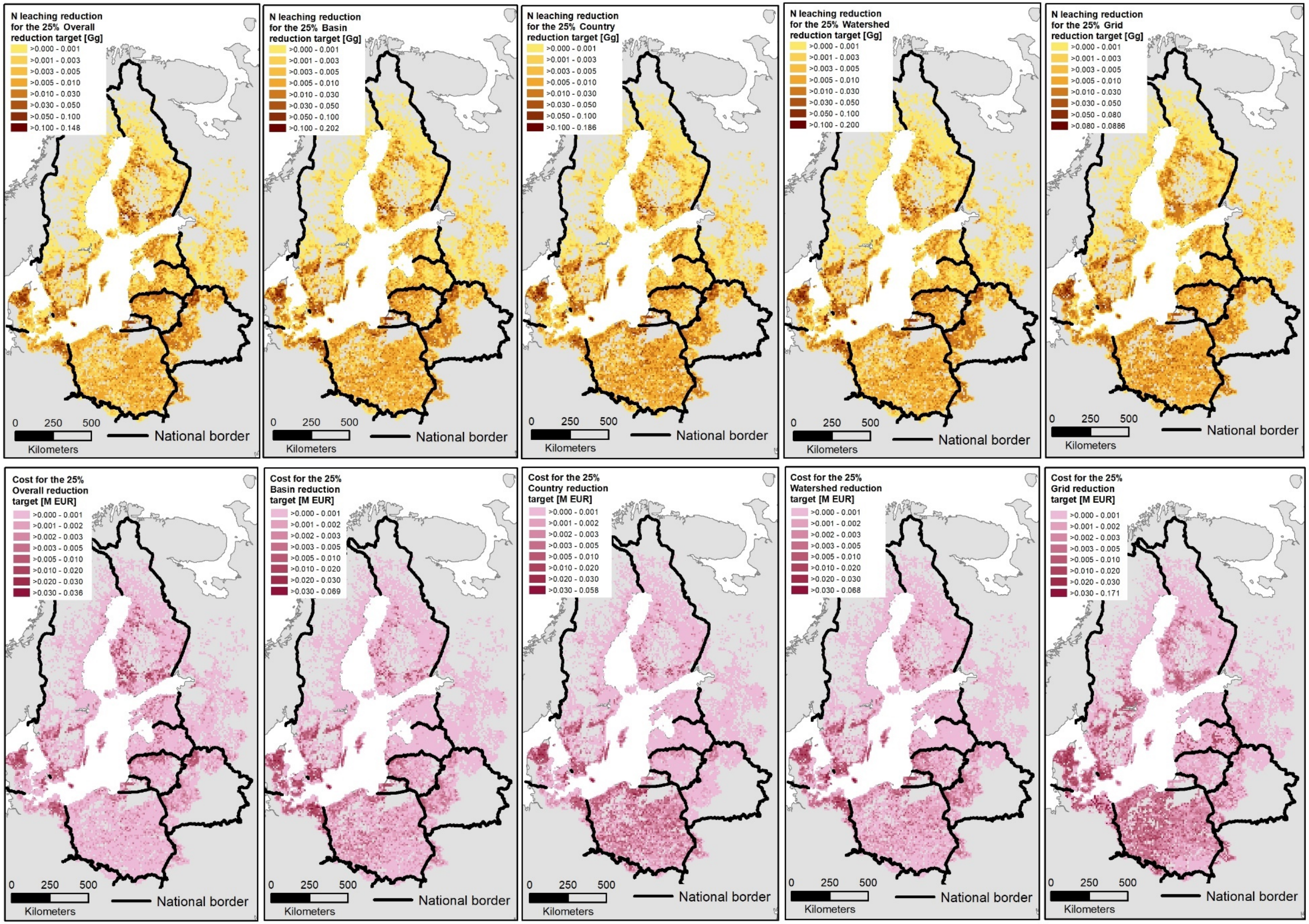
Total annual cost of reaching N reduction targets specified at different spatial scales

Reduction relative to maximum possible	0%	5%	10%	15%	20%	25%	30%	35%	40%	45%	50%
Absolute reduction [Gg]	0	14.11	28.22	42.33	56.44	70.55	84.66	98.77	112.88	126.99	141.10
N load [Gg]	337.68	323.57	309.46	295.35	281.24	267.13	253.02	238.91	224.80	210.69	196.58
Total cost [million EUR] for targets specified at:											
Baltic Sea level – Overall	0.0	0.18	1.03	3.31	7.35	13.30	21.59	32.67	47.22	66.31	91.61
sea basin level – Basin	0.0	0.28	1.39	3.91	8.47	15.48	25.41	38.75	56.16	78.62	108.61
country level – Ctr	0.0	0.29	1.37	4.05	9.00	16.58	27.13	41.05	58.99	81.82	111.54
watershed level – Wts	0.0	0.25	1.26	3.71	8.23	15.18	25.03	38.25	55.52	77.81	106.69
grid square level – Grid	0.0	0.53	2.45	6.52	13.66	25.75	45.76	78.71	133.20	205.87	306.72

The total annual cost of reaching the same relative N load reduction, with N reduction targets specified at different spatial scales




Total cost per country (M EUR)
N loadings reduction (Gg) - Overall target
N loadings reduction (Gg) - Country target
N loadings reduction (Gg) - Grid target
Average cost per country (EUR/kg)
Marginal cost per country (EUR/kg)
Belarus
Denmark
Estonia
Finland
Germany
Latvia
Lithuania
Poland
Russia
Sweden



N leaching reduction for the 25% Overall reduction target [Gg]
>0.000 - 0.001
>0.001 - 0.003
>0.003 - 0.005
>0.005 - 0.010
>0.010 - 0.030
>0.030 - 0.050
>0.050 - 0.100
>0.100 - 0.148
N leaching reduction for the 25% Basin reduction target [Gg]
>0.000 - 0.001
>0.001 - 0.003
>0.003 - 0.005
>0.005 - 0.010
>0.010 - 0.030
>0.030 - 0.050
>0.050 - 0.100
>0.100 - 0.202
N leaching reduction for the 25% Country reduction target [Gg]
>0.000 - 0.001
>0.001 - 0.003
>0.003 - 0.005
>0.005 - 0.010
>0.010 - 0.030
>0.030 - 0.050
>0.050 - 0.100
>0.100 - 0.186
N leaching reduction for the 25% Watershed reduction target [Gg]
>0.000 - 0.001
>0.001 - 0.003
>0.003 - 0.005
>0.005 - 0.010
>0.010 - 0.030
>0.030 - 0.050
>0.050 - 0.100
>0.100 - 0.200
N leaching reduction for the 25% Grid reduction target [Gg]
>0.000 - 0.001
>0.001 - 0.003
>0.003 - 0.005
>0.005 - 0.010
>0.010 - 0.030
>0.030 - 0.050
>0.050 - 0.080
>0.080 - 0.0886
Cost for the 25% Overall reduction target [M EUR]
>0.000 - 0.001
>0.001 - 0.002
>0.002 - 0.003
>0.003 - 0.005
>0.005 - 0.010
>0.010 - 0.020
>0.020 - 0.030
>0.030 - 0.036
Cost for the 25% Basin reduction target [M EUR]
>0.000 - 0.001
>0.001 - 0.002
>0.002 - 0.003
>0.003 - 0.005
>0.005 - 0.010
>0.010 - 0.020
>0.020 - 0.030
>0.030 - 0.069
Cost for the 25% Country reduction target [M EUR]
>0.000 - 0.001
>0.001 - 0.002
>0.002 - 0.003
>0.003 - 0.005
>0.005 - 0.010
>0.010 - 0.020
>0.020 - 0.030
>0.030 - 0.058
Cost for the 25% Watershed reduction target [M EUR]
>0.000 - 0.001
>0.001 - 0.002
>0.002 - 0.003
>0.003 - 0.005
>0.005 - 0.010
>0.010 - 0.020
>0.020 - 0.030
>0.030 - 0.068
Cost for the 25% Grid reduction target [M EUR]
>0.000 - 0.001
>0.001 - 0.002
>0.002 - 0.003
>0.003 - 0.005
>0.005 - 0.010
>0.010 - 0.020
>0.020 - 0.030
>0.030 - 0.171
0 250 500
Kilometers
National border

Conclusions

- We simulate cost-effective targets at different spatial scales for target setting
- We show that the most cost-effective policy should fulfil Baltic-wide reduction targets, while distributing the application of measures in highly area-specific manner.
- Demonstrate the extent of the economic benefits of policies targeting larger geographical scales
  - May require international cooperation, compensations since some countries suffer net losses in the most cost-effective scenarios
- Identify efficiency hot-spots, which should be targeted first
  - May require using location-specific measures and incentives
- HELCOM targets for basins are likely not efficient, as they were not based on economic analysis
- Need a spatially differentiated N tax implemented across all Baltic Sea countries? (or estimated N leaching tax)

Limitations of this study

- Considers nitrogen run-off only (not phosphorus)
- Only looks at farmland reduction measures: no other measures included (for either diffuse or point-sources)
- Ignores side benefits (e.g. improvements in lakes and rivers)
- The results based on several strong assumptions (e.g., yield functions)

Thank you

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