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Abstract	This policy brief gives an overview of the results and recommendations from the NAPSEA project for policy makers.
Keywords	Policy brief; recommendations; source-to-sea; NAPSEA

The eutrophication problem and the NAPSEA approach

A wide range of measures adopted since the late 1970s to combat eutrophication e.g. in the frameworks of OSPAR and the EU (among others WFD and MSFD) resulted in a substantial reduction of nutrient emissions and in healthier ecosystems in the North Sea and the adjacent Wadden Sea. Nevertheless, eutrophication targets in many affected inland and marine waters are not reached. Further progress—particularly for diffuse sources in regional inland waters—requires more complex and costly interventions, and the pace of nutrient reductions is slowing down. At the same time, societal fatigue around nitrogen-related issues (in particular related to agriculture) has grown, and the topic has become increasingly politicized. This makes it more challenging to maintain momentum for additional measures.

The NAPSEA project aimed at supporting national and local authorities in selecting effective nutrient load reduction measures and policies and in gaining societal support for their implementation. The project's geographical scope covered the catchment of the Wadden Sea, with case studies for the Rhine, Elbe and Hunze catchments and the Wadden Sea itself. NAPSEA proposed an integrated approach to address nutrient pollution from source to sea, combining three complementary perspectives: governance and social acceptance, nutrient pathways and measures and ecosystem health, as illustrated in Figure 1:

1. For the perspective of **ecosystem health,** we analysed currently used indicators as well as their thresholds and explored the development of additional more comprehensive indicators—moving beyond the current targets for chlorophyll-a. The aim was to better reflect the benefits of nutrient reduction measures for ecosystem functioning and resilience.
2. The perspective of **pathways and measures** quantified nutrient emission sources and their pathways to the Wadden Sea with models, to assess how nutrient loads are affected by various scenarios of nutrient reduction measures and climate change.
3. The **governance and social acceptance and acceptability** perspectives assessed the coherence of the relevant policy frameworks across scales and the public and farmer support for nutrient reduction measures.

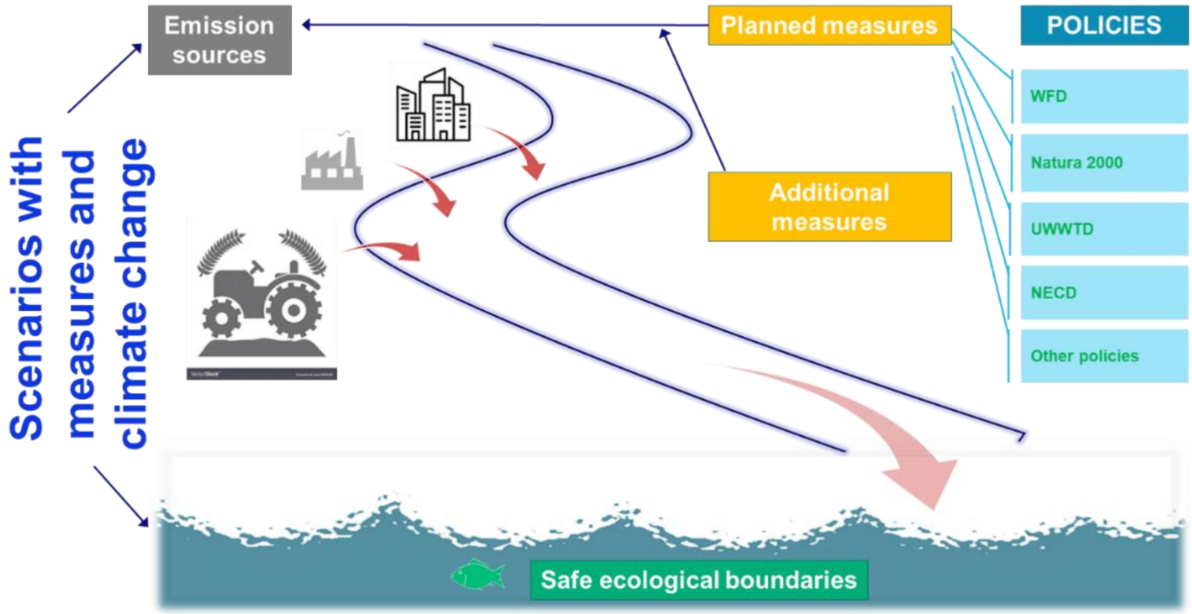

Figure 1: Schematic overview of interconnected activities in the NAPSEA project.

Ecosystem Health perspective

Water quality objectives in Europe are currently governed by multiple policy frameworks (e.g. WFD, MSFD, ND, UWWTD, NECD). Both the WFD and MSFD aim at good ecological/environmental status for inland and marine waters respectively. For both policy frameworks, indicators and threshold values have been developed to quantify good ecological/environmental status and safe ecological boundaries. For the MSFD, the eutrophication thresholds developed by the regional sea convention OSPAR are used. For the assessment of eutrophication, chlorophyll-a concentrations during the growing season are used as ecological indicators in both policy frameworks. But the thresholds and corresponding nutrient thresholds have been defined differently in different countries, policies and water bodies. In NAPSEA, we evaluated the consistency of currently used indicators and thresholds for eutrophication and their narratives. We also proposed nutrient thresholds for alternative indicators for 'good ecological status' based on alternative narratives. The addition of these alternative indicators and their thresholds provide a more comprehensive representation of the various ecological benefits of nutrient reduction measures. We aim to gain more societal and political support for nutrient reduction measures with this approach.

Currently used indicators and thresholds are inconsistent

The currently used indicators and thresholds for nutrients are inconsistent between inland waters and marine waters: both in 1) the definition of the season, 2) the type of measurement and 3) the use of nitrogen or phosphorus. For chlorophyll-a only the threshold levels were inconsistent between inland waters and marine waters. Following a source-to-sea approach the nutrient thresholds for upstream waters should allow for good ecological/environmental status of downstream waters. Therefore, two types of nutrient thresholds are required for preventing eutrophication impacts from source to sea: concentration thresholds safeguarding local ecological status and load thresholds safeguarding downstream ecological status. These two types of nutrient thresholds are linked because the nutrient load is defined as the nutrient concentration multiplied by the water discharge from one water body to the next. For the Netherlands, WFD nutrient thresholds are defined as summer mean values, arguing that this is the relevant period of the year for local eutrophication effects. For Germany, WFD nutrient thresholds are defined as annual means, arguing that a large part of the nutrient loads to downstream waters occurs in winter so nutrient loads throughout the year are relevant for downstream waters. For some transitional water types under WFD, the nutrient threshold is based on the load target to achieve good environmental status in coastal waters, but then these areas lack nutrient thresholds for their local ecological status. Furthermore, inland waters use the indicator "total nutrients" and coastal waters use the indicator "winter mean nutrient concentrations". The latter is used by OSPAR as approximation of total nutrient concentrations, due to lack of field observations of total N and total P in marine waters. This difference hampers the transparency and consistency of thresholds from source to sea. Thirdly, some (mostly inland) water bodies use phosphorus as nutrient threshold and others use nitrogen thresholds. This is often based on the assumption that phosphorus is typically the limiting nutrient in freshwater and nitrogen in marine waters. Drawbacks of this approach are: 1) that this general scheme does not apply everywhere, particularly in the land-sea interface, 2) even if a nutrient does not cause eutrophication locally, it still may cause eutrophication downstream and 3) it does not take into account that the ratio of N and P affects the phytoplankton community and disrupts food web interactions.

Additional indicators are needed

The narrative for currently used thresholds is based on a 50% allowable deviation from 'natural reference conditions'. For OSPAR, this is the period before the introduction of artificial nitrogen fertilizer, around the year 1900. Observations from this period are virtually absent so models are used to reconstruct these conditions. We propose 4 additional indicator definitions: 1) seagrass recovery in the Wadden Sea, 2) natural nitrogen to silicate ratios, 3) prevention of oxygen depletion in the Elbe estuary and 4) recovery of macrophytes in lakes. Based on data analysis and modelling, we estimate that this would require a further 30–55% reduction of nitrogen loads from the Rhine and 45% reduction of nitrogen loads from the Elbe compared to the period 2010–2017 (Table 1). Although the specific nutrient reduction needs differed between ecological indicators, they are in the same range of 30–50%. This is more than the reduction needs from current WFD targets for nitrogen in the Rhine and Elbe. On the other hand, the chlorophyll-a concentrations in the Dutch Wadden Sea would need to be reduced by approximately 50%, in the Lower Saxonian Wadden Sea by up to 77% and in the Schleswig-Holstein Wadden Sea by around 40% to comply with the current WFD threshold for chlorophyll-a. In recent years (2018 – 2023). Part of the proposed nutrient load reduction has already been achieved. In the Rhine, winter mean nitrogen concentrations reduced by approximately 7% and the annual nitrogen loads reduced by even 17%, due to a decrease in river discharges. In the Elbe, annual mean total nitrogen concentrations decreased by 12% and the annual nitrogen loads reduced by 38% due to a decrease in river discharges. The large decrease in river discharges between 2010 – 2017 and 2018 – 2023 may be due to climate change or natural variability. Drier years lead to lower volumes of river water and also longer residence time in the catchment, with higher nitrogen losses due to denitrification.

Table 1. Safe ecological limits with related N and P reduction needs compared to 2010-2017 for the four case studies (Hunze, Rhine basin, Elbe lower river and upper estuary, Wadden Sea), proposed in the NAPSEA project as well as those in the current framework (WFD). For certain ranges average is provided between brackets.

Source	Case study	Indicator	Mainly impacted by:	Reduction needs for:	N reduction:	P reduction:
NAPSEA	**Wadden Sea**	Sea grass recovery Western Dutch Wadden Sea [2]	Riverine TN loads	Rhine/ Meuse/Ems	34-43% (~38%)	
		Sea grass recovery Lower Saxonian Wadden Sea [2]	Riverine TN loads	Rhine/ Meuse/Ems	39-46% (~43%)	
NAPSEA	**Wadden Sea**	Minimize blooms by non-silicifying algae (e.g. *Phaeocystis*)	Winter riverine Si:N ratio	Rhine	50%	
				Ems	55%	
				Weser	40%	
				Elbe	30%	
NAPSEA	**Elbe estuary**	O_2 >7 mg/l	Import riverine organic matter (phytoplankton)	Elbe	~45%	~45%
WFD-GE	**Elbe river**	Phytoplankton biomass < 40 µg Chl-a/l	Organic matter loads	Elbe	63%	63%
WFD-GE	**Elbe river**	N concentrations		Elbe	23%	
NAPSEA	**Hunze**	Recovery of submersed vegetation in the Zuidlaardermeer	Incoming TP load	Hunze		40%
NAPSEA	**Hunze**	Reduction need for Wadden Sea (sea grass recovery)	TN loads (mainly winter)	Hunze	34-43%	
NAPSEA	**Rhine catchment**	N and P concentrations below safe ecological boundaries from literature		Rhine tributaries	44%	50%
WFD-NL	**Rhine**	N concentrations		Rhine mouth	0%*	
WFD-GE	**Rhine**	N concentrations		Rhine NL-GE border	0%*	

* No further reduction is required for nitrogen in the Rhine according to Dutch and German WFD thresholds. It is currently already below the threshold value.

Pathways and measures perspective

The NAPSEA project applied models describing nutrient pathways from source to sea. To support effective nutrient reduction strategies, different scenarios were developed for both large river basins (Rhine and Elbe) and the smaller Hunze catchment (Figure 2). Including these scenarios in our models enabled us to assess the effectiveness of different types of measures, applied to the whole catchment, to achieve safe ecological boundaries under moderate climate change conditions (RCP 4.5) by 2050. Earlier, such model studies have been performed only per country, leaving a large part of the sources out of scope. The nutrient load reductions from the Elbe and Rhine have been compared to the load reduction targets from the WFD and our additional proposed ecological indicators.

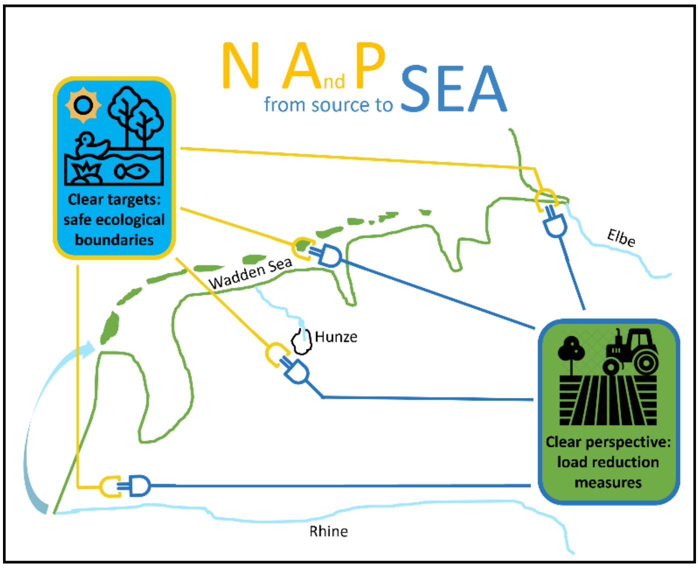

Figure 2: The 4 NAPSEA case study areas where we tested nutrient reduction scenarios to meet ecological objectives.

Scenarios for Rhine and Elbe catchments

Seven scenarios were developed and modelled with process-based basin-scale models, incorporating international and national open-access datasets. For comparison we also ran a reference scenario representing 2010 – 2020. The scenarios ranged from business-as-usual to increasingly ambitious policy interventions:

- Scenarios 1–4: Measures already planned from different policies, per type of measure: 1) wastewater treatment, 2) agriculture, 3) clean air policies, and 4) nature-based solutions: buffer strips and floodplain restoration.
- Scenario 5: Combined effect of all planned measures of scenarios 1-4.
- Scenario 6: Impact of climate change without additional policy measures (i.e. business as usual).
- Scenarios 7A–C: Increasingly more ambitious strategies on top of scenario 5 to see what would be required to achieve our proposed nutrient reductions. These included: stricter implementation of current measures (7A), intensified nature-based solutions (7B) and 50% reduction of livestock in the Netherlands [3] and reduction of nitrogen fertilizer to 80% of plant uptake in Germany [4] (7C).

All scenarios assume full implementation and enforcement of the included measures, and therefore serve as “best-case” projections of the policy interventions.

Scenarios for the Hunze catchment

Scenarios for the Hunze catchment were developed using a more complex small-scale model and bottom-up input from the local water authority, enabling a nuanced assessment of planned and potential measures. Fourteen scenarios were explored, ranging from land use changes and wastewater treatment upgrades to agricultural best practices and nature-based solutions. These scenarios, including climate projections for 2050, helped to evaluate the feasibility of achieving both local and downstream ecological targets under varying conditions.

Effectiveness of scenarios in reaching required nutrient reductions

Current nutrient reduction policies appeared to be insufficient to achieve safe ecological nutrient levels according to our newly proposed indicators in the Rhine and Elbe. Achieving these would require significant reductions across agriculture, wastewater, and atmospheric sources, combined with nature-based solutions, beyond the planned interventions (Figure 3 and Figure 4). In NAPSEA model results climate change lead to considerable changes in river flows and thereby nutrient loads to downstream ecosystems. The impact of buffer strips around farmland was lower in the Netherlands than in Germany due to the frequent use of tile drainage in Dutch farms. Flood plain restoration along rivers was only effective if these are not just flooded during peak flood events in winter. Land use changes from grassland to arable land led to a strong increase of nitrogen loads in the Hunze scenarios.

Knowledge gaps

The understanding of nutrient pathways was hampered by limited observation data on water flows combined with nutrient concentrations. Particularly in the Netherlands such observations were limited and often not in the same location, so the calculation of loads is rather uncertain. Moreover, the hydrology of the Netherlands, where water flows are regulated in a network rather than following physical laws of gravity, made it complicated to reconstruct nutrient pathways. There is large uncertainty about the effectiveness of different measures, especially those of nature-based solutions, in different environments.

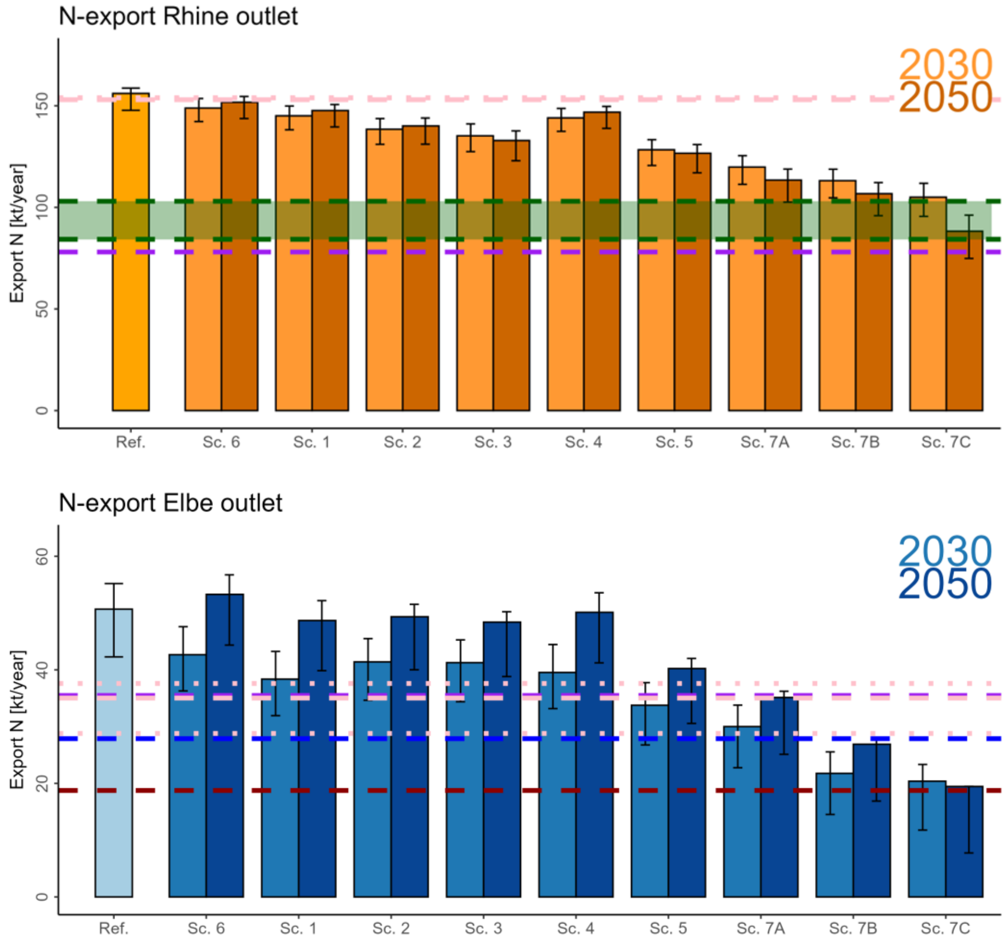

Figure 3: Nitrogen loads from the Rhine at Lobith (top) and the Elbe outlet (bottom) for all model scenarios. The dashed horizontal lines show the reduction targets for: seagrass recovery in the Wadden Sea (green), natural nitrogen to silicate ratios preventing blooms of non-silicifying phytoplankton in the Wadden Sea (purple), preventing oxygen depletion (blue), phytoplankton biomass below WFD threshold (red), and WFD threshold for which modelled discharges where used for the reference (dashed pink) year as well as 2030 and 2050 (dotted pink; for Rhine overlaps with dashed line). Ref – reference period 2010–2020, lighter colours in scenarios – average 2028–2032, darker colours – average 2046–2050, whiskers – 5–95% confidence interval of the best performing 100 model realizations.

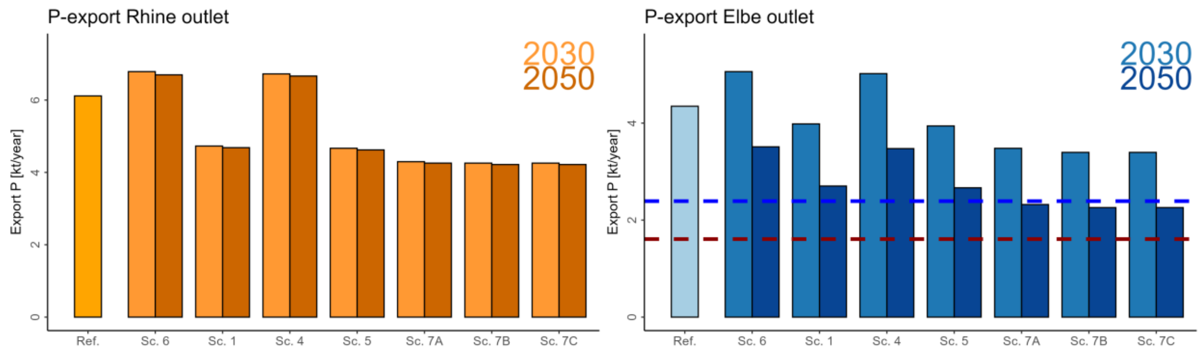

Figure 4: Total phosphorus loads from the Rhine at Lobith (left) and the Elbe outlet (right) for model scenarios. Scenarios 2 and 3 are not shown because they did not result in a decrease in P-loads. The dashed horizontal lines show the reduction targets for: preventing oxygen depletion (blue) and phytoplankton biomass below WFD threshold (red). Ref – reference period 2010–2020, lighter colours in scenarios – average 2028–2032, darker colours – average 2046–2050.

Governance and social acceptance perspective

Governance

The inputs of nutrients to surface waters are addressed by a wide range of national and European policy frameworks and strategies. An evaluation of the effectiveness of the current policy framework and its implementation identified some issues where the policy framework and its implementation can be improved to more effectively reduce eutrophication. Although the policy framework is well aligned at the European level, the local implementation is not well coordinated between different responsible authorities at different geographical levels. The large number of actors involved and fragmented monitoring efforts make it difficult to implement effective measures. The Source-to-Sea approach should be strengthened and a better link between marine and inland waters should be established in the policy framework. This refers to work on the EU level by harmonizing the implementation between the different policy instruments, e.g. ensuring that the WFD measures and CAP measures better support the MSFD goals or harmonizing nutrient thresholds. On the national level, the Program of Measures under WFD needs to better align the needs of downstream freshwater and coastal waters. This approach requires stronger coordination among different authorities at the local level and strengthening the coherence across policy instruments on the local level.

Stronger cooperation could improve the situation for the marine environment as a more holistic approach would be established, tracing nutrient travel routes, effects of measures and travel times from point and diffuse pollution. Such an approach could be achieved by establishing a cross-border nutrient management task force focused on the Wadden Sea. This way the nutrient input can be reduced at the source. To facilitate the exchange, invitations to yearly overview- or working group meetings from the river basin authorities and secretariats of RSCs with members of each of the groups should be ensured.

Social acceptance

Social acceptance refers to the degree to which stakeholders and the broader societal support and embrace a policy or intervention. Social acceptance influences the willingness of farmers, local communities, and other actors to adopt and sustain nutrient-reducing practices. This is important because the success of environmental policies depends not only on their technical effectiveness but also on public and stakeholder support.

As part of the project, the social acceptance of nutrient reduction measures was assessed from the citizens' and farmers' perspectives. The purpose of the study was to understand how socially acceptable a measure is, what barriers and supporting factors affect its implementation, and how aware farmers and citizens are of their activities' effects on the Wadden Sea, and if there are differences, depending on their geographical distance from the Wadden Sea.

The survey results show that citizens are generally in favour of the measures. Of the three common nutrient-reducing measures mentioned in the survey, buffer strips are the most popular. The reduction of livestock intensity and stricter fertilization management are slightly less popular. Most farmers, by contrast, reveal that they implement those measures, that they perceive as logical from a farming perspective. Farmers demonstrate high engagement with debates over nutrients and they recognise their role in nitrate and phosphorus loading to the environment, but they also feel that they are disproportionally blamed compared to other sectors such as industry, municipal wastewater, and households. Both citizens and farmers acknowledge the risks of eutrophication, especially for biodiversity and future generations. However, citizens appear to be more concerned about the downstream effects on the Wadden Sea than farmers, who focus more on local soils and groundwater.

Farmers' acceptance of nutrient-reducing measures is more conditional, often driven by economic and agronomic logic rather than societal expectations, and shaped by frustrations with rigid regulations, administrative burdens, and insufficient compensation. Many highlight the need for policies that strike a balance between environmental goals and financial viability, as well as practical farming realities. Farmers mentioned the following enabling factors for socially acceptable nutrient reduction policies: fairer subsidies, long-term planning security, advisory support, and stronger cooperation across sectors. The findings underscore the importance of bridging the gap between public expectations and the reality of farmers to ensure both ecological effectiveness and social acceptance of nutrient reduction strategies.

Conclusions

The NAPSEA project aimed to demonstrate the added value of an integrated source-to-sea approach from 3 different perspectives. This approach allowed to evaluate the impact of nutrient sources and reduction measures in both Germany and the Netherlands in both inland and coastal waters. The modelling approach also helped to highlight current knowledge gaps in understanding nutrient pathways and impact of measures. The understanding on eutrophication status based on current WFD and MSFD assessments is hampered by inconsistencies in the definition of indicators and their thresholds, between inland and marine waters and between countries. We proposed additional ecological indicators and corresponding thresholds for nutrient loads for the Rhine and Elbe. These were considerably lower than current WFD thresholds for river loads. But their ecological impacts would be easier to communicate and more convincing to citizens and stakeholders. The social acceptance and acceptability assessment showed that a key enabling factor is the transparency about the background and aim of the targets.

Recommendations

- Create more transparency about the aims and narratives of nutrient reduction targets by:
    - Developing separate nutrient thresholds to prevent **local and downstream** eutrophication problems and use the minimum of both thresholds to design nutrient reduction scenarios
    - For the thresholds to prevent downstream eutrophication, nutrient loads and concentrations should be included for the **whole year**, including winter.
    - Developing thresholds for both **nitrogen and phosphorus** and their ratios for each water body, so that downstream eutrophication impacts and ecological impacts of imbalanced nutrient ratios can be taken into account.
    - Taking into account **multiple ecological impacts** of eutrophication and their specific nutrient reduction needs.
- Support a better understanding of current nutrient loads and pathways by:
    - Aligning and extending the **monitoring locations** for water flows and nutrient concentrations
- Take **climate change** impacts into account when designing nutrient reduction measures. Our model simulations showed that climate change can have a large impact on total river discharges and residence time. These analyses can be further elaborated by:
    - Taking into account seasonal variability in model scenario runs for climate change. Climate models suggest river discharges may increase in winter and decrease in summer.
- Adopt an **integrated source-to-sea approach** for selecting and implementing nutrient reduction measures across the entire catchments areas, including all countries involved.
    - Reliable models and data are crucial for a science-based and quantitative coherent analysis.
    - Compare different model approaches for more insight in the uncertainties of model outcomes.
- Use **ecological indicators that resonate with the public**, such as seagrass recovery, to build support for nutrient reduction strategies.
- Gain more support for nutrient reduction measures by collaborating with other policies aiming at climate adaptation and terrestrial biodiversity.
- The selection of measures should be more aligned with farmers motivation to pick up measures, such as planning security and low bureaucratic burden.

More information

More information about the NAPSEA project can be found on the project website: napsea.eu. All project deliverables summarized in this policy brief can be downloaded from there.

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