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# DELIVERABLE 3.3

# SET OF SCENARIOS

## Work Package 3
## Measures & Pathways

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| **Abstract** | Based on previous assessments, we propose a set of management scenarios for the catchments of the rivers Elbe and Rhine to reduce nutrient inputs to the Wadden Sea. The scenarios address nutrient inputs from urban wastewater treatment plants, from agriculture, and via atmospheric deposition as well as nature-based solutions for nutrient retention, while considering the effects of climate change. The scenarios shall be discussed with stakeholders before being implemented in the calibrated nutrients models mQM and $C^{n}$ANDY. |
| **Keywords** | Climate change, nitrogen, nutrient reduction, phosphorus |

# Contents

# LIST OF ABBREVIATIONS

C$^n$ANDY ........ *Coupled Complex Algal-Nutrient Dynamics*
LULC ........ *Land use and land cover*
mHM ........ *Mesoscale Hydrologic Model*
mQM ........ *Multiscale water Quality Model*
N ........ *Nitrogen*
NECD ........ *National Emissions Reduction Commitments Directive*
P ........ *Phosphorus*
p.e. ........ *Population equivalent*
UWWTD ........ *Urban Wastewater Treatment Directive*
UWWTP ........ *Urban wastewater treatment plant*

# 1. INTRODUCTION

## 1.1. The NAPSEA project

This project addresses the effectiveness of 'Nitrogen And Phosphorus load reduction measures from Source to sEA, considering the effects of climate change' (NAPSEA). The primary objectives of NAPSEA are to support national and local authorities in the selection of effective measures to reduce nutrient loads and to create political support for their implementation. The project applies an integrated approach spanning from pollution sources to sea, considering governance, nutrient pathways and measures, as well as ecosystem health. Geographically, the project focuses on the Wadden Sea catchment area, with specific case studies for the Rhine, Elbe, Hunze, and the Wadden Sea itself. NAPSEA serves as a platform to showcase practices in the implementation of socially acceptable, sustainable, and efficient measures.

The Work Package (WP) 3 aims to evaluate the connection between nutrient concentration and load reduction measures as well as the safe ecological boundaries for the Wadden Sea. The efficiency of nutrient reduction and enhanced retention measures will be assessed with a set of scenarios which will be discussed by stakeholders and integrated into the modelling framework. In this way, mitigation measures can be prioritized under climate change.

## 1.2. Objectives

The assessment of the feasibility of measures (Gericke and Leujak 2023) concluded that scenarios should focus on agriculture, optimization of urban wastewater treatment plants (UWWTP), and nature-based solutions. The wide range of (already planned) specific measures target high atmospheric losses of nitrogen (N), point sources and diffuse losses of dissolved and particulate nutrients to the water bodies, as well as the retention during transportation. Their effects are highly variable depending on e.g. where, when, and how the measures are implemented.

The objective of this report is to provide a set of scenarios as input for the upcoming stakeholder workshops to discuss the selection, assumptions, and database (Task 2.4). Scenarios are plausible and coherent descriptions of potential future conditions or states of the environment, often based on a set of assumptions and factors. in general, creating scenarios involves identifying key driving forces and uncertainties, developing narratives or storylines, and modeling the potential outcomes. From the perspective of nutrient modelling, scenarios are sets of management measures and climate change (or other site) conditions which result in changed input data and internal model parameters. In this deliverable, we focus on scenarios based on current and planned policies, because this allows for a practical evaluation of what is achievable at the basin scale under the existing legal frameworks on reducing nutrient emissions and managing nutrient inputs. The approach should also allow to disentangle the effect of different scenarios.

After the scenarios were discussed in the stakeholder workshops, the final set of scenarios will be implemented in the process-based models mQM and C$^n$ANDY (Task 3.4). The modelling will deliver quantitative estimates of the effectiveness of current or planned measures under the existing legal framework. The results can then be compared to the nutrient reductions required to achieve the safe ecological boundaries for the rivers and the Wadden Sea to be developed from various ecological indicators (Tasks 4.2 and 4.3). If this comparative analysis between the required status and the measures' effectiveness reveals that the measures are not efficient enough to achieve the required nutrient concentrations and loads at the outlet of the river basins, further scenarios with additional measures have to be discussed and modelled to evaluate how the remaining reduction needs can be achieved in a realistic way.

## 1.3. Study area

The scenarios mainly address the German and Dutch parts of the Elbe and Rhine catchments, which amount to two thirds of their total basin area. Their selection has to consider the relevant sources and pathways of nutrients in the study area in order to be effective. Previous model results revealed that the relative importance of nutrient pathways and sources varies not only among the main nutrients nitrogen (N) and phosphorus (P) but also in space and among the chosen model setups. The overall picture, however, remains consistent: the intensive agriculture with its high N surplus on agricultural soils causes high N inputs via tile drainage and subsurface flow, while for P urban sources including wastewater treatment are at least equally important as the agricultural input, e.g. via soil erosion. Accordingly, the river basin management plans for Rhine and Elbe focus on inputs from agriculture and wastewater treatment, and nature-based solutions to reduce nutrient inputs and improve water quality. Given the larger area of surface waters, the share of atmospheric N deposition is higher in the Netherlands than in Germany. Besides traffic and industry, agriculture is a major source of atmospheric N – and thus a focus of the national programs of measures (cf. Gericke and Leujak (2023) and the references therein).

# 2. SCENARIOS

## 2.1. Overview

We propose a set of 7 scenarios (Table 1), which addresses the key targets of measures to reduce N and P in rivers Elbe and Rhine together with the effect of climate change. All scenarios are run for the period 2024 to 2040. To disentangle their effects on nutrient input and load, the measure targets shall be modelled individually (scenarios 1–4) before quantifying their combined impact in scenario 5. Each of these five scenarios consists of a multitude of measures and actions to achieve existing or planned policy targets (cf. next chapter). Scenario 5 is used to derive the gap to the envisioned environmental targets, i.e. the remaining amount of nutrient reduction needed to meet the current thresholds for the good status (cf. Task 4.1) and the safe ecological boundaries for the Rhine, Elbe (and Hunze) basins as well as the Wadden Sea. Scenario 6 assesses the future conditions without additional management measures but including the expected effects of climate change alone on hydrology and nutrient turnover and export. The seventh scenario consists of adapted measures and measure effects with which we aim at achieving the safe ecological boundaries. The exact specifications of this adapted scenario will be based on the model outcomes of the first six scenarios, as well as on the social acceptability of the evaluated measures (Task 2.4).

*Table 1. Proposed set of scenarios. All scenarios include climate change impacts in the river basins. More details provided in chapter 2.2.*

| Scenario | Target of measures | Narrative |
|---|---|---|
| 1 | Wastewater treatment | The revised Urban Wastewater Treatment Directive is implemented |
| 2 | Agricultural input | The Nitrates Directive is implemented, the new Soil Health Law is implemented with a soil erosion ≤ 2 t $ha^{-1}$, and/or 25% organic farming on agricultural land according to the Farm-to-Fork Strategy |
| 3 | Atmospheric deposition | The NECD is implemented, the Dutch atmospheric target for the protection of the Natura 2000 areas is reached. |
| 4 | Nature-based solutions for nutrient retention | The Biodiversity Strategy 2030 is implemented in combination with restoration of riparian areas, floodplains, and/or bogs, potentially also fulfilment water-related goals of the EU Nature Restoration Law |
| 5 | All measures | All the scenarios 1-4 are implemented together |
| 6 | No measures | None of 1-4 is implemented |
| 7 | Adapted | The reduction needs as the difference between 5 and 6 are achieved |

## 2.2. Narratives and background

**Scenario 1: Wastewater treatment**

As the level of wastewater treatment is already high, we assume that the revised Urban Wastewater Treatment Directive with its higher treatment levels (and improved stormwater management) will be implemented. Achieving the stricter targets of nutrient retention and/or concentration in the outflow has an immediate effect on surface waters. For UWWTP within the Rhine and Elbe basins, we re-estimate the effect on nutrient concentration and load in combination with climate change effects, i.e. under future hydro-climatological conditions (scenario 6). As the connection rate is generally high, we do not alter the connection rates to wastewater collection and treatment. The scenario also neglects changes in the water discharge from UWWTP.

- Database: The current dataset (EEA 2023; Umweltbundesamt n.d.; Büttner 2020) lacks UWWTP < 2000 p.e. and water discharge outside Germany which limits the use of target concentrations in the scenarios
- Measures: various measures exist to remove nutrients from sewage water, e.g. electrocoagulation and electroflotation (Pistocchi et al. 2023)

**Scenario 2: Agricultural input**

This scenario assumes that the Nitrates Directive is fully implemented, i.e. the Fertilizer Ordinance is implemented in Germany and the (7th) Action Program and/or in combination with the BOOT list of the Deltaplan Agrarisch Waterbeheer is implemented in the Netherlands. We quantify the consequences for N and P concentration and load within the Rhine and Elbe basins in combination with climate change effects.

In contrast to N, the current P balance is already almost closed and even negative. However, the historical imbalance resulted in a high P accumulation in topsoil and, thus, an elevated risk of P leaching to surface waters (e.g. Fischer, Pöthig, and Venohr 2017). Measures addressing N surplus can also contribute to a lower risk of soil erosion. For instance, integrating sod (e.g. clover-grass) in the crop rotation – typical for organic farming – can significantly reduce the risk of soil erosion. Achieving the ambitious goal of the Farm-to-Fork Strategy of organic farming on 25% of the agricultural land by 2030 will also lower the P input into surface waters (cf. Table 2 in the Annex). Reduced P input via soil erosion can also be achieved by adopting the new Soil Health Law which proposes a maximum soil erosion of 2 tons $ha^{-1}$. The target is above previously proposed rates of tolerable soil loss for Europe (Verheijen et al. 2009). The target value includes all erosion processes and not only the water erosion which is commonly used in nutrient emission modelling. Based on a European assessment of concurrent erosion processes (Borrelli et al. 2023), we can estimate a lower input of particulate P via wind and water erosion.

- Database: regional N surplus estimated in the DüngEval project for Germany (UBA unpubl.), map of soil erosion via different erosion processes (Borrelli et al. 2022), estimation of lower soil erosion for different crop rotations based on Auerswald et al. (2021).
- Measures: numerous measures to lower the soil-surface N surplus and the risk of soil erosion, e.g. by intercropping, conservation tillage, lower fertilizer application, the suitable choice of measures depends on farm and site characteristics

**Scenario 3: Atmospheric deposition**

This scenario assumes that the NECD is implemented, and in the Netherlands also the emissions of the 3000 peak-emitters reduced to reach the annual target deposition of 2500 mol N on Natura 2000 areas (van der Maas, Jones, and Hazelhorst 2023). This results in lower $NH_3$ emissions from agriculture and $NO_x$ emissions from traffic and industry. Due to lower emissions, the atmospheric N deposition also decreases. The consequences for N concentration and load within the Rhine and Elbe basins are determined in combination with the effect of climate change (6).

- Database: modelled N deposition for Germany and the Netherlands (UBA unpubl., Hoogerbrugge et al. (2022), RIVM (2023b)), the Natura 2000 areas in the Netherlands (RIVM 2023a)
- Measures: e.g. improve storage and application of manure and slurry, improve nutrition and housing of livestock

**Scenario 4: Nature-based solution**

Scenario 4 considers the restoration of riparian buffers, wetlands and/or bogs which affects the land-water transfer of nutrients in agricultural areas and the transport within water bodies. We quantify the consequences for N and P concentrations and loads within the Rhine and Elbe basins in combination with climate change effects.

- Database: LULC changes in the riparian zone (Dou et al. 2023), average nutrient retention in riparian buffers (e.g. Gericke and Leujak (2023), pp. 30–31 and reference therein), adjusting the current floodplain denitrification in Rhine and Elbe (Kaden et al. 2023)

Unlike the other scenarios, the implementation of nature-based solutions requires adjusting internal nutrient retention parameters of the model rather than model input. Riparian buffers are not mentioned in Dutch river basin management plans likely due to the reported low efficiency under Dutch conditions (Gericke and Leujak (2023), pp. 25 and 31). The details and assumptions of this scenario should be carefully discussed with stakeholders as the measures are considered effective in the literature but rarely acceptable by farmers in comparison to agricultural measures (e.g. Gericke and Leujak (2023), Table 24).

- Measures: extensive farming along water bodies, if any; re-establishing riparian zones and wetlands

**Scenario 5: All measures**

This scenario considers the overall N and P input reduction from wastewater (1), agriculture (2), atmospheric deposition (3), and nature-based solutions (4) in the Rhine and Elbe basins. The consequences for N and P concentrations and loads are determined in combination with climate change effects (6).

- Database: See scenarios 1–4
- Measures: See scenarios 1–4

**Scenario 6: No measures**

In this scenario, no reduction of N and P inputs (scenarios 1–4) is implemented. Instead, it quantifies the consequences of climate change effects on N and P concentration and load within the Rhine and Elbe basins. In combination with scenario 5, we quantify the remaining reduction needs. As a climate change scenario, we will use RCP 6.0. For this scenario, the hydrological modelling in mHM is readily available across Europe (Samaniego et al. 2018) and can be used in the mQM and $C^n$ANDY water quality modelling frameworks.

- Database: Output of the hydrological model mHM until 2040 (to be discussed with stakeholders)
- Measures: None

**Scenario 7: Adapted**

Based on discussions with stakeholders and the analysis of social acceptance, this scenario will consider a set of measures that addresses the (remaining) N and P reduction needs resulting from scenarios 5 and 6. Depending on the results, stricter or less intense measures (targets) are evaluated. For instance, we may assume that all UWWTP fulfil existing technological benchmarks in the case study, or that agricultural regulations for hotspot (“red”) areas are applied everywhere. We quantify the consequences for N and P concentration and load within the Rhine and Elbe basins.

- Database: to be discussed with stakeholders, e.g. the DüngEval project provides scenarios results for N surplus in Germany beyond scenario 2
- Measures: to be discussed with stakeholders

The scenario offers the option to reflect higher levels of ambition, an approach conceptually similar to other scenario assessments (e.g. Grizzetti et al. 2021). The scenarios in Table 1, for instance, do not consider behavioral changes and dietary shifts which could most likely induce further reductions in livestock density and the agricultural N balance, especially in the lower Rhine catchment. However, the relationships between livestock density and the soil-surface balance as model input are complex as farmers may replace the missing organic fertilizer with mineral fertilizer to reach the politically allowed maximum. Nonetheless, it has been repeatedly argued, e.g. by Desmit et al. (2018) or Leip et al. (2022), that dietary shifts are mandatory to achieve the ambitious environmental goals of the European Union. While meat consumption is expected to drop on average from 69.8 kg capita$^{-1}$ in 2018 to 67 kg capita$^{-1}$ in 2031, the national trends differ and cannot simply be extrapolated (Figure 1).

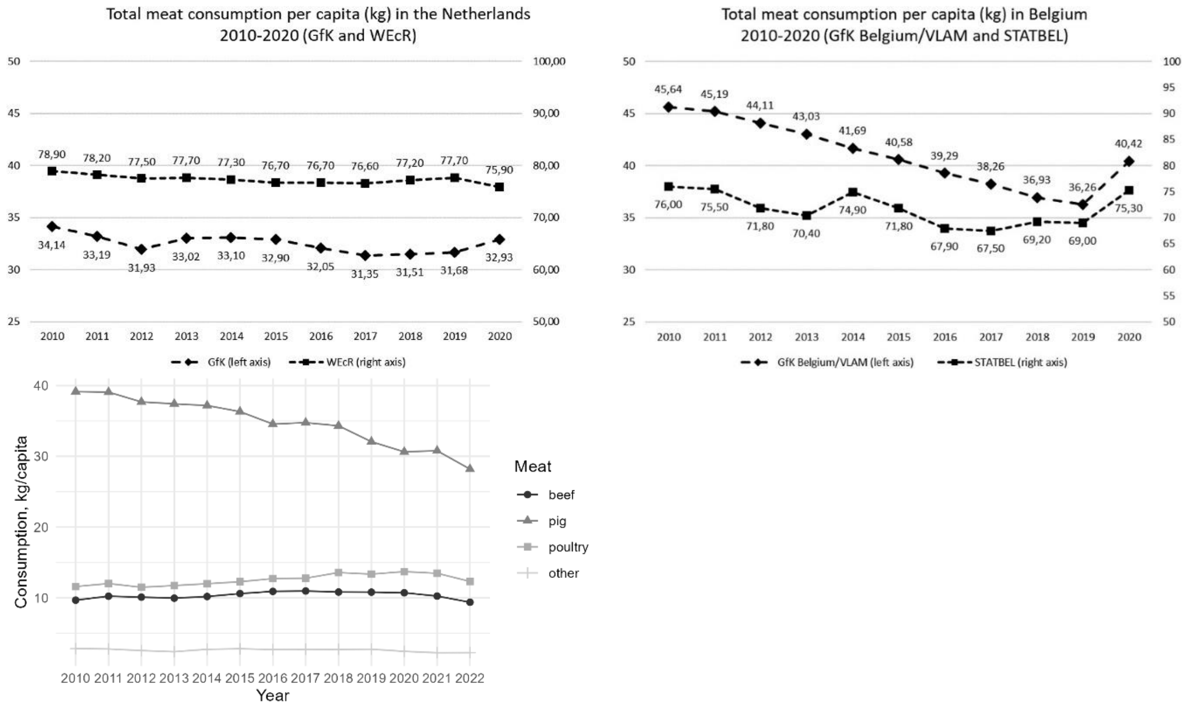


*Figure 1. Evolution of meat consumption, top row: Netherlands and Belgium using different datasets (source: Dagevos and Verbeke 2022), bottom row: Germany for different types of meat (data: BMEL 2023).*

## 2.3. Discussion

The scenarios are intended to demonstrate the regional and basin-wide effects on various nutrient sources/ pathways which are pivotal for water quality in the basins of rivers Rhine and Elbe. We use them to adjust the modelled nutrient concentration and load at the outlet of the two river basins which can be compared to existing threshold values or values within safe ecological boundaries. The abstract concept of measures reported at the basin scale (e.g. the key type of measures in river basin management plans), the huge variability of measure effects in the literature, and the complex inter-dependency with site and farm conditions does not allow to consider specific measures in our scenarios. Instead, we rely on existing data and current or planned policy targets for the relevant sources of nutrients. By calculating the scenarios separately, we can evaluate which set of measures (target of measures) is most effective to reach the requirements. Table 2 in the Annex provides a range of possible reductions based on literature and data.

The planned stakeholder workshops should be used to discuss and refine the set of scenarios. At the current stage, the scenarios 2, 3, and 6 strongly depend on available (published) input data as the complex modelling of soil-surface N balances, atmospheric N deposition, or water discharge is out of scope of NAPSEA. In addition, the scenario data for DE and NL differs not only in availability but also in terms of scenario assumptions. For instance, the atmospheric deposition in 2030 assumes the implementation of the NECD in foreign countries although the Dutch scenarios are also based on the implementation of the Habitats Directive. It is therefore recommended to discuss with stakeholders in the Rhine basin how to cope or communicate with such inconsistencies and uncertainties.

The details and assumptions of the “adapted” scenario should be discussed with stakeholders to foster the acceptance of assumptions beyond existing policy goals. This scenario could be complemented by a) extrapolating the reduction needs at the basin outlets based on the in-stream retention and b) analyzing the (spatially variable) exceedance of critical nutrient inputs required to fulfil existing policy targets. Such critical inputs were derived for the European Union by de Vries et al. (2022). If the agricultural contribution is known, a maximum allowable soil-surface nutrient surplus can be derived and used as model input to verify the results. For Germany, the agricultural share of about 80% on the national N target of 1000 kt N $a^{-1}$ (Bach et al. 2020; Geupel et al. 2021) corresponds to a maximum (farm-gate) N surplus of about 50 kg $ha^{-1}$ (A.-S. Katte, pers. comm.).[1]

Likewise, the year 2040 for the scenarios should be accepted by stakeholders. The current choice is a trade-off between the target periods of the considered Directives (and available scenario data), the expected effect of climate change, and the residence time of nutrients in the catchment. Depending on the residence (travel) time of nutrients in the catchments, the effect of measures on water quality might not be fully “visible” in the stream network if the scenario period is short. However, it must be noted that further extending the scenarios has several consequences besides the delay in nutrient transport. Firstly, the scenario definition might require further adjustments, e.g. to include foreseen changes in land use and land cover (LULC). According to national projections, urban areas are expected to increase at the expense of agricultural land in Germany during the next two decades (Figure 2). Such a decline in agricultural land is also expected in the Netherlands until 2050 (Lesschen et al. 2020). A recent study on how the implementation of sustainability targets can shape the LULC in Europe modelled a general increase of urban areas while the future extent and pattern of agricultural land and forests depends on the use intensity and on the adopted view on nature (Dou et al. 2023). Secondly, population changes become more important with migration being the most important source of uncertainty (Figure 3), which would in turn affect the regional pattern of urban and point source emissions. Thirdly, the impact of climate change may increase nutrient mobilization as various studies indicate an increasing risk of rainfall erosivity in the study area (e.g. Gericke et al. 2019; Uber et al. 2022; 2024). Likewise, more intense precipitation may result in more stormwater flow from combined sewers as well as more preferential surface runoff which reduces the efficiency of riparian buffers as a nature-based solution – without more efficient countermeasures in the future.

[1] The regioNat project is currently regionalizing the national N target for Germany.

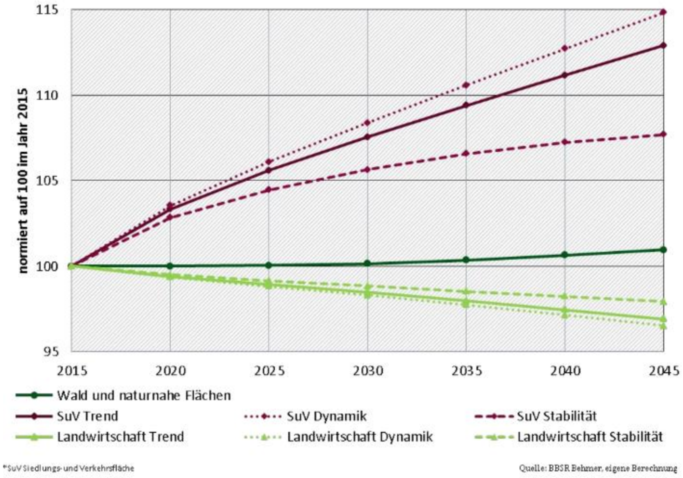


*Figure 2. Projected relative change in urban and traffic areas (lilac), agriculture (green), and forests and natural areas (dark green), 2015–45. The scenarios “Stabilität” (stability), “Trend”, and “Dynamik” (dynamic) reflect different socio-economic changes and whether policy goals are achieved (“Stabilität”) or not (“Dynamik”) (source: Behmer 2020).*

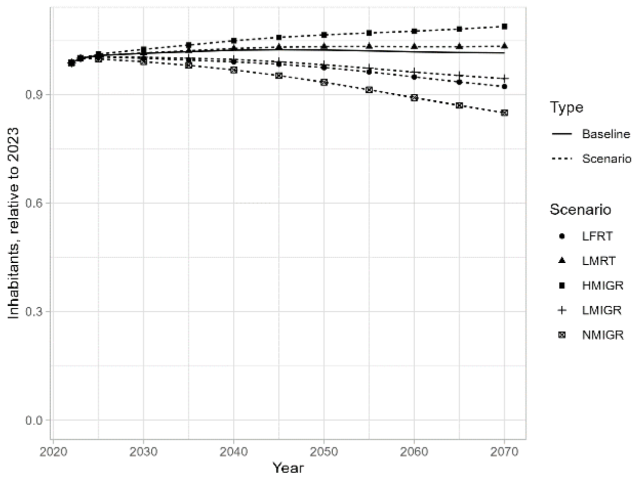


*Figure 3. Overview of population scenarios for FR+BE+LU+NL+DE+CZ (Eurostat 2023b). The scenarios consider no (N), low (L), and high (H) fertility (FRT) and migration (MIGR).*

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# ANNEX

*Table 2. Estimated overall reduction of nutrient emission for the proposed scenarios in Table 1. These exemplary numbers do not consider the spatial variability, the travel time within the catchment, and other factors. More details on the datasets in Deliverable D 2.2.*

| Scenario | Narrative | Source | Nutrient | Reduction | Reference year | Reference area | Reference of data |
|---|---|---|---|---|---|---|---|
| 1 | Implementation revised UWWTD | UWWTP | N | 22% | 2020 (DE), 2022 (NL) | Rhine+Elbe (DE+NL) | (EEA 2023; |
| 1 | Implementation revised UWWTD | | P | 15% | 2020 (DE), 2022 (NL) | Rhine+Elbe (DE+NL) | Umweltbundesamt n.d.) |
| 3 | Lower deposition on Natura 2000 areas, NECD 2030 | Atmosphere | N | 10% | 2020 | NL (Natura 2000) | (RIVM 2023a) |
| 3 | Lower deposition on Natura 2000 areas, NECD 2030 | | N | 15% | 2018 | NL | (Hoogerbrugge et al. 2022) |
| 3 | Implementation NECD 2030 | | N | 23–29% | 2015 | DE | UBA (unpubl.) |
| 4 | Thünen-Baseline including Implementation CAP, 2030 | Agriculture | N | 24 kg/ha | 2021 | DE | UBA (prelim.) |
| 4 | Thünen-Baseline including Implementation CAP (AGRUM-DE project), 2027 | | N | 23 kg/ha | 2014-2016 | DE | (Zinnbauer et al. 2023) |
| 4 | ditto and good status of groundwaters (AGRUM-DE), 2027 | | N | 31% | 2014-2016 | DE | (Zinnbauer et al. 2023) |
| 4 | Full ensemble of source-oriented voluntary measures (DAW) on all farms (scenario C), 2027 | | N* | 10% (clay, peat) – 19% (sand) | 2019 or 2027 | NL | (van Boekel et al. 2021) |
| 4 | Implementation of Soil Health Law, soil erosion ≤ 2 t $ha^{-1}$ | | P** | ≈ 30%*** | | DE + NL (arable land) | (Borrelli et al. 2022; 2023) |
| 4 | +20% organic farming to meet the goal of the Green Deal | | P** | ≈ 10****% | 2021 | arable land | (based on Auerswald et al. 2021; Eurostat 2023a) |

* only locally significant effect on P load, ** without considering P content, sediment delivery ratios, and P enrichment, *** total erosion reduced from 4.45 t $ha^{-1}$ to 2 t $ha^{-1}$ assuming that wind and water erosion (50%) contribute to sediment in rivers, **** 5% organic arable land increased to 25% organic farming, the average C factor of the universal soil loss equation for Germany changes from 0.124 to 0.109.