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The Novel Impact Monitoring of Germany's Nitrates Directive Action Program – From Concept to Implementation

Abstract

In 2018, Germany was found guilty by the European Court of Justice for insufficient implementation of the European Nitrates Directive and assured to implement a monitoring framework. Since then, a nationwide impact monitoring system has been developed to assess effectiveness of mitigation measures, analyze nitrate pollution trends, and provide early warnings for regulatory adjustments. The monitoring combines three levels: agricultural emissions, immissions to waters, and nutrient flux modeling combined with field measurements. Data from around 7,500 groundwater stations and farm records are analyzed alongside model-based estimates to assess trends in fertilization and water pollution. First results indicate a recent decline in fertilization intensity in many regions, yet rarely significant water quality improvements. Model validation with empirical data on fertilizer expenses from German Farm Accountancy Data Network shows high accuracy. Future enhancements, including expanded data access and optimized methodologies, will strengthen regulatory assessments and support targeted mitigation measures for EU compliance.

Keywords: impact monitoring, nitrogen, fertilization, Nitrates Directive, regulation

The submission is well-suited for a digital poster as it outlines both the structural process and first results of the novel impact monitoring program. Spatially highly differentiated maps underpin the status quo and the development of relevant emission and immission indicators in Germany and a comparative table illustrates differences between federal states in time. These visual elements, combined with a succinct representation of the latest modeling enhancements as well as the authors' insights into the ongoing political debate, make the poster both accessible and impactful, bridging academic insights with political and practical relevance.

Problem statement

In 2018, Germany was found to be in violation by the European Court of Justice after the European Commission had initiated infringement proceedings due to insufficient implementation of the Action Program under the European Nitrates Directive (91/676/EEC) (European Court of Justice, 2018). Consequently, Germany was required to amend its Fertilizer Application Ordinance, which serves as a key regulatory instrument of the program. The revisions included the designation of “Nitrate Vulnerable Zones” with additional mitigation measures, as well as the establishment of a novel monitoring framework to assess the program’s effectiveness. In this context, a consortium of research institutions and federal organizations was commissioned to carry out a comprehensive “impact monitoring”.

Research Questions and Objectives

The impact monitoring is designed to assess the effectiveness of the Fertilizer Application Ordinance and serves as an early warning system to enable timely policy adjustments. A key objective is to analyze how nitrate pollution levels evolve in both already affected and less affected areas. This includes evaluating whether the implemented mitigation measures are sufficient or if further adaptations are necessary. By continuously tracking trends and regional differences, the monitoring aims to identify potential policy shortcomings and provides scientific evidence to support targeted improvements based on the polluter-pays principle. The collected data shall help policymakers refine regulations to ensure long-term compliance with the European Nitrates Directive.

Methods

The monitoring is designed as a comprehensive, nationwide system that considers both water quality and agricultural emission data, with a primary focus on displaying the developments in the newly designated Nitrate Vulnerable Zones. The program is built on three interconnected pillars: (i) monitoring of agricultural emissions, (ii) monitoring of immissions (water quality), and (iii) nutrient flux modeling combined with long-term field measurements in selected model regions, culminating in a comprehensive federal database.

The main focus of this contribution is the emissions level of the impact monitoring. Here, we compile and analyze statistical and empirical farm data to derive spatial indicators that assess fertilizer application trends. This approach enables the monitoring of regional fertilization intensity. Key parameters include changes in the use of mineral and organic fertilizers, livestock numbers, and land use. Also, nitrogen and phosphorus budgets on soil level are modeled to assess pollution risks of (ground-) water bodies. These key indicators provide valuable insights into farmers' adaptation to regulatory changes, with observable effects on emissions within just a few years after the revised Fertilizer Application Ordinance took effect.

A trend analysis for relevant emission indicators was conducted by using Mann-Kendall Test with *R* statistical software. To ensure accuracy, we validate the modeled quantities with empirical data on annual mineral fertilizer expenses from the German Farm Accountancy Data Network (FADN) using different statistical approaches (Zinnbauer *et al.*, 2024).

To account for immissions, over 7,500 groundwater stations track nitrate and phosphorus levels. However, due to dwell and residence time and accumulation of nutrients in soil and water, measurable effects of regulations on water bodies may become apparent only in the medium to long term (Basu *et al.*, 2022; Kumar *et al.*, 2020). To bridge the gap between emissions and immissions, nutrient flux modeling plays a crucial role. The AGRUM-DE model network integrates spatial agricultural, hydrological, and biogeochemical models to simulate how fertilizer regulations impact groundwater and surface water (Zinnbauer *et al.*, 2023).

Data

A novel national database is being developed to compile area-wide data on water quality, land use, and fertilization intensity. Major data sources are manure transport records, data from the Integrated Administration and Control System (IACS), remote sensing data and national agricultural statistics. However, data acquisition remains challenging due to German federalism, which introduces path dependencies and institutional lock-ins. Furthermore, not all data sources originally envisioned have been incorporated, because the revision of the German Fertilizer Law remains pending and thus has not yet provided the necessary legal framework. Continuous improvements and expansions are made annually.

For validation and plausibility checks, empirical data from FADN is included. This dataset covers a sample of around 61,600 annual observations from 12,500 unique farms between 2017 to 2023, providing valuable insights into fertilization practices (Löw and Osterburg, 2024).

Results

First results indicate a significant decline in agricultural fertilization intensity on federal level, likely driven by a combination of economic, structural, and policy factors. However, groundwater and surface water quality have not yet improved considerably. It is a major challenge to account for and to communicate the time lag between changes in soil surface processes and in the water bodies.

In Germany, nitrogen inputs from organic and mineral fertilizers are decreasing. Nevertheless, between 2018 and 2021, more than 80% of the groundwater bodies show no significant decreasing trend in their nitrogen budgets ($p < 0.1$). However, nitrogen budget surpluses have decreased in 17% of groundwater bodies classified as being in poor chemical condition for nitrate and in 8% of those in good condition. This reduction is particularly evident in livestock-dense regions of northwestern Germany. In contrast, some groundwater bodies in southwestern Germany show increasing nitrogen budget surpluses, though these areas generally maintain good groundwater status and relatively low nitrogen levels. Phosphorus surpluses are negative in large parts of the country, indicating a reduction of phosphorus stocks in soil, while hotspot regions still exist.

The model generally captures the regional magnitudes of mineral fertilizer application rates. In federal states with intensive farming activities, such as Schleswig-Holstein, Lower Saxony, and North Rhine-Westphalia, model estimates align closely with FADN values weighted according to national farm survey. The mean absolute deviation is around 8 kg N/ha utilized agricultural area (UAA), with the root mean squared error of 10 kg N/ha UAA. The model tends to overestimate application rates in Bavaria while underestimating them in Mecklenburg-Western Pomerania and Saarland. Nevertheless, no systematic bias in mineral fertilizer application rates is indicated.

Modeling methods are continuously refined through targeted improvements, expanded access to reliable data sources, and ongoing evaluation in committees and expert working groups. While existing limitations persist, annual enhancements ensure increasing accuracy. Empirical data from FADN provide valuable validation and plausibility checks. Given the legal basis will be provided in the near future, the inclusion of further farm level data sources will improve the precision and scope of the database. That allows for a reliable impact monitoring which offers a comprehensive assessment of agricultural fertilisation management in Germany and supports policy makers in defining targeted mitigation measures.

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