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Decision-support tool (DST) for the analysis of NbS related, regional nutrient budgets and management optimization

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1. Executive summary

European agriculture faces persistent challenges related to nutrient losses, soil degradation, and water pollution. While nutrient management decisions are typically taken at the farm or field level, their environmental impacts, such as nitrogen (N) leaching to water bodies, manifest at the landscape scale. This mismatch makes it difficult to identify solutions that are both environmentally effective and economically viable, particularly when trade-offs between environmental performance and farm income must be considered. Consequently, there was a clear need for decision support that could operationalise Nature-based Solutions (NbS) for nutrient management while explicitly addressing spatial interactions across the landscape.

The trans4num Decision Support Tool (DST) is a spatially explicit, data-driven optimisation tool designed to support collective decision-making on nutrient management at landscape scale. It enables users to explore how different management strategies and NbS interventions affect both environmental outcomes (e.g. N leaching) and economic performance, across a whole region rather than considering individual farms in isolation. The effects depend not only on the NbS themselves but also on geographic context, such as local soil type, proximity to bioindustry, or nearby sensitive environmental sites and habitats. Importantly, the DST does not prescribe decisions or predict the outcomes of specific choices. Instead, it is initiated with a desired effect and then visualises possible solutions to achieve that effect. In this way, it helps stakeholders jointly explore scenarios, visualise trade-offs, and identify efficient, collaborative solutions across the landscape. Users can interact with the tool through a frontend guiding them through the tool and providing them with a range of outputs. The tool was tested with groups of stakeholders at various sites (D3.3 - Testing the DST (Vestergaard Odgaard et al. 2026)) and has been improved through this process. The model engine in the backend is versatile and can be adapted to a range of different settings. It is openly accessible to allow researchers, advisors or policy makers to adapt and further work with it.

2. Background

2.1 Context and rationale

European agriculture faces persistent challenges related to nutrient losses, soil degradation, and water pollution. While nutrient management decisions are typically taken at the farm or field level, their environmental impacts, such as nitrogen (N) leaching to water bodies, manifest at the landscape scale. This mismatch makes it difficult to identify solutions that are both environmentally effective and economically viable, particularly when trade-offs between environmental performance and farm income must be considered. Consequently, there is a clear need for decision support that could operationalise Nature-based Solutions (NbS) for nutrient management while explicitly addressing spatial interactions across the landscape.

The current deliverable reports the outcomes of trans4num Task 3.2: Development of a Decision Support Tool for optimum nutrient supply at farm, regional, and watershed scales. The overall ambition of this task was to develop a decision-support tool (DST) capable of

improving nutrient management at the landscape scale. The task began with a review of existing farm- and national-level DSTs and aimed to optimise regional nutrient flows by building on existing tools and knowledge. Explicitly, the ambition was to establish a tool that:

- Is flexible and versatile, capable of accommodating a broad range of actors and sites and supporting multiple agricultural practices, including conventional, organic, and agro-ecological systems.
- Supports linkages between spatial scales and the respective stakeholders through being spatially explicit.
- Can be fed with different input data, including data from remote sensing on crop types and nutrient management (Task 3.1).
- Visualises trade-offs and stimulates dialogue between actors to identify collaborative solutions and NbS along the value chain.
- Is accessible through a user-friendly frontend, developed in collaboration with a software subcontractor.

Ultimately, the DST was intended to be tested and applied at the trans4num NbS sites (Task 3.3), based on a prototype delivered by M24, with stakeholder feedback used to iteratively improve the tool's functionality and structure.

2.2 Review of existing DSTs

As a starting point for developing the DST, existing end-user decision support tools (DSTs) were reviewed at both farm, regional and national scales. A three-step approach was followed, including the use of existing project databases (e.g., FAIRWAY, FAIRshare, Super-G), a review of scientific literature, and consultation with trans4num partners to identify tools currently used in their countries. The review focused on operational, digital tools supporting nutrient management for arable farming, with potential end-users including farmers, advisors, policy makers, educators, scientists, and water managers. Tools addressing other aspects, such as pesticide application or greenhouse crops, were excluded unless directly relevant.

The review identified over 100 tools, roughly half supporting fertilization planning and more than 20 assisting with record keeping or legal compliance (Figure 1). Only 13 tools addressed nutrient losses or gaseous emissions. Most tools operated at field or farm scale, with few covering regional perspectives, and many were country-specific due to differing agroclimatic conditions, farming practices, and legislation. With respect to the trans4num NbS sites, it was found that at each site, at least one tool capable of supporting fertilization planning and one for record keeping and compliance were available.

Importantly, we found that very few existing DSTs explicitly account for spatial distribution of fields, farms, or nutrients. However, being spatially explicit was identified from discussions among project partners across different sites as a key requirement for Task 3.2. It is critical both for enabling collaboration between farmers and biomass industries, where proximity affects the feasibility of nutrient and biomass transport, and for ensuring the effectiveness of NbS, which vary depending on local field conditions.

The review revealed a clear gap: there is a wide range of farm-level tools and some regional planning tools, but no tools simultaneously cover farm and regional scales while supporting collaboration and nutrient exchange. To address this gap, it was decided to develop a new DST focused on linking farm and regional scales in a spatially explicit manner, leveraging existing tools and data to calculate regional nutrient balances and to populate the underlying data structure.

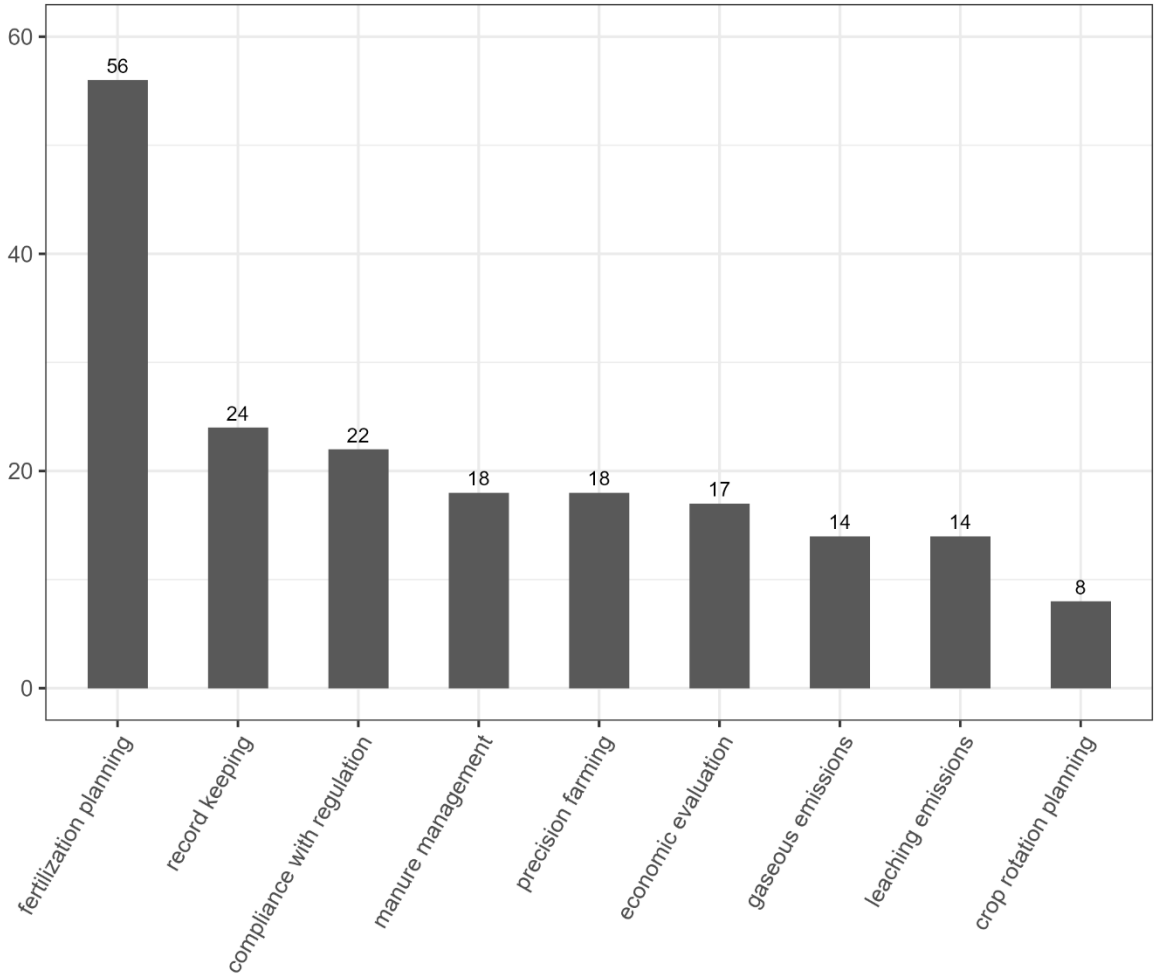

Figure 1: Purpose/functionality of the reviewed decision support tools (note: tools can be in multiple categories; total number of tools n=109).

3. Describing the DST – general principle

3.1 General principle and target audience

The trans4num DST works in a way that users describe the desired goals of implementing an NbS in their region based on the effects of the NbS. The tool calculates an optimal and efficient solution to how the goals can be achieved.

The DST functionality includes an optimization tool that considers geographic aspects to strategically place NbS in such a way that certain goals can be optimized at landscape scale.

The DST is designed to support transformative change. It targets workshop settings where farmers, local planners, and other stakeholders can collaboratively define inputs and constraints for the optimisation model. The collaborative process encourages participants to

reflect on priorities and regional NbS goals. The output of the optimization model facilitates comparison between status quo and one or several optimized solutions. This is achieved by visualizing the degree of achieving the goal, economic impact, regional nutrient balance and other relevant indicators as maps, graphics and numeric data. These outputs present a common ground for discussion and reflection on NbS implementation to achieve regional environmental or agronomical targets.

The DST is designed for collective planning and strategic exploration, rather than individual farm advisory use. Key user groups include:

- Policymakers and regional authorities
- Advisors and extension services
- Water and environmental managers
- Cooperatives and producer organisations
- Farmer clusters or associations
- Researchers and students

The core idea is to link farm-level management choices to landscape-level outcomes, making the green transition more tangible and transparent. In doing so, the DST intends to foster dialogue between stakeholders across different levels and initiate the adoption of NbS.

3.2 The design process

The development process was grounded in a user-experience workshop moderated by an external software company, during which trans4num partners from Denmark (ICOEL, AU, CO, CFS), Switzerland (FiBL) and the Netherlands (SPNA) jointly identified gaps in the existing agricultural DST landscape and clarified what would be required to translate NbS interventions for nutrient management into practical, actionable strategies (D3.3: Vestergaard Odgaard et al. 2026). Key aspects identified during this co-development process include the lack of tools linking field-level actions with landscape-scale outcomes, the necessity for active collaboration to enable circular nutrient flows, and the importance of spatially explicit information to evaluate the impact of NbS interventions on broader environmental targets.

The DST was developed through close collaboration among modellers and researchers from diverse fields, including soil sciences, agronomy, spatial data science, and social sciences. The initial design was presented and discussed with trans4num partners at other European case study sites, ensuring the tool could accommodate a wide range of contexts. Importantly, the NbS tested in trans4num include diversified crop rotations, bio-based fertilizers, and other integrated management practices, while environmental and productivity targets encompass yield resilience under weather extremes, soil health, biodiversity, and water quality. Consequently, the DST was designed to be versatile and flexible, enabling site-specific customization to different landscape settings.

3.3 Terms and definitions

Problem: Nutrient management related challenge at regional scale. E.g. nitrate leaching loads to the fjord are too high, causing detrimental ecological effects (Figure 3a).

Optimization goal: Overarching ideal for the region of interest. The DST allows the user to consider trade-offs between contrasting factors, such as minimizing nitrate leaching and optimizing economy for a region. This can be done either as "optimize one aspect while not impeding the other aspect by more then x" (e.g. minimize nitrate leaching, but do not reduce economy by more than 15 %) or by calculating an optimum with as little nitrate leaching per reduced economy as possible (Figure 3a).

Raw input data (Figure 3b): Relevant raw data sufficient to process and compile input data to the DST (see more in section 4.2).

Data input to the DST (Figure 3c): Underlying data for the DST consists of two different types.

- **Geographic data**: A spatial data file containing at least the crop distribution at field plot level or as grid (e.g. 100 m x 100 m). Further parameters such as soil properties, proximity to bioindustry, etc. should be included if they are relevant to the optimization goal or for certain *constraints* (see below).
- **Transition matrices**: Table(s) containing (semi-)quantitative information on the change from one management option to another (i.e. the implementation of NbS). For each parameter of interest, a separate transition matrix is needed (e.g. change in N load as affected by the transition from cereal to a crop rotation with a higher proportion of grass). The tables are informed by results from field trials, other models or expert judgment.
- **Constraints**: Constraints define the option space in which the model searches for an optimal solution. There are two types of constraints (Figure 3c):
    - Aspects that are not allowed (e.g. limitations of fertilization level, increase of potato area cannot be more than x % etc. (no go`s) → hard-coded
    - Aspects that stakeholders would be interested in choosing as constraints – binary or continuous (sliders) (e.g. limitation on fields in proximity to bioindustry) → allow stakeholders to prioritize certain aspects and set customized system boundaries.
- **Nutrient flux parameters**: Data file that contains the relevant information for calculating the regional nutrient balance based on crop shares. Data includes inputs via manure and fertilizers (in tons of nutrient for the whole region), nutrients removed with crop harvest and biological N fixation (both in kg nutrient/ha).

Effect: The DST calculates the effect of implementing an NbS for each field plot or grid cell (depending on the spatial resolution of the *geographic data*) (Figure 3c). For this, the model combines the geographic data with the transition matrices. For example, N load for each field is calculated based on its soil type and the effect of the transition from a specific crop rotation to another rotation.

- **Geographic effect**: Based on *geographic data*, the DST selects the correct transition table or conversion factors for deriving an effect on the target parameter (e.g. N load).
- **NbS effect**: The NbS effect is encoded in the *transition matrices*.

Input: Users create an alternative by selecting an optimization goal (from a pre-defined selection, specific to each site). Optionally, also *constraints* can be defined.

Output: The model behind the DST calculates an alternative, spatially explicit allocation of management practices in the selected region. This alternative represents the output of the DST consisting of a map alongside some indicators such as for instance the development of N load compared to status quo or a change in the economy over the whole region. Also, the regional N-balance for status-quo and alternative are displayed.

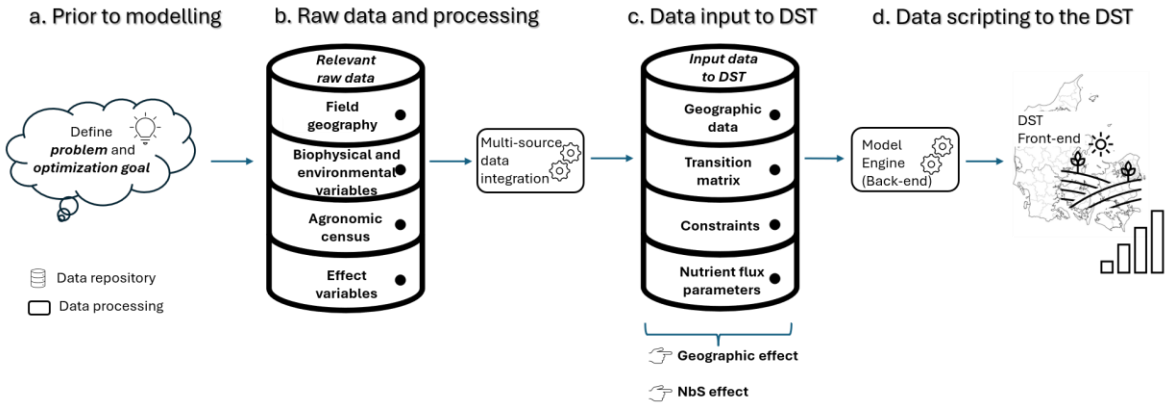

Figure 2: Overview of the DST flow showing a) what to define prior to modelling and application of the tool in a specific site, b) raw input data and data processing, c) processed input data to the tool, d) Scripting and final tool ready for use. Bold text indicates the terms defined in section 3.3.

3.4 Calculation of a regional nutrient balance

In order to provide stakeholders with a general overview of the nutrient status of a region, the model output includes a soil surface nutrient balance based on the OECD methodology (Kremer 2013). The tool currently focusses on N while other nutrients could be calculated in a similar way.

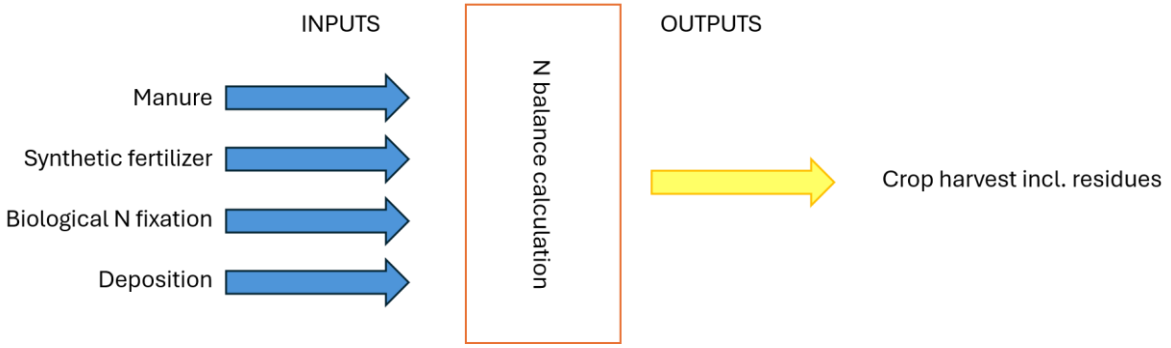

Figure 3: Visualization of the input and output parameters for the N balance calculation

The regional N balance assesses the relationship between crop N demand (represented by N removed through harvest) and current N inputs (Figure 3). The soil N balance serves as a circularity indicator, capturing whether nutrient cycling is broadly aligned with crop uptake, whether the system accumulates excess reactive N likely to leak beyond the managed agroecosystem, or whether nutrient mining and undersupply may become a problem.

Within the DST, only the crop N demand and the input from biological N fixation change as a result of optimised crop rotations and crop shares, whereas N inputs remain fixed because

the model does not simulate changes in livestock production or N input from mineral fertiliser. The resulting balance provides a baseline for evaluating how changes in cropping systems influence regional N demand. It encourages stakeholders to reflect upon strategies to omit or replace synthetic fertilizer inputs or to think about innovative strategies to cope with regional N deficits.

The required input data (Figure 3) can be derived from existing datasets and calculations. We utilised the preprocessing routines of the GeoSOL tool, as developed within the PATHWAYS project (more details on the underlying data and assumptions can be found in Pfeifer et al. (2026)). GeoSOL provides a spatially explicit framework that translates NUTS2-level livestock numbers and crop areas into layers at 1 km² resolution on the CORINE grid and combines them with elaborate datasets on the herd structure and feeding rations of the European livestock system.

Based on the outputs from the GeoSOL preprocessing module, the N balance calculation for any European region can be obtained. For this, the harmonized data from GeoSOL on N harvested and N fixed by crop (kg N/ha) as well as total N inputs (kg N/ha or kg N/NUTS2 region) can be integrated into the trans4num DST. Aggregation of crop and livestock categories are based on Eurostat (Eurostat 2024a, 2024b, 2024c, 2024d, 2024e, 2024f, 2024g). Any other local crop categorization could be linked to these by providing a matching file that links the local crop categories to the Eurostat database. This approach was illustrated for the Danish case (see 4.2.2). This work is currently still ongoing, and the outcomes are expected to be presented in more detail in a forthcoming scientific publication.

Linking with GeoSOL opens up further potential for synergies. In the future, a connection with the downstream modelling aspects of PATHWAYS, in which crop production is integrated with animal husbandry and linked to outcomes at the wider food system level, would allow for a more holistic picture and the assessment of the consequences of new crop allocations on the wider food system through a direct linkage to the SOLm model (trans4num task 4.2).

3.5 Functionality and features of the backend

The backend and frontend code is made available at:

https://github.com/trans4num/trans4num-dst

The backend is made of two individual modules: one module for the API service enabling the frontend to interact with the model engine, and one module for the modelling engine. Both modules have been implemented in python and utilize a common module for shared datatypes.

The primary reason for separating the components is that the model engine is computationally intensive and can require significant time to complete. Hence, we provide a lightweight API layer that can run on low resources, while the computationally intensive model engine can be scaled independently as needed.

In general, the backend module is a RESTful API. It is secured by a simple authentication scheme, requiring an auth token which can be retrieved at the login endpoint using a valid username and password.

The API is documented here https://trans4num.cordulus.dev/api/v1/docs and exposes info about regions, fields and simulations. It further exposes an endpoint where new simulations can be posted, effectively submitting a job to the model engine.

The persistence layer, and interaction between the backend and model engine is based on a simple object storage layout.

The model engine is responsible for setting up and solving the optimization problems. To support optimal spatial allocations of management practices across a large number of fields, the tool uses mixed-integer programming which enables evaluation of alternative crop rotations and management strategies in a spatially explicit manner.

Jobs are submitted to the model engine through the API using parameters such as constraints and optimization goals provided by the frontend. It further processes internal data supplied in compatible formats, including tabular data (CSV, JSON) as well as raster (GeoTIFF) and vector data (GeoJSON, Shapefile). In addition, a data pipeline has been established to enable future integration of remote sensing data (D3.1: Birk 2023).

The output of the model engine is a vector dataset, describing the optimal crop rotation of each individual field, computed relevant metrics for each field which are relevant for analysis, and summaries of the optimization as well as nutrient balance calculations.

3.6 Functionality of the frontend

The software company *Better Developers* was subcontracted to programme the frontend to the tool. A first version was set-up and used for stakeholder workshops in Denmark in February 2025. The frontend is a web interface developed in React. Through this frontend, users can interact with the optimisation model. From a list of pre-defined options, they can choose a regional optimization goal and introduce constraints that limit the option space for the optimization model and that allow to calculate realistic scenarios that are meaningful to involved stakeholders.

The model then runs the calculations and produces a range of outputs:

1. Spatial map outputs showing the status quo and the optimized allocation of crop rotations, as well as additional parameters such as field-level N loads, yields, and economic returns.
2. Pie charts summarizing the regional crop shares under the status quo and after optimization.
3. Summary indicators, including the regional nutrient balance, that enable comparison not only with the status quo but also between other modelled alternatives in terms of overall regional performance.

If the selected goal is too ambitious and/or the constraints are too restrictive, the model run may fail. Such outcomes provide valuable insight into the realistically achievable goals and trade-offs.

3.7 Intellectual property and access rights

The model engine underlying the DST is designed to be modular and versatile, enabling customization to new use cases. To support transparency and future development, the codebase of the model engine is openly accessible on GitHub, together with comprehensive documentation, allowing researchers and software developers to extend and further develop the tool in the future.

The frontend, including its source code, remains the intellectual property of ICOEL. During the lifetime of the trans4num project, maintenance of the DST will be the responsibility of the project consortium. Following the completion of the project, the web-based interface will remain operational but will be protected by password authentication. Access to the trans4num DST may be requested from ICOEL and can be provided free of charge to users with a genuine research or professional interest. The tool is available under https://trans4num.cordulus.com/.

Further maintenance and continued development of the DST will be carried out within the framework of the PlantPerform project, through a collaboration between AU, ICOEL, and CO.

The dataset used in the Danish case study is owned and maintained by AU and is shared with ICOEL, CO, and FiBL for the purposes of the project and related research activities.

4. Development of the DST at the Danish NbS site

4.1 Background of the Danish DST prototype

Developed for the Limfjord region in Denmark, the DST prototype focuses on reducing N leaching to coastal waters defined as N loads. One key NbS explored is the increased use of perennial grass and catch crops, which can reduce N losses while creating opportunities for new value chains through green biorefining, including plant protein, biomaterials, and bioenergy (D2.1: Graversgaard et al. 2023). Users collectively define goals and constraints, for example, “reduce N leaching to the fjord while maximizing regional economic performance” (Figure 4, Figure 5). The DST then identifies the spatial allocation of crop rotations across the region that most efficiently meets these goals.

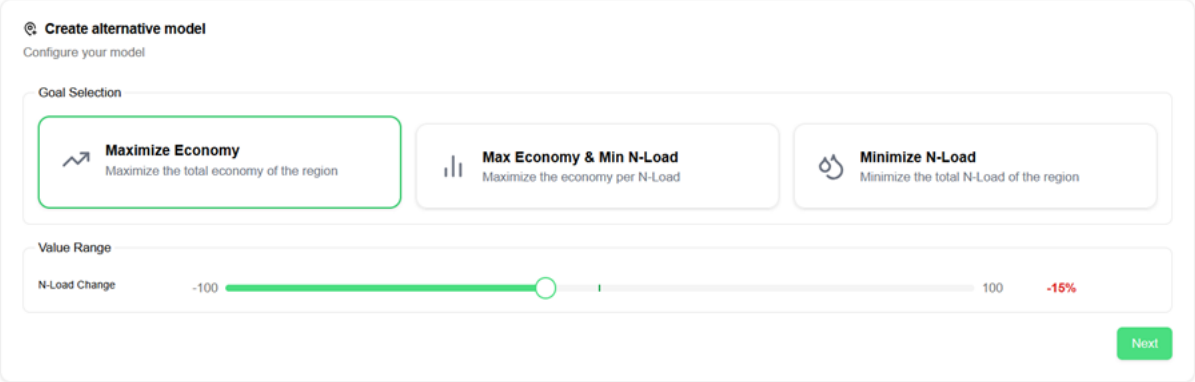

Figure 4: How to choose an optimization goal in the DST (example screenshots from the Danish DST prototype).

Figure 5: Selection of constraints in the Danish DST prototype.

4.2 Raw data integration towards data input in the backend

At its core, the DST combines multiple data sources (Figure 3b, Table 1). In the Danish context, these include spatial information on fields, crops, soils, yields, and the location of bioindustries such as biogas plants or biorefineries, as well as the effect of management interventions on environmental and economic parameters, such as N losses and farm profitability. As mentioned in section 3.3, the raw data is processed to compile the input data to the DST which is composed of geographical data and transition tables which quantify the effect of NbS implementation (Figure 3c and Table 1).

Table 1: Overview of raw and calculated data inputs to the backend.

Data	Usage	Type	Definition	Reference
Raw data				
Agricultural field boundaries	Geographical data and spatial sampling unit	Feature polygons	In Denmark regulation is linked to field boundaries.	(Landbrugsstyrelsen 2025)
Register data (field and farm ha, manure, and crop type)	Geographical data Nutrient balance	Table	Each year the Danish farmers must register crop type on field level and manure usage on farm level in the registration system.	(Landbrugsstyrelsen 2025)
Soil data	Geographical data and transition table	Raster 10x10m	Based on 30000 sample points and a suit of geographic drivers, soils have been modelled in 10x10m resolution.	(Adhikari et al. 2013)
N retention	Geographical data	Raster 100x100m	Retention defines denitrification from the rootzone to the coast. Low retention % means low denitrification and thereby high risk of N losses.	(Højberg et al. 2025)
Biorefinery location	Geographical data	Feature points	It is assumed that biorefineries will be built in conjunction with existing biogas plants.	(Danish Energy Agency, n.d.; Danish Veterinary and Food Administration, n.d.; Geodatastyrelsen, n.d.)
High Nature Value (HNV)	Geographical data	Raster 10x10m	HNV is based on landscapes, habitats, farm management and species information. Values range from 0-14 where 14 indicate high nature value.	(Ejrnæs et al. 2012)
N leaching	Transition table	Model derived	N leaching has been derived from the NUAR model.	(Ørum et al. 2024)
Economy	Transition table	Model derived	Economy is based on the Danish contribution margin.	(Seges Innovation, n.d.)
Yield and N content of crops (*)	N flux parameter calculation	Tables	National and European standard values for yield and N content; share of harvested residues; factors for calculating biological N fixation.	(Nucera et al. 2023; Eurostat 2024c; Einarsson et al. 2021)
Calculated data				
N Load	Model output	Raster 100x100m	N load is calculated based on N leaching and N retention.	-
Biorefinery distance	Geographical data	Table	Road distance from the centre of the field to the nearest biorefinery.	-
N flux parameters	Nutrient balance	Table	N harvested with crops incl. residues and N fixation is calculated by combining farm registration data with standard values (see above). N input from manure and mineral fertilizer is based on farm registration data.	-

(*)More detailed information on the data sources for calculating the N flux parameters for the N balance can be found in Annex Table 1.

4.2.1 Geographic data

The Danish prototype is based on farm registration data including tabular and geospatial data files, detailing current and past crops (Figure 3b, Table 2). In addition, spatially explicit data on soil (Adhikari et al. 2013) and on N retention from the root zone to the coast are included as inputs to account for geographic variation in N leaching (Højberg et al. 2025).

The sampling unit of the geographical data is the agricultural field boundaries, derived from the Danish agricultural agency for the year 2023 (Landbrugsstyrelsen 2025). All subsequent datasets were spatially linked to these field boundaries. Register data containing crop type and agricultural area were joined using field ID, while manure application data were joined using farm ID. Crop types were aggregated from approximately 200 original categories to 11 broader classes (potato, maize, rape seed, legumes, spring cereals, winter cereals, grass for seed, grass (incl. grass-clover), grass-clover with reduced fertilization, takeout, other). To enable the reconstruction of crop rotations (crop type sequence over time), field data from 2017–2022 were also included (Landbrugsstyrelsen 2025). Past crop types were added to the 2023 dataset by extracting all historical crop types from the centre point of each 2023 field (Esri 2024). In addition to the existing crop rotations, 12 NbS rotations with more perennial grass were established. Perennial grass was included in rotations fitting different types of farming. For this, each field was assigned to a farm type based on seven-year crop rotation patterns, distinguishing five broad farm types: conventional arable, organic arable, conventional dairy, organic dairy, and monogastric farms. In addition, the use of cover crops was introduced. For this, two additional crop categories (winter cereal + cover crops and spring cereal + cover crops) were introduced. Both the NbS rotations and the cover crops are included in the alternative calculations but are not part of the status quo.

Additional spatial datasets included N retention, soil type, high nature value (HNV) areas, and distance to biogas and biorefinery facilities; the latter two are described in Section 4.2.

N retention is defined as the percentage of N leached to the root zone that is removed through denitrification before reaching the coast ($NO_3^- \rightarrow N_2$). Consequently, areas exhibiting low N retention can be identified as vulnerable zones characterised by high N loads to the receiving water body or coastline. The N load is calculated as follows:

$$N\ load = N\ leaching\ \times (\frac{100 - N\ retention}{100})$$

N retention was aggregated to fields as the mean N retention in ArcGIS (ESRI 2024).

Soil type data were derived from a 10 × 10 m raster (Adhikari et al. 2013). This dataset integrates multiple sources reporting the percentage composition of sand, silt, and clay. In the original classification, these percentages are grouped into 11 soil types; for the present study, these were further aggregated into two contrasting categories (sand and clay). Soil type was assigned to each field based on the dominant soil type within the field boundary (Esri 2024).

Table 2: Example of the data structure of the geographical table (see also Figure 3c). Numbers are only for illustration and were chosen randomly.

Agri. field ID	Crop code	Crop name	Crop rotation	Field size (ha)	Farm ID	Farm size (ha)	soil type 1_sand, 2_clay	HNV	N ret. %	Spatial linkage crop name and soil	etc.
1	10	potato	11_12_13_10	2	1	11	1	5	34	101 potato on sand	
2	11	maize	14_12_14_11	4	1	11	2	7	2	112 maize on clay	
3	12	rape seed	13_12_14_12	5	1	11	1	1	5	122 rape seed on sand	
4	13	cereal spring	12_12_13_13	7	2	34	1	4	70	131 cereal spring on sand	
5	14	cereal winter	11_12_14_14	5	2	34	2	8	60	142 cereal winter on clay	
6	15	Grass clover	11_12_15_15	22	2	34	2	9	44	152 grass clover on clay	
etc.	etc.	etc.	etc.	etc.	etc.	etc.	etc.	etc.	etc.	etc.	etc.

4.2.2 Transition matrices

To quantify the effects of the NbS, lookup tables (so-called transition matrices) have been developed (Figure 3c, Figure 6). These matrices capture the impact of changing from one management practice to another, i.e. the effects of the NbS, for example changing single crops within crop rotations such as growing grass instead of maize or including more perennial crops and catch crops in traditional cereal crop rotations, at field level. Input parameters to the transition matrices include N leaching, economic return (net gross margins at crop level), yield, and crop rotation related to specific farm types (dairy, arable, conventional and organic etc.) with data derived from established models and databases such as NUAR (Ørum et al. 2024) (see e.g. https://github.com/national-underground-asset-register/nuar-datamodel) and from the Danish contribution margin framework (see e.g. Seges Innovation, n.d.). With the tool Kalkulemark that uses the NUAR model it is possible to state a spatially explicit climatic grid in Denmark, soil type, fertiliser type and application rate, as well as modelled crop distribution per year and in a specific rotation. This returns annual N leaching estimates for transitions between all crops in the rotation, thereby providing the N leaching values that populate the crop-to-crop transition matrix (Figure 6). These values vary depending on factors including crop type, fertilization level in both the current and previous year, soil type, and other spatially explicit variables at the field level.

The spatial linkage between the transition matrices and actual agricultural fields is provided by the combination of crop rotation and soil type, which, together with the N retention input, informs the final maps of coastal N load (Table 2).

CropName	Potato, sand	Maize, sand	Rape seed, sand	legumes, sand	Cereal spring, sand	Cereal spring, with cover crop, sand	Cereal winter, sand	Cereal winter, with cover crop, sand	Grass for seed, sand	Grass/clover fertilized to norm, sand	Grass/clover reduced fertilization, sand	Take out, sand	Potato, clay	Maize, clay	Rape seed, clay	legumes, clay	Cereal spring, clay	Cereal spring, with cover crop, clay	Cereal winter, clay	Cereal winter, with cover crop, clay	Grass for seed, clay	Grass/clover fertilized to norm, clay	Grass/clover reduced fertilization, clay	Take out, clay
Potato, sand	79	93	69	40	37	30	60	32	35	19	14	25	0	0	0	0	0	0	0	0	0	0	0	0
Maize, sand	87	80	72	40	40	35	59	31	60	70	61	25	0	0	0	0	0	0	0	0	0	0	0	0
Rape seed, sand	107	120	72	60	60	45	61	33	6	34	25	25	0	0	0	0	0	0	0	0	0	0	0	0
legumes, sand	107	120	80	38	67	50	63	36	38	52	39	25	0	0	0	0	0	0	0	0	0	0	0	0
Cereal spring, sand	107	120	73	64	64	40	63	44	25	44	33	25	0	0	0	0	0	0	0	0	0	0	0	0
Cereal spring, with cover crop, sand	107	116	50	67	61	35	53	40	20	44	33	25	0	0	0	0	0	0	0	0	0	0	0	0
Cereal winter, sand	104	120	64	67	64	41	56	40	25	64	48	25	0	0	0	0	0	0	0	0	0	0	0	0
Cereal winter, with cover crop, sand	104	120	55	63	61	45	49	49	24	64	48	25	0	0	0	0	0	0	0	0	0	0	0	0
Grass for seed, sand	76	180	80	85	60	43	78	57	40	30	25	20	0	0	0	0	0	0	0	0	0	0	0	0
Grass/clover fertilized to norm, sand	180	220	91	93	69	50	112	67	30	52	39	25	0	0	0	0	0	0	0	0	0	0	0	0
Grass/clover reduced fertilization, sand	160	187	88	93	64	45	100	67	26	30	23	32	0	0	0	0	0	0	0	0	0	0	0	0
Take out, sand	75	120	67	72	51	27	53	27	34	17	20	24	0	0	0	0	0	0	0	0	0	0	0	0
Potato, clay	0	0	0	0	0	0	0	0	0	0	0	0	59	70	52	30	28	14	45	35	15	10	5	19
Maize, clay	0	0	0	0	0	0	0	0	0	0	0	0	65	60	54	30	30	14	44	35	35	10	7	19
Rape seed, clay	0	0	0	0	0	0	0	0	0	0	0	0	80	90	54	45	45	23	46	35	32	20	10	25
legumes, clay	0	0	0	0	0	0	0	0	0	0	0	0	80	90	60	33	50	23	47	35	34	29	28	25
Cereal spring, clay	0	0	0	0	0	0	0	0	0	0	0	0	80	90	55	48	48	20	47	35	32	25	21	25
Cereal spring, with cover crop, clay	0	0	0	0	0	0	0	0	0	0	0	0	80	87	67	50	46	16	60	55	30	25	21	25
Cereal winter, clay	0	0	0	0	0	0	0	0	0	0	0	0	78	90	48	50	48	21	42	35	24	36	32	25
Cereal winter, with cover crop, clay	0	0	0	0	0	0	0	0	0	0	0	0	75	90	59	47	46	17	54	37	24	36	32	25
Grass for seed, clay	0	0	0	0	0	0	0	0	0	0	0	0	129	140	54	56	55	32	34	23	34	19	15	9
Grass/clover fertilized to norm, clay	0	0	0	0	0	0	0	0	0	0	0	0	135	170	68	70	52	32	84	60	40	29	15	24
Grass/clover reduced fertilization, clay	0	0	0	0	0	0	0	0	0	0	0	0	120	140	66	70	48	29	75	60	38	17	20	24
Take out, clay	0	0	0	0	0	0	0	0	0	0	0	0	60	100	50	54	38	20	40	20	2	5	3	6

Figure 6: Illustration of a transition table to exemplify the structure. More details on the transition tables can be found in https://github.com/trans4num/trans4num-dst/blob/main/engine/src/models/denmark/transitions.py

4.2.3 Constraints

The DST includes two types of constraints: i) hard-coded constraints that do not allow user to interact with them, and ii) constraints that can be manipulated based on stakeholder preferences and discussions through the frontend interface.

The constraints utilize the geographical table and transition tables – hence they are calculated at field level. Type i) can be pre-set to avoid unrealistic scenarios or cases which are not defined feasible and ii) can be manipulated by the user.

For the Danish prototype eight constraints have been implemented (Figure 5):

N-Load change: If the optimal solution has the best economy, we can specify by which percentage we allow the N-Load to change. For instance, we can specify that we require a reduction by at least 10%. This aspect is chosen as part of the optimization goal.

Economy Change: If the optimal solution has the lowest N-Load, we can specify by which percentage we allow the economy to change. For instance, we can specify that we allow at most a reduction of the area's economy by 5%. This aspect is chosen as part of the optimization goal.

Distance to Biogas: We can enforce that changed field rotations can only be applied within a maximum distance to a biogas plant. Distance to biogas is calculated using network analysis in GIS (Esri 2024) with a detailed road network (Krak 2020) accounting for bridges and one-way directions. Distances were calculated from nearest road segment to the field centre, to the biogas plant or the biorefinery location, respectively.

Single farmer impact: We can specify by which percentage a single farmer can at most be affected on his/her economy. For instance, we can specify that no single farmer must lose more than 20% of revenue.

Nature Value: We can specify if we would like to make changes on HNV areas. We can for instance say that only fields with less than 20% of their area having HNV can get new crop rotations. The classification as HNV has previously been calculated based on landscapes, habitats, farm management and species information (Ejrnæs et al. 2012). The map is in 10x10m resolution with values from 0-14 where 14 indicate the highest HNV score. The idea is that agriculture production should not happen on fields with a HNV score >5.

Area change: We can specify on which percentages of the total agricultural area change is allowed. This enables us to make a less extreme scenario. For instance, we can say that only 10% of the entire area can get a new rotation.

Field change: We can specify on which percentage of the total fields change is allowed. This enables us to make a less extreme scenario. For instance, we can say that only 10% of all fields can get a new rotation. In contrast to "area change", which is based on total acreage, "field change" is based on the number of fields affected by change.

Farm type change: We can specify on which percentage of the total fields a large change is allowed which would result in a different farm type. This enables us to make a less extreme scenario. For instance, we can say that only 10% of all fields can get a new rotation which does not match the existing farm type. The change of farm type is based on a transition table describing the similarities between crops in terms of their use (feed, human consumptions) and machinery needs. For instance, it might not make sense for a potato farmer to have grass rotations.

4.2.4 N flux parameters and regional N balance

The DST computes a regional N balance for both the status quo and optimized crop rotation. The general approach follows section 3.4, but uses region-specific data at higher spatial resolution wherever available. Data preparation and processing have been implemented in R (R Core Team 2023).

Data and Crop Categorization: The prototype uses 2023 Danish farm registration data: crops at field level and N inputs at farm level. The >200 registered crop types were manually categorized into 11 classes (Figure 7). Minor crops and vegetables ("other"), comprising all together <2% of agricultural land, were excluded, leaving 124 relevant crop types. These were matched to different datasets on yield, N content, and dry matter (DM) (see appendix 8.1). Values for the total N harvested with crops and residues as well as N input via biological N fixation were calculated at the highest possible resolution and aggregated only later.

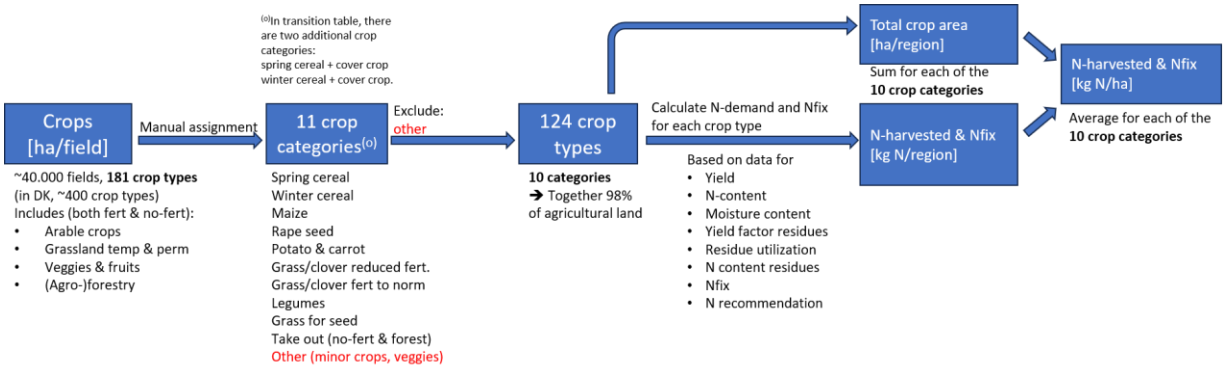

Figure 7: Workflow for calculating N-harvested and N fixation through biological N fixation from the Danish crop registration data.

Harvested N (in crop product and residues):

> **Main crop product**: N_harvested (product)= Crop area (ha) × yield × (1 − humidity) × N-content of product

Residues: N_harvested (residues) = Crop area (ha) × yield × (1 − humidity) × straw yield factor × proportion of straw harvested × N-content of straw

N Fixation: The approach by Nucera et al. (2023) was chosen to estimate the N input through biological N fixation from legumes (see appendix 8.2 for more details on the underlying assumptions).

Average harvested N and N fixation per crop type: Assuming constant crop shares within categories, weighted averages for total N_harvested (sum of product and residues) and N_fixation were calculated per crop category. Two additional categories were introduced for cover crops (not in Danish registration): spring cereal + cover crop; winter cereal + cover crop, using base cereal parameters.

Spatial Distribution of Farm-Level N Inputs: On the input side, farm level inputs as manure, synthetic mineral fertilizer and other organic fertilizer had to be spatially distributed from farm scale to field scale. This was based on the demand according to the Danish fertilizer guidelines:

Livestock manure: N_applied (kg/ha) = N_applied_manure (farm) × fertilization_norm (field) / total_fertilizer_recommendation (farm)

Mineral fertilizer: N_applied (kg/ha) = N_applied_fertilizer (farm) × fertilization_norm (field) / total_fertilizer_recommendation (farm)

Other organic fertilizers: N_applied (kg/ha) = N_applied_other (farm) × fertilization_norm (field) / total_fertilizer_recommendation (farm)

Atmospheric deposition: The additional N input through deposition was set to 14 kg N/ha/year (Ellermann et al. 2018). This is a simplification as local differences are not taken into account.

Losses via NH_3 volatilization: Assumed at 10% of total N in applied manure after storage. Stable/storage losses are already accounted for in the manure N_applied as reported in the registration data. Background: In Denmark, approx. 50% of the slurry is applied via injection, the other half via trailing hose. Trailing hose losses are 11–16% of total N; injection reduces losses by ~50%, yielding average application losses of 8–12%.

Regional N balance: The average N harvested and N fixed in the region are calculated based on the crop shares both before and after optimisation (Figure 9):

$$N_{harvested_{tot}[kg\ ha^{-1}]} = \frac{\sum \%cropshare\ \times area_{tot}[ha] \times N_{harvested}[kg\ ha^{-1}]}{area_{tot}[ha]}$$

$$N_{fix_{tot}[kg\ ha^{-1}]} = \frac{\sum \%cropshare\ \times area_{tot}[ha] \times N_{fix}[kg\ ha^{-1}]}{area_{tot}[ha]}$$

Where $area_{tot}$ corresponds to the total agricultural land, including unfertilized areas (take out).

The **average regional N input** is calculated by summing the spatially downscaled field-level N inputs for the different fertilizer types across the entire region (kg N) and dividing the total by $area_{tot}$. The resulting value therefore represents the average N input per hectare of total agricultural land, including take-out areas. In the current model, crop and livestock production are not directly linked. Consequently, changes in crop rotations following optimisation do not result in corresponding changes in livestock-related N inputs. This represents a potential for further development in the future.

4.2.5 N flux parameters and regional N balance

The model engine code has been implemented to handle the specific constraints and optimization goals for the region. Any other region can utilize the same implementation if the goals are the same. The model is agnostic to the input data, if it follows the specified format. Hence, in the current prototype we have implemented a version for the Hungarian region, however it utilizes fake data, so it only demonstrates the model's capability of working in other regions, if the correct data is available.

There is no tight coupling between the frontend/api and model engine, hence another application can directly utilize the Danish model implementation if the correct input data is made available. The other way around, the existing frontend/api layer can also directly adapt to a new model engine, where for instance other constraints are required.

4.3 Data output in the frontend

The outputs of the tool include several map views, allowing comparisons of the current state with the alternative after optimization (Figure 8). These maps include field-specific information on the distribution of crop rotations, N leaching, economic return, yield and nature value. Summarizing the results, the tool provides a pie chart with crop production shares before and after optimization (Figure 9) as well as a radar view for efficient comparison of different model runs in terms of N load reduction, effects on economy and other parameters (Figure 10). Ultimately, the regional N balance including N inputs via manure, fertilizers, N fixation and deposition on the one hand and the harvested N and losses via NH_3 volatilization on the other hand is presented (Figure 11).

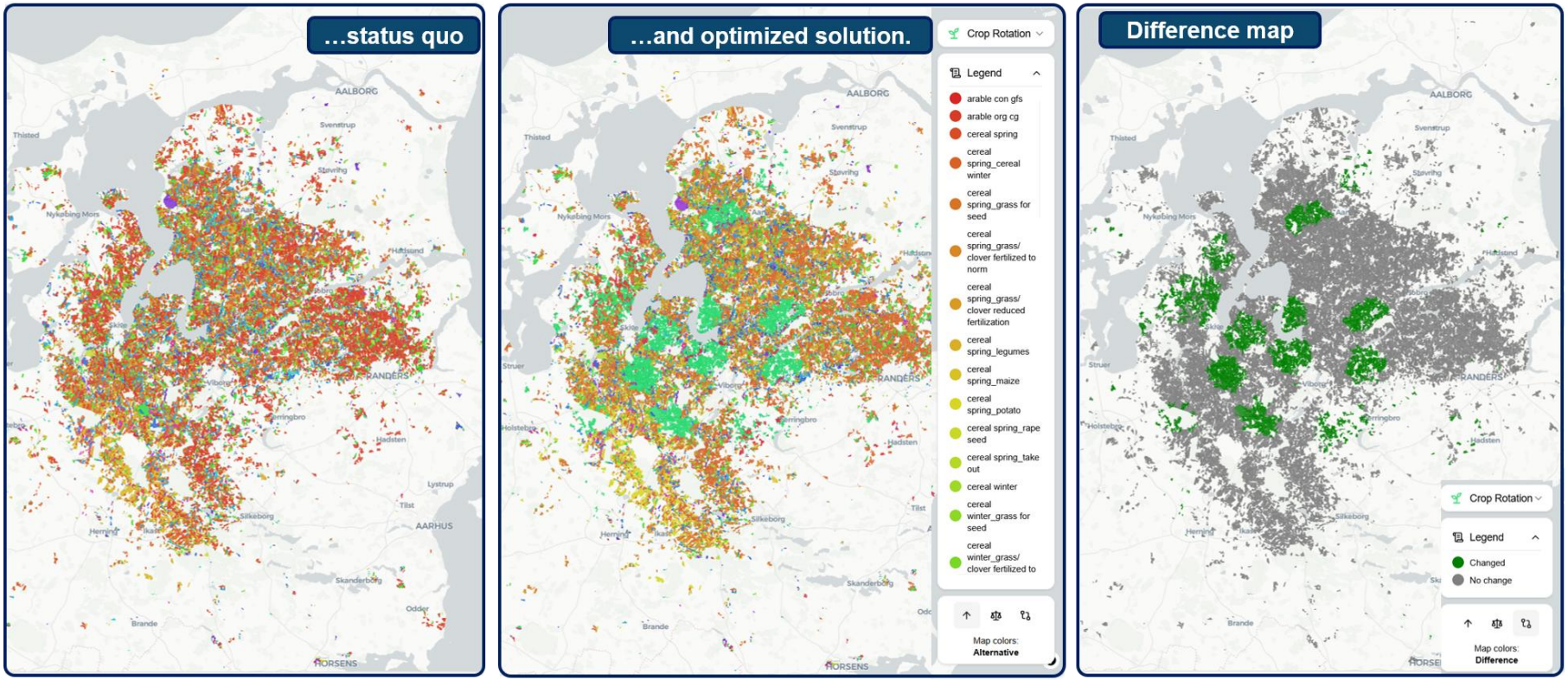

Figure 8: Map output of the DST, allowing to compare between status quo (left) and alternative after optimization (middle). To facilitate navigating on which fields differences are induced by the optimization, a difference map (right) can be displayed (example screenshots from the Danish prototype).

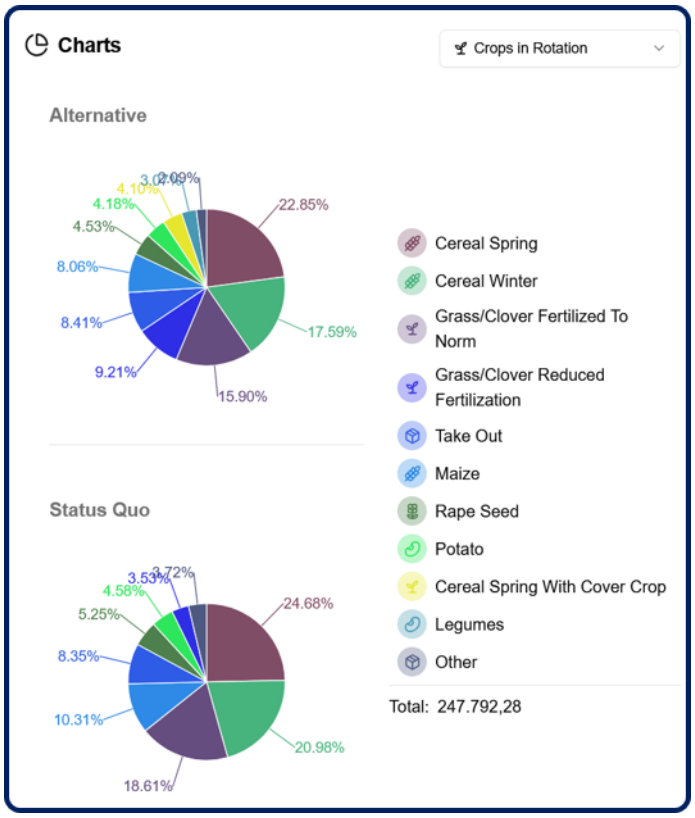

Figure 9: Crop shares before (status quo) and after optimization (alternative) (example screenshot from the Danish prototype).

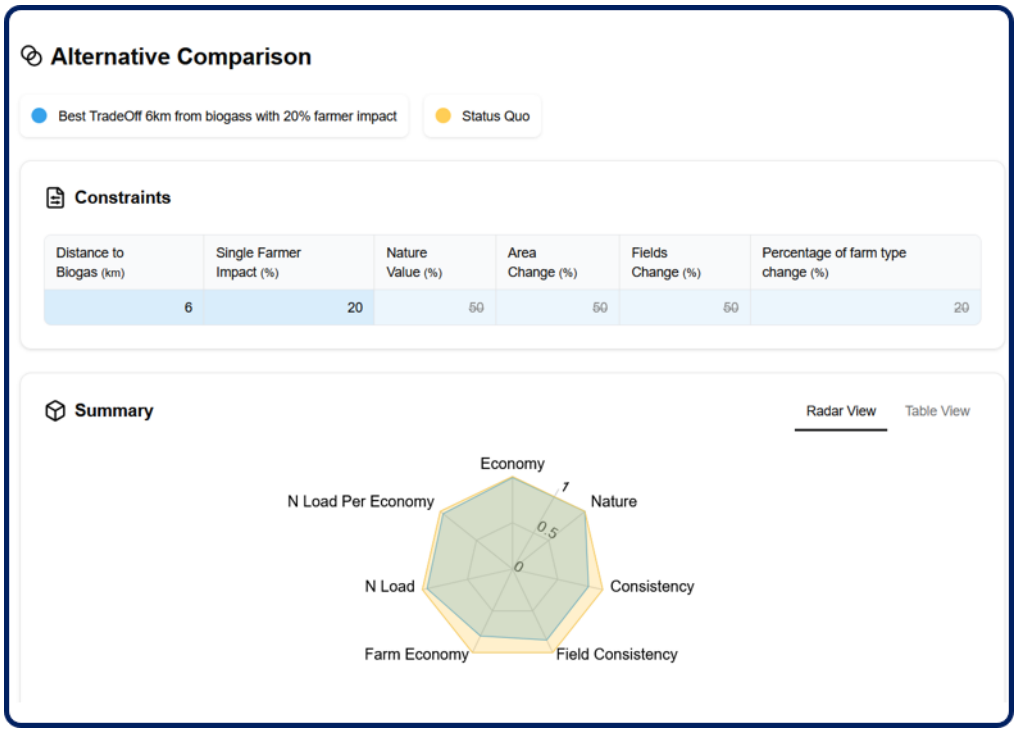

Figure 10: Summary of regional performance parameters after optimization (example screenshot from the Danish prototype).

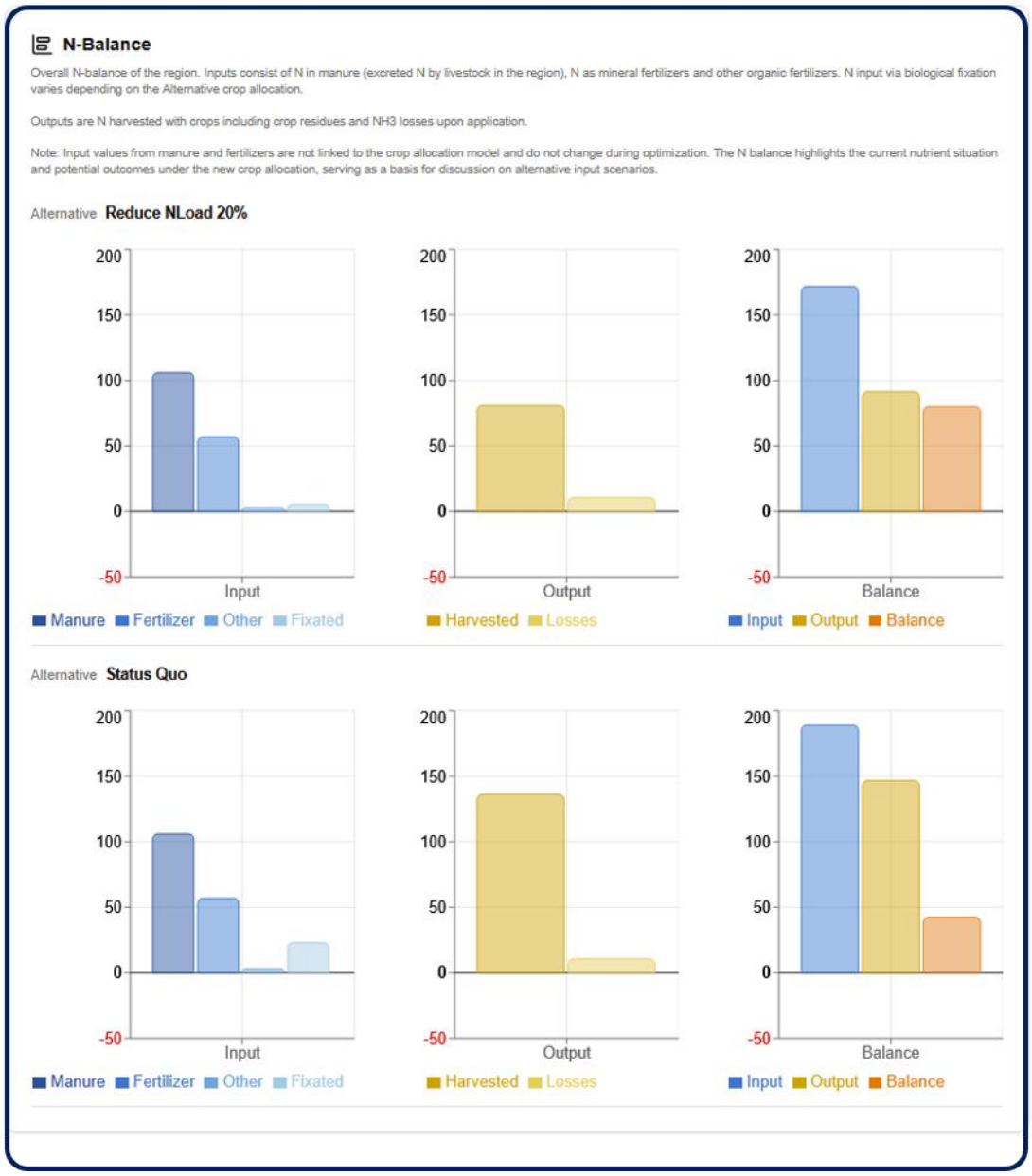

Figure 11: Example N balance for Status Quo and an alternative after optimization. (screenshot from the Danish DST prototype)

4.4 Testing and improving the DST

A first prototype of the decision support tool (DST) was tested in Denmark in February 2025 through two workshops: one with farmers and advisors, and another with regional planners. Feedback from these stakeholder workshops led to refinements of several key aspects of the tool to better reflect real-world farming practices, enhance usability, and ensure the relevance of the underlying data (Table 3).

Table 3: DST improvements and updates, partly based on the feedback from two workshops held in Denmark, February 2025

Initial version of the DST	Improved version of the DST
Worked with individual crops for single years, treating each year independently.	Works with crop rotations, considering temporal dynamics and giving farmers more flexibility on when to grow which crop.
No explicit restriction on changing farm types during optimization.	Farm type change[1] introduced as an additional constraint, ensuring changes remain within acceptable and realistic limits (no "clean slate" starts).
Farm registration data from 2021.	Updated to use more recent data from 2023 for improved relevance and accuracy.

[1] The assignment of fields to farm types is based on seven-year crop rotation patterns derived from farm registration data. The DST distinguishes five farm types: conventional arable, organic arable, conventional dairy, organic dairy, and monogastric farms.

Further details describing the perception and stakeholder feedback during the two workshops can be found in D3.3 (Vestergaard Odgaard et al. 2026).

5. Transfer of the DST functionality to the trans4num NbS sites

The general principle is versatile and can be adopted to a broad range of sites and situations. Given the differences in location and NbS ambitions across the trans4num case study sites, the functionality of the DST requires adaptation at each site. This involves

1. Defining site-specific goals with local partners.
2. Providing relevant data to that goal for the tool's backend, consisting of
    a. Geographic data such as tables or maps describing the geography and agricultural landscape of the region (e.g. spatial distribution of crops, yields, soil data, etc.)
    b. Transition tables describing the effect of an NbS intervention (e.g. the effect of adapting crop rotations towards yield stability, N leaching, etc.)

Despite substantial efforts, it was challenging to obtain the required data for all NbS sites and to define relevant regional optimization objectives that were directly linked to the measures studied at the trans4num NbS case study sites. This was mainly because most case study sites (except Denmark) followed an approach in which field experiments were used as platforms to discuss pathways towards more sustainable nutrient management. Consequently, it was difficult to establish locally owned optimization objectives within the project consortium that adequately reflected the specific regional contexts and stakeholder priorities.

To address this challenge, we showcased the Danish DST prototype and organized workshops to demonstrate its functionalities and discuss its potential application with stakeholders. The workshops provided a basis for exploring whether the DST could serve as a platform to

connect different stakeholder groups and support collaborative engagement around regional nutrient management challenges. It also enabled discussions on how the DST approach could be adapted to the specific contexts and needs of the different NbS case study sites.

In Hungary, the DST was tested in November 2025 with a diverse group of stakeholders, including large-scale farmers, precision farming experts, and representatives from the Chamber of Agriculture and the agricultural statistics office. In this session, the Danish version of the DST was demonstrated to illustrate how the tool could be applied at other sites, followed by discussions on stakeholder interest and options for developing a customized versions for the Hungarian case study site.

Based on these experiences, updated guidelines have been developed for further testing in the other trans4num case study sites in Europe (Vestergaard Odgaard et al. 2026). These recommend involving approximately five to ten stakeholders per workshop, supported by two to three project facilitators and researchers responsible for facilitation, tool navigation, and data collection. Participants should have a solid understanding of nutrient-related challenges and regional environmental or agricultural objectives. Experience has shown that involving higher-level stakeholders, such as regional planners, local administrators, regulatory authorities, and researchers with an interest in digital tools or agricultural policy, is particularly effective for initial testing.

Building on these guidelines and the insights gained from previous stakeholder consultations, DST workshops were organized in the Netherlands and the United Kingdom in April 2026, in Groningen (Waterschap Noorderzijlvest) and London (Farmers Club), respectively. Discussions with researchers, advisors, and policymakers highlighted strong interest in applying the tool to nutrient management, water quality, and landscape recovery initiatives. Participants emphasized the value of existing modelling approaches as a foundation for developing the required input data for the DST`s transition tables, while identifying data trust, and the integration of empirical and model-based evidence as key challenges. Both workshops highlighted the need for a scalable approach that captures multiple objectives, trade-offs, temporal dynamics, climate impacts, and stakeholder incentives to support effective implementation.

During the workshops, a primary point of discussion among participants was the appropriate level of quantification required for the transition tables to be effective. From a modelling perspective, it was noted that qualitative or semi-quantitative information can often be sufficient to generate meaningful outputs and identify general trends. However, from an operational perspective, a different requirement emerged: the closer the users are to making actual operational decisions, the more detailed and accurate the inputs must be to ensure the reliability of the resulting management strategies. In other words, trust of operational managers is lost easily if numbers are not close to reality.

Experiences from Denmark offer a pragmatic way to reconcile these perspectives and operationalise the transition tables. The recommended approach is to begin with rough, best-available values rather than waiting for complete datasets, and then progressively refine the tables by drawing on complementary models and field trial results. Initial inaccuracy should be accepted as an inherent feature of early-stage implementation, with regulatory-accepted data used wherever available to anchor the values. Crucially, co-developing the transition tables with stakeholders, incorporating their local expert knowledge, is not merely a data-gathering exercise but an integral part of the transformation process itself. This iterative, participatory approach ensures that the tables evolve in tandem with stakeholder understanding and trust, reinforcing the DST's role as a shared platform for navigating nutrient management transitions.

Overall, the workshops in Hungary, the Netherlands, and the United Kingdom demonstrated that the DST could serve as a boundary object to facilitate discussions among diverse stakeholders on regional-scale nutrient management optimization and the development of management strategies. By providing a shared framework for exploring transition pathways, trade-offs, and implementation challenges, the DST supports collaboration between researchers, farmers, advisors, and policymakers. Further details on the workshops and stakeholder engagement activities are provided in D3.3 (Vestergaard Odgaard et al. 2026).

6. Outlook and conclusion

The Danish prototype has been deemed useful in supporting the ambitions of the Danish Green Tripartite Agreement. As part of the project *Embedding the new nitrogen regulation in farmer and advisor decision support, PlantPerform* (https://icoel.dk/om-os/projekter/novo-nordisk-fonden/2026/plantperform/), the trans4num DST is currently being further developed to support the implementation of the forthcoming Danish Nitrogen Regulation (NNR), scheduled for 2027. The tool will be adapted for use by agricultural advisors, enabling scenario-based dialogue with farmers to navigate the NNR's landscape-differentiated requirements. While the trans4num DST frontend will remain active, further development of the tool will be carried out by the PlantPerform project and in collaboration between trans4num and PlantPerform. The project is led by ICOEL with AU and SEGES Innovation as partners. This continuation is a very positive perspective which allows the investment made into the DST throughout the trans4num project to be built on for real-world implementation and facilitation of transformative change.

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8. Appendices

8.1 Data sources for calculation of the total N harvested as part of the N balance for the Danish prototype

Priorisation of data sources for crop parameters:

1. **Yield (at typical moisture content upon harvest)**: Danish norm yield → Statistikbanken → Eurostat
2. **Humidity of main product at harvest**: Statistikbanken → Eurostat → IPCC
3. **N-content of main product (based on dry matter)**: Statistikbanken → Einarsson et al. (2021)
4. **Straw yield factor (relative factor for calculating straw yield based on yield of main product)**: Statistikbanken → IPCC ("Ratio of above-ground residue dry matter to harvested yield")
5. **Proportion of straw harvested**: Statistikbanken → Herrero utilisation factor
6. **N-content of straw**: Statistikbanken → IPCC N rate

Applied Selection rule for data sources: Use norm yield based on the fertilization recommendation and combine with humidity and N content from Statistikbanken. If no norm yield is available, use Statistikbanken yield. Otherwise use Eurostat yield with IPCC humidity and N-content based on Einarsson et al. (2021).

Annex Table 1: Parameters to calculate N harvested and alternative data sources

Reference	Yield	Moisture content (product)	N-content (product)	Yield factor straw/ residues	Residue utilization (how much of residues is harvested)	Moisture content (residues)	N-content residues	Resolution	Remark
Fertilization recommendation 2024/25 (Landbrugsstyrelsen 2024)	norm yield at typical moisture content upon harvest [dt/ha] = [hg/ha] or [t] or [FE]	-	-	-	-	-	-	Corresponds to crop categories in farm registration; differentiation based on soil type	No info for crops without fertilization norm or for vegetables.
Agricultural Statistics Denmark (Statistics Denmark 2023b, 2023a)	average yield at normal humidity upon harvest (year 2023) [dt/ha]	dry matter content of harvested product [%]	-	factor for straw yield for cereals, legumes and rape seed	proportion of harvested straw for different crop categories	-	-	Aggregated for 27 crops (arable and fodder crops); NUTS2 level specific	
Eurostat (Eurostat 2024c)	Yield [t/ha] at national humidity	Moisture content of harvested product [%]	-	-	-	-	-	Average yield on NUTS2 (data from 2011 - 2015) in 46 crop categories (+41 categories for permanent crops)	Moisture content incomplete

Scientific publication (Einarsson et al. 2021)	-	-	N content of harvested product relative to total dry matter	-	-	-	-	National level; 168 crop categories in total	
IPCC (IPCC 2019)	-	Dry matter fraction of harvested product	-	Ratio of above-ground residue dry matter to harvested yield (to be multiplied with dry matter yield of product)	-	-	N content of aboveground residues		
Feed Table (Møller et al. 2005)	-	Dry matter ratio of harvested product	Raw protein content of feed products (can be converted into N-content)	-	-	-	-	National data	Only used to back-up and complement data from Statistics Denmark
Scientific publication (Herrero et al. 2012)	-	-	-	-	Proportion of harvested residues (relative to total residue yield) [%]	Dry matter factor straw (equal 0.9 for all categories)	-	Global data set	Only 6 categories (quite unspecific!)

8.2 Approach for Biological N fixation (BNF)

A slightly adapted approach according to Nucera et al. (2023) was used to estimate biological N fixation through legumes.

This requires assumptions on the legume proportion (especially for different grassland types) as well as an estimation of the N input. For the latter, the norm fertilization according to the Danish recommendation was used as approximation (Landbrugsstyrelsen 2024).

For grassland:

$$N_{fix} = Yield\ [DM] \times Leg_{RA} \times N_{con} \times (0.73 - 0.001 \times N_{fert} + 0.2(1 - e^{3.34(Leg_{RA}^{-1})} \times BGTNF$$

With

Yield [DM] = Dry matter yield

Leg_{RA} = Legume proportion

N_{con} = N-content in the legumes

N_{fert} = N fertilization

BGTNF = Belowground and N transfer factor (equals 1.6 for legume ratios <= 0.5)

For pulses:

$$N_{fix} = \left(\alpha_{crop} \times Yield\ [DM] \times N_{con} \times NHI + \beta_{crop}\right) \times BGNF$$

With

α_{crop} and β_{crop} = crop specific regression coefficients

Yield [DM] = Dry matter yield

N_{con} = N-content in the pulses

NHI = N harvest index

BGNF = Belowground N factor

Annex Table 2: Crop specific coefficients for calculating biological N fixation of pulses based on the approach of Nucera et al. (2023)

	α_{crop}	β_{crop}	N_{con} [kg N dt^{-1} DM]	NHI	BGNF
Faba bean	0.73	5.45	4.46	0.75	1.3
Lentil	0.64	3.32	3.43	0.75	1.3
Field pea	0.66	4.32	3.43	0.75	1.3
Soybean	0.66	-19.00	6.34	0.75	1.3

Underlying assumptions for proportions of legumes in grassland in Denmark:

- pulse, fodder legumes (pure): 1
- grassland with >50% legumes: 0.7
- grassland or cereal-pulse-mix with <50% legumes: 0.3
- permanent grass, fallow, grass for outdoor pigs, henyard etc.: 0.05 – 0.1

Categorization of grassland into different intensities, i.e. pasture vs rotational grassland, each with 4 intensities based on the Danish fertilization norm:

- Intensive: Nnorm >160
- Semiintensive: 80<Nnorm<=160
- Semiextensive: 30<Nnorm<=80
- Extensive: Nnorm<=30