LEX4BIO

Case study report on existing inter-regional and trans-boundary exchange of NRSS/BBFs flows

Deliverable 1.4 – D8 – WP1

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OPTIMISING BIO-BASED FERTILISERS IN AGRICULTURE – PROVIDING A KNOWLEDGE BASIS FOR NEW POLICIES

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Deliverable 1.4 – D8
Work-package n°1

Nature of the deliverable		
R	Report	X
Dec	Websites, patents, filling etc.	
Dem	Demonstrator	
O	Other	

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PU	Public	X
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LEX4BIO aims to reduce the dependence upon mineral/fossil fertilisers, benefiting the environment and the EU's economy. The project will focus on collecting and processing regional nutrient stock, flow, surplus and deficiency data, and reviewing and assessing the required technological solutions. Furthermore, socioeconomic benefits and limitations to increase substitution of mineral fertiliser for BBFs will be analysed. A key result of LEX4BIO will be a universal, science-based toolkit for optimising the use of BBFs in agriculture and to assess their environmental impact in terms of non-renewable energy use, greenhouse gas emissions and other LCA impact categories. LEX4BIO provides for the first-time connection between production technologies of BBFs and regional requirements for the safe use of BBFs.

The project runs from June 2019 to May 2024. It involves 20 partners and is coordinated by Luke (Luonnonvarakeskus - Natural Resources Institute Finland).

More information on the project can be found at: http://www.lex4bio.eu

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D1.4: CASE STUDY REPORT ON INTER-REGIONAL AND TRANS-BOUNDARY NRSS/BBF FLOW

I. INTRODUCTION

In Task 1.4 regions will be chosen for more detailed case studies on existing inter-regional and trans-boundary exchange of nutrient-rich side-streams (NRSS) and bio-based fertilisers (BBF). The choice will be made based on the findings of Task 1.1 and the analysis will be aimed at regions with extreme nutrient imbalances, i.e. regions of highly intensive animal husbandry with excess manure and regions with intensive crop production dependent on nutrient imports.

These selected regions and relevant transports of NRSS or BBFs are NL-DE; NL-FR; BE-FR; NL-BE. Flanders and The Netherlands have hotspots with the highest nutrient density in the EU or even worldwide far exceeding the nutrient disposal space on agricultural soils. Nutrient disposal space is defined here as the amount of nutrients that can be spread on agricultural land within the legal fertilisation standards. These hotspots of nutrient production in NRSS and BBFs drive a market mechanism of transporting nutrients to regions with disposal space in France and Germany.

The objective is to collect data on interregional and trans-boundary transport mechanisms of different NRSS/BBFs and evaluate the consistency in different datasets, because a comprehensive dataset is currently lacking. Export and import data of different national managing authorities will be collected and compared with international information such as info from the TRACE-trade dataset.

In addition, the feasibility of the observed exchange flows (as recorded in the different datasets) will be assessed by comparing them with the theoretical flows from the NRSS/BBF transport model used in WP7 (Task 7.3). The model will therefore be simulated in a normative way (i.e. the theoretical optimum) with current price information on NRSSs. The theoretical optimal flows of nutrients will be compared with the observed flows. This model has been developed and applied in the FP7 INEMAD project (https://cordis.europa.eu/project/id/289712) and some other regional and European funded projects.

This report will provide a comprehensive overview of the data on trans-boundary NRSS/BBF flows and result in recommendations to improve data collection, data usage and data consistency.
Alternatively, model calibration can also be suggested in order to provide a reliable and operational model for further application in WP7.

The knowledge generated will be used by WP7 as a basis to develop potential future scenarios for a more sustainable use of NRSS within the EU and to validate the transport model.

II. METHODOLOGY

Data Collection on nutrients in NRSS and BBF transport

Data about nutrient transport is not uniformly collected throughout the EU and the data collection differs between member states. The data is more accurately collected, reported and analysed in regions or member states where BBFs or NRSS transport plays an essential role in the control systems.

In the Netherlands, for example, a control system for the transportation of manure is established since 1998. Principally each transport is weighed and sampled. Registered transporting companies exclusively transport surplus animal manure apart from exceptions. These companies use special vehicles equipped with prescribed automated data registration system and satellite navigation. Also, an automatic weighing and sampling is required. The transporter guarantees that each sample is sent to an accredited laboratory for analysis.

In Flanders a quite similar system is established. Only licensed manure carriers have the permission to perform manure transportation. Every transport must be weighed and each transport that is executed in the framework of a neighbour arrangement needs to be declared to the Mestbank, which is the regional manure management authority in Flanders, at the latest 24 hours preceding the transport by the provider or buyer.

Also in Germany the efforts to track and register transport has further developed during the last decade. Note that the competence is authorized to regions resulting in different information sources between different regions in Germany also called Bundesländer in German.
In Lower Saxony, for instance, a service, legal framework and information campaigns are installed to report and track all manure transport (https://service.niedersachsen.de/en/detail?pstId=378661381). This information is compiled into the yearly regional fertiliser reports.

The Netherlands, Flanders, North Rhine Westphalia and Lower Saxony collect and report the most detailed information on transportation, volume flows and about suppliers and buyers as well as on import and export of manure. Based on this information databases an analysis for the import and export of manure within selected European countries has been conducted.

Modelling methodology

To simulate the flows of nutrients from animal origin in NW-Europe, a mathematical model was developed in earlier projects (FP7- INEMAD) that describes the production, processing, separation, transport and disposal of nutrients in each of the selected regions. We repeat the model description here for completeness and better understanding.

The conceptual outline of this model is illustrated in Figure 1. Each region (i) has a certain number of animals producing manure with a certain nutrient content (nutrient supply). On the other hand, each region has a limited capacity for nutrient disposal into agricultural fields, as depicted by fertilisation standards (nutrient demand). To balance nutrient supply and demand, there are technologies that can separate or remove nutrient streams. Consequently, a nutrient stream produced in each area can have a multitude of destinations (as shown by the dark and light blue arrows in Figure 1). First of all, these nutrients can be disposed directly on land within the same region they are produced, or they can be transported as raw manure stream to any other region. Alternatively, they can be further processed to having different nutrient composition, which again can be disposed on own land or transported to any other region of the system. The benefit of these technologies is to better meet the N and P[1] legislation by transforming nutrient ratios to meet these requirements. Finally, some processed streams are also potential inputs for a biological processing system that removes the nutrients from the system. It is clear that decisions in each area influence the situation in other areas and that the result is a complex system of nutrient streams. The question is which combination of streams can minimize the total cost while staying within the legal and technical constraints defined by the system. The model does not allow areas to strategically change the amount of manure surplus, for example by changing the animals produced or by changing the land use in order to have a larger nutrient disposal capacity. The model thus only focuses on optimizing strategies to adapt to current nutrient production levels and thus not allow optimization of the production level itself. For a detailed description of the model, the reader is referred to Box 1.

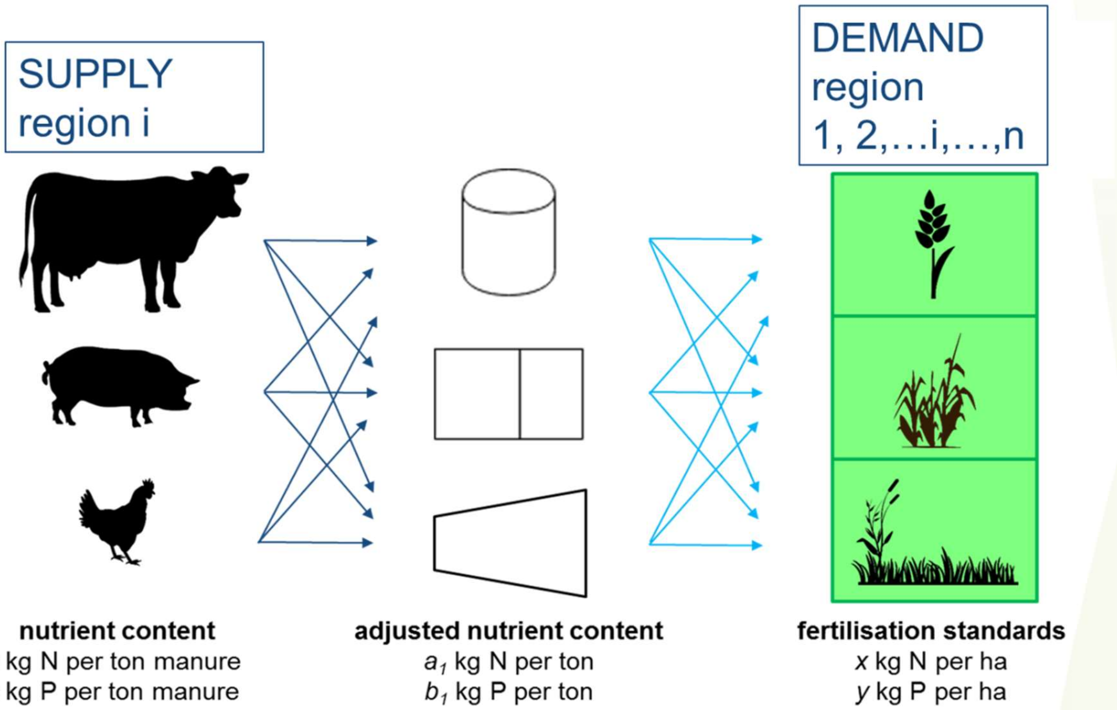

Figure 1. Conceptual framework of the linear programming model. Note that region i can transport to all n regions including region i itself.

Box 1 Model formulation
For readability purposes, equations are constructed in words rather than in symbols. Variables are indicated with a prefix 'v' before the actual name. The dimensions of variables and parameters are given in small characters.

[1] By applying raw manure on the land, one applies a more or less fixed ratio of N and P. In some cases, the application in ton will be limited by the P norm and in others by N norm, but very unlikely this fixed ratio will be able to fill both norms for 100 %. This means that available nutrients space is inefficiently used. Separation typically leads to a N-rich and P-rich fraction, which can be applied on the land to fill empty nutrient capacity.

Overview of dimensions used in the model

Dimension	Meaning
i,j,k	Geographical regions in NW-Europe
t	Manure processing technologies
a	Animals
c	Crops
n	Nutrients
e	Manure process endproducts (liquid fraction, solid fraction)

A constrained optimization problem is defined by an objective function expressing the variable that should be minimized/maximized and a (set of) constraint(s) that keep the variables within the legal, physical, or other boundaries of the system.

The first constraint of the model is a mass balance on manure type level which expresses that total use of manure of certain animal origin a in a certain region i must be equal production in that same region $production_{i,a}$

$$\sum_j vtransport_{i,j,a} + \sum_t vprocess_{i,k,t,a} = manureproduction_{i,a}$$

Where $vtransport_{i,,j,a}$ equals the transport of raw manure of certain type a from region i to region j in ton and $vprocess_{i,k,t,a}$ equals the amount of raw manure of type a processed in region i, for which the resulting product is sent to region k. Note that for both variables, origin and destination indices can by identical (i=j or i=k) expressing the cases where manure/processed fraction are disposed and produced/processed in the same area. In Flanders, the according tonnage of manure ($manureproduction_{i,a}$) was calculated by dividing the amount of nutrient per animal type per area ($nutrientproduction_{i,a,n}$) by the P content ($manurecomposition_{a,n}$, Table A.2) as follows:

$$manureproduction_{i,a} = \frac{nutrientproduction_{i,a,P}}{manurecomposition_{a,P}}$$

For the other regions and countries, nutrient production was calculated by multiplying the amount of each type of animal a with a fixed amount expressing nutrient excretion for each type of animal $nutrientexcretion_{a,n}$ (Table A.2):

$$nutrientproduction_{i,a,n} = numberanimals_{i,a} * nutrientexcretion_{a,n}$$

The second constraint is a mass balance on nutrient level which expresses that the total amount of nutrients of certain type n disposed in an region i, cannot exceed the nutrient disposal rights entitled to this region

$$\sum_a \sum_j \left(\frac{vtransport_{j,i,a} * manurecomposition_{a,n}}{acceptancy_j} \right) + \sum_j \sum_t \sum_a \left(\frac{vprocess_{j,i,t,a} * manurecomposition_{a,n} * fractiondisposed_{a,t,n}}{acceptancy_j} \right) \leq disposalpermits_{i,n}$$

Where $manurecomposition_{a,n}$ is a parameter expressing the average content of nutrient n of a manure type a and $fractiondisposed_{a,t,n}$ a parameter expressing the fraction of incoming nutrient n that need to be disposed after treatment of a unit manure of type a with technology t (see Table 1), and $disposalpermits_{i,n}$ a parameter defining the amount of nutrient n that can be disposed in area i. The latter parameter is calculated by multiplying the total amount of hectares of each crop c in area i ($cropsurface_{i,c}$) with the nutrient disposal standards for each crop c and each nutrient n ($standards_{c,n}$)

$$disposalpermits_{i,n} = cropsurface_{i,c} * standards_{c,n}$$

$Acceptancy_j$ is an extra parameter which has been added to account for the effect that some regions do not accept manure to the full extent as they are legally entitled to and is defined as the fraction of the manure disposal space in region i that is actually used for animal manure disposal. This effect ('acceptatiegraad' in Dutch) is due to (1) the uncertainty about the composition and nutrient leaching of organic fertilizers and (2) the lack of experience of farmers of using organic fertilizers (Vermeire et al. 2008). In Belgium, areas with high acceptancy level (around 0.85) are found in livestock intensive regions such as West-Flanders and Antwerp, while the other provinces have an acceptancy of around 0.65 (VLM 2014c).

The objective function reflects the total cost associated with manure management in all countries, and this function will be minimized by the linear programming algorithm. This cost breaks down in transportation costs of raw as well as processed manure, costs for processing manure, and the cost for hygienisation compulsory before exporting unprocessed manure.

(1) Transport costs

$$\sum_i \sum_j \sum_a vtransport_{i,j,a} * \frac{1}{density_a} * distance_{i,j} * unittransportcost$$

$$\sum_i \sum_j \sum_t \sum_a vprocess_{i,j,t,a} * separation_{t,a} \frac{1}{density_a} * distance_{i,j} * unittransportcost$$

(2) Processing costs

$$\sum_i \sum_j \sum_t \sum_a vprocess_{i,j,t,a} * techcost_{a,t}$$

(3) Cross-border hygienisation of raw manure

$$\sum_i \sum_j \sum_a vtransport_{i,j,a} * hygcost_{i,j,a}$$

Where $density_a$ is the density of each type of manure a, $distance_{i,j}$ the distance between two area's i and j, unittransportcost a fixed transport cost per ton and per km, $separation_{t,a}$ the fraction of manure of type a entering a processing technology t that needs to be disposed of afterwards, $techcost_{a,t}$ the per ton costs to process manure by a certain technology and $hygcost_{i,j,a}$ the cost of hygienisation of raw manure before crossing international/regional borders. The latter parameter is function of origin i, destination j and manure type a in order to allow different rules for certain manure types and certain regions even allowing unhygienized transport of certain raw manure.

The model assumes decision making is done on municipality level for Belgium and on province level (NUTS 2) for the other countries. This is due to both data availability and computational complexity issues.

The model includes manure production for the following categories of animals: cows, pigs, poultry horses and others (such as sheep and goats). Area specific animal number and land use data were available from various sources (Eurostat, Belgian Federal Government and VLM). Nutrient production was derived from the amount of animals and fixed excretion coefficients. Manure production in ton was derived from the P flow based on a fixed P content of the different manure types. An average N content was then calculated in order for the mass balance to fit.

Figure 2 shows the connection between the manure processing technologies that were included in this model. The different treatment pathways are composed of three basic operations: separation of raw manure into a liquid and solid fractions, biologic treatment of liquid fraction (nutrient removal) and composting of the solid fractions. This leads to four different possibilities identified by the end products: (i) a raw liquid and solid fraction (liquid-solid), (ii) a raw liquid and a composted solid fraction (liquid-compost), (iii) a removed liquid and a raw solid fraction (biology-solid) and (iv) a removed liquid and composted solid fraction (biology-compost). The separation efficiencies and composting parameters for cow and pig manure are presented in Table 1 (Lebuf & Snauwaert 2015). Total cost associated with the four process pathways are presented in Table 2. It was assumed that only pig or cow manure could be used as input for these technologies. For poultry manure it was assumed that complete removal of nutrients was possible through burning. The P is still contained in the ashes but the transport costs of it are so low that the logistics of this stream is not further considered. For the other manure types processing was not considered as an option.

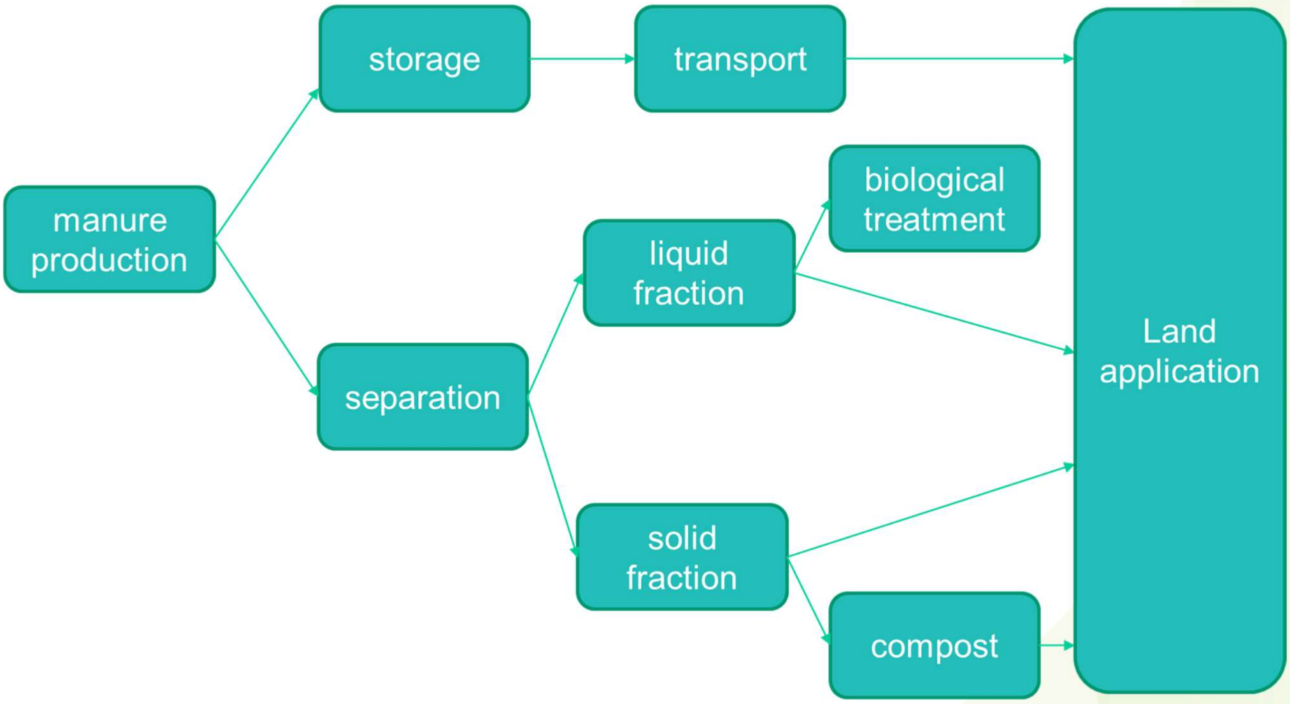

Figure 2. Overview of the different manure processing technologies pathways.

Table 1. Separation efficiencies and composting mass reduction for cow and pig manure. In % unless mentioned otherwise.

	Pig manure		Cow manure	
	Liquid	Solid	Liquid	solid
Separation				
Dry matter content (g/kg)	34	288	34	288
N total	65	35	60	40
P2O5	25	75	30	70
Composting				
Water reduction		77		77
Dry matter reduction		31		31
Total mass reduction		61		61

Source: (Lebuf & Snauwaert 2015; Lemmens et al. 2007)

Table 2. Cost for manure processing and transport (Lebuf & Snauwaert 2015), (Lemmens et al. 2007). In €/ton raw manure unless mentioned otherwise.

Process	Manure type applied	Cost
Liquid-Solid	Cow/Pig	3.5
Liquid-compost	Cow/Pig	7.7
Biology-Solid	Cow/Pig	16
Biology-compost	Cow/Pig	20.2
Incineration	Poultry	0
Hygienisation	All	5
Unit transport (€/m³/km)	All	0.075

Source: (Lebuf & Snauwaert 2015; Lemmens et al. 2007)

Research approach and objectives

The goal of this report is to use the transport model combined with data on NRSS production, land and fertilisation standard to evaluate whether statistics of reported trade in NRSS can be simulated. This report is thus a validation exercise of the data, an investigation in data inconsistencies to later make recommendation to improve data collection or reported.

Alternatively, improvements for model calibration can also be made to better reproduce observation fertilisation behaviour and NRSS transports.

III. RESULTS/DELIVERABLE CONTENT

Overview of collected information sources on NRSS transport

The data on transport of NRSS and BFF is based on

- the Flemish Voortgangsrapport Mestbank 2012, 2013, 2014, 2015, 2016, 2017, 2018, 2019, 2020.
- The Dutch Mesttransport 2015 - 2021.
- The manure report of two German federal states (North Rhine-Westphalia & Lower Saxony).

European Trade Control and Expert System, TRACES, controls import and export of live animals and animal products within and without the borders. The transport of raw manure and digestate is not subject of the system.

The figures and table below give an overview of this data. Compilation into one uniform database is not possible at this moment because the way data are reported and the timelines are different. However, the detail of the data give a overview and specific numbers and trend that can be used to validate, calibrate parameters of a model simulation logistics of nutrient rich side streams in Northwest Europe.

Here follow some key aspects of transport patterns to take into consideration in modelling and evaluating policies related to nutrients that can be derived from the data.

- Most regions are importing and exporting regions

Figure 3 shows for instance that Flanders is importing from almost all neighbouring regions while Figure 4 shows the export to the other regions. Figures 3 and 4 illustrates that the type of products coming in and going out in Flanders is different. This means that the Flemish region is acting as a transport and processing hub for nutrient rich side streams. Raw manure is coming in, mostly horse manure from all regions or pig or poultry manure from the Netherlands, while compost, substrates or other soil improvers are going out. This is also to some extend the case in the Netherlands or in Lower Saxony.

- The transport within a region can be as important and the transport between regions

This point is best illustrated by the transports of nutrient rich side streams in Lower Saxony. The transport within the region is of the same order of magnitude as the export to other regions in Germany. Lower Saxony exports 38395 t0 N to other German regions while there is internal transport from the west region within Lower Saxony to the other for the amount of more than 20 million ton N. (NÄHRSTOFFBERICHT FÜR NIEDERSACHSEN, 2020)

- The Netherlands, Flanders and Lower Saxony are the main exporters

Each of the three regions export between 30 and 40 million kg N in nutrient rich side streams to other regions in their latest reported data.

- France and all German regions except Lower Saxony are the main sink for nutrients of NRSS. Nordrhein-Westfalen accepts more than 50 kg N per ha in NRSS from The Netherlands in the most western municipality while in the east it is less than 2 kg of N per ha (NÄHRSTOFFBERICHT Nordrhein-Westfalen, 2017).

- Pig manure and its derivatives are the most important nutrient transports between regions

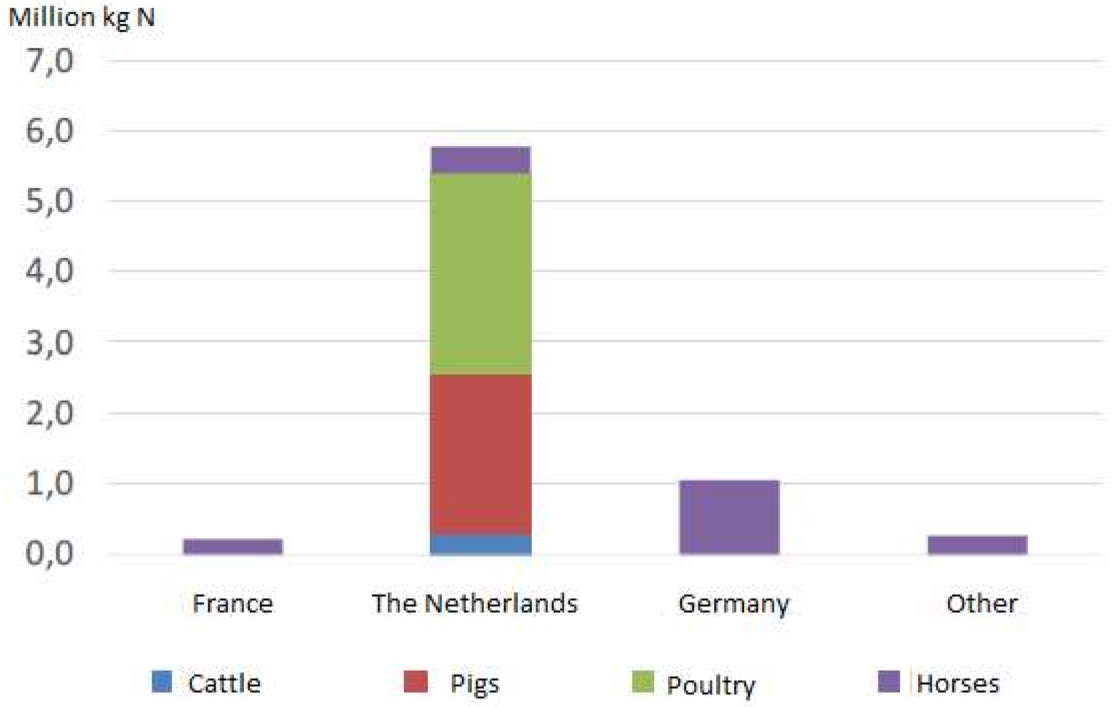

Figure 3. Import of manure from abroad to manure processing in Flanders in 2019 (source: Mestrapport 2020).

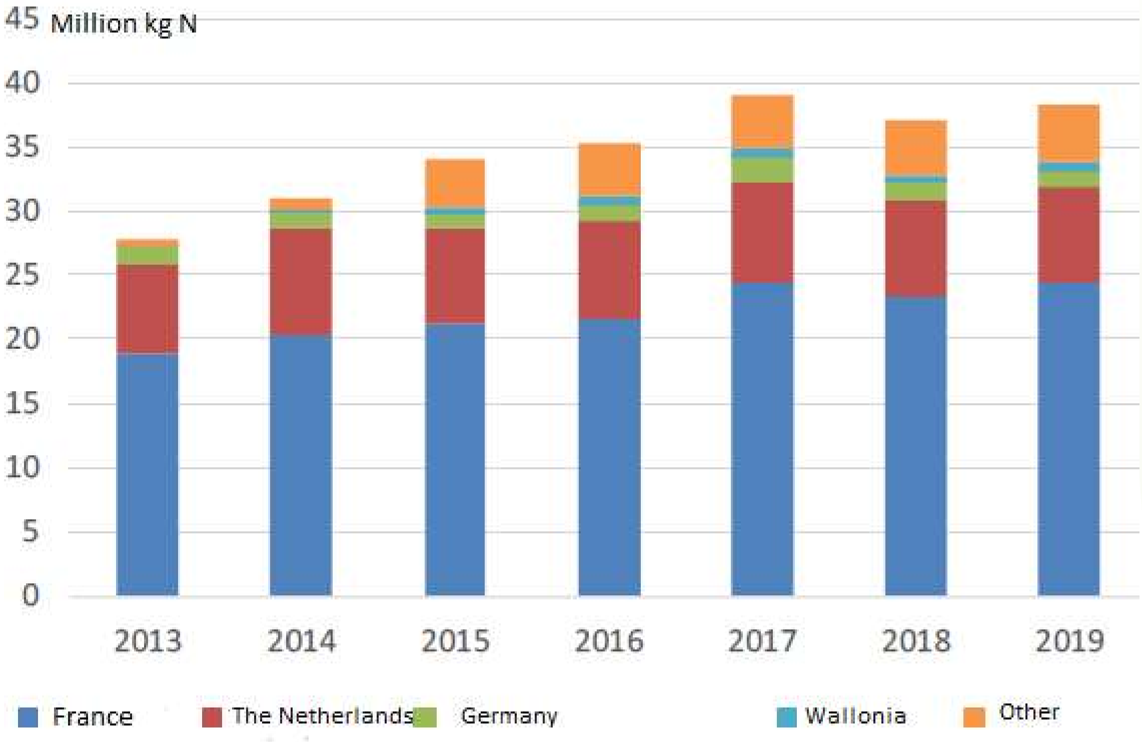

Figure 4. Export of nutrient rich side streams from Flanders in 2019 expressed in kg N content (source: Mestrapport 2020).

Table 3. Export of Nutrient Rich Side Streams from The Netherlands in 2021 (Rijksdienst voor Ondernemend Nederland 2021).

	Year	Number	Ton	kg P2O5	kg N	% difference in
Germany	2015	69.467	2.110.507	22.630.416	26.175.586	
	2016	75.535	2.263.927	24.208.003	26.684.901	7,3%
	2017	68.879	2.091.582	20.914.133	23.129.671	-7,6%
	2018	51.752	1.567.941	13.633.368	17.492.176	-25,0%
	2019	50.848	1.502.788	13.269.178	17.176.870	-4,2%
	2020	47.106	1.391.017	10.990.641	14.206.612	-7,4%
	2021	27.612	816.999	5.617.886	7.771.203	-41,3%
Belgium	2015	19.924	545.379	6.235.284	8.612.881	
	2016	22.684	635.245	6.797.926	9.148.232	16,5%
	2017	24.390	663.939	6.949.779	8.681.630	4,5%
	2018	27.356	742.746	7.812.453	8.406.759	11,9%
	2019	25.883	709.755	6.904.133	7.973.758	-4,4%
	2020	26.713	793.753	7.934.404	9.348.967	11,8%
	2021	11.394	325.289	2.756.047	3.666.131	-59,0%
France	2015	12.263	362.658	8.605.860	7.184.620	
	2016	12.992	389.216	9.631.577	7.249.856	7,3%
	2017	15.452	467.680	11.357.577	7.807.420	20,2%
	2018	20.678	629.488	11.676.473	10.167.361	34,6%
	2019	24.915	764.006	14.018.733	11.396.210	21,4%
	2020	24.758	759.248	13.941.273	11.081.939	-0,6%
	2021	14.491	440.808	7.657.171	6.290.804	-41,9%
Other	2015	1.653	46.035	915.578	815.805	
	2016	2.669	73.676	1.307.995	1.014.154	60,0%
	2017	2.359	63.742	1.018.637	722.861	-13,5%
	2018	2.824	78.230	1.335.102	1.021.425	22,7%
	2019	4.084	113.148	1.963.390	1.407.813	44,6%
	2020	4.578	127.829	1.899.537	1.379.300	13,0%
	2021	2.910	83.510	1.186.694	863.260	-34,7%

Comparing the simulation and the reported trade flows of NRSS and BFF.

The objective of the manure transport model is to simulate the processing technologies, transport routes and volumes of the main NRSSs and BBFs that would occur in the simulate economic and legal environment. The model operates in a normative way (see Buysse et al., 2007 for more explanation of the difference with a positive approach). This implies that the outcome of the model might be different from the actual data. This subsection makes a validation of some of the outcomes. The objective of this validation is to find data inconsistencies, to suggest model or data collection improvements.

Without going into the details of all simulation results, the model outcome corresponds well with the reported data on the following points.

- The Netherlands and Flanders are net exporting regions of nutrients, while all others are zero trade or net importing regions.
- The most common processing technologies are separation, drying or composting and nitrification-denitrification.
- The most common exported product is the solid fraction of pig manure and raw (or hygienised) pig manure.
- Flanders is an importing and exporting region.
- Germany is the most important export destination of nutrient products from the Netherlands and France is the most important destination from Flanders.
- Intra-regional trade is more important than interregional trade.

There are, however, also some significant differences between the simulation results and the reported data. We focus here on the most important trading EU member state: The Netherlands.
In the case of the Netherlands, there are significant differences between the reported exported nutrients and the simulated exports.

Total N export from the Netherlands varied between 35 and 45 million kg annually between 2010 and 2020. These numbers refer to the sum of all NRSS and BBF products and to all export destinations. The simulated total export was more than 140 million kg N.
A further investigation of the input data show that there are two possible explanations for this difference.

1. The data used for the calculation of the nutrient disposal space is based on data available at Eurostat. Eurostat does not report the nutrient disposal space as the result of the voluntary participation with the derogation options in the different member states. In the Netherlands, the amount of increase in manure disposal space because of the derogation to the Nitrates Directive could be between 50 and 60 million kg N. This explains thus half of the difference between the simulated and the reported NRSS exports. Unfortunately, the data on nutrient disposal space of the derogation of member states to the Nitrates Directive is not available at EU level. In addition, regional differences in uptake of the derogation option would only be available at the Dutch national statistical office. Finally, the update is voluntary so one needs to think of a mechanism to describe the amount of this voluntary uptake.
2. The second explanation of the simulated difference is a general underestimation of the nutrient disposal space. This disposal space is the result of the legal requirement and the actual acceptance rate by farmers. As indicated earlier in this document, the acceptance rate varies between regions and because of differences in the economic and agronomic conditions. The acceptance rate in the model is likely underestimated for the Netherlands. A solution would be to calibrate the model on observed trade flows by using the acceptance rate as a calibration parameter.

IV. DISCUSSION AND CONCLUSIONS

This report provides an overview of the data available and published by regional administrations on transport of NRSS. Unfortunately, these data do not exist at EU level and they are not collected and reported in a uniform way. Yet, the level of detail is sufficient to be able to validate model simulations of transports of NRSS and derived products.
Validation of the transport model on the reported data was done based on the order of magnitude of net export of BBF and NRSS at NUTS 2 level expressed in kg N and share of the importance of different

product types in the export mix of a region at NUTS 2 level (raw manure or compost or comparable soil improvement products).
The validation indicates that the general mechanisms of nutrient flows in Northwestern Europe are correctly represented in the presented simulation model. There is however, a large discrepancy in the magnitude of the reported and simulated trade flows between The Netherland and Germany. Much lower trade is reported in the national statistics than simulated based on Eurostat data.

Based on this observation two recommendation can be made.

First, at the level of data collection, more efforts should be done to uniformly collect data on nutrient import and export and on the nutrient disposal space because of the implementation of derogation. Especially derogation is important because it is a key policy mechanism with a significant impact on the possibility of the use and costs of NRSS and BBF. In addition, the implementation of the derogation is very different between member states. An overview of older types of implementation is made by Vanderstreaten et al. (2012)

Second, at the level of modelling transport of NRSS and BBF, the validated model should be adjusted to more accurately simulate the acceptance rate. Different options exist to do so. The least sophisticated would be to calibrate the model to observed trade flows by adjusting the acceptance rate. One challenge is that there are multiple trade flows against which the model can be calibrated. To solve this issue a maximum entropy calibration approach can be proposed as described in Buysse et al. (2007). An approach based on more agronomic information is to simulate the optimal acceptance rate used crop yield functions for the different BBFs. This would be much more time and resource consuming but it might more accurately reflect the biophysical properties that explain how and why BBFs can replace mineral fertilizers.

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