



Research paper

Nutrient Cycle Assessment Tool: A tool for dialogue and *ex ante* evaluation of policy interventions aiming at closing nutrient cycles in agricultureBart Bremmer^a, Ferry Leenstra^{b,*}, Theun Vellinga^b^a *Innovatiesocioloog, Kerkstraat 51, 6871 BH, Renkum, the Netherlands*^b *Wageningen Livestock Research, POB 338, 6700AH Wageningen, the Netherlands*

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ABSTRACT

One of the main challenges for modern agriculture is closing nutrient cycles better since nutrient deficits as well as nutrient surpluses can cause severe ecological issues. Current efforts to improve nutrient management are mainly focused on the farm level. However, closing nutrient cycles is not only a farm management issue, but also a policy issue. Here the farm should be considered in interaction with other scale levels: regional, national, and international. To develop effective policy interventions a thorough understanding of this complex system and the effects of the policy interventions is needed. The Nutrient Cycle Assessment Tool (NCAT) was developed as a tool to perform *ex ante* evaluations of policy interventions aimed at closing nutrient cycles in agriculture. To contribute to meaningful change, active involvement of stakeholders in applying the NCAT is essential. This article describes the design of the NCAT, and explains why and how complexity and joint learning, single and double loop learning, and systems thinking approaches are used as the key elements of the design. The NCAT focuses on facts and stimulates participants to postpone value judgements. A case study indicated that the tool provided stakeholders with clear insights in the potential effects of policy interventions. Applying the NCAT can lead to shared and enhanced understanding of the effects and consequences of an intervention among participating stakeholders, which is an important prerequisite when developing implementable and supported policy decisions. Observations and evaluation interviews indicate that this process stimulates cognitive learning as well as relational learning. By reflecting on the case study and the resulting insights, the scientific status of the results from using the NCAT is discussed, as well as its value for policy processes.

1. Introduction

The worldwide demand for animal products has increased sharply in the past decades, giving rise to a rapid growth in livestock production. This growth occurred alongside massive structural changes in the livestock sector (Delgado, 2003; Worldbank, 2009; MacDonald, 2018). Livestock production has shifted towards intensification, specialisation, and geographical concentration (Steinfeld et al., 2006). This process has been defined as the 'livestock revolution' (Delgado, 2003).

A consequence of this livestock revolution is the geographical distance between the location for feed production and that of animal production. Additionally, since feed transport is not accompanied with transport of animal products and manure in the opposite direction, there are high nutrient surpluses in livestock dense regions and high nutrient deficits in feed producing regions (e.g. MacDonald et al., 2011). In feed producing regions this leads to issues of soil quality and fertility. The use of chemical fertilizers is often used to compensate,

which subsequently induces the use of scarce geological resources – phosphorous (P) and, to a lesser extent, potassium – alongside the use of (fossil) energy to recover nitrogen (N) (Fernandez-Mena et al., 2015). Simultaneously, in livestock dense regions N and P surpluses can be harmful when they emit to the air, ground, and surface water. Closing nutrient cycles has consequently become an important ecological issue.

Many efforts have been undertaken in the past decades to improve nutrient management in crop and animal production (Gerber et al., 2014). However, most of these efforts concentrate on the field or farm scale and do not consider key nutrient cycle segments that occur on higher levels; such as material flows between farms, regions, and countries (Fernandez-Mena et al., 2015). To close nutrient cycles better it is imperative to intervene at the farm level. Yet, this can only have far-reaching effects if it is combined with interventions at other scale levels and with other stakeholders. For this reason nutrient cycles can only be truly understood and effectively managed if the different scale levels are considered in interaction with each other. Hence, nutrient

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cycles are not only a farm issue, but also a policy issue. Governments, together with industry, are trying to find effective policy interventions to close nutrient cycles better.

To bring about effective policies aimed at closing nutrient cycles, instruments are needed that assess the effectiveness of interventions. Fernandez-Mena et al. (2015) made an overview of the available instruments and identified three main approaches that help evaluate nutrient flows in agrifood systems: a) environmental assessment tools, b) stock and flow analysis methods, and c) agent-based models. They concluded that all three types have their pros and cons and should be combined to explore scenarios for closing of nutrient cycles better. Furthermore, the three approaches have some shared weaknesses. They are all analytical and can be used to explore different scenarios, but they do not explicitly focus on interaction between different levels of scale. Moreover, their application requires massive involvement of different disciplinary experts. In addition, other authors stress the importance of stakeholder involvement and facilitating debate amongst stakeholders (Kragt et al., 2016; Delmotte et al., 2013). However, they establish that the available instruments are either too complex for stakeholders to truly participate in the analysis, or they are too simple by not accounting for the complex interactions that have to be understood (De Kraker and Van der Wal, 2012).

In this paper a new tool is introduced and discussed: the Nutrient Cycle Assessment Tool (NCAT). The NCAT is developed in field work to perform *ex ante* evaluations of policy interventions aiming at closing nutrient cycles. The tool's development resulted from fierce discussions in The Netherlands about the future of livestock production, most prominent in the province Brabant with a combination of high livestock density and a high population density (CBS, 2019). The provincial government brought together livestock farmers, livestock industry, nature and citizen organisations to discuss this future (see for an overview in Dutch: Brabant agrofood, on its way to sustainable livestock production, 2020). In these discussions many stakeholders and policy makers mention the option of closing nutrient loops at a regional level as the way. Circular agriculture ('Kringlooplandbouw') is additionally the central theme in the Vision by the Minister of Agriculture in the Netherlands (LNV, 2018). However, in the realization plan (LNV, 2019) indicates translating this idea to concrete interventions as the main challenge. In an iterative process with stakeholders, based on questions from different stakeholders and policymakers, we developed a tool to explore the concept of closing nutrient cycles. The process of developing the tool probably can be characterized as a kind of 'action research' rather than formal research, fully grounded on the different disciplines that are reflected in the tool.

The tool is designed to stimulate stakeholders to untangle the complexity of closing nutrient cycles and collectively consider the effects of hypothetical interventions. This paper describes how a series of considerations and input from participants led to the design of the NCAT (Section 3) and – based on a case study – what insights the tool can produce (Section 4). Furthermore, a reflection is given on the NCAT as a tool to achieve substantive results (Section 5). But before the NCAT itself is discussed, two essential elements are considered as the foundations for the design of the tool (Section 2): the issue of closing nutrient cycles as a 'wicked' problem, and learning as a condition for change.

2. Complexity and learning

The Nutrient Cycle Assessment Tool (NCAT) uses the theory of wicked problems and theories of learning as a conceptual framework. Together they form the basis for the design of the tool.

2.1. Complexity: closing nutrient cycles as a 'wicked problem'

Closing nutrient cycles is a great challenge due to the complexity of the issue. In the development of the NCAT, closing nutrient cycles is

understood as a 'wicked problem' (Churchman, 1967; Rittel and Webber, 1973): a problem that is characterised by high complexity with numerous causes and effects which are often interrelated and reciprocal (Van Bueren et al., 2003). It is extremely difficult to understand how the variables within the system interact, and what consequences interventions will have. As a result, solving one issue within a wicked problem will often lead to the rise or aggravation of other issues. Yet, the 'wickedness' of closing nutrient cycles is not limited to technical complexity. As with other sustainability problems, the dynamics of environmental and technological issues can only be understood when their interaction with the economic, social, cultural, and institutional context is considered; i.e. a systems approach (Elzen and Wieczorek, 2005). A purely scientific understanding of nutrient cycling will often not provide direct applicable solutions. Hence, another characteristic of wicked problems is that they have no true or false answers (Rittel and Webber, 1973). Therefore, 'solving' a wicked problem requires deliberations that cannot be made by scientists alone. Since the preferred solution depends on the position, values, and motives of the stakeholders, choices cannot be made purely on the basis of scientific knowledge. Hence, it is essential to closely involve stakeholders in an issue like closing nutrient cycles (Termeer et al., 2016).

The difficulty in untangling wicked problems is that stakeholders do not only bring in varying perceptions of problems and solutions - each based on their own values, convictions, and interests - but these viewpoints are also closely interwoven with facts and theories. Farmers and environmental organisations not only have different views on how to deal with nutrient flows; they selected factual evidence that explains why their position is correct, makes sense, and should be the starting point for policy decisions. Science cannot simply act as an independent judge, since science itself has become part of the debate (Andrews, 2002; Karl et al., 2007). Stakeholder discussions can easily become long-lasting pointless affairs, in which stakeholders only exchange their viewpoints without considering the whether other facts and viewpoints are valid.

That is exactly where NCAT intervenes: it attempts to separate the normative and factual components to give each its own place in the process. To that end, a form of joint fact finding is applied (Andrews, 2002; Karl et al., 2007). This analysis does not result in judgements about who is right on what point, but explores how the factual views of different stakeholders, all in themselves correct, are different parts of a larger story. A farmer might highlight the facts that are important from an entrepreneurial perspective, while an environmental organisation emphasizes the facts that are relevant from an ecological and environmental point of view. The positions they hold are contradictory in many respects, but the facts with which they underpin their positions are compatible. By distinguishing the facts from the viewpoints, a space is created for a shared factual story between stakeholders: a mutual understanding of the complexity of closing nutrient cycles. This is a process that, by definition, requires learning.

2.2. Learning as a condition for better closing nutrient cycles

The types of learning that are required for dealing with wicked problems are not primarily about knowledge transfer, but about reflecting and adapting one's perception of reality, and grasping the perspectives on reality of others (Leeuwis, 2004). It is especially this kind of learning that is needed in the case of closing nutrient cycles. Haug et al. (2011) distinguish three types of learning: cognitive, normative, and relational learning.

Cognitive learning refers to stakeholders acquiring new facts and ideas and relating them to existing knowledge. More importantly, it involves the reflection on the solutions employed by others. Cognitive learning is closely related to single loop learning (Argyris and Schön, 1996; Greenwood, 1998; Loeber et al., 2007), where the question is: 'will my action lead to the desired results?'

Normative learning refers to a change in norms, values, and

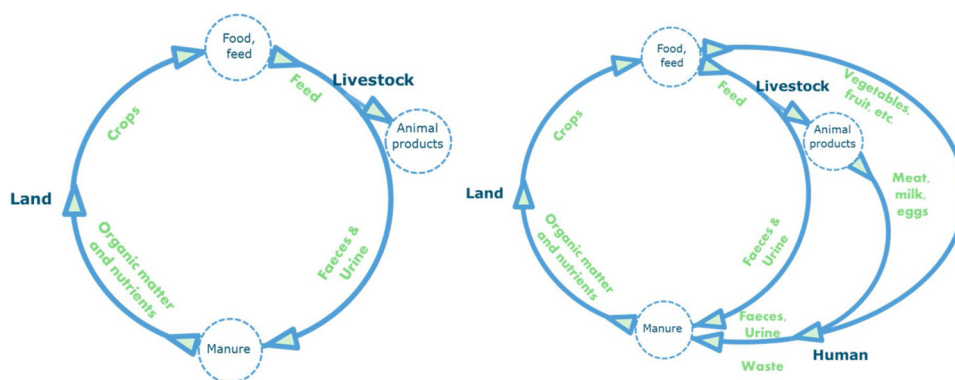


Fig. 1. The nutrient cycling framework after Schröder et al. (2003) on the left and the extended version on the right with human consumption and the compartments defined as secondary processes or transfer points (dotted circles).

viewpoints. As with double loop learning (Argyris and Schön, 1996; Greenwood, 1998; Loeber et al., 2007), in normative learning the guiding question is: ‘Why do I desire these results?’. By answering this question stakeholders challenge their own cultural and personal pre-suppositions. Haug et al. (2011) emphasize that normative learning takes place at a different level than cognitive learning, but that it is not of a higher order.

Relational learning refers to an enhanced understanding of viewpoints, and the underlying mindsets and frames, of other stakeholders; and consequently, a change in trust and the ability to cooperate.

Cognitive, normative, and relational learning are all essential in participatory policy processes; especially in complex cases such as closing nutrient cycles. The ultimate purpose of the NCAT is to motivate stakeholders to come to action. It is assumed that this requires the stakeholders to reflect on their own thinking, the position of others, and the functioning of the system as a whole. However, the NCAT does not offer a comprehensive solution; its primary focus is on cognitive learning and by doing so it stimulates relational learning. Whether the NCAT stimulates normative learning is questionable, as discussing norms and values is not part of the tool.

Yet, closing nutrient cycles better is technically so complex that there is a need for an instrument with a focus on content. Hence, the NCAT must always be embedded in a broader process, to offer a ‘complete’ collaborative governance process.

Bennett and Howlett (1992) suggest that to exemplify learning processes in public policy, three basic questions should be answered: who learns, what is learned, and to what end? For the NCAT itself this is that the most relevant stakeholders (‘who’) learn about the complexity of closing nutrient cycles better (‘what’) to achieve a mutual understanding and shared language to talk about nutrient cycles and related policy interventions (‘to what end’). The tool must be embedded in a broader process in which the same group of stakeholders not only learn about the system, but also about the variety of problem definitions and their interrelationships, in order to obtain a constructive conversation mode and a careful process that leads to endorsed solutions.

By combining a focus on complexity and a focus on learning, the NCAT enables stakeholders to better understand the functioning of nutrient cycles, so that better informed (policy) decisions can be made. Hence, the NCAT is a distinctive tool. Although there are models of nutrient cycle assessment that reveal complexity (e.g. Wang et al., 2010; Zhu et al., 2019), and others that facilitate learning (e.g. Drohan et al., 2019), there are no models that do both (Fernandez-Mena et al., 2015). To obtain this distinctive position, the NCAT was designed to satisfy the following requirements:

- It should reveal the technical complexity of closing nutrient cycles; including the different levels of scale, the various components of nutrient cycles, and side-effects.

- There should be considerable attention for the economic, cultural, social, and institutional aspects of closing nutrient cycles and how these elements constantly interact and constitute a dynamic whole.
- It should actively and intensively involve stakeholders, so that a joint learning process takes place to facilitate cognitive and relational learning.

3. The design of the nutrient cycle assessment tool

In this section the design of the NCAT is described. The requirements presented at the end of paragraph 2.2 are introduced consecutively: the technical complexity (3.1), the wider system (3.2), and the stakeholder participation (3.3). Together they form the essential components of the tool: a series of workshops, described as a step-by-step plan in paragraph 3.4.

3.1. The structure of the nutrient cycling framework

The NCAT takes as a starting point the human activities in nutrient cycling. The basis of the framework comes from a simple farm cycling approach as presented by Schröder et al. (2003). The original framework (Fig. 1a) is extended (Fig. 1b) by adding a human. This framework of connected compartments distinguishes between primary (arrows) and secondary (dotted circles) processes. The primary processes are (1) plant production: starting with manure and soil, and ending with plant products; (2) animal production: starting with plant products, and ending with animal products and manure; (3) human consumption: starting with plant and animal products, and ending with human excreta (green waste included). The secondary processes (or transfer points) entail transport, trade, and processing of (4) plant products, (5) animal products, and (6) manure of animal and human origin.

Most models depicting nutrient cycling focus on biogeochemical processes and describe the use of nutrients in agricultural production systems and the associated losses to air, soil, and water (e.g. the nitrogen cycle in IPCC, 2006; Zhu et al., 2019). The NCAT delivers broader insights by focusing on human activities as well as differentiating between primary and secondary processes and their respective stakeholders. Closing nutrient cycles better is not only the farmers’ responsibility, all chain partners, upstream and downstream, also play a key role. A clear understanding of the role for all stakeholders is required to underpin a Circular Economy for nutrients, a policy being pursued in Europe (European Commission, 2020)

The primary processes (the arrows in Fig. 1b) can be considered as bound to one location. In primary processes nutrient cycles can be closed better by improving nutrient efficiency and minimizing losses. This can be shown in terms of a balance sheet presenting all inputs, outputs, and losses. In plant and animal production the primary producers, farmers, are at stake in these processes. In human consumption,

the consumer is at stake.

The secondary processes (the dotted circles in Fig. 1b) connect the various primary processes, but are also the connection between different geographical areas: plant products produced at one location can be processed and traded to be used as feed or food at other locations, while animal products and manure (livestock and human) can also be produced at one location and used at another (Fig 2).. Therefore, these are called transfer points: existing outputs from one primary process become input for another primary process via processing, trading, and transporting. In secondary processes nutrient cycles can be closed better by changing nutrient allocation. Most models merely focus on the primary processes, thereby showing the nutrient flows as inputs and outputs on the balance sheet. The fate of these inputs and outputs of primary producers and consumers is the central item of the transfer points. Additionally, chemical and mineral fertilizers import and export takes place at the transfer points, putting the fertilizer industry itself outside the system boundaries. Transporters, traders, and processors are the main stakeholders in the transfer points. If the aim is to close nutrient cycles, the options related to primary processes are limited to 'doing things better' and mainly concern biological processes. At the transfer points activities concern the transport and distribution of products, and almost always physical and chemical processes, often at an industrial and international scale. Stakeholders in the transfer points operate across scales and locations, whereas the stakeholders in primary processes operate at one scale - their farm or household. This implies that transfer points have other options to close nutrient cycles like (re)organising nutrient flows across scales ('doing better things'), including the organisation of return flows of nutrients from manure and excreta, a key issue in livestock production and human consumption.

While most models assess one scale level, the model presented in Fig. 1b is applicable across scale levels: farm, regional, national, international. Analysing nutrient cycling is about improving both primary and secondary processes. This is achieved in the workshops by using four posters in parallel, each reflecting a specific scale level with the transfer points as connectors between the scales. Fig. 2

This interaction between the various nutrient cycles as described above, is not only a technical story. The status quo as well as the potential changes caused by policy interventions are driven by economic, political, social, and cultural aspects; as is discussed in the next section.

3.2. Transfer points: adding the economic, wider environmental and other dimensions

The different scale levels are connected not just by nutrient cycles, since nutrient pathways are part of larger interrelated systems. Farming and food production systems are to a great extent driven by economic principles. The fact that feed for pig and poultry production in The Netherlands is largely produced outside The Netherlands can be explained through economic and historical reasons. As a result, policy interventions aiming to change this – to close nutrient cycles better – are not only affecting the environment, but also the economy. Likewise, if these interventions actively engage in import and export, this can also

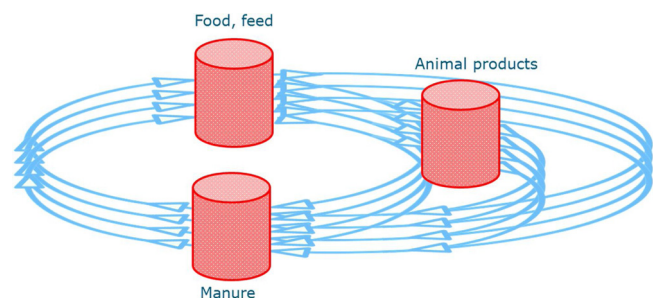


Fig. 2. Exchange of products between locations takes place at the three transfer points.

have political implications.

To get an overview of the effects of an intervention, stakeholders participating in the NCAT also investigate the consequences for the economy – differentiated by land use, productivity of labour and capital, and allocation of resources – and the wider environmental consequences – differentiated by greenhouse gasses, soil, air, (surface) water, biodiversity, and living environment. Furthermore, stakeholders have the freedom to bring in political and cultural issues.

3.3. The nutrient cycle assessment tool as a stakeholder process

Stakeholder participation is the driving force in the design of the NCAT. Stakeholder participation is important because it provides experiential knowledge from practice about how the agrifood system functions, how change is brought about, and what is manageable and prudent from a practical point of view. This is needed to uncover how the system will react to certain interventions and how effective these interventions will be, especially as these stakeholders are the same parties that must bring about this change. At this point, they are the 'experts'. Stakeholder knowledge is of a different order than scientific knowledge. In mapping the changes in the system both kinds of knowledge are needed and are highly complementary (Funtowicz and Ravetz, 1991). Simultaneously, stakeholder participation enables action. Often interventions introduced by a government or a single company are not sufficient to make a significant contribution, and collective action is needed to close nutrient cycles better. The NCAT does not actively work towards collective action. It does, however, create joint insights which stakeholders can build upon afterwards towards collective action.

In Section 2 it was mentioned that bringing stakeholders together does not automatically lead to results and this can easily become a repetition of moves. In developing the NCAT we experienced that four important elements must be built in the design of the NCAT.

- (1) The NCAT aims for a discussion focusing on facts, figures and, above all, relations. Participants are not facilitated to discuss about right or wrong, desired or undesired. Although the normative aspect is certainly as relevant as discussing the facts, here it is (temporarily) excluded. Common ground is sought in the factual understanding of the situation. It is assumed that when a mutual understanding of nutrient cycles is achieved, a more constructive dialogue can be conducted as to what is desirable. After the NCAT has done its job, other instruments can be used to support a dialogue on norms and values.
- (2) A diversity of stakeholders is needed to ensure (a) a broad range of relevant questions (often related to their specific viewpoints); (b) a broad knowledge base; (c) to prevent participants to act strategically, as this will be neutralized by others; and (d) a joint learning process by all relevant parties (Karl et al., 2007).
- (3) With the NCAT, stakeholders analyse a possible solution instead of the problem. This forces the participants to take a different entry point, challenging them to put aside their viewpoint. Simultaneously, this builds on the idea that wicked problems can be better understood by investigating solutions (Conklin, 2006).
- (4) The NCAT is always a thought experiment. In the workshops, stakeholders are not analysing the current situation, but explore 'what would happen if ...'. This may be related to actual policy decisions, in which case an extreme intervention is chosen. Analysing an extreme intervention ensures a maximum of insights to be harvested. Simultaneously, this hypothetical approach will take away most of the direct threat stakeholders experience.

Although the direct results of the NCAT can be substantive, in its current form it is primarily a discussion tool: the focus is on the stakeholders' learning process. The quality of this learning process is secured in four ways:

- Social-emotional aspects: pay attention to existing tensions among stakeholders to enable fruitful interaction.
- Visualization: visualize the process of nutrient cycles and relevant interventions to enable fruitful interaction.
- Multiple meetings: successive meetings enable reflection, verification of findings by experts and consultation of the rank and file.
- An experienced facilitator who can avoid value judgements among and framing of the discussion by the participants, and to handle the social-emotional aspects between the stakeholders.

3.4. The step-by-step plan of the nutrient cycle assessment tool

The ingredients above are translated to a step-by-step plan that combines complexity and stakeholder participation. Each application of the tool is different and requires customization. For this reason, the first step is a thorough preparation. This is done with the project client – a government, company, NGO or partnership – possibly assisted by a few key stakeholders. The process is supervised by a process facilitator, supported by preferably two substantive experts who have experience with the NCAT.

- The preparation always starts with a comprehensive deliberation of the assignment, including a detailed definition of the purpose and an outline of the context. These are important to determine the further requirements to apply the tool, but it also has a crucial function in managing expectations. The NCAT offers opportunities, but it also has its limitations: in particular, it is not suitable as a calculation model or a decision-making tool. Sometimes, it must be decided that the NCAT is not the right instrument.
- Subsequently, the client should define an intervention: this is the policy intervention that will be analysed by the stakeholders. An intervention in the NCAT must be concrete and well defined. The intervention must also be accompanied by a logical explanation as to why it is chosen. That does not mean that the intervention itself should be logical or plausible; the criterion here is that the chosen intervention makes sense to the participants, as the start of a thought experiment. As the policy intervention to be analysed is hypothetical, the intervention can have a normative character. For a successful exercise, stakeholders do not have to agree with the actual implementation of the intervention, they must agree to explore the effects of the intervention. In addition, the definition of the intervention is discussed by all participants in the first workshop.
- After the case and intervention are defined, all relevant stakeholder parties are identified and specific representatives invited to analyse and evaluate the intervention in the forthcoming workshops. Stakeholders can be companies, governments, or NGOs, with a high involvement in the issue at hand. After a first selection of organisations, it should be carefully examined which persons within these organisations should be invited. Knowledge in the field of nutrient cycles and the broader system is important, as is the influence of the person within the organisation alongside a certain level of open-mindedness. In total, the workshops offer space for eight to fifteen people.

After the preparations, a series of approximately three stakeholder workshops will be organised. This number depends on the requirements of the problem. In between the workshops expert input is collected and handed to the stakeholders as material for the next workshop. This entire process is supervised by the aforementioned process facilitator and the two substantive experts.

- The first workshop is meant to (a) introduce the nutrient cycle framework, (b) establish the intervention with the stakeholders, and (c) start exploring the effects of the intervention. The framework is printed on a set of four posters (derived from Fig. 1b) to reflect the relevant spatial scales, namely: farm, region, national and

international. Stakeholders are invited to write down and map expected effects and questions on material flows, emissions, and other side effects in the various parts of the framework and at the various spatial scales. All comments and questions are written on post-its and placed on the relevant location and scale of the framework. Usually this framework is illuminating, although at the same time it raises many questions. At the end of the first workshop the most important questions are identified for expert consultation.

- After the first workshop a group of experts with various backgrounds – usually a group of five to ten people, mostly scientists – is assigned to consider the effects of the intervention. The experts are instructed (a) to check results found by the stakeholders and, where possible, verify them; (b) to supplement the analysis where relevant; and (c) to answer the questions formulated by the stakeholders. This is partly done in a group session that is similar to the stakeholder workshop. The experts build upon the analysis by the stakeholders and on each other's knowledge and insights. The experts partly work on the assignments individually, so they can easily use literature and other sources.
- In the second workshop the expert information is presented and discussed. Subsequently, the workshop is used to further explore the effects of the selected intervention and come closer to conclusions. Based on this more extensive and in-depth overview of effects, new questions are formulated for experts.
- After the second workshop the same experts are consulted. The emphasis is now on answering the questions of the stakeholders. Now the experts work individually, as a group process with the experts does not have much added value in this phase due to the specificity of the questions.
- In the third, and last, workshop, the expert information is used to further elaborate on the effects of the intervention. The workshop continues by summarising the results and formulating conclusions. Finally, stakeholders agree upon what is communicated externally and in what form this communication will take place. In most cases the substantive experts who were present in the workshops will assist the stakeholders in the reporting, but this can also be done by independent reporters or by the stakeholders themselves. The reporting should always be accompanied by a process description, to prevent the results from being taken out of context.

4. Insights of the nutrient cycle assessment tool applied in practice

The NCAT was tested and further developed in several pilots with NGOs, private sector organisations, ministries, researchers, and the project steering committee. In each of these pilots only one of these stakeholder groups participated in one workshop. The first real life case of the NCAT was in the Dutch province Brabant, where it was applied as part of a participatory policy making process.

4.1. The case and its background

Brabant is a province in the south of The Netherlands where, besides a high population density, there is a high livestock concentration, provoking a range of issues. The high livestock density causes high ammonia and particulate matter emissions as well as a manure surplus, especially in the middle and eastern parts of Brabant. The ammonia emissions can be linked to human health impacts, as a precursor of particulate matter (PM_{2.5}), and acidification and eutrophication effects (such as biodiversity loss and species composition change in ecosystems). Inappropriate manure use practices can lead to nitrate leaching into watercourses and GHG emissions (N₂O) (and pollution swapping). (<http://www.rivm.nl/media/milieu-en-leefomgeving/hoeschoonisonzelucht/>). The compulsory emissions reduction and the export of manure lead to a considerable cost price increase for many livestock farmers in the province. The livestock industry is an important

socio-economic contributor in the province, but the high livestock concentration also causes inconveniences for society: nuisance due to odour; traffic problems due to transport of feed, livestock and manure on small country roads; and degradation of landscape quality. Recently, the impact of high livestock densities on public health was evaluated (Maassen et al., 2016). This has led to a fierce public and political debate on the future of livestock production in the province.

The province organised a platform with representatives of different stakeholder groups as part of this debate: citizens, environmental protection agencies, farmers and farmers' organisations, and policy makers discussed about the future of livestock production in Brabant. One of the recurring possible solutions in this debate was to close nutrient cycles better. This idea is not unique to Brabant; within various platforms and debates about the future of agriculture, closing nutrient cycles on a regional scale is advocated with the expectation that the harmful effects of food production on the environment are decreased, and in relation to self-sufficiency (Ministry of Economic Affairs, 2009). However, in these discussions it does not become clear what closing nutrient cycles entails, nor what the exact effects are on agriculture and the environment. In light of this, the provincial staff asked for an analysis of closing nutrient cycles at a regional scale with the help of the NCAT. In this context the NCAT can be considered a joint fact-finding exercise within a larger participatory policy process.

4.2. Applying the nutrient cycle assessment tool in Brabant

In the provincial debate three stakeholder groups could be distinguished: the citizens and environmental organisations, represented by the Brabant Environment Federation; the farmers, united by their organisation Southern Farmers Union; and provincial policy officers. In the workshops the Environment Federation was represented by five persons, the Farmers Union by three persons, and the province by two persons. An independent process facilitator and two scientists facilitated the process and provided the connection between the stakeholders and experts. An observer reported on the process, actions, and attitudes of participants and how this affected the exploration of the effects of the scenario.

In a preparatory meeting, the alignment of the assignment was largely determined by the policy officers, in consultation with representatives of the Farmers Union and the Environment Federation. The parties decided that implementing the NCAT should lead to a better understanding of the significance and consequences of closing nutrient cycles on a regional scale. That region was demarcated as Northwest Europe (NW Europe): a thought that had emerged from the participatory policy process at an earlier stage. In this same meeting a list was created with stakeholders to be invited.

In the first workshop, it took a while before the participants actually got to work. Although in the preliminary discussion a fairly clear delineation was made of the case and all parties were involved in this process, the group had a need for an extensive discussion about the precise intervention. Ultimately, NW Europe was defined as Belgium, France, Germany, Luxemburg, The Netherlands and United Kingdom, and the intervention as: 'these countries together do not import animal feed (ingredients) and neither import nor export animal products'. When this was determined, the participants mapped out the effects of this intervention, especially on NW Europe and Brabant levels. In addition, they investigated the effects on farm level and global level. Results were discussed qualitatively, and at the end of the first workshop questions for quantification were identified.

Subsequently, the process proceeded as described in Section 3.4: experts were deployed to give their input; based on this, stakeholders broadened and deepened their analysis; experts were then asked again for their input; and ultimately in the third workshop, the stakeholders drew their conclusions and determined how to report. The report (Leenstra et al., 2017) was made by the two experts present in the workshops, based on the analysis by the participants and input from the

Table 1

The import and export of plant and animal materials in the six countries of the case study in NW Europe in 2014, expressed in Mega tonnes of product and kilo tonnes of N and P. (Bruschke et al., 2016, personal communication based on EU-statistics).

Product category	Import			Export		
	Mton product	Kton N	Kton P	Mton product	Kton N	Kton P
Plant products						
Cereals	18.4	332	57	31.7	570	98
Co products milling	1	18	3	5.2	93	16
Oil seeds	15.9	889	84	1.4	79	7
Oil & fat	7.8	0	0	4.4	0	0
Grain products	2.9	52	9	3.5	64	11
Residues food industry	19.6	1428	127	10.3	754	67
Other	1.8	75	11	2.3	95	14
Animal products						
Live animals	0.5	12	3	0.9	23	6
Meat and edible offals	3.4	151	9	6.3	258	12
Dairy products & other	4.6	251	46	8	440	80
Other animal products	0.8	37	2	0.7	30	1
Processed meat, fish	1.6	164	38	0.7	67	15
Mineral and synthetic fertilizer	12.6	0	1390	9.7	2610	0
Total	90.9	3409	1779	85.1	5083	327

broader expert group. The next section is a comprehensive summary of this report.

4.3. Substantive findings: Effects of limiting imports and exports at Northwest European level

The NCAT was used to determine what happens if import and export possibilities are limited at Northwest European level. This yields a multitude of effects on a range of dimensions. Some of these effects are obvious, while the total scenario that unfolds also has far less obvious aspects.

4.3.1. Changes in import and export

The current import and export of the main categories - plant products, animal products, and mineral and synthetic fertilizers - are summarised in Table 1, including the nitrogen (N) and phosphorous (P) they contain. In total about 91 Mton of product are imported and 85 Mton are exported. The largest source of N imports is the residues from the food industry, mainly soybean cakes, palm kernel expeller, and citrus pulp. The most important N export is synthetic fertilizer, produced in large quantities from aerial N₂ for the world market by the fertilizer industry, which happens to be in NW Europe. Excluding the N-fertilizer from the balance, as it is not related to the focus of the study, NW Europe imports more N in plant and animal products than it exports. The main P import is rock phosphate. The most important exports of P occur with cereals and dairy products. This results in a large P surplus of 1350 kton in the six countries.

If the proposed intervention is implemented - meaning that feed and feed ingredients imports as well as livestock products import and export are completely stopped in NW Europe - the flow of several products will change considerably. Due to the existing infrastructure, knowledge, and entrepreneurship, combined with constituted economic interests, it is very plausible that the livestock sector will put effort on maintaining production in Europe. Nevertheless, there will be a strong shift in import and export of feed materials, and thus in production. Assuming that feed materials are represented by oil seeds and residues

from food industry, both mainly acting as protein sources for the livestock industry, the net import to the six countries will decline by $(15.9 + 19.6 - 1.4 - 10.3 =)$ 23.8 Mton of products (since, if import stops, it is obvious that export will also stop), with a reduction of 1484 kton of N and 137 kton of P.

The total import and export of animal products is 10.9 and 16.6 Mton respectively. If the import is replaced by former export, a surplus in the region of 5.7 Mton will remain, representing about 6% of the total volume of production. This results in a decline in net export of 200 kton N and 16 kton P. These figures are, however, based only on a change in imports and exports, without looking at the changes in production resulting from the intervention. These production changes will be discussed in the following sections.

4.3.2. The search for protein alternatives

The strong reduction in availability of protein as feed ingredient (no more import of soy or other protein rich co-products) will lead to several outcomes. The following list is neither exhaustive nor completely accurate, but reveals the possible consequences in broad terms:

- If no more feed is imported, there will be an increase in internal demand for protein crops, accompanied by a price increase. This in turn leads to an increased use of marginal (grass)lands and a decrease of fallow land. Due to the growing demand, the European soy production – which is currently in an experimental phase – might expand rapidly, at the expense of other oil seed crops due to a higher price of the co-product. 1 million hectares of currently fallow land could produce 3 Mton of soy, with 189 kton N and 18 kton P. Additionally, 1 million hectares of marginal grassland could produce 3 Mton of DM grass with 75 kton N and 12 kton P.
- Furthermore, re-allocation will take the place of former exports to internal use. When the export surplus of cereals (Table 1) is considered as feed, there will be an extra 13.3 Mton of cereals available for livestock production, with 238 kton N and 41 kton P, or a corresponding area of arable land will become available for protein crops. Such changes will affect the prices of arable products considerably.
- Due to the new animal feed scarcity, a strong lobby will arise for the legalization of currently forbidden by-products, like meat and bone meal and swill. In the region about 2 Mton of swill is available with 40 kton N and 70 kton P (estimates for the 6 countries based on Ermgassen et al., 2016) and 4.4 Mton meat and bone meal with 387 Kton N and 224 Kton P (estimates based on Veldkamp, 2012). Currently, these products are either composted or burned (swill) or used as ingredients in feed for pet animals and aquaculture. Consequently, animal production will have to compete with these existing applications.
- There is a great chance perverted imports will occur: because of the price increase in animal feed, it is likely that private companies will see business opportunities in importing human food products that can be used for animal feed or from which (new) co-products can be derived.

The resulting changes at the import-export balance are summarized in Table 2. This rough calculation indicates that if meat and bone meal will be made available for pigs and poultry, there is a shortage of at least 500 Kton N (1484 – 929). If meat and bone meal are not available, the shortage increases to about of 900 Kton N (1484 - (929 – 387)). The P balance is about neutral (137 vs 141) if meat and bone meal are not considered for pigs and poultry, while the P-surplus in manure will increase if it is included.

4.3.3. The change in production and consumption of animal products

Due to the new feed and land scarcity and the disappearance of export demand, shifts will take place in production volume between animal species. Poultry and dairy are the most N-efficient, but poultry

Table 2

Changes in import and likely replacement if the 6 countries stop importing feed ingredients.

Product	Change in net import		
	Mton product	Kton N	Kton P
Not imported			
Oil seeds	-14.5	-810	-77
Residues food industry	-9.3	-674	-60
Total	-23.8	-1484	-137
Not exported + extra production/ use			
Cereals	+13.3	+238	+41
Swill	+2	+40	+70
<i>Meat and bone meal</i>	<i>+4.4</i>	<i>+387</i>	<i>+224</i>
Grass	+1.5 – 3.0	+75	+12
Protein crops (soy)	+3	+189	+18
Total		+929	+365 (141)
		(542)	

requires high-quality protein. As a result of a shortage in the right protein sources, poultry production might decrease. Pigs are less demanding, although they are also less N-efficient. Cattle is the least affected, due to their rumen function they need relatively little high-quality protein. When meat and bone meal is allowed as feed, a large part of the protein quality issue for poultry might be solved, however at the expense of protein for pet and fish feed.

All in all, the total animal production will decrease due to higher prices and the loss of export surplus. It is difficult to predict exactly how this decrease will be partitioned among the sectors, as this is the outcome of many variables on both the production and the consumption side. Experts expect a reduction in milk production, a small decline in pig production, and a somewhat stronger decline in poultry production. Due to the increase in consumer price for chicken and pork, the demand for beef will probably rise at the expense of other meat. This demand can be met by extra beef production on marginal land. Due to the new feed and land scarcity, all meat types, milk, and eggs will become more expensive in NW Europe. This may lead to increased consumption of vegetable proteins such as beans, nuts, and legumes – which may still be imported in the scenario – as they become more interesting for consumers in terms of price. In addition, the export ban keeps for instance legs, wings, and ears in NW Europe. This will most likely lead to food innovation and the use of these products in processed food.

For all products mentioned, supply and demand will change. If the intervention were actually implemented, this would lead to a very dynamic economic situation: despite changes, actors stick to how things were while at other times, overcompensation will take place when all parties simultaneously adapt to the new situation. In time, the market will find a new balance for each product.

The proposed intervention is quite extreme and unrealistic, and the effects are far-reaching. However, the scenario that unfolds does not create any outcomes too difficult to overcome on both the production and consumption side. There will certainly be losers, but there will not be an extreme increase in food prices or famine; individual companies will go bankrupt, but production sectors as a whole will remain intact.

4.3.4. The consequences for Brabant

The consequences for NW Europe are not in all instances the same as for Brabant. Despite the decline of animal production on a NW European scale, the livestock population in Brabant will not shrink. The new scarcity of land, feed, and animals makes each of these more valuable. Consequently, efficiency will be even more important than it already was. Due to the available infrastructure, knowledge, and entrepreneurship, Brabant has an advantage compared to other livestock dense regions in NW Europe. Therefore, the decline in the number of animals is expected to take place in areas such as Brittany and southern

Germany.

As a result, the P-surplus in the province Brabant from animal manure will roughly remain as it is. Currently this surplus is transported to arable areas in The Netherlands and exported to arable areas in Germany and France. In the future there might be more demands regarding quality of manure, which will increase export costs, but competing livestock areas in NW Europe will face the same problem. Given the policy developments on nutrient management in Europe (decreasing allowance for N and P application to protect surface and ground water), manure management will be challenging, but not impossible. Nitrogen is expected to be a bigger challenge than phosphate, being extremely soluble and highly volatile.

4.3.5. Substantive conclusions

If the intervention “ban on animal feed (ingredients) import, as well as on import and export of animal products” is applied, there will be a multitude of effects. Feed will become more scarce, implying plant products and land scarcity. This leads to higher prices and higher efficiency with more efficient use of nutrients such as N and P. As a result, the nutrient cycle is closed better in this scenario than in the current situation. This applies to the NW Europe region as a whole, but only to a limited extent to Brabant.

Since plant products and (chemical) fertilizers may still be imported, nutrient scarcity remains limited, especially when it comes to phosphorus. Consequently, hardly any incentive arises in this scenario to start valuing human excreta and integrate it into the nutrient cycle. Hence, an extreme intervention as proposed here, although it has far-reaching consequences, does not produce the effect in terms of nutrient cycles that governments and others claim to aim for.

4.4. Process results

To determine what the application of the tool yielded for the participants, meetings were observed, tape recordings were analysed, and interviews were conducted with 5 participants. Although this should be considered anecdotal evidence – it is not based on a rigorous method as Gerlak and Heikkilä (2019) propose – it does give an impression of the learning processes that have taken place among the participants.

The implementation of the NCAT in Brabant was perceived as useful by all parties involved. Participants remark that it has not only provided them with new insights, it also brought them closer to each other. The most concrete indication of this is the fact that participants not only jointly wrote a foreword to the report (Leenstra and Vellinga, 2017), but also contributed a joint statement to the political debate at their own initiative.

4.4.1. Cognitive learning

Participants' statements in meetings and interviews show that in the course of the workshops they not only collected new facts, but also at some points adjusted their solution directions. An interesting example of this that came up several times in the meetings and interviews is that the members of the Environmental Federation had thought that a ban on the import of soy would result in a lower density of livestock in Brabant. However, the exercise shows that this is not the case. Apparently, an intervention that closes nutrient cycles better does not automatically lead to a smaller number of animals.

More generally, participants learned to reason better in terms of (nutrient) cycles and to link changes in different parts of the system in order to gain insights into the parts of the system that they normally do not care about. In this sense, cognitive learning in the NCAT is not only linked to first order learning, but also to system learning (Van Mierlo et al., 2010, based on: Senge, 1990; Kim, 1993; Kim and Senge, 1994).

4.4.2. Relational learning

Participants state that they succeeded in having a substantive discussion with each other. The parties became more open during the

process and there was increasing willingness to jointly explore the effects of the intervention. Observations of meeting dynamics underline this. Where the discussions in the preliminary meeting and the first workshop were fierce, emotional, and frontal, there was a curious attitude in workshops 2 and 3, also towards the input of others. During the process, trust in the group grew so much that people felt safe exploring the facts that questioned their own views.

Interestingly, it seems that the approach to cognitive learning not only leads to relational learning – the creation of ‘factual’ common ground allows participants to get closer to each other – but relational learning, conversely, also promotes cognitive learning – trust stimulates learning from each other and to learn independently of whether that contributes to substantiating one's own point of view.

4.4.3. Normative learning

The development of a shared factual basis does not lead to a common political position. In fact, neither the meetings nor the interviews show that participants changed their positions in the debate in any way. At the same time, they began reflecting on their own point of view as well as that of others. One of the participants mentions that he has come to understand that, based on the same factual story, the stakeholders (still) came to different positions and conclusions. Participants from the Environmental Federation and the farmers now understand how their own point of view alongside that of others both fit within the complexity of the system. They still strongly disagree with each other and there is no sign of normative learning. However, it seems that we have succeeded in separating the discussion about how things are and what stakeholders desire. Whether this really leads to a breakthrough in the subsequent discussions will have to be investigated further.

5. Discussion

Based on observations and interviews, we can tentatively conclude that the NCAT contributes to both cognitive and relational learning. At the same time, we noted that we are not there yet. As a result of the NCAT alone, participants are unable to come up with common policy proposals. Their values, motives and interests are still different, and it has not been explored where commonalities lie in this area and where there is room for compromise.

It is a deliberate choice to have the discussion on what is desirable and the negotiation on what should be done outside the NCAT. However, for the impact of the NCAT this follow-up is crucial, and the NCAT must therefore always be embedded in a broader participatory policy process. Further investigation is needed to determine how successful the NCAT actually is, with more attention than in the present study for the preceding and subsequent process.

For now, we, together with the participants, tentatively establish that the NCAT can be a valuable tool in a participatory policy process. At the same time, we must conclude that there is still much to learn about the implementing NCAT and that steps must be taken to develop the tool towards its full potential. In the discussion we take a first step, and we reflect on three themes: the scientific nature of the results, the value for the policy process, and the NCAT as a tool that combines complexity and stakeholder participation.

The lessons learned while developing the NCAT are summarized in Table 3.

5.1. The scientific status of the results of the NCAT

The case described in Section 4 is highly hypothetical. It could even be conceived as considering a future that will probably never occur, so the outcomes cannot be verified. However, the value of the NCAT lies not in the separate results, but (1) in the whole and (2) in the process. The value of the individual facts and figures in Section 4 may perhaps be questioned, but when viewed collectively, they are valuable. The

Table 3

Critical points identified in developing the NCAT.

Preparation and definition of the case with stakeholders
Careful selection of all essential stakeholder groups to be involved
Selection of participants based on knowledge, position within stakeholder group, and willingness to accept exploration of a hypothetical intervention
Clear definition of the intervention, straightforward and not multi-interpretable
Careful selection of the experts, based on their knowledge, track record, and ability to think outside the borders of their specific discipline
A skilled process facilitator, able to stimulate a factual discussion at the right level of detail

participants gained insight into how the system functions by viewing the whole. The data on which this is based mainly results from personal communication with scientists, but is in turn based on peer-reviewed publications and public reports. These personal communications, publications and reports are an important part of the scientific underpinning, but this is not all. The scientific underpinning emerges partly from the context itself: the individual pieces have their place in a larger story. Moreover, by entering a conversation with each other and (indirectly) with the participants, they will see their own knowledge more in perspective, and connect it to the knowledge of others, namely experts and stakeholders. Subjectivity and bias of an expert panel can never be completely ruled out. Uncertainty as well as personal and disciplinary views and assumptions also play a role. But by engaging a wide range of experts and giving (well-informed) stakeholders a voice, a balanced, although not neutral, story is constructed. The resulting synthesis confirms not just the relevance, but also the validity of the individual pieces. Here is also an important connection with the second aspect, the (scientific) value of the process.

In Section 4 the effects of the proposed intervention in Brabant were discussed in detail. Although the scenario sketched is interesting in itself, the main reason for this detailed description here is not to show 'what happens if ...'. Above all, it is about giving an impression of what the NCAT is capable of. The results are particularly valuable in combination with the process by which those involved have achieved these results. It is the joint effort of the participants, therefore this result is also borne by them. That does not apply exclusively to the participants, the experts (scientists) who contributed also go through such a process. When they make their contribution, they encounter knowledge from alternative disciplines and are confronted with practical knowledge. Through this they will connect their own knowledge to that of others and learn to see their own knowledge in a different light. This is not only valuable within the framework of the NCAT but can also have its effect on their broader work.

Still, the scientific basis is a point of attention for the NCAT: the scientific quality of the final results is highly dependent on the quality of the experts and the extent to which they take their work within the NCAT seriously. It is therefore important to carefully select the experts and to monitor their commitment. Working with the experts in a group and discussing their results with the stakeholders creates a form of peer review that improves the quality of their answers to the questions. In the future, we could further protocolize the selection and working methods of experts to better guarantee quality (Karl et al., 2007). In addition, the participants applying NCAT are faced with the challenge of thinking through interventions and scenarios that are less hypothetical, and that are closer to practice and real policy decisions. To be able to assist in such situations, more quantification is needed. Quantification makes the results richer and more tangible. At the same time, there is a danger in using more figures and formulas. Participants and experts can easily lose themselves in the details in the figures. The primary focus must remain on the larger whole, because there lies the NCAT's strength. Here, the facilitator has an important role.

5.2. The value of the nutrient cycle assessment tool for policy processes

Implementing the NCAT in Brabant shed light on what the value of the tool can be for a policy process. Scientific insights and practical knowledge are combined into a comprehensive image that is related to practice and policy issues. The value of this is in the content of the scenario that is outlined, as well as in the fact that this content originates from a stakeholder process. Consequently, the results are interspersed with practical knowledge and connected to relevant stakeholders, who can therefore play a constructive role in the further policy process. With the implementation of the NCAT in Brabant an additional quality of the tool has been discovered, namely the transparency of agendas. At the end of the process in Brabant, the representatives from the Environment Federation seemed somewhat disappointed with the results. Not because the nutrient cycles are not sufficiently closed due to the proposed intervention, but because the intervention did not lead to fewer animals in Brabant. In the reflection it became clear - also for themselves - that closing cycles was actually of secondary importance to them, and that closing cycles on a regional level is seen as a means to arrive at a lower density of livestock: their actual purpose. The NCAT is not able to change the agendas of participants, but, as became clear, it can put the agendas on the table for everyone to see.

A lasting limitation of the NCAT is the fact that it always clings to an analysis. Just as scientists generally do not express a value judgment based on their research, participants in the NCAT do not do so based on their findings. This must remain this way because it is precisely the discussion on the basis of facts that ensures that in-depth analyses are possible by stakeholders with very diverse viewpoints. In the further development of the NCAT it is advisable to think about possible follow-up processes, in which values and stand points play a role. If this is indeed implemented, to maintain the strength of the NCAT it is vital that such a follow-up process is well separated from the NCAT

5.3. Combining complexity and stakeholder participation

In Sections 1 and 2 it was made clear that the combination of complexity and stakeholder participation should be the most important distinguishing feature of the NCAT compared to other models. Building on the results so far, it can be concluded that this is indeed a crucial characteristic of the tool. The combination of complexity and participation in the process leads to an overview that provides insights into complex relationships. Although the complex image that is outlined is not easy to understand, the NCAT makes sure that it is the stakeholders themselves who build up this analysis step by step, so that it is understandable to them.

This is also a vulnerability of the NCAT. The quality of the results is strongly dependent on how the participants are represented and the presence of all relevant viewpoints. This is not only important for the role of these stakeholders in the further policy process, the substantive knowledge that they introduce also matters. For the case that was carried out in Brabant, this became clear when the results were presented to compound feed industry representatives. As the compound feed industry was not involved in the policy process until then, they were not invited to the workshops. When the results were discussed with them, it turned out that they had a number of essential additions to the analysis. No issues drastically changed the existing results, but the additions were so important that they should not be missing in the final report. In the future the NCAT will work with external control for the completeness of invited participants, because this is an important element to guarantee quality.

Another important lesson from Brabant is the importance of a clear structure. During the process it became clear that in fact not one, but two interventions had been placed central: 'no import of feed ingredients' and 'no import and export of animal products'. This complicated the process because if a part of the participants places the emphasis on one intervention and another part on the other, unnecessary

miscommunication arises. More generally, the NCAT requires a lot of creativity and freedom in the participants' thinking. Particularly within the comprehensive and complex matter of nutrient cycles and the wider systems around it, it should be very clear within what limits creativity must be applied. A script is being developed for the NCAT to provide this structure based on the experiences from the case in Brabant.

With the further development of the NCAT there are also opportunities to use the tool for other complex environmental issues. When it comes to CO₂ emissions, for example, there is a wide range of stakeholders, decisions that interact in chains and systems in various ways, close relationships with other (sustainability) themes, and it is of great importance to understand the relationship between scale levels. Positioning the NCAT as a Complex Problem Assessment Tool might trigger others to use (elements of) the tool for other environmental problems, and thereby create a broader package of learning experiences.

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