Effects of banning imports of animal feed raw materials from outside the EU on the circularity of the European agricultural and food system

Exploration using the KringloopToets

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This study was carried out by Wageningen Livestock Research and was funded by the Ministry of Agriculture, Nature and Food Quality as part of the research theme AF-18016 KringloopToets 2.0 (Project code: BO-55-001-005)

Wageningen Livestock Research
Wageningen, June 2021

Report 1299

WAGENINGEN
UNIVERSITY & RESEARCH

Bremmer, B., O.N.M. Van Eijk, T.V. Vellinga, C. Te Pas, J. Scholten, C Meerburg, B.G., Verburg, 2021. Effects of banning imports of animal feed raw materials from outside the EU on the circularity of the European agricultural and food system; Wageningen Livestock Research, Public Report 1299.

Samenvatting NL In deze rapportage is met behulp van de KringloopToets verkend, wat er gebeurt wanneer Europese landen geen veevoer en veevoergrondstoffen meer van buiten Europa importeren. Deze rapportage combineert a) de analyse die een groep stakeholders (bedrijfsleven, overheden en ngo's) heeft gemaakt in een serie workshops, en b) de doorrekening van responsscenario's die daaruit voortkwamen. De inhoudelijke resultaten kunt u vinden in de uitgebreide samenvatting elders in het rapport. De resultaten van deze studie kunnen sector, overheden en Ngo's helpen om het gesprek te voeren, hoe zij samen de beoogde kringloopdoelen kunnen realiseren, op een manier die de vitaliteit van de plantaardige en dierlijke productie niet onnodig raakt. De resultaten van deze studie leggen een basis voor dit gesprek.

Summary UK In this report, the *KringloopToets* was used to explore what happens when European countries no longer import animal feed and raw materials for feed from outside Europe. This report combines a) the analysis made by a group of stakeholders (industry, governments and NGOs) during a series of workshops, and b) the calculation of the response scenarios that resulted from this analysis. The substantive results can be found in the extensive summary elsewhere in the report. The results of this study can help the sector, government agencies, public bodies and NGOs to discuss how they can achieve the intended circularity together in a way that does not unduly impact the vitality of plant and animal production. The results of this study provide a basis for this discussion.

This report can be downloaded for free at https://doi.org/10.18174/543106 or at www.wur.nl/livestock-research (under Wageningen Livestock Research publications).

Public Wageningen Livestock Research Report 1299

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Foreword

How do you tackle a complex issue, especially if such an issue has many dimensions and many stakeholders play a role, each of whom has access to part of the relevant expertise? How do you ensure that there is a shared understanding of the baseline situation and the direct and indirect consequences, regardless of everyone's perspective? And finally, how do you map out possible adaptive and mitigating strategies without arriving at a value judgement? In that case, you start a discussion with each other. You look for differences in perspective and for shared insights. The Nutrient Cycle Assessment Tool provides a structured method for stakeholders to have that discussion regarding complex issues related to circularity in the European agricultural and food system.

At the initiative of Nevedi, a diverse group of stakeholders has used the *KringloopToets* to explore the consequences of a scenario in which European livestock farming no longer imports animal feed raw materials from outside Europe. This enabled a discussion in which we delved into the complexity of our agricultural and food system with participants from the grain trade, the animal feed sector, livestock farming, civil society organisations and government agencies and public bodies. By sharing practical and scientific knowledge, by distinguishing between facts and stories and by understanding each other's perspectives, we have improved our understanding of each other and of the complex cycle of the European agricultural and food system in which many of us work.

The report that is presented here is the end result of an intensive process involving inspiring collaborative sessions and much knowledge input and calculation work from the experts at Wageningen UR and Blonk Consultants.

And as you will see, despite all that knowledge and practical experience, we were unable to find an unambiguous answer to our initial question. What we did find is a shared understanding of a very complex system. We found that a single measure cannot solve all the problems that prevent circularity. It is up to the sector and government to discuss how they can jointly achieve the intended circularity goals in a way that does not unduly affect the magnitude of plant and animal production. It is precisely a shared view of the complexity in the cycle that can help to achieve these goals, perhaps even without the measure (banning imports of animal feed raw materials from outside the EU) with which we started this study.

On behalf of the *PPP KringloopToets* 2.0: A design tool for closing nutrient cycles.

Frank Gort, Secretary

Extensive summary

In this report, it was explored using the "KringloopToets" what happens when European countries no longer import animal feed and raw materials from outside Europe. This report combines a) the analysis that a group of stakeholders (industry, governments and NGOs) has made in a series of workshops and b) the calculation of response scenarios that resulted from this. The direct effect of the measure and of seven responses directly associated with it are described. Together they clarify what will happen when Europe no longer imports sources of animal feed. Based on a joint interpretation of the intended purpose of the measure, it was decided to map the effects of the measure by means of:

- The quantified N cycle of the European agricultural and food system, based on a scientifically founded model;
- The N-balance to be read from this, including imports, exports, losses, vegetable and animal N-production and European N-consumption.
- A qualitative estimate of the effects on the indicators for circular agriculture of the Dutch Ministry of Agriculture, Nature and Food Quality (LNV)

Direct effects of the measure

When Europe no longer sources animal feed raw materials from outside the continent, it intervenes in the cycle. It immediately causes a shift in the existing balance. The scenario "direct effects" (3.2) describes the effects of the measure without stakeholders in the chain having anticipated that imbalance. The "direct effects" of the measure show a decrease in the amount of animal feed. This reduces the volume of European animal production. This leads to a shortage of manure, resulting in a decline in European crop production. So fewer plant products are produced for both animal and human consumption. The amount of (animal and vegetable) products available for human consumption within Europe is declining; the amount of animal products available for human consumption will decrease by one third. The effect on closing cycles is small.

Seven response scenarios

The imbalance in the system leads to responses. These responses have been elaborated in 7 response scenarios.Chapter 4 describes 4 repair scenarios. These are scenarios in which parties are fully committed to recovery of the shortages in order to be able to meet the existing demand for animal and plant food. Chapter 5 describes 3 adaptation scenarios. The focus is on various ways of adapting consumption within the space offered by the system.

Repair scenarios (Chapter 4)	Adaptation scenarios (Chapter 5)
4.1 More European animal feed production and more import of vegetable products for human consumption	5.1 Import (and decrease export) of animal products.
4.2 More fertilizers and synthetic amino acids.	5.2 Consumption of less animal, more vegetable proteins.
4.3 Increasing the efficiency of cultivation and livestock farming.	5.3 Consumption of less meat, more fish
4.4 Making use of residual flows.	

Effects of the separate scenarios
Each response has its own effect on the N-cycle, the N-balance and the indicators for circular agriculture of the Ministry of Agriculture, Nature and Food Quality. These effects are described in Chapters 4 and 5.

• The response to more European animal feed production and more import of plant products for human consumption (4.1) leads to a recovery of the original level of animal production and consumption. This recovery is brought about by a shift in land use within and outside Europe, and does not, on the whole, deliver any sustainability gains.
• The response to the use of more fertilizers and synthetic amino acids (4.2) brings crop production back to the original level; the volume of livestock production is partially recovering. By replacing organic with synthetic inputs, this response causes loss on various sustainability aspects.
• The response to increasing the efficiency of cultivation and livestock farming (4.3) can, with the necessary investment in land and innovation, increase crop production and bring animal production back to the current level. It requires more input from additives (such as fertilizers), which has negative sustainability effects.
• The response to the greater use of residual flows (4.4) helps to close cycles better, because residual flows are used for a higher quality purpose. This makes it possible to absorb about half of the decrease in the amount of animal feed. A major obstacle is the risk to food safety.
• The response to more imports (and fewer exports) of animal products (5.1) is leading to an apparent sustainability gain within Europe. But both the economic yield and the undesired environmental impact have thus been moved to regions outside Europe.
• When the total amount of protein is produced in Europe, the response to consumption of less animal and more vegetable protein (5.2) leads to an increase in plant production and a greater decrease in animal production. This has a positive effect on closing cycles and on other sustainability aspects. However, this is a system innovation, with far-reaching changes in both production and consumption.
• With the response to consumption of less meat, more fish (5.3), the current consumption level of animal proteins can be restored. This mainly results in a shift of side effects from land to sea and / or from within Europe to outside Europe.

Interaction between scenarios
In this study, the scenarios have been worked out and calculated separately from each other. This provides insight into the effect of each scenario in the cycle. In reality, however, they occur simultaneously and interact with each other. So, in a sense, the responses compete with each other. The final ratio between the responses depends on the speed at which responses occur, the degree to which they are actively inhibited or stimulated and which responses persist for a long time. Chapter 6 describes the relationship between the responses. Based on economic laws, it can be expected that a number of relatively fast and "simple" trading responses will occur first. Existing European livestock farming will continue to demand animal feed, as a result of which animal feed prices will rise and European arable farmers will switch from food production to feed production (4.1). The decrease in manure and the decrease in the protein quality in the feed will soon be compensated by additional input of fertilizers and synthetic amino acids (4.2). When food chains cannot meet a constant demand for animal proteins, they will in response to this obtain more animal products from outside Europe and/or export less (5.1). And the same food chains will try to meet the demand for meat through extra supply of fish (5.3). The other responses are deeper and slower changes. These will occur less automatically. For the response of upgrading residual flows (4.4), the risks to food safety must first be minimized. Increasing efficiency (4.3) and replacing animal proteins with vegetable proteins (5.2) will also be slower than the trade responses. These are larger, partly systemic, changes. The occurrence of this is particularly dependent on ancillary policy. Based on the desirability of responses, these can be stimulated or inhibited in a targeted manner.

Conclusions
Based on the results described, the following conclusions emerge. These conclusions are explained in more detail in Chapter 7:

• Determining the consequences of stopping the import of animal feed and raw materials from outside Europe requires in-depth insight into the highly complex cycle of the European agricultural and food system;
• Consequences of the measure can only be assessed, if the variety of responses that occur within the chain as a result of the measure is also taken into account;
• The decrease in the available quantity of animal feed, raw materials and human foodstuffs will lead to rapid trade responses while demand remains the same. These responses have a damping effect on the production decline and reduce the closing of cycles;
• Shortages of fertilizer and specific amino acids will lead to the extra use of fertilizers and synthetic amino acids if the policy remains unchanged. This reduces decline in production, improves production efficiency and leads to negative sustainability effects;
• Use of residual flows helps to close cycles better and reduces the decline in production. The extent to which this response will occur is determined by safeguarding food safety through technology and regulations;
• Adjustment of the consumption pattern from animal to more vegetable protein strengthens the intended circular effects of the measure. At the same time, it causes a greater decrease in animal and an increase in vegetable production. Introducing the measure, without additional policy, will not lead to a faster change in consumption pattern;
• To estimate the actual effect of the measure, the effect of the total responses must be considered. Separate effects of individual responses say little about this;
• More insight into the market and price effects of (the effects of) the measure is necessary to estimate the extent to which the various responses will interact autonomously in mutual interaction.

The question what the effect of the measure is cannot be answered unambiguously. One thing is clear: introducing the measure without paying attention to other responses does not ensure a better closure of the European agricultural-food cycles and has a major negative impact on the vitality of the agriculture and food system in Europe. The workshops showed that stakeholder appreciation for the desirability and likelihood of the different scenarios in the long term are not far apart. Short-term cooperation to achieve these goals is hampered by the major impact of the measure on the European agricultural system. The results of this study can help sector, governments and NGOs to have a discussion about how they can achieve the intended cycle goals together, in a way that does not unnecessarily affect the vitality of plant and animal production. The results of this study provide a basis for this conversation.

Uitgebreide samenvatting

In deze rapportage is met behulp van de KringloopToets verkend, wat er gebeurt wanneer Europese landen geen veevoer en veevoergrondstoffen meer van buiten Europa importeren. Deze rapportage combineert a) de analyse die een groep stakeholders (bedrijfsleven, overheden en ngo's) heeft gemaakt in een serie workshops en b) de doorrekening van responsscenario's die daaruit voortkwamen.

Het directe effect van de maatregel en van zeven daar direct aan verbonden responsen zijn beschreven. Samen maken deze duidelijk wat er gebeurt wanneer Europa geen veevoer meer van buiten haalt. Vanuit een gezamenlijke duiding van het beoogde doel van de maatregel, is ervoor gekozen om de effecten van de maatregel in beeld te brengen door middel van:

- De gekwantificeerde N-kringloop van het Europese landbouw- en voedselsysteem, gebaseerd op een wetenschappelijk gefundeerd model;
- De daaruit af te lezen N-balans, inclusief import, export, verliezen, plantaardige en dierlijk N-productie en de Europese N-consumptie
- Een kwalitatieve inschatting van effecten op de KPI's Kringlooplandbouw van LNV.

Directe effecten van de maatregel

Wanneer Europa geen veevoergrondstoffen meer van buiten haalt, grijpt dat in op de kringloop. Het zorgt direct voor een verschuiving in de bestaande balans. Het scenario 'directe effecten' (3.2) beschrijft de effecten van de maatregel zonder dat stakeholders in de keten hebben geanticipeerd op die onbalans. De 'directe effecten' van de maatregel, tonen een afname van de hoeveelheid veevoer. Hierdoor daalt de omvang van de Europese dierlijke productie. Dat leidt tot een tekort aan mest, met een daling van de Europese plantaardige productie tot gevolg. Er worden dus minder plantaardige producten geproduceerd voor zowel dierlijke als humane consumptie. De binnen Europa beschikbare hoeveelheid (dierlijke én plantaardige) producten voor humane consumptie dalen; de beschikbare hoeveelheid dierlijke producten voor humane consumptie neemt met een derde af. Het effect op het sluiten van kringlopen is gering.

Zeven respons scenario's

De onbalans in het systeem leidt tot responsen. Deze responsen zijn uitgewerkt in 7 responsscenario's. Hoofdstuk 4 beschrijft 4 reparatiescenario's. Dit zijn scenario's waarin partijen maximaal inzetten op herstel van de tekorten, om te kunnen voldoen aan de bestaande vraag naar dierlijk en plantaardig voedsel. Hoofdstuk 5 beschrijft 3 adaptatiescenario's. Daarbij ligt de focus op verschillende manieren van aanpassing van de consumptie binnen de ruimte die het systeem biedt.

Reparatiescenario's (H4)	Adaptatiescenario's (H5)
4.1 Meer Europese veevoerproductie en meer import van plantaardige producten voor humane consumptie.	5.1 Import (en afname export) van dierlijke producten.
4.2 Meer kunstmest en synthetische aminozuren.	5.2 Consumptie van minder dierlijke, meer plantaardige eiwitten.
4.3 Verhogen van de efficiëntie van teelt en veehouderij.	5.3 Consumptie van minder vlees, meer vis
4.4 Benutten van reststromen.	

Effecten van de losse scenario's
Elke respons heeft een eigen effect op de N-kringloop, de N-balans en de indicatoren voor kringlooplandbouw van het Ministerie van LNV. Deze effecten zijn beschreven in hoofdstuk 4 en 5

- De respons tot meer Europese veevoerproductie en meer import van plantaardige producten voor humane consumptie (4.1) leidt tot een herstel van het oorspronkelijke niveau van dierlijke productie en consumptie. Dat herstel komt tot stand door een verschuiving van grondgebruik binnen en buiten Europa, en levert over het geheel genomen geen duurzaamheidswinst op.
- De respons tot gebruik van meer kunstmest en synthetische aminozuren (4.2) brengt de plantaardige productie terug op het oorspronkelijke niveau; de dierlijke productieomvang herstelt gedeeltelijk. Door vervanging van organische door synthetische inputs zorgt deze respons voor verlies op verschillende duurzaamheidsaspecten.
- De respons tot het verhogen van de efficiëntie van teelt en veehouderij (4.3) kan met de nodige investering in land en innovatie de plantaardige productie vergroten en de dierlijke productie terugbrengen naar het huidige niveau. Het vraagt meer input van hulpstoffen (denk aan kunstmest), wat zorgt voor negatieve duurzaamheidseffecten.
- De respons tot het meer gebruik van reststromen (4.4) helpt kringlopen beter sluiten, doordat reststromen voor een hoogwaardiger doel worden benut. Hiermee kan ongeveer de helft van de daling in de hoeveelheid veevoer worden opgevangen. Grote belemmering is het risico voor de voedselveiligheid.
- De respons tot meer import (en minder export) van dierlijke producten (5.1), zorgt voor een schijnbare duurzaamheidswinst binnen Europa. Maar zowel de economische opbrengst als de ongewenste milieu-impact zijn hiermee verplaatst naar regio's buiten Europa.
- De respons tot consumptie van minder dierlijke en meer plantaardige eiwitten (5.2) zorgt, wanneer de totale hoeveelheid eiwit binnen Europa geproduceerd wordt, voor een stijging van plantaardige productie en een grotere afname van dierlijke productie. Dit heeft een positief effect op het sluiten van kringlopen en op andere duurzaamheidsaspecten. Het gaat hier echter over een systeeminnovatie, met ingrijpende veranderingen op het gebied van zowel productie als consumptie.
- Met de respons tot consumptie van minder vlees, meer vis (5.3) kan het huidige consumptieniveau van dierlijke eiwitten worden hersteld. Dit levert voornamelijk een verschuiving op van bijeffecten van land naar zee en/of van binnen Europa naar buiten Europa.

Interactie tussen scenario's
In deze studie zijn de scenario's afzonderlijk van elkaar uitgewerkt en doorgerekend. Dit biedt inzicht in de doorwerking daarvan in de kringloop. In werkelijkheid treden ze echter tegelijkertijd op en interacteren met elkaar. In zekere zin concurreren de responsen dus met elkaar. De uiteindelijke verhouding tussen de responsen is afhankelijk van de snelheid waarmee responsen optreden, de mate waarin ze actief worden geremd of gestimuleerd en welke responsen lang blijven doorwerken. Hoofdstuk 6 beschrijft de samenhang tussen de responsen.

Op basis van economische wetmatigheden mag worden verwacht dat een aantal relatief snelle en 'eenvoudige' handelsresponsen als eerste optreden. De bestaande Europese veehouderij zal veevoer blijven vragen, als gevolg waarvan veevoerprijzen zullen stijgen en Europese akkerbouwers overstappen van voedselproductie naar voerproductie (4.1). De afname van mest en de daling van de eiwitkwaliteit in het voer zullen snel gecompenseerd worden door extra input van kunstmest en synthetische aminozuren (4.2). Wanneer voedselketens niet kunnen voorzien in een gelijkblijvende vraag naar dierlijke eiwitten, zullen zij als respons daarop meer dierlijke producten van buiten Europa halen, en/of minder exporteren (5.1). En diezelfde voedselketens zullen in de vraag naar vlees proberen te voorzien door extra aanbod van vis (5.3).

De overige responsen zijn diepgaander en langzamere veranderingen. Deze zullen minder automatisch optreden. Voor de respons van het opwaarderen van reststromen (4.4) moeten de risico's voor voedselveiligheid eerst worden geminimaliseerd. Ook het verhogen van de efficiëntie (4.3) en het vervangen van dierlijke door plantaardige eiwitten (5.2) zullen minder snel op gang komen dan de handelsresponsen. Dit zijn omvangrijker, deels systemische, veranderingen. Het optreden hiervan is

met name afhankelijk van flankerend beleid. Op basis van de wenselijkheid van responsen kunnen deze gericht worden gestimuleerd of geremd.

Conclusies
Op basis van de beschreven resultaten komen de volgende conclusies naar voren. Deze conclusies worden in hoofdstuk 7 nader toegelicht:

- Het bepalen van de consequenties van het stoppen met import van veevoergrondstoffen van buiten Europa, vereist diepgaand inzicht in de zeer complexe kringloop van het Europese landbouw- en voedselsysteem.
- De consequenties van die maatregel kunnen alleen beoordeeld worden, wanneer ook de verscheidenheid aan responsen wordt meegewogen, die als gevolg van de maatregel binnen de keten optreden.
- De afname van de beschikbare hoeveelheid diervoergrondstoffen en humane voedingsmiddelen leiden bij een gelijkblijvende vraag tot snelle handelsresponsen. Deze responsen hebben een dempend effect op de productiedaling, en verminderen het sluiten van kringlopen.
- Tekorten aan mest en specifieke aminozuren leiden bij gelijkblijvend beleid tot extra gebruik van kunstmest en synthetische aminozuren. Dit vermindert daling in productie, verbetert productie-efficiëntie en leidt tot negatieve duurzaamheidseffecten.
- Inzet van reststromen helpt kringlopen beter te sluiten en vermindert de daling van productie. De mate waarin deze respons zal optreden, wordt bepaald door borging van voedselveiligheid via techniek en regelgeving.
- Aanpassing van het consumptiepatroon van dierlijk naar meer plantaardig eiwit, versterkt de beoogde kringloopeffecten van de maatregel. Tegelijkertijd zorgt het voor een groter daling in dierlijke en een stijging in plantaardige productie. Instellen van de maatregel leidt, zonder aanvullend beleid, niet tot een snellere verandering van het consumptiepatroon.
- Voor inschatting van het werkelijke effect van de maatregel, moet het effect van het totaal aan responsen worden bekeken. Losse effecten van individuele responsen zeggen daar weinig over.
- Meer inzicht in markt- en prijseffecten van (effecten van) de maatregel is noodzakelijk om een inschatting te maken van de mate waarin de verschillende responsen autonoom in onderlinge interactie zullen optreden.

De vraag wat het werkelijke effect is van het instellen van de maatregel, is daarmee niet eenduidig te beantwoorden. Eén ding is duidelijk: het instellen van de maatregel zonder aandacht voor overige responsen zorgt niet voor een betere sluiting van de Europese landbouw-voedsel kringlopen en heeft een grote negatieve impact op de vitaliteit van het landbouw en voedselsysteem binnen Europa.

In de workshops bleek dat waardering van stakeholders voor wenselijkheid en waarschijnlijkheid van de verschillende scenario's op de lange termijn niet ver uiteen liggen. Samenwerking op de korte termijn om deze doelen te realiseren, wordt in de weg gestaan door de grote impact van de maatregel op het Europese landbouwsysteem.

De resultaten van deze studie kunnen sector, overheden en Ngo's helpen om het gesprek te voeren, hoe zij samen de beoogde kringloopdoelen kunnen realiseren, op een manier die de vitaliteit van de plantaardige en dierlijke productie niet onnodig raakt. De resultaten van deze studie leggen een basis voor dit gesprek.

1 Background and ambition

In recent years, improving the circularity of nutrient cycles in food production and consumption has become an increasingly explicit aspiration. The use of animal feed that originates exclusively in Europe is often mentioned as a possible measure to address this problem. In practice, however, the focus on closing nutrient cycles and/or increasing regional food production has led to few concrete policies or actions. An important cause of this slow progress in this is the lack of clarity about what closing nutrient cycles means, and what consequences it would have if the Dutch or EU livestock farming sector no longer imports animal feed raw materials from outside Europe. Indeed, is this a solution for improving the circularity of nutrient cycles?
That is why a number of parties in the animal production chain, at the initiative of Nevedi, have explored the consequences of a measure where European livestock farming no longer imports animal feed raw materials from outside Europe. This exploration was carried out using the Nutrient Cycle Assessment Tool (NCAT / KringloopToets*;* Bremmer et al., 2020): an instrument that uses interactive workshops to create a broad picture of the influence of measures on cycles based on a combination of practical and expert knowledge. Unlike most other analysis and exploration tools, the NCAT visualises the total complexity in such a way that it is manageable for the stakeholders involved. In this case, that broad picture includes the effects of a ban on animal feed raw materials produced outside Europe on a range of cycle parameters and on the size and balance of production of the agricultural and food system in Europe. This report presents this broad picture.

1.1 No animal feed from outside Europe

The attention for sustainable animal feed is increasing. The origin of animal feed raw materials plays an important role in this. According to ABN Amro (Hilkens, 2015; Berntsen, 2015) there are three reasons why animal feed from outside Europe, and specifically soy from South America, is under pressure:

- Soybean production negatively impacts ecosystems and communities in Brazil and Argentina. It negatively impacts valuable natural habitats, it violates the land rights of the local population and it uses pesticides heavily.
- Imports of South American soy makes Europe vulnerable to geopolitics and currency fluctuations.
- International flows of raw materials cause the mineral balance to become distorted, both in South America and in Europe.

These arguments are used by NGOs, businesses, government agencies and public bodies. In doing so, each party has a different emphasis. As a result, the parties also have a different focus when it comes to solving these issues. There are also differing opinions about the effect of banning imports of animal feed raw materials from outside Europe.

The animal feed sector has long been committed to making existing flows more sustainable. For soy, one example is the Fefac Soy Sourcing Guidelines (FSSG), which also include the RTRS label. For palm oil, one example is the Roundtable on Sustainable Palm Oil (RSPO). Soy and other animal feed raw materials are now produced at the location where the production conditions for those products (such as climate) are most suitable. Reducing that efficiency not only has economic consequences, but can also have negative consequences for the environment. Less efficient production means a higher environmental impact per unit of product.

Policy makers and civil society organisations often prefer shifting entirely to animal feed that is sourced locally instead of making incremental improvements to the sustainability of existing flows. By

shifting entirely to local sources, feed-manure cycles can be closed more easily and transport distances can be reduced. Production that takes place closer to home may also be easier (more reliable, cheaper) to certify and monitor.

However, locally sourced livestock feed is not only valued based on technical considerations. In the eyes of the general public, 'locally sourced' intuitively matches sustainability. Technical considerations aside, this more emotional argument plays an important role in the considerations that are made. In the choices they make, companies want to have a story that appeals to consumers, just as government agencies, public bodies and NGOs take into account the preferences of voters and supporters.

Ambitions for using animal feed of European origin have already been laid down in *Het Verbond van Den Bosch* – a sustainability agreement between farmers, value chain parties and government – (Van Doorn Commission, 2011), and are explicitly mentioned in the context of circular agriculture (LNV, 2019). The European Commission has also initiated policy to promote the production of plant proteins in Europe (European Commission, 2018). It is also relevant in relation to the promotion of Land-based dairy farming (Commissie Grondgebondenheid, 2018).

1.2 Managing complexity with the *KringloopToets*

In both the Dutch and European context, therefore, there is talk about reducing imports of feed raw materials from outside Europe. But the consequences – positive and negative – of this reduction are estimated very differently. And that makes it extremely difficult to develop effective policies. Making animal feed production more sustainable and improving the Nutrient circularity is extremely complex because the system in question has grown in recent decades and many different parties have become involved. Changing this system is a major challenge due to the large number of factors and actors involved, all of which need to be set in motion. At the same time, the complex interrelationships have many beneficial aspects. This can change when you start creating movement. Due to all these interrelationships and possible consequences, a simple answer to the question of what will happen when animal feed no longer originates from outside Europe is not possible.

Any potential change in such a complex issue requires collaboration. At the same time, the inherent complexity causes an impasse between parties. After all, everyone has their own position and holds on to it. That position is based on their own values and interests and often has a strong factual underpinning to justify itself. As a result, the various parties use different sets of facts and have different values and interests. It is therefore desirable that these parties enter into discussions about what should be done. In doing so, they should agree on how things are interrelated (how the system actually works).

The *KringloopToets* (NCAT) contributes to this process. Experience has shown that the 'stories' (the position and its substantiation) the parties tell themselves and each other are generally valid, but that they only paint part of the big picture. They are part of a larger story, in which the stories of others also have a place. The NCAT helps to provide insight into this broader story. Your own point of view is put into perspective, just like the views of others. This creates a solid, factual basis, which is essential for a constructive discussion with each other.

The value of the process lies in jointly understanding the interrelationship of our agricultural and food system. The essence is in the complexity and the sum of nuances. To understand this, in this report we describe various responses and their effects in separate scenarios. The scenarios provide insight into mechanisms and how they operate. It can be tempting to pick out that one scenario that substantiates and confirms your own point of view. However, a real answer to what will happen if animal feed no longer originates from outside Europe can only be found by looking at the scenarios outlined and their effects in relation to each other. We hope that this report will invite you to connect your own arguments with the arguments of others and join this broader, shared story that can break through impasses on improving the Nutrient circularity.

2 The NCAT (*KringloopToets)* approach

The central question in this report is what happens when European countries use only animal feed (or raw materials for feed) of European origin. This question has been answered with the help of the *NCAT*: a discussion model that helps stakeholders to jointly gain insight into what it means to improve the Nutrient circularity. In this chapter we briefly introduce the NCAT, and how we have used it to help answer this question.

2.1 The NCAT for tackling complex issues

The NCAT is a discussion and analysis model. It helps parties to formulate a collective image of options for closing nutrient cycles with the aim of making this concept tangible.

The NCAT is a process involving multiple workshops in which government agencies and public bodies, businesses and NGOs look together at what happens when measures aimed at closing nutrient cycles are introduced. The goal is to work together on a common basis, so that parties are talking about the same thing. On that basis, they can arrive at responsible, constructive and well-supported measures for closing nutrient cycles.

During the workshops, coordination and joint fact-finding are paramount. With the NCAT, the participants take a broad look at all parts of the cycle and how those parts are interrelated; the cycle at the farm, regional, national and international level; the consequences for the economy and trade flows; the conflicts or connections with other sustainability themes; and the short term and the long term.

The results of the NCAT are always based on the following combination: a concrete issue from practice, practical knowledge from various fields, and expert state-of-the-art knowledge from various disciplines. One or two experts always participate in the workshop. They supplement the existing images of participants with relevant expertise. Between the workshops, they also specify the consequences of measures. Based on the input of this expert knowledge, participants take joint follow-up steps.

The insights gained are always discussed in the interim, so that a truly shared picture is created. At the end, the results are recorded in a report. This establishes a shared basis that participants can fall back on and allows non-participants to also benefit from the insights gained.

2.2 Application of the NCAT to the case of European feed raw materials

A series of workshops was held with a diverse group of stakeholders using the NCAT. In these workshops, participants analysed system responses if European countries ceased importing raw materials for feed from outside Europe. The measure – a ban on imports of animal feed from outside Europe – was used as a hypothesis. It was a scenario exercise aimed at elucidating the possible effects of such a measure. To ensure understanding, this hypothesis was implemented quite rigidly in the workshops. By participating in this scenario exercise, the participants did not make any statements about the desirability or probability of introducing such a measure.

Despite its hypothetical nature, this exercise is certainly relevant. Government agencies and public bodies at various levels are looking at regional animal feed sourcing; in the societal debate (Fueled by

NGOs) this topic is appearing more and more frequently; and in response to this, chain parties are exploring options for achieving this in practice. For these considerations and dialogues, the NCAT offers a broad view of the possible consequences of increasing the regional sourcing of animal feed. It provides insight into the complexity of making food production more sustainable, especially closing nutrient cycles. This creates a strong factual basis that can serve as input for each of these considerations and dialogues.

2.3 The realisation of results based on workshops and expert knowledge

The results presented in this report came about in interaction between participants with practical knowledge and scientific experts. In a step-by-step approach, a series of five workshops explored the possible effects of the aforementioned measure and how this would impact the agricultural and food system. Government agencies and NGOs were strongly under-represented in the initial group of participants. To overcome this, two of the five workshops were therefore repeated with additional participants. Ultimately, a diverse group of stakeholders from business, government and NGOs took part. Business was most strongly represented, not only with delegates from the animal feed industry, but also from the primary sector and the fertiliser industry.

In mapping out the consequences of a ban on the input of feed raw materials from outside Europe, the knowledge of the participants was taken as a starting point. Due to the diversity of the group and the close involvement of many participants with the theme, this quickly provided a rich picture. At the same time, questions also arose on various points. Experts from Wageningen UR and Blonk Consultants worked on these in between the workshops. The input from experts was always presented in the workshops, where it was discussed and then used by the participants in subsequent steps in the process of mapping out the possible consequences of the measure. Various scenarios were discussed and explored in the workshops.

In this report these scenarios have been specified and presented in greater depth. The aim of this was to provide readers who did not attend the workshops with insight into the various effects and the additional complexity and nuance in relation to the issue. The starting points for the scenarios were based on the workshops. In order to provide an understanding of mechanisms of action and effects, the principles of each separate scenario have been implemented radically. In reality, none of these responses will occur independently of the others. Every reality will therefore be less radical than each individual scenario.

To describe these scenarios in a well-founded manner, a scientifically-based model was developed on the basis of which Nitrogen balances could be specified for the various scenarios. Calculations with this model form the basis for the numerical elaboration of the scenarios.

The estimates of the participants were used to elaborate the broader circular effects – based on the key performance indicators (KPIs) of Circular Agriculture of the ministry of agriculture (LNV). These have been checked and, where necessary, supplemented by the experts involved. This estimate therefore concerns an expert opinion based on robust knowledge from practice and science. Estimates of the broader circular effects remain open to discussion, and that is precisely the intention. The exact score of benefits and disadvantages is less relevant than the fact that a diverse group of stakeholders has been involved in thinking about all the aspects that play a role in circularity. It is important to consider these broad effects in the choices that are made.

2.4 Definitions used

To gain a better understanding of the consequences of imposing a ban on non-EU raw materials, a distinction was made between the measure, the direct effects of the measure, responses of

stakeholders to these effects and the subsequent effects on the cycle in both a narrow sense and a broader sense. We explain this below:

The measure is the *imaginary*[1] intervention that is central to this exploration: a ban on the import of raw materials for animal feed from outside Europe. This measure is delineated as follows:

- Europe includes the EU27, UK, Norway and Switzerland
- The import of animal feed raw materials from outside Europe is banned. This also applies to products with a dual purpose such as soy, palm kernels and sunflower seeds; they are no longer imported.
- To estimate the direct effects, imports and exports of chemical fertiliser, animal products and plant products have been fixed at the current level; for a number of responses, one of these parameters was made variable and studied.

The direct effects of the measure are effects that arise from the way in which the cycle operates physically. These are effects that occur independently of a change in the behaviour of players in the system. Direct effects have a logical sequence through the chain. For example, a decrease in animal feed (without changing the behaviour of players in the system!) results in fewer livestock, which causes a decrease in animal manure, and this in turn results in a decrease in fertilisers for plant production. Direct effects reveal where the existing system will come under pressure as a result of the measure.

Responses describe the ways in which the stakeholders in the system respond to this pressure, i.e. the ways in which they change their behaviour or choices. This response can be aimed at 'repairing' the available amount of animal protein, so that the market demand can be met (**repair** response); or the decrease in the available amount of animal protein is considered to be a fact and the response is aimed at adapting to the newly created situation (**adaptation** response).

The subsequent effects are the consequences of the response of stakeholders for the nutrient cycle. These have been made transparent with the help of the NCAT. A distinction was always made between:

- **Effects of the response on the nutrient cycle in a narrow sense**. By this we mean the effects on the actual mineral flows. The N cycle was always used as the starting point in the exploration and was quantified based on existing knowledge.
- **Effects of the response on the nutrient cycle in a broader sense.** By this we mean the effects on other sustainability criteria. These were derived from the criteria for circular agriculture as used by the Ministry of Agriculture, Nature and Food Quality (LNV, 2018). These include the effect on greenhouse gases, biodiversity and animal welfare. These effects were assessed qualitatively.

2.5 Explanation of the NCAT model

In the NCAT, a figure is used that shows which parts the cycle consists of, and how they are related to each other. This can provide insight into how nutrients move through the cycle. This figure can relate to various scales (local, regional, national, international). In this report we use this figure to indicate the cycle at the European level.

1 This is a thought experiment. By examining this measure, participants do not in any way give their approval. The experiment is purely to gain more insight into the consequences of the measure ('what if')

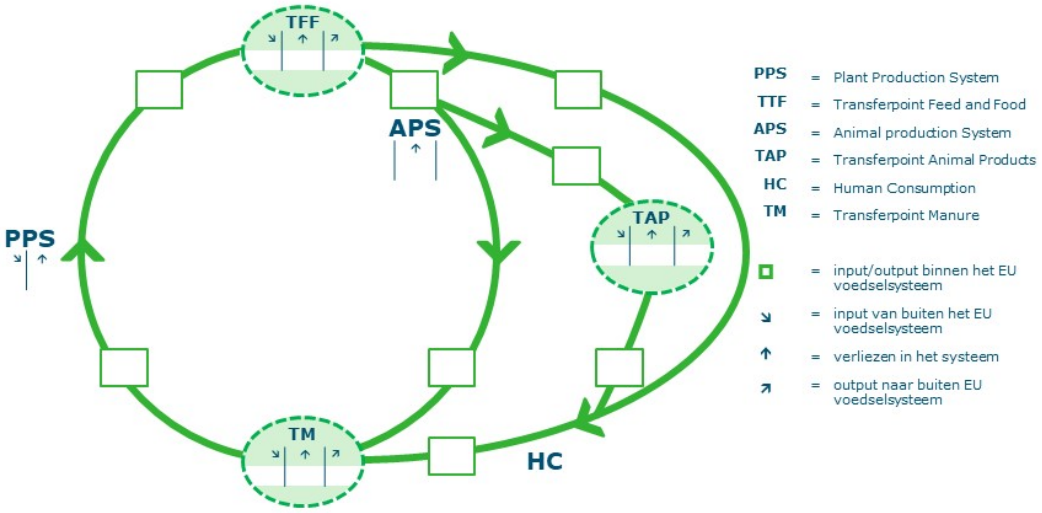

Figure 2.1 *Basic KringloopToets model.*

The figure indicates three primary processes in the agricultural and food system:

- Plant Production System (PPS), in which plant products are produced for animal feed and for human consumption with the help of animal manure.
- Animal Production System (APS), in which animal products are produced for human consumption with the help of animal feed. In addition, animal production generates manure.
- Human Consumption (HC), where people are fed with animal and plant products. This process also generates manure (human waste).

These three primary processes are linked by three transfer points at which plant products, animal products and manure are collected, processed, traded and transported. These three transfer points are: Transfer Point Feed & Food (TFF), Transfer Point Animal Products (TAP) and Transfer Point Manure/Fertiliser (TM).
Transfer points connect to production systems of different locations. Animal feed production outside Europe provides input into the European agricultural and food system via the Transfer Point Feed & Food.

Each cycle (at any scale level) is linked to cycles at other locations or scale levels. Each link in the chain has inputs and outputs. In addition, nutrients are lost at every link. No nutrient cycle is completely closed.

Various nutrient streams can be used in NCAT. In the present study, the nitrogen cycle (N; proteins) was used, which indicates the quantities of nitrogen that move through the cycle. At each transfer point you can see how much nitrogen comes from outside the cycle under consideration, how much loss occurs, and how much nitrogen disappears from the cycle to another cycle (including gaseous and soluble nitrogen compounds, which end up in the air or ground and surface water: losses). For example, at the TM there is no output (organic manure is not traded as a product outside Europe). Human waste is defined as a loss because it leaves our agriculture and food system via the sewage system. The input at the TM here is chemical fertiliser (regardless of whether or not it originates from Europe).

In the primary processes, nitrogen is converted from one product to another, for example from animal feed to animal products and manure. The figure quantifies how much nitrogen (expressed in Mt N) flows through the cycle in which form: how much N is in animal feed, and how much is in animal products and how much is in manure. An additional loss item has been included in the animal production system (in particular ammonia emissions), and in plant production there is a loss of

nitrogen to soil, water and atmosphere, while at the same time nitrogen deposition and fixation take place. There is a balance between input and output at every part of the cycle.

The N cycle of the NCAT model has been mapped out for each scenario. In addition, a table summarises the following data:

- The **total N input** as the sum of external N input from all transfer points
- The **total N loss** as the sum of the N losses at all transfer points
- The **total N export** as the sum of the total amount of N leaving the European agricultural and food system via the transfer points
- Total **plant N production** and total **animal N production** within the European agricultural and food system

2.6 Quantification of the effects with the help of the NCAT

To quantify the effects of measures on raw material flows, a simple balance has been developed, based on the structure of the NCAT. Each component of the NCAT as shown in Figure 2.1 has its own balance. Losses are shown per component.
For the quantification of nitrogen flows in the baseline situation, various datasets were used, including data on the current input of raw materials from Nevedi's raw materials index (2019) and the N balance for Europe based on the calculations of Leip et al. (2011) and FAO trade statistics and human consumption data (FAO, 2020). These existing databases and statistics do not always match exactly. In the final N balance, these differences have been eliminated based on expert judgement. In these cases, the values in the balance will not match the original numbers exactly.

2.7 Approach and result

In this exploration, the direct effects, responses and subsequent effects have been considered separately. First, the direct effects were examined, without any responses from the system occurring. Subsequently, seven response scenarios and their subsequent effects were examined one-by-one. Each of these scenarios provides insight into the dynamics of the system and increases understanding of the functioning of the cycle and the way in which other cycles operate within it. In reality, responses take place simultaneously and influence each other. Such a detailed picture is not provided here.

Chapters 3, 4 and 5 describe the results of the workshops and the underlying quantification. In addition, the insights that emerged from the various responses during the in-depth study are presented. In Chapter 6, the responses are explored in more detail and the relationship between the scenarios is described. Finally, Chapter 7 presents the conclusions.

3 Baseline situation and direct effects of the measure

3.1 Baseline situation

The starting point for the study is the baseline situation of the current food system in Europe. This is represented by the quantities of N that flow through the cycle. All N flows are shown in Figure 3.1, expressed in Mt N (megatons = million tons). The totals of N input, N loss and N export are shown in Table 1.

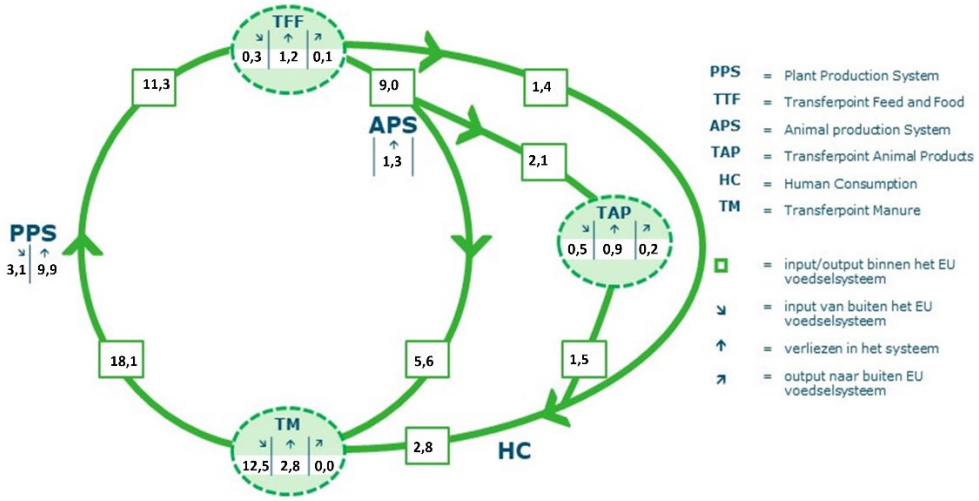

Figure 3.1 *Baseline situation for the N cycle of the current agriculture and food system in Europe.*

The key points from the European N balance are the following:

- A total of 17.4 Mt N enter the agriculture and food system. More than half of this amount consists of N from chemical fertiliser N (10.9 Mt)[2]. In addition, 3.1 Mt N enters plant production via deposition and N binding by legumes. 3.0 Mt N also enters through the Transfer Point Feed & Food (TFF). This consists of 2.7 Mt N of animal feed raw materials and 0.3 Mt N from imports of plant products for human consumption. At the latest, 0.5 Mt N enters through the Transfer Point Animal Products (TAP).
- The N losses in the current agricultural food system are large. N is lost in all phases of the cycle, totalling 17.0 Mt N. More than half of this is lost in plant production (9.9 Mt N). A second major loss is the loss from human excrement (3.1 Mt N). All N in human excrement disappears from the food cycle and is considered a loss. The losses in the animal production system are relatively small because the manure is used in the plant production system. The loss consists of emissions (1.7 Mt N), mainly ammonia. During the industrial processing of plant and animal products, 1.2 Mt N and 1.1 Mt N, respectively, is lost.

[2] Production of chemical fertiliser takes place outside the agricultural food system. Therefore no distinction has been made between fertiliser production from inside or outside Europe.

- In addition, 0.4 Mt N is exported as plant and animal products (0.1 Mt at the TFF and 0.3 Mt at the TAP).
- The total human N consumption in Europe is 3.1 Mt, which consists of 1.8 Mt N of animal products and 1.4 Mt N of plant products.[3] That total includes waste. The production and consumption of fish are not included in this model, because the production of farmed fish in particular then becomes intertwined with the production of meat, dairy and eggs. This makes the picture very complex.
- All output from human consumption (human manure and food waste) goes to the Transfer Point Fertiliser/Manure, where the full amount is counted as a loss. Some of the food waste may return to the cycle as compost, but these are very modest amounts.
- Based on 17.4 Mt N input (in addition to the throughput of N from animal manure), 3.5 (= 3.1 + 0.4) Mt is therefore fixed in products for human consumption. That is an N efficiency of 20%. This means that out of every 100 kg N, about 20 kg ultimately ends up in food.

Table 1 *N cycle (Mt) in the baseline situation.*

	Baseline situation
Total N input	17.4
Total N loss	17.0
Total N export	0.4
Total N plant production	11.3
Total N animal production	2.7
Total N consumption	3.1

3.2 Direct effects of the measure

3.2.1 What happens in this situation?

As soon as the measure is introduced, it has a direct impact on the nitrogen cycle within the European food system. The reduced availability of feed raw materials affects the entire nutrient cycle. To estimate **the direct effects**, we first looked at what would happen if, after the measure was introduced, the behaviour of all stakeholders remains the same. As a result, there is no change in the demand for food, input of chemical fertiliser, etc. The decrease in available raw materials leads to a series of successive effects (see Figure 3.2).

Less animal feed leads directly to lower production of animal products and thus less animal manure. This in turn leads to a decrease in plant production within the EU. In the model, this further decrease is allocated proportionally between plant production for human consumption and plant production for animal feed. Animal production continues to decline due to the decrease in available animal feed. Less production also reduces nitrogen losses (emissions) throughout the cycle.

[3] All amounts in the text and figures are rounded off/up to one decimal place. The amount of N for human consumption is 1.38 Mt N from plant products (rounded up to 1.4) and 1.75 Mt N from animal protein (rounded up to 1.8). In total this is 3.13 Mt N, which has been rounded off to 3.1 Mt N; the difference is the result of rounding. The total is therefore *not*: 1.4 + 1.8 = 3.2. These rounding differences occur more often.

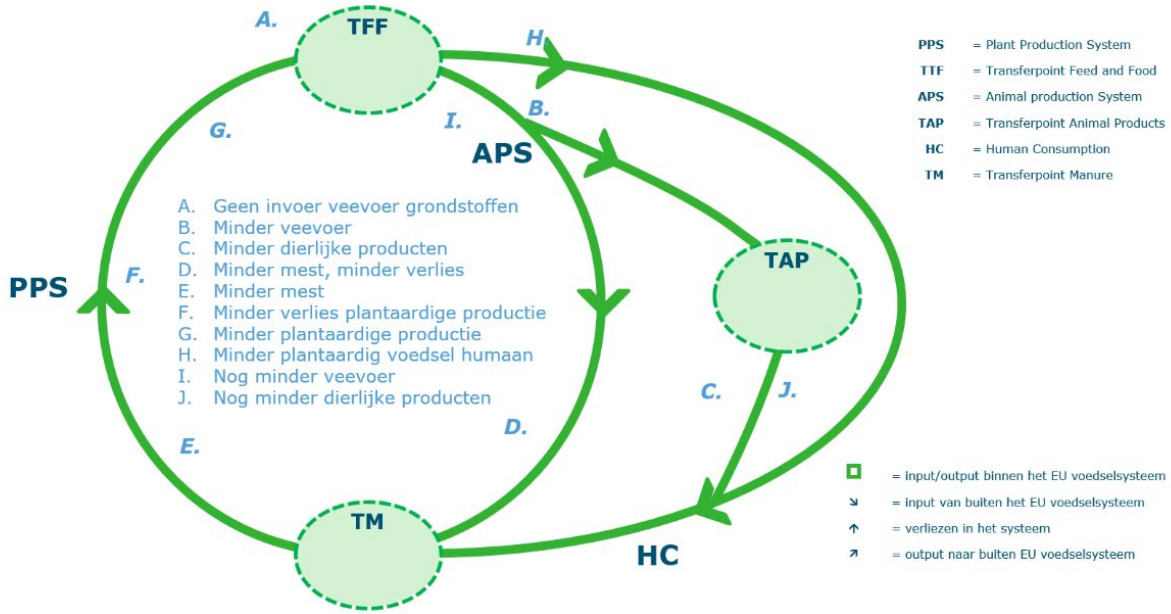

Figure 3.2 *Description of the events in the agriculture-food cycle when imports of animal feed raw materials from outside Europe are stopped.*

3.2.2 Effects on the nitrogen cycle

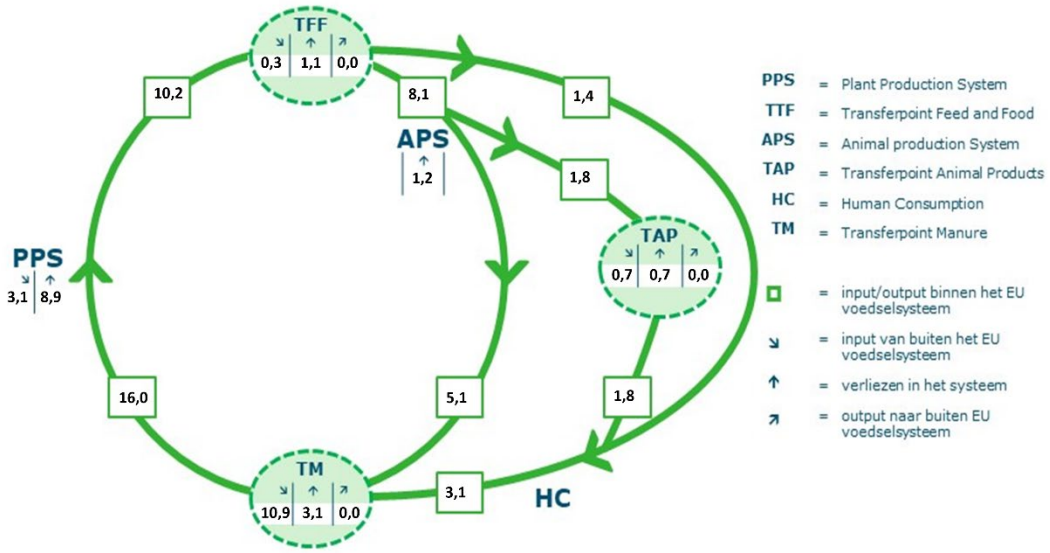

Figure 3.3 *N cycle in Europe after direct effects of the measure.*

The effects become more tangible in the quantified nitrogen cycle.

- The ban on imports of animal feed raw materials from outside the EU creates a gap of 63 Mt of feed raw materials (= 2.7 Mt N).

- The reduced supply of N leads to a decline of 30% in the total protein available for animal feed (8.1 Mt N instead of 11.6 Mt N). This protein is of lower quality on average than in the baseline situation because specific feed raw materials, especially soy, are less available.
- Due to the lower quantity and quality of animal feed, animal production decreases by 33% (1.8 Mt N instead of 2.7 Mt N).
- Due to the decrease in animal production, the amount of animal manure also decreases (5.1 Mt N instead of 7.2 Mt N), a decrease of 29%. This is smaller than the decrease in production volume, which is due to the reduced feed quality. Smaller numbers of livestock also lead to lower emissions during production (1.2 Mt N instead of 1.7 Mt N).
- Less animal manure (without change in fertiliser use!) means that less N is available as manure. The total amount of N available for plant production thus decreases by 12% (16.0 Mt N instead of 18.1 Mt N). That means lower N losses (8.1 Mt N instead of 9.9 Mt N).
- Less N manure leads to a 10% decrease in total plant production (10.2 Mt N instead of 11.3 Mt N).
- This decrease has an effect on both the availability of animal feed and the amount of plant protein for human consumption. The ultimate effect is a 28% decrease in animal products for human consumption (1.3 Mt N instead of 1.8 Mt N) and a decrease of 11% in plant-derived food for humans (1.2 Mt N instead of 1.4 Mt N). The total availability of protein for human consumption decreases by 22% (2.5 Mt N instead of 3.2 Mt N).
- This completes the cycle. Due to the decrease in the amount of imported animal feed, animal production decreases; this means that less manure is available; this means that less livestock feed can be grown and the amount of livestock feed decreases even further. For the calculations, this cycle was completed a number of times until the difference between two successive calculations was negligible.

Table 2 *N cycle (Mt) baseline situation and situation after direct effects of the measure.*

	Baseline situation now	Direct effects	%
Total N input	17.4	14.7	-15%
Total N loss	17.0	14.5	-15%
Total N export	0.4	0.3	-28%
Total N plant production	11.3	10.1	-10%
Total N animal production	2.7	1.8	-33%
Total N consumption	3.1	2.6	-18%

3.2.3 Effects on the nutrient cycle in a broader sense

The measure has a broader effect than on the nitrogen cycle alone. These effects have been mapped out qualitatively on the basis of the KPIs of circular agriculture as described in the *realisatienota Kringlooplandbouw* (circular agriculture realisation memorandum) of the Ministry of Agriculture, Nature and Food Quality. The effects are depicted in a spider web diagram, in which the baseline situation is shown as a 0-line.

- The cycle within Europe is not fundamentally changed by the measure. Input and losses decrease in absolute terms, but minerals are used in the same way.
- Due to the decrease in available animal feed, animal production and plant production (to a lesser extent) decrease. This also reduces the environmental impact. This is reflected in a positive effect on emissions, climate, ecosystems and biodiversity.
- The same decline in production has a negative economic impact, both for individual farms and for rural areas in general.
- The reduced production also means that less plant and animal food is available for human consumption. This does not lead to health deficiencies, but the effect on consumption is certainly noticeable (reduced food security). Without additional responses, less supply will also have an effect on food prices.

- With regard to the effect outside Europe, the positive effect on ecosystems (rainforests) is particularly worth mentioning.
- Not only the quantity of the animal feed declines, but also the quality, which causes feed conversion efficiency to deteriorate. This has an almost negligible negative effect on establishing circularity; that is why closing nutrient cycles scores 0 here. The effect on the health and welfare of the animals has also been kept at zero. There may be an effect, but it would also be very small.

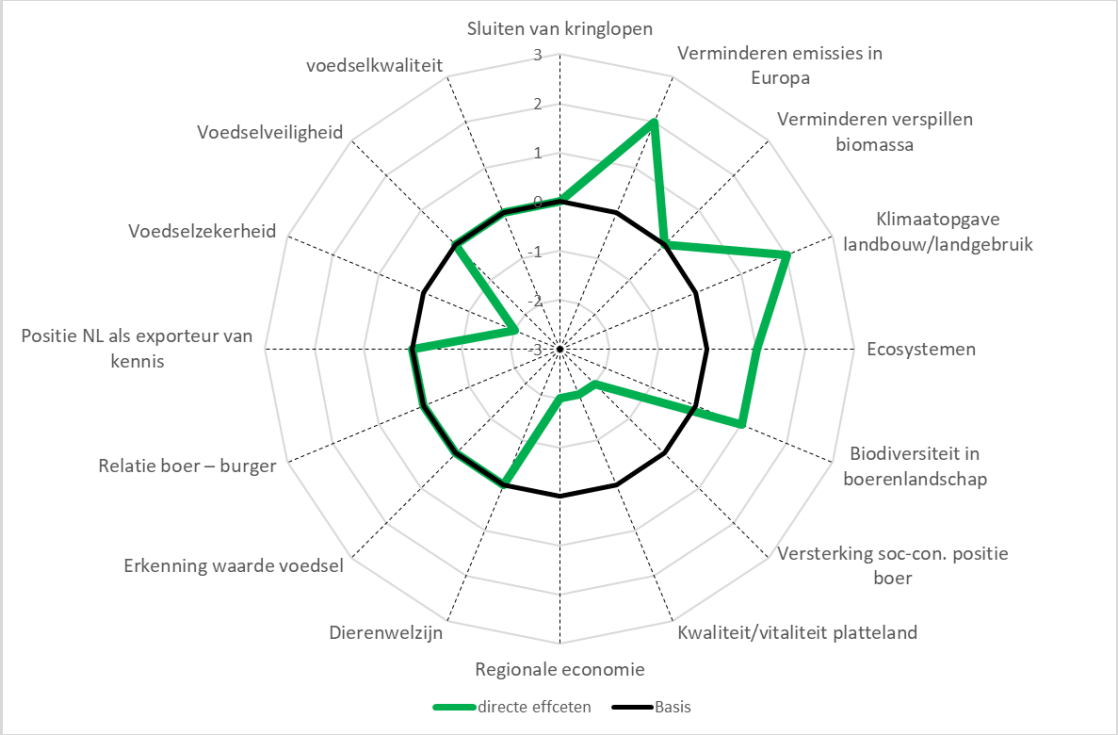

Figure 3.4 *Qualitative comparison of the direct effects of the measure versus the baseline situation, in accordance with KPIs of Circular Agriculture*.

3.2.4 Insights

- Introducing the measure has a direct effect on the production chain. Throughout the cycle, the decline in animal feed and animal production is greater than you would expect based on import figures alone. This has a direct effect on the products (both animal and plant) available within Europe for human consumption, but only a minor effect on closing nutrient cycles.
- The measure leads directly to shortages and imbalances in the existing system. Shortages of animal feed, chemical fertilisers and manure, agricultural land, and animal and plant products lead directly to strong responses in the system. These responses are described below.

3.2.5 Remarks

- The effects are described for the European agriculture and food system as a whole. The effects will be different for specific sectors and specific countries. This is related to their dependence on imported feed raw materials and to the competitiveness of the countries and sectors and their competitiveness vis-à-vis comparable sectors outside the EU.
- The effects within Europe are described, but of course the measure also has effects outside Europe. European imports of animal feed raw materials amount to approximately 12% of the total world trade in these commodities. Demand will fall, which will slow or even stop the expansion of agricultural land. This is expected to have a positive effect (albeit temporary) on emissions and land use. But the regional economy in the exporting regions will also decline, because the prices of raw materials will fall. Stopping these imports will certainly have an effect on the world market, but it will not disrupt it.

4 Repair responses

Shortages arise in the existing system immediately after the measure has been implemented. As a result, parties will change their behaviour and choices. We distinguish two types of responses: repair responses and adaptation responses. In this section we discuss repair responses. These are choices and adaptations with which parties try to close the resulting 'protein gap' – a decline in available animal feed, manure and land for animal feed production. With these responses the system continues to meet the existing demand for animal protein.

In this study, four repair scenarios have been distinguished

1. The shortage of animal feed leads to an increase in European animal feed production at the expense of European plant production for human consumption. As a result, more plant foods for human consumption are imported.
2. The shortage of manure leads to increased use of chemical fertilisers. At the same time, the lower protein quality leads to increased use of synthetic amino acids.
3. The shortages that have arisen lead to a further increase in efficiency in production within Europe. To deal with the shortages of plant and animal proteins that have arisen, the yield gap is narrowed (the difference in production efficiency between regions). Where possible, more fallow land will also be used to produce feed or food.
4. The resulting shortages lead to increasingly targeted use of residual flows for animal feed.

Each response has a specific effect on the cycle. The various responses were considered completely separately from each other. Each effect was quantitatively mapped for the N cycle. In addition, a qualitative estimate was made of other aspects of circular agriculture (KPIs circular agriculture).
To understand the expected effects, the responses were calculated separately. In reality, responses never occur sequentially and independently, but always simultaneously and in interaction with each other. In the description, the effects of each response are always compared with the direct effects of the measure. This is to estimate how the response attenuates or amplifies the effects of the measure. In a number of cases, a comparison is also made with the baseline situation, which is explicitly stated.

4.1 Repair through increased production of animal feed in Europe and increased imports of plant products for human consumption

4.1.1 What is the response?

Due to the ban on imports of animal feed raw materials from outside Europe, the pressure on agricultural land within Europe is increasing. Increased demand for feed crops grown within Europe is putting pressure on plant production for human consumption within the EU. As a result, land use within the EU for animal feed production is increasing, coupled with increased imports of plant products for human consumption. This response has a direct effect on the nutrient cycle.

4.1.2 Effects on the nitrogen cycle

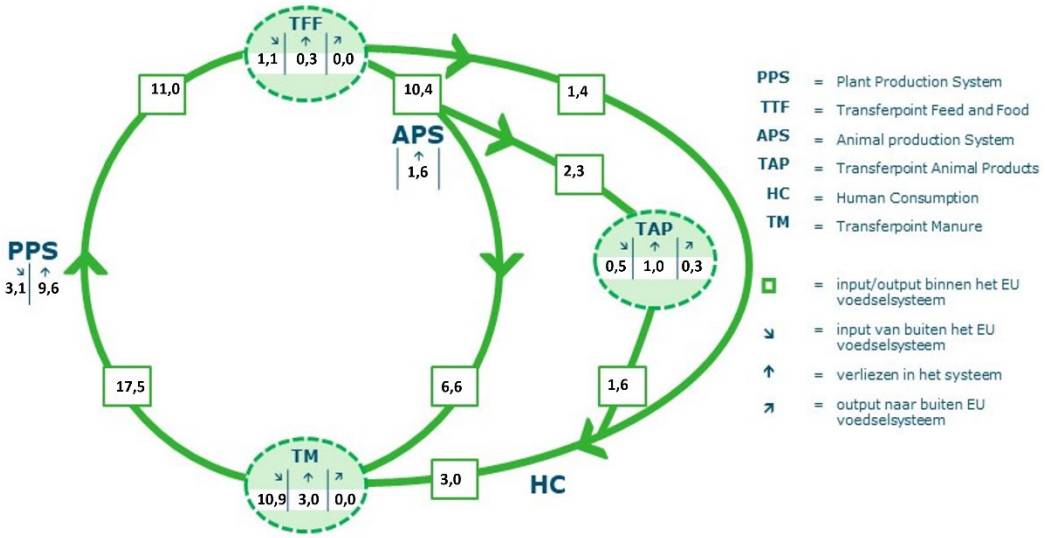

Figure 4.1 *Effects of the measure on the nitrogen cycle after the response (increased imports of plant-based food products).*

- A total of 2.7 Mt N additional animal feed is produced in Europe, which is at the expense of 2.7 Mt of plant production for human consumption. The resulting decrease in plant products for human consumption and the previous decrease in the baseline effects are compensated by imports of plant products for human consumption.
- Because there is a shortage of plant-based *raw materials* for human consumption, the decline in plant-based *products* can be offset with additional imports (for human consumption) of 0.8 Mt N (1.1 Mt N instead of 0.3 Mt N). As a result, a number of co-products from plant production that could otherwise be used as animal feed are absent.
- The amount of animal feed available for animal production therefore increases from 8.1 Mt N to 10.4 Mt N; and not to 11.6 Mt N as in the baseline situation.
- As a result of the direct effects, the amount of animal products available for consumption will be 1.6 Mt N instead of 1.3 Mt N.
- The increase in animal production results in more manure (6.6 Mt N instead of 5.1 Mt N), which leads to slightly higher plant production (11.0 Mt N instead of 10.2 Mt N).

Table 3 *N cycle baseline situation, direct effects of the measure and effects of the response of increased imports of plant-based foods (% change compared to the baseline situation).*

	Baseline situation	Direct effects	%	Increased imports of plant-based foods (4.1)	%
Total N input	17.4	14.7	-15%	15.6	-11%
Total N loss	17.0	14.5	-15%	15.3	-10%
Total N export	0.4	0.3	-28%	0.3	-30%
Total N plant production	11.3	10.2	-10%	11.0	-3%
Total N animal production	2.7	1.8	-33%	2.3	-13%
Total N consumption	3.1	2.6	-18%	3.0	-5%

4.1.3 Effects on the nutrient cycle in a broader sense

- Due to the displacement within the EU of the production of plant-based foods by animal feed crops, a substantial part of the contraction in animal production is attenuated. The direct effects are thus partly cancelled.
- As a result, the indirect positive effects on emissions, climate, ecosystems and biodiversity are lower compared to the direct effects: higher production leads to more environmental pressure. But the production and environmental pressure are still lower than in the baseline situation.
- For the same reason, the negative economic effects are attenuated. A partial recovery in production volume means that more producers can increase their production to previous levels.
- Due to the higher production, the amount of food for human consumption has also returned to the level in the baseline situation: food security has improved compared to the direct effects.

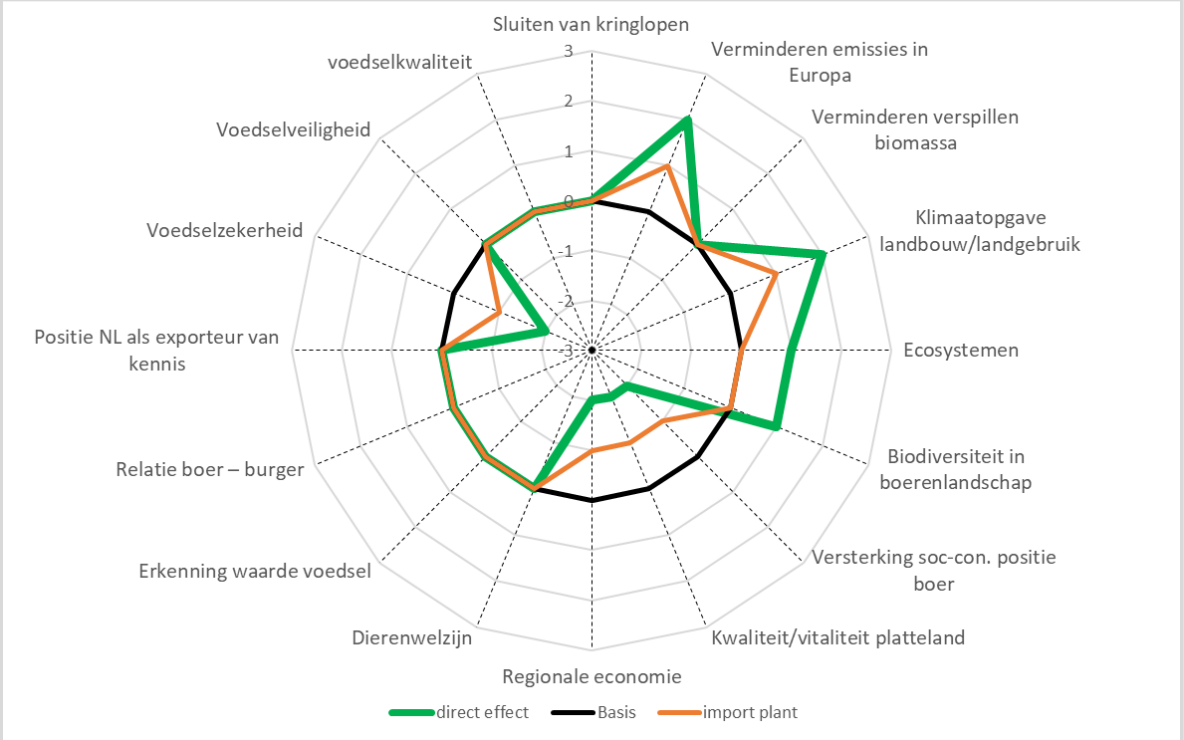

Figure 4.2 *Qualitative comparison of the effect after the response – increased imports of plant-based foods – with the direct effects of the measure and with the baseline situation, in accordance with KPIs of Circular Agriculture.*

4.2 Repair response with chemical fertiliser and synthetic amino acids

4.2.1 What is the response?

The measure reduces the amount of manure available for plant production. The protein composition of the available animal feed raw materials also worsens. An obvious response is to mitigate these effects with artificial means. This entails increased use of chemical fertiliser and more synthetic amino acids added to the feed to improve protein quality. Increased use of chemical fertiliser and synthetic amino acids increases the magnitude and efficiency of plant production and animal production, respectively. This response partly repairs the 'protein gap'. It also has effects on the nutrient cycle.

4.2.2 Effects on the nitrogen cycle

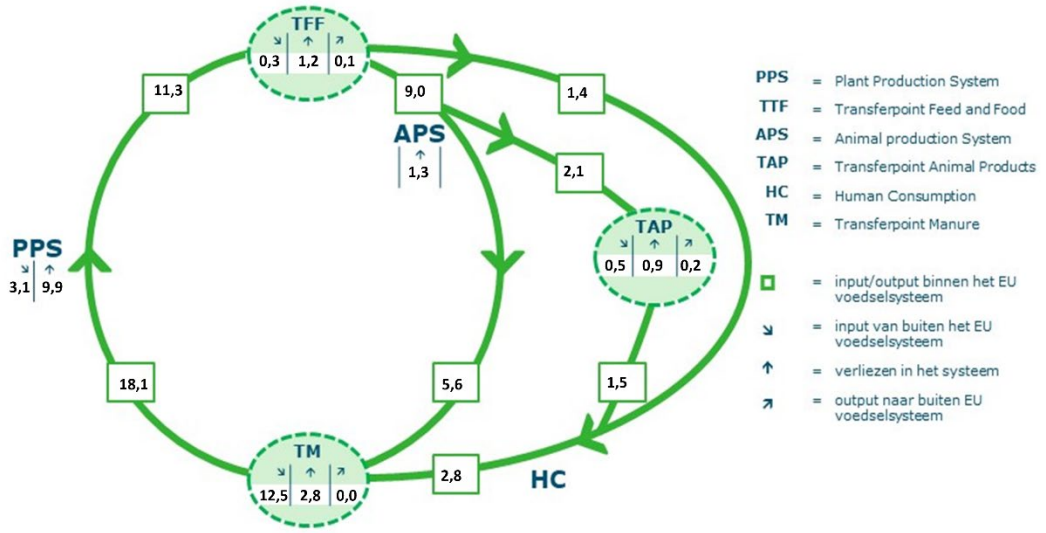

Figure 4.3 *Effects of the measure on the N cycle after the response of using more chemical fertiliser and synthetic amino acids.*

- By using chemical fertiliser, extra nitrogen (1.6 Mt N) is brought into the cycle (12.5 Mt N instead of 10.9 Mt N).
- By eliminating the shortage of available manure, plant production returns to the baseline level (11.3 Mt N instead of 10.8 Mt N).
- The amount of plant protein for human consumption also returns to the baseline level. The amount of available animal feed increases compared to the direct effects of the measure (9.0 Mt N instead of 8.1 Mt N), but a shortage continues due to the lack of imported animal feed.
- By using extra synthetic amino acids, the feed quality and efficiency of animal production return to the baseline level.
- More and better feed, in combination with higher efficiency, thus ensures a partial recovery of animal production (2.1 Mt N instead of 1.8 Mt N).
- At the same time, the quantity of manure (5.6 Mt N instead of 5.1 Mt N) and gaseous losses (1.3 Mt N instead of 1.2 Mt N) also increase slightly.
- The total effect is an increase in available animal products and the associated losses in processing. With unchanged exports, this means that 1.5 Mt N of animal proteins is available for human consumption. About one-third of the decrease in animal protein consumption is thus offset by this response.

Table 4 *N cycle baseline situation, direct effects of the measure and effects of response of using additional chemical fertiliser and synthetic amino acids (% change compared to the baseline situation).*

	Baseline situation	Direct effects	%	Chemical fertiliser and synthetic amino acids (4.2)	%
Total N input	17.4	14.7	-15%	16.3	-6%
Total N loss	17.0	14.5	-15%	16.1	-5%
Total N export	0.4	0.3	-28%	0.3	-18%
Total N plant production	11.3	10.2	-10%	11.3	0%
Total N animal production	2.7	1.8	-33%	2.1	-23%
Total N consumption	3.1	2.6	-18%	2.8	-9%

4.2.3 Effects on the nutrient cycle in a broader sense

- The use of additional chemical fertiliser and synthetic amino acids attenuates the direct effects of the measure, but does not return it to the baseline situation in most areas. Plant production is completely restored, and animal production is partially restored.
- The effects of the response on emissions, climate and ecosystems are still positive compared to the baseline situation, but less positive than the direct effects of the measure. In addition to emissions and climate, the production of chemical fertiliser (instead of the use of organic manure) results in more greenhouse gas emissions.
- Generally, chemical fertiliser is more harmful to ecosystems and biodiversity than organic manure, causing a lower score relative to the baseline situation.
- The use of synthetic amino acids and chemical fertiliser does lead to recovery of crop and animal production levels to some extent, but the effects on farmers' incomes, rural areas and the regional economy are still negative compared to the baseline situation.
- More food is again available for consumption, but there is no full recovery.

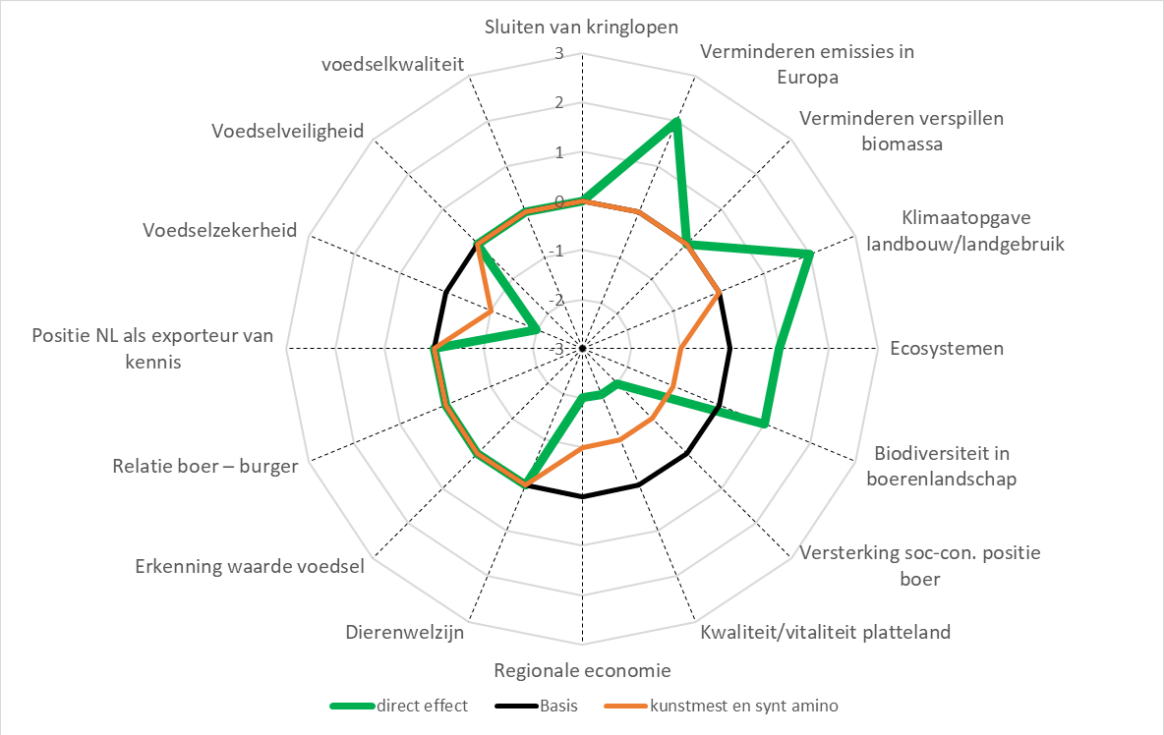

Figure 4.4 *Qualitative comparison of the effect after the response – using more chemical fertiliser and synthetic amino acids – with the direct effects of the measure and with the baseline situation, in accordance with KPIs of Circular Agriculture.*

4.3 Increasing the efficiency

4.3.1 What is the response?

Due to the scarcity of feed within Europe, more focus will be placed in plant and animal production on increasing the efficiency of the production and reducing losses. The crop yield per hectare can be improved with cultivation measures and additional fertilisation. This is possible especially at locations in Europe where the yield per hectare is still relatively low (yield gap). As a result of the scarcity, some of the land that is currently fallow will be used for production. The same mechanism applies to the animal sectors. Here too, the shortages of animal feed will increase efficiency, especially in regions where production is relatively low. Everywhere, efforts will be made to use the feed that is available as efficiently as possible.

4.3.2 Effects on the nitrogen cycle

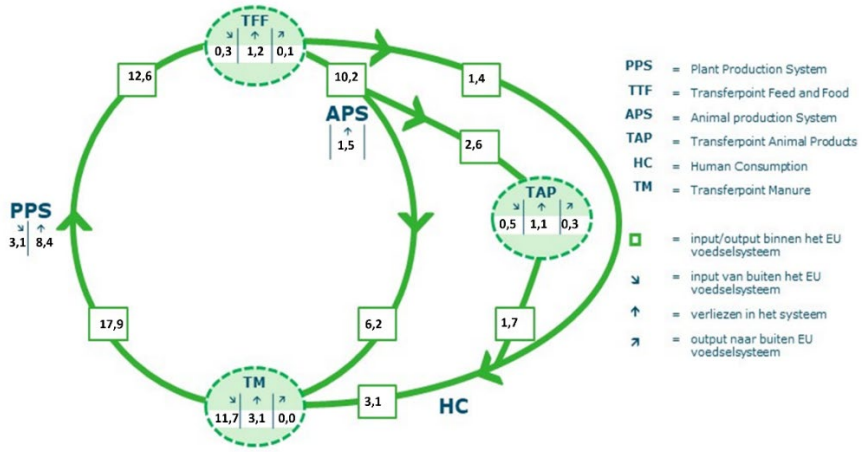

Figure 4.5 *N cycle effects of the measure after the response of improved efficiency in cultivation and livestock farming.*

- This scenario is based on the possibility of improving cultivation efficiency (more efficient nitrogen use through precision agriculture, for example) by 15%. In livestock farming, improved feed conversion of 15% for pigs and poultry and 5% for cows is assumed based on medium-term and long-term estimates (see Kuling & Blonk, 2016; Lesschen et al., 2020).
- In addition, crop production in Europe has increased to such an extent in this scenario that the consumption level returns to the baseline situation. Sufficient scope for this increased production appears to be available. Reducing the yield gap in Europe from an average of 42% to 20% would, according to Schils et al. (2018), lead to a total production increase for grains of 39%. In addition, the total amount of land available in Europe for protein-rich crops that does not directly compete with other land use is estimated at 1.8 million hectares as a minimum (Van Krimpen et al., 2013). With this production area, an increase in plant production of 9% can theoretically be realised. To restore consumption to the level in the baseline situation, the yield gap only needs to be partly closed and only part of the fallow land needs to be used for production.
- The increases in cultivation efficiency and production (closing the yield gap and using fallow land) together result in an increase in total plant production of 19% (12.6 Mt N instead of 10.2 Mt N). This more than compensates for the decreased plant production resulting from the direct effects: it amounts to a production increase of 12% compared to the baseline situation.
- For animal production, 10.2 Mt N is available for animal feed, restoring the magnitude of livestock farming to 2.6 Mt N. Due to the higher efficiency, the total amount of animal products is (approximately) restored to the baseline level of 1.7 Mt N.

- Due to more efficient production, however, less animal manure is generated than in the baseline situation. This is supplemented with additional chemical fertiliser (11.7 Mt N instead of 10.9 Mt N).

Table 5 *N cycle baseline situation, direct effects of the measure and effects of the response of improved efficiency in cultivation and livestock farming (% change compared to the baseline situation).*

	Baseline situation	Direct effects	%	Increased efficiency (4.3)	%
Total N input	17.4	14.7	-15%	15.5	-11%
Total N loss	17.0	14.5	-15%	15.2	-11%
Total N export	0.4	0.3	-28%	0.4	-3%
Total N plant production	11.3	10.2	-10%	12.6	12%
Total N animal production	2.7	1.81	-33%	2.6	-3%
Total N consumption	3.13	2.56	-18%	3.1	-2%

4.3.3 Effects on the nutrient cycle in a broader sense

- With increasing efficiency in cultivation and livestock farming, plant production rises above the baseline situation. Animal production rises to slightly below baseline.
- Due to improved feed conversion in animals and the improved input-output ratio in cultivation, nutrients are used more efficiently. This results in increased closure of cycles.
- Production is not only more efficient, production as a whole is also increasing. Total emissions and climate pressure are comparable with the baseline situation (with higher production). Additional input of energy and phosphate is needed to make marginal land more suitable for production.
- The more intensive use of land has a negative impact on ecosystems and biodiversity.
- More efficient production has positive effects for the economy: it restores the baseline situation.
- The knowledge and innovation needed for increased production efficiency is valued internationally.
- Because Europe now grows its own animal feed and crops for human consumption, the dependence on regions outside Europe has decreased considerably, thus enhancing food security. However, this makes Europe more dependent on aspects such as regional weather conditions.

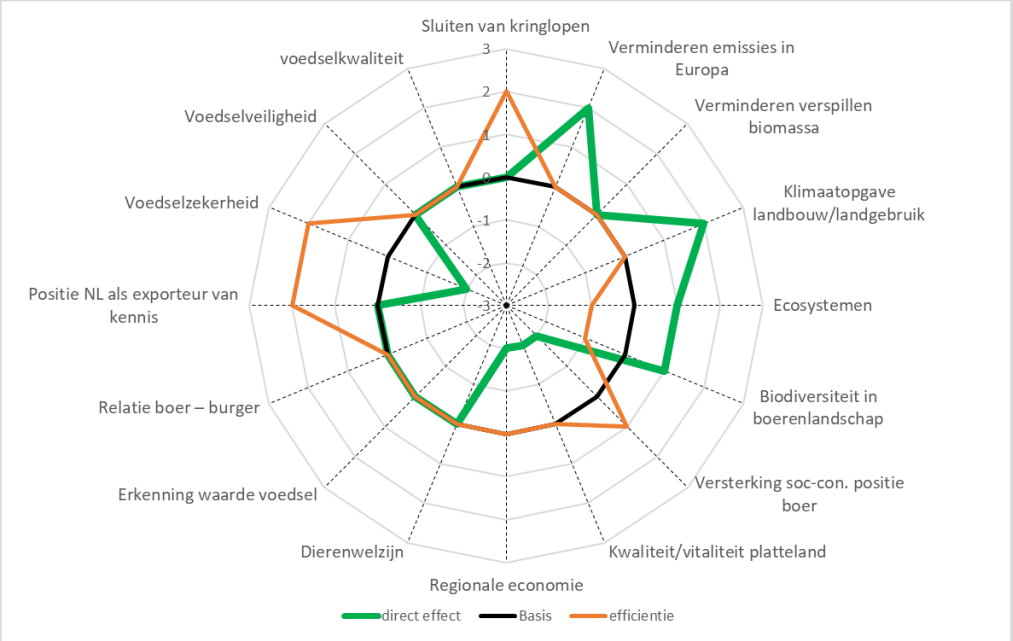

Figure 4.6 *Qualitative comparison of the effect of the response – improved efficiency in cultivation and livestock farming – compared to the direct effects of the measure and the baseline situation, in accordance with KPIs of Circular Agriculture.*

4.4 Repair response: Utilising residual flows

4.4.1 What is the response?

Due to the increasing scarcity of high-quality raw materials for animal feed, parties are looking for more options for utilising residual flows as animal feed. Animal meal (offal), swill (food waste) and poultry manure are potential high-quality raw materials for animal feed, but are not permitted at the moment due to food safety regulations. In addition, residues from plant production can potentially be used for animal feed.
When the scarcity of animal feed raw materials increases, investments in the safe and effective use of these residual flows will increase. The pressure on politicians to allow these residual flows to be used in animal feed will also increase. If the regulations become more flexible, more residual flows – that are currently underutilised – will be used directly or indirectly as raw materials for animal feed.

4.4.2 Effects on the nitrogen cycle

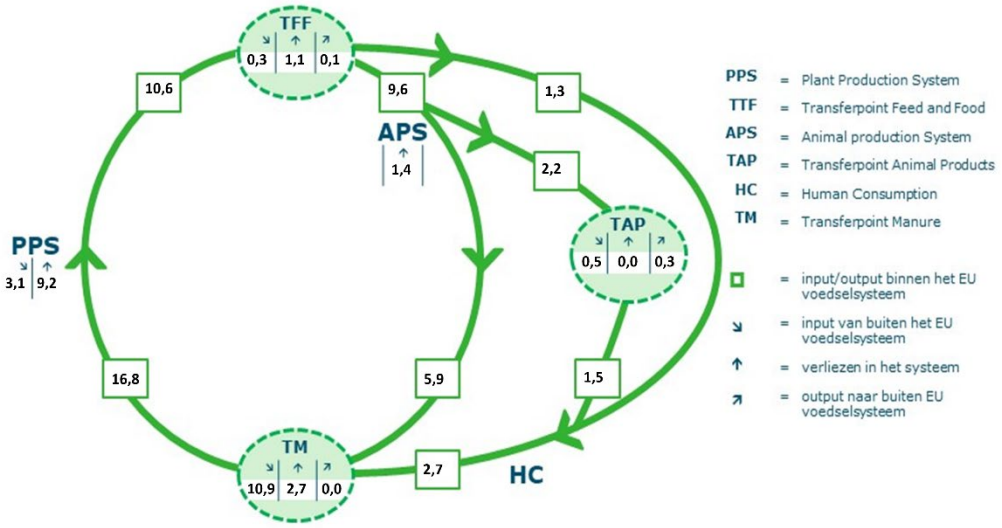

Figure 4.7 *N cycle effects of the measure after utilisation of residual flows.*

- Not every potential residual flow can be fully utilised. For the calculations it was assumed that 100% of offal can be used, 30% of poultry manure and 25% of swill.
- The resulting increase in available animal feed leads to increased animal production of 0.4 Mt N, thus totalling 2.2 Mt N instead of 1.8 Mt N.
- This results in 15% more animal products for human consumption (1.5 Mt N instead of 1.3 Mt N).
- Due to the higher production – and despite the lower availability of poultry manure for use in cultivation because it is partly used as animal feed – the total amount of animal manure increases.
- Due to the extra manure, plant production increases from 10.2 Mt N to 10.6 Mt N. This leads to a small increase in the amount of plant protein for human consumption of 0.04 Mt N (1.3 Mt N instead of 1.2 Mt N). Additional plant protein is also available for animal feed.
- More animal production in turn leads to more meat and bone meal and also more poultry manure, which further enhances the effects of the intervention. This effect has been included in the aforementioned figures.

- Due to the additional input of 1.2 Mt N of residual flows, the functioning of the cycle ultimately makes an additional 1.5 Mt N available as animal feed (9.6 Mt N instead of 8.1 Mt N).

Table 6 *N cycle basic situation, direct effects of the measure and the effects after utilisation of residual flows (% change compared to the baseline situation).*

	Baseline situation	Direct effects	%	Use of residual flows (4.4)	%
Total N input	17.4	14.7	-15%	14.7	-15%
Total N loss	17.0	14.5	-15%	14.5	-15%
Total N export	0.4	0.3	-28%	0.3	-15%
Total N plant production	11.3	10.2	-10%	10.6	-6%
Total N animal production	2.7	1.81	-33%	2.2	-18%
Total N consumption	3.13	2.56	-18%	2.8	-11%

4.4.3 Effects on the nutrient cycle in a broader sense

- By making better use of residual flows (for a higher-value purpose), nutrient cycles are closed more effectively. The use of animal meal also improves feed conversion.
- Higher production partly reverses the improvements in emissions, climate, ecosystems and biodiversity. Additional energy input is also required for the safe use of residual flows such as swill and animal meal, which has a negative effect on the climate.
- Negative economic effects from the 'direct effects' scenario have been partly reversed, because production recovers.
- Technical, logistical and organisational knowledge about the use of residual flows can be valued internationally.
- The amount of food available within Europe has not yet returned to its previous level, but more use is being made of European raw materials, which reduces dependence on external regions. At the same time, sourcing from a single region can also lead to vulnerability. Food security is therefore comparable to the baseline situation, but is different than before.
- Food safety of the scenario is neutral, because the use of residual flows is not permitted if food safety is endangered.

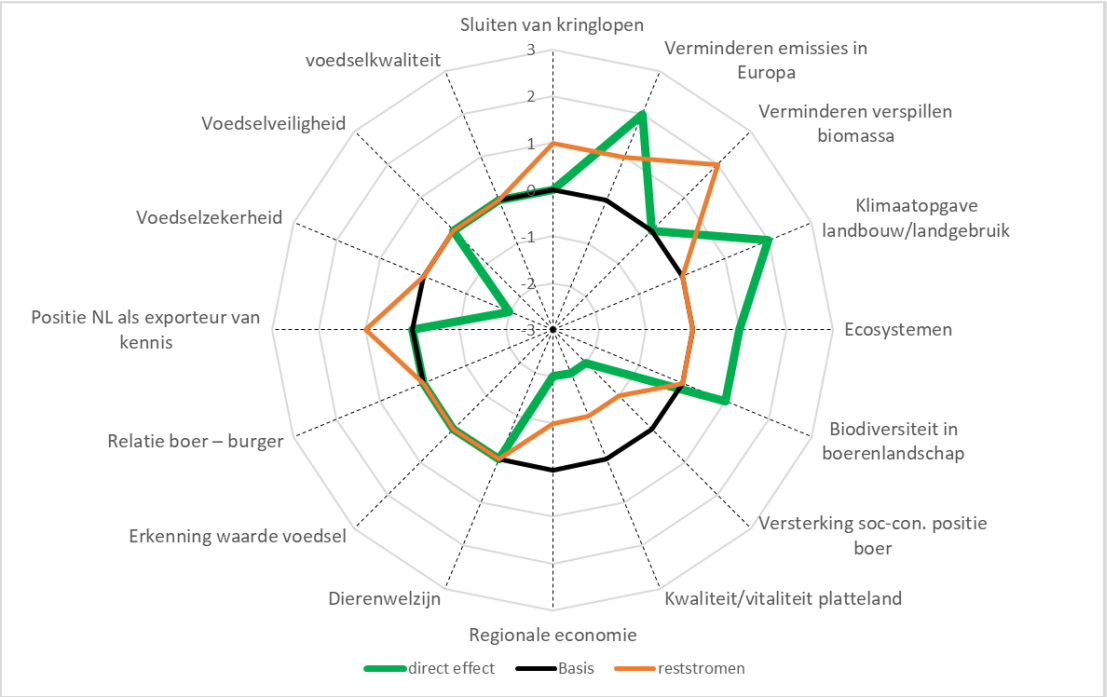

Figure 4.8 *Qualitative comparison of the effect of the response – improving utilisation of residual flows – in comparison with the direct effects of the measure and the baseline situation, in accordance with KPIs of Circular Agriculture.*

5 Adaptation responses

In addition to repair responses aimed at the animal production chain itself, responses will also occur in which consumption adapts to the new situation. Due to the reduction in the amount of available animal feed, animal production within the EU is falling. Consumers and retailers respond by adapting their consumption and purchasing patterns accordingly. We distinguish three responses here.

- The first response assumes that the consumption of animal products will remain stable and that shortage will be filled by additional imports of animal products from outside the EU (Section 5.1).
- The second response is that a lower supply of animal products leads to a shift in consumption from animal protein to more plant protein (Section 5.2).
- The third response involves the effects of replacing the lower supply of animal proteins from livestock farming with animal proteins from fish (Section 5.3).

As in the previous chapter, the responses are viewed separately. The effects of the response are always compared with the direct effects of the measure. This is to estimate how the response attenuates or amplifies the effects of the measure. In a number of cases, a comparison is also made with the baseline situation. This is stated explicitly.

5.1 Adaptation of human consumption through imports of animal products from outside Europe

5.1.1 What is the response?

With a constant demand for animal products and a decrease in the supply of animal products within the EU, increasing imports of animal products is a logical, direct response. The effects on the nutrient cycle within Europe are small. This is because the increasing demand for animal products is largely from outside the EU.

5.1.2 Effects on the nitrogen cycle

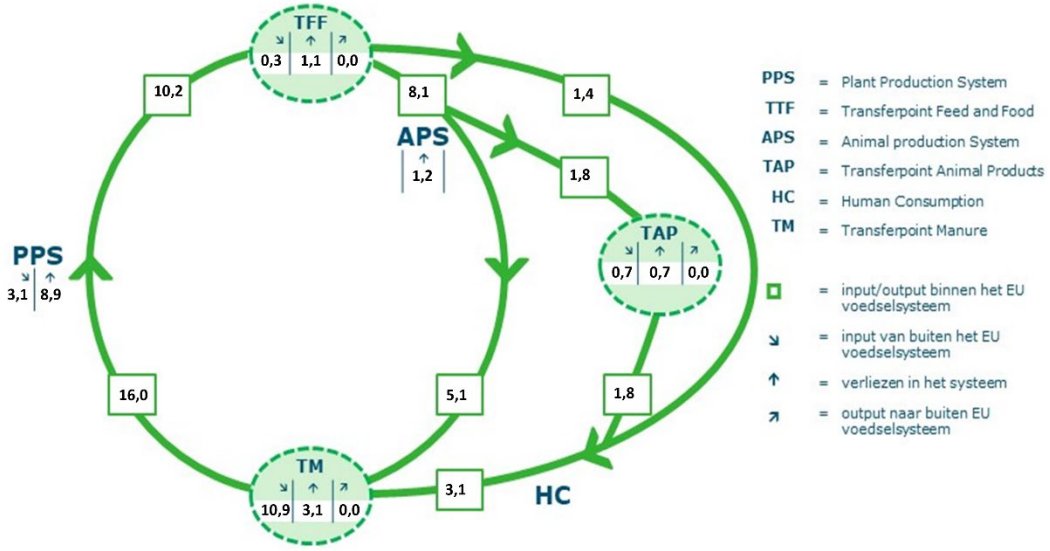

Figure 5.1 *N cycle effects of the measure after the response of increased imports of animal products.*

- This response is relatively simple. The declining availability of animal protein for human consumption as a result of the measure (-0.43 Mt N) is offset by fewer exports (-0.2 Mt N) and additional imports from outside the EU (+0.2 Mt N). This means that the amount of animal products for human consumption will increase by 0.4 Mt N.
- The shortage of plant protein for human consumption – which is caused by a lower availability of manure in the 'direct effects' scenario (0.24 Mt N) – is also compensated by the measure due to fewer exports and more imports in plant production (TFF).
- The quantity of manure and the magnitude of plant production remain the same as in the 'direct effects' scenario.
- This response therefore has no direct influence on the N flows in the rest of the system.

Table 7 *N cycle baseline situation, direct effects of the measure and effects after response of increased imports of animal products (% change compared to the baseline situation).*

	Baseline situation	Direct effects	%	Imports of animal products (5.1)	%
Total N input	17.4	14.7	-15%	15.0	-14%
Total N loss	17.0	14.5	-15%	15.0	-12%
Total N export	0.4	0.3	-28%	0.0	-100%
Total N plant production	11.3	10.2	-10%	10.2	-10%
Total N animal production	2.7	1.1	-33%	1.8	-33%
Total N consumption	3.1	2.6	-18%	3.1	0%

5.1.3 Effects on the nutrient cycle in a broader sense

- Increased imports of animal products (and/or decreased exports) have a small effect on the cycle parameters.
- The production remains the same as in the direct effects scenario. The side effects – both positive and negative – are therefore equal to the direct effects of the measure.
- The only change concerns food security. The decrease in animal proteins for human consumption as a result of the direct effects has been eliminated. The consumption level has been restored to the baseline situation. The dependence on imports of animal feed raw materials in the baseline situation has now been replaced by dependence on imports of animal products for human consumption. Food security has thus returned to the baseline level.

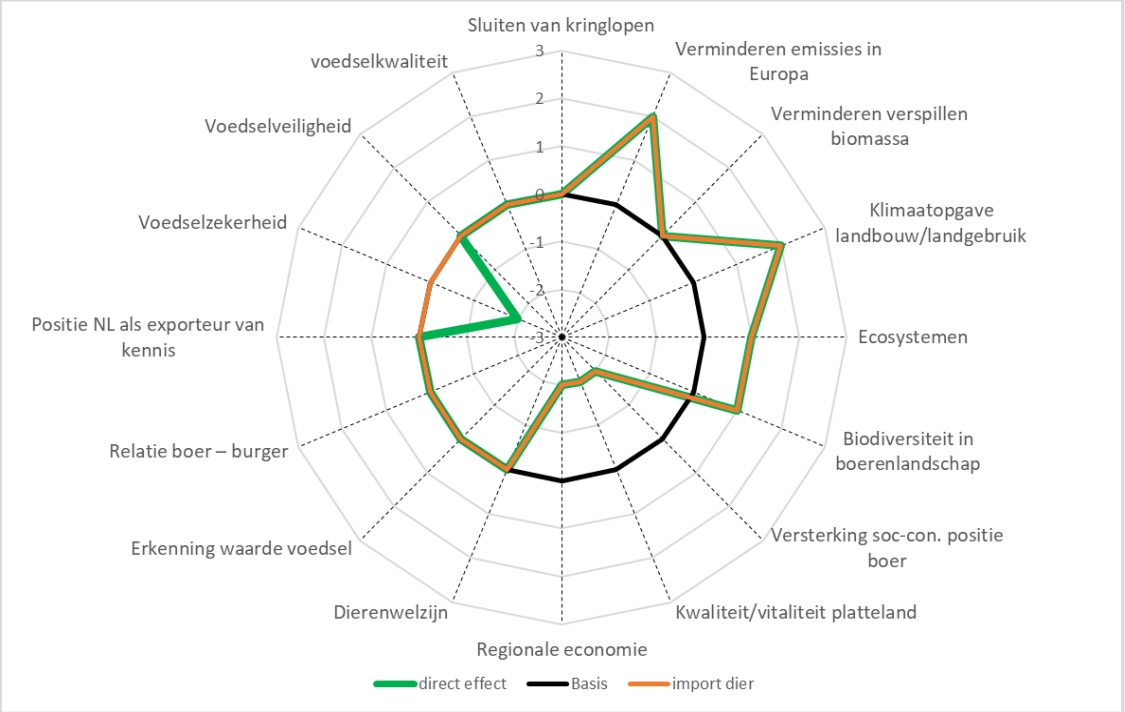

Figure 5.2 *Qualitative comparison of the effect after the response – increased imports of animal products – in comparison with the direct effects of the measure and the baseline situation, in accordance with KPIs of Circular Agriculture.*

5.2 Adaptation of human consumption from animal to more plant protein

5.2.1 What is the response?

The scarcity of animal products can also lead to a response of consuming more plant protein and less animal protein.
The effect of importing these plant products was shown previously in Section 4.1. However, it is also possible that the increased demand for plant proteins is met entirely by European production. This has major effects on the nutrient cycle. More land will be needed for plant production for human consumption. This will further reduce the availability of feed crops. The effect of this response is described below.

5.2.2 Effects on the nitrogen cycle

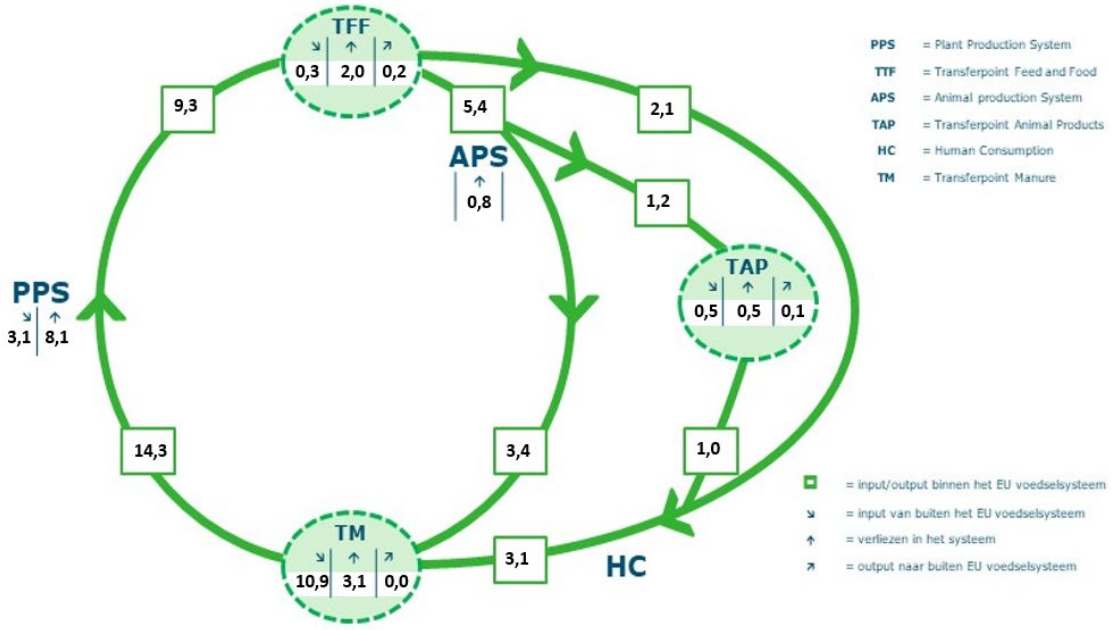

Figure 5.3 *N cycle effects of the measure after the response of shifting consumption from animal to plant products.*

- To compensate for the resulting decrease in animal protein, an increase in plant protein for human use is necessary (2.1 Mt N instead of 1.2 Mt N).
- If this entire increase is produced in Europe (the assumption in this response), then less land is available for growing animal feed.
- This displacement leads to an additional decrease in available feed (5.4 Mt N instead of 8.1 Mt N)
- As a result, animal production declines further from 1.8 Mt N to 1.2 Mt N. That is a decrease of 33% compared to the 'direct effects' scenario and 56% compared to the baseline situation.
- This also reduces the amount of animal manure, which in turn has an effect on crop production.
- The consumption ratio of plant protein:animal protein changes from 44%:56% (baseline situation) to 67%:33%. The total amount of protein for human consumption remains the same.
- The limitation of the amount of land creates a new balance in the production and consumption of animal and plant protein. The cycle was therefore completed several times for the calculation.

Table 8 *N cycle baseline situation, direct effects of the measure and effects after the response of shifting consumption from animal products to plant products (% change compared to the baseline situation).*

	Baseline situation	Direct effects	%	Shift in consumption from animal to plant products (5.2)	%
Total N input	17.4	14.7	-15%	14.7	-15%
Total N loss	17.0	14.5	-15%	14.5	-15%
Total N export	0.4	0.3	-28%	0.3	-28%
Total N plant production	11.3	10.2	-10%	9.3	-17%
Total N animal production	2.7	1.8	-33%	1.2	-56%
Total N consumption	3.1	2.6	-18%	3.1	0%

5.2.3 Effects on the nutrient cycle in a broader sense

- Because plant production systems are more efficient than animal production systems in converting nutrients for human consumption, circularity is improved.
- Due to a further contraction of livestock farming, emissions also decrease.
- Other environmental pressures remain the same, mainly due to continuing high load on farmland.
- Economically, there is a slightly positive effect for arable farmers – their products gain in value – but there is considerably less land for livestock farmers.
- The level of self-sufficiency in Europe improves regarding protein for human consumption. Without additional external input, the protein deficit can be supplemented by producing more plant-derived food. As a result, food security within Europe increases. However, this makes Europe more dependent on its own production conditions.

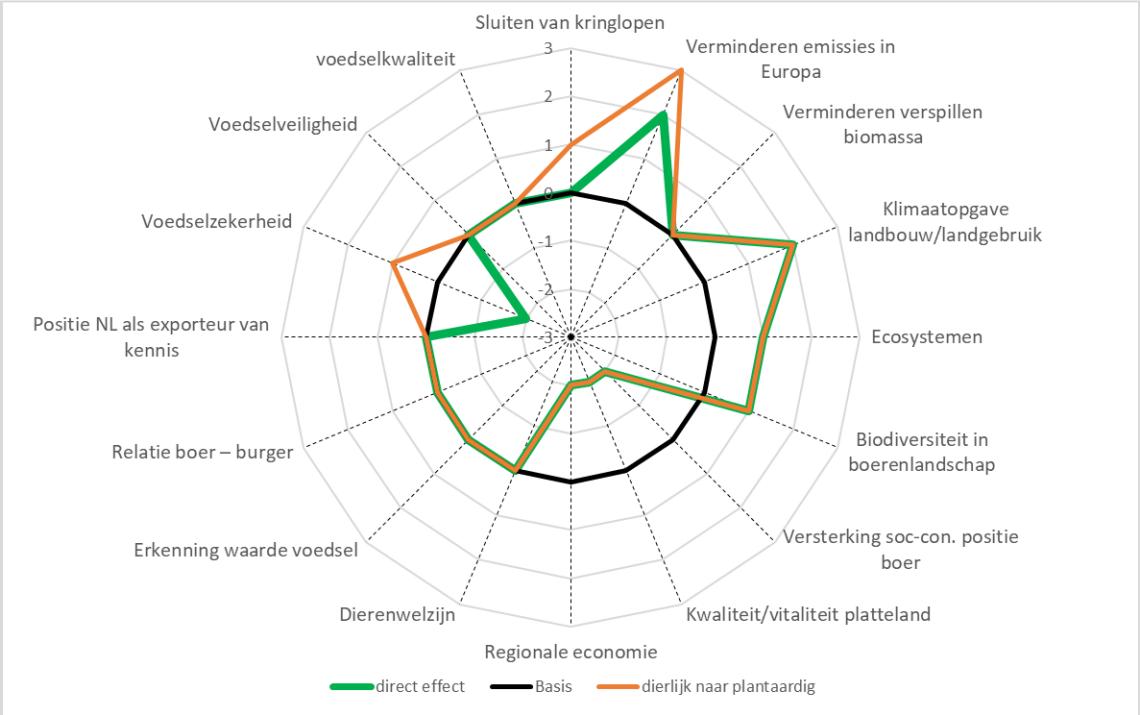

Figure 5.4 *Qualitative comparison of the effect after the response – increased imports of animal products – in comparison with the direct effects of the measure and the baseline situation, in accordance with KPIs of Circular Agriculture LNV.*

5.3 Adaptation by supplementing the diet with extra fish

5.3.1 Explanation of the response

Due to a decrease in products from livestock farming, consumers can also shift to higher fish consumption. The scope for this shift has been examined. Larger catches of fish are problematic. Moreover, fish farming often uses the same protein sources as livestock farming, which is why this is not considered as a solution[4]. Another possibility is to reduce exports of fish and use it for consumption within Europe. The effect of this has been described.

5.3.2 Effects on the nitrogen cycle

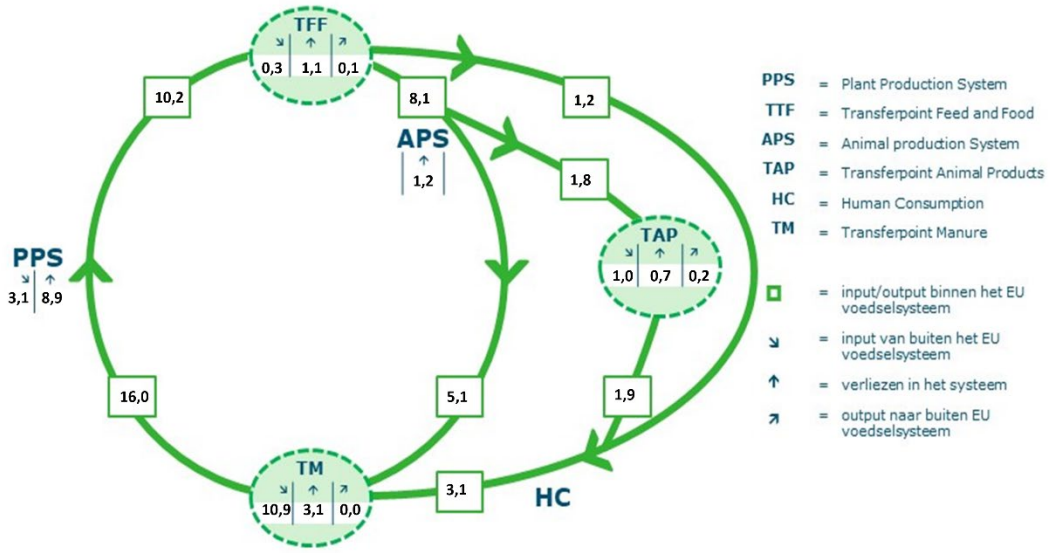

Figure 5.5 *N cycle effects of the measure after the response of supplementing the diet with fish.*

- In this scenario, the total protein deficit for human consumption (0.57 Mt N) is compensated by fish that was previously exported (0.36 Mt N). The remaining 0.21 Mt N will have to be supplemented with additional fishing or imports of fish from outside Europe. In total this means an extra input of 0.57 Mt N in TAP.
- Consequently, the quantity of animal products increases (from 1.32 Mt N to 1.89 Mt N) and exceeds the baseline level (1.75 Mt N). The extra fish thus compensates for the direct effect of the decreased availability of plant protein.
- The increase in fish consumption does not change anything else in the nutrient cycle.

[4] Even though the feed conversion efficiency of fish is favourable (slightly better than chicken), when looking at the protein retention (relevant for nitrogen), fish are comparable to pigs (Fry et al., 2019). Most European farmed fish – especially Atlantic salmon (Eurostat, 2019) – requires feed with a high protein content, but the protein retention is relatively low. In open water fish farming, such as salmon farming, potential fertilisers are lost, which leads to poor circularity.

Table 9 *Overview of totals of the N cycle baseline situation, the direct effects of the measure and the effects after the response of supplementing the diet with fish (% change compared to the baseline situation).*

	Baseline situation	Direct effects	%	Shift in consumption from animal to fish protein (5.3)	%
Total N input	17.4	14.7	-15%	15.3	-12%
Total N loss	17.0	14.5	-15%	15.0	-12%
Total N export	0.4	0.3	-28%	0.3	-28%
Total N plant production	11.3	10.2	-10%	10.2	-10%
Total N animal production	2.7	1.8	-33%	1.8	-33%
Total N consumption	3.1	2.6	-18%	3.1	0%

5.3.3 Effects on the nutrient cycle in a broader sense

- As with section 5.1, consumption is restored; production remains the same as in the 'direct effects' scenario.
- Extra fishing (slight increase) has a negative effect on marine ecosystems. Due to the reduced pressure on ecosystems on land (as in the 'direct effects' scenario), this results in a score of 0 in the figure.
- Consumption has returned to baseline levels and self-sufficiency in Europe has improved. Food security thus also increases compared to the baseline situation. However, this makes Europe more dependent on its own production conditions.

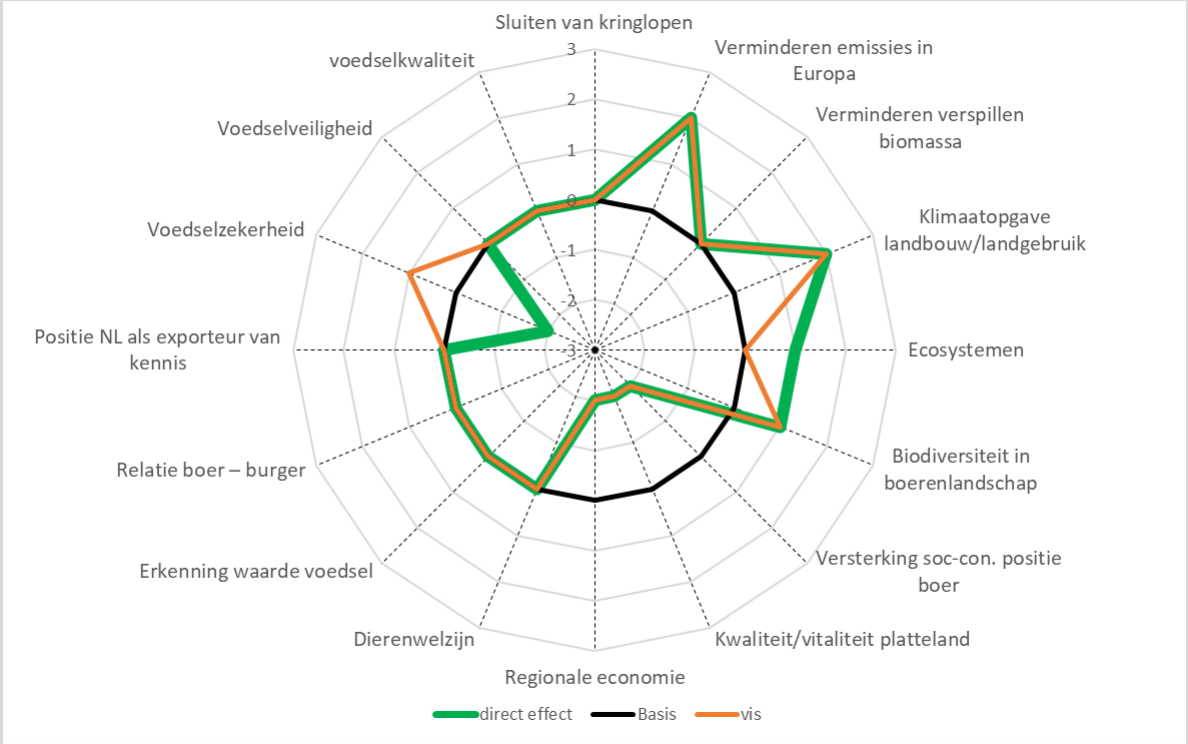

Figure 5.6 *Qualitative comparison of the effect after the response of shifting from meat to fish consumption compared to the direct effects of the measure and the baseline situation, in accordance with KPIs of Circular Agriculture LNV.*

6 In-depth analysis of the scenarios

6.1 Comparison of and interaction between the scenarios

The scenarios were discussed separately in the previous chapters. In reality, the various responses occur simultaneously and influence each other. Several aspects of this process are discussed below. The scenarios are listed side-by-side in Table 10 (a and b). This creates a complete overview and provides insight into the interaction that the different scenarios have with each other. The table describes the most important mechanism in each scenario, and subsequently the extent to which this mechanism affects the consumption of animal and plant protein and the changes this causes in plant and animal production systems.

6.1.1 Effects on consumption

The elaboration of the various scenarios makes it clear that various responses are possible in the system that ensure restoration of animal protein consumption when animal feed is no longer sourced from outside Europe. In the repair scenarios, this happens because the shortage of animal feed is supplemented from alternative sources. When European animal feed is produced at the expense of human food (4.1) or by increasing efficiency (4.3), it is possible to restore the baseline level of animal feed. When using residual flows (4.4), approximately half of the shortage of animal feed can be restored. In the adaptation scenarios, the decrease in consumed protein is compensated with proteins of different origin: animal protein from outside Europe (5.1), plant protein (5.2), and protein from fish (5.3).

6.1.2 Effects on production systems

Various scenarios lead to a new equilibrium in the production systems. This equilibrium is either comparable to the original equilibrium (4.1 and 4.4) or the size and intensity of production systems have decreased because protein production takes place elsewhere (5.1 and 5.3). Particularly in the case of higher efficiency (4.3) there is a shortage of organic fertiliser, which can be compensated by the use of chemical fertiliser (4.2). In Scenario 5.2, the desired amount of protein for human consumption can still be produced with less available fertiliser. This requires a major shift in consumption ratio from animal protein to plant protein (from 44:56 to 67:33).

6.1.3 Probability of the response scenarios

When the measure – no animal feed from outside Europe – comes into effect, this leads to a certain imbalance. Each of the responses described here aims at reducing that imbalance. The responses influence each other directly. When a first response partially restores the imbalance, the pressure decreases on the occurrence of other responses. In a sense, the responses thus compete with each other. The final relationship between the responses depends on the speed at which responses occur, the degree to which they are actively inhibited or promoted and which responses persist for a long time. Under the term ‘probability’, an estimate is made of the pressure on the occurrence of the described response and how permanent that response is. This differs between responses.

First of all, a number of relatively ‘quick and simple’ trade responses can be expected:

- The demand for feed from the existing European livestock sector will continue. As a result, animal feed prices will rise and European arable farmers will partially switch from food production to feed production (4.1).
- The decrease in available manure and the decrease in protein quality in feed can be quickly compensated by additional inputs of chemical fertiliser and synthetic amino acids (4.2).

- When food chains cannot meet a constant demand for animal proteins, in response they will obtain more animal products from outside Europe and/or export less (5.1).
- In addition, the same food chains will try to meet the demand for meat through an extra supply of fish (5.3).

The other responses involve more substantial and slower changes. These will occur less automatically. The response of upgrading residual flows (4.4) will require new policy and technology to minimise the risks to food safety. If food safety can be guaranteed, this response can still come into effect. In that case, it seems probable that this response will still compete with responses that came into effect previously. Increasing efficiency (4.3) and replacing animal proteins with plant proteins (5.2) will also be slower than the trade responses. These are larger, partly systemic changes. These responses depend especially on possible supporting policies.

6.1.4 Desirability of response scenarios based on the objectives of the measure

The desirability of the various scenarios cannot simply be estimated. The desirability depends on more than just the identified effects and the relative importance that is assigned to each of those aspects. A specific consideration, however, is how the various scenarios contribute to the realisation of the intended objectives of the measure described in the introduction. Therefore, what is the 'desirability' of the various responses within the narrower scope of the intended objectives of the measure? Do the responses contribute to the realisation of those objectives? Or do they in fact lead away from it?

As described in the introduction, the attention for a ban on imports of animal feed raw materials stems from the desire to improve the circularity of nutrient cycles and at the same time to benefit from other sustainability aspects. The measure could also reduce Europe's vulnerability to geopolitics and currency fluctuations. The contribution of the measure to these objectives has been assessed by means of the effect on the N cycle, the N balance and the KPIs for circular agriculture of the Ministry of Agriculture, Nature and Food Quality. Clear differences between the scenarios were shown here.
The four scenarios described above as a likely trading response (4.1, 4.2, 5.1 and 5.3) each score relatively poorly on the given objectives. Circularity of the nutrient cycles did not improve and the food security or self-sufficiency of Europe did not benefit. At the same time, the economic efficiency of these scenarios was lower than the current situation.
The response of using new (currently not utilised) residual flows (4.4) improved the circularity of nutrient cycles. Other sustainability aspects were also positively influenced, and Europe became less dependent on imports. The implementation of this response, however, depends especially on the continued assurance of food safety.
The slower, systemic response to increasing efficiency (4.3) would make Europe less dependent on external countries, but the intensification and additional use of chemical fertiliser would have a negative sustainability effect.
The response of consumers adapting their consumption and eating more plant-based products and fewer animal products (5.2) would not improve circularity, but it would provide positive sustainability effects (on aspects such as emissions and climate) and it could reduce European dependence on external countries.

For the sake of clarity: the desirability of the various response scenarios described above only concerns their contribution – positive or negative – to the intended objectives of the measure. Desirability in a broader sense also requires a broader consideration. It requires an assessment of how you prioritise economic and social effects in relation to sustainability, and how you prioritise circularity and other sustainability aspects in relation to each other. These considerations are policy questions for stakeholders and were therefore beyond the scope of this study.

Table 10a *Overview of response scenarios and their effects.*

	Increased imports of plant-based food products (4.1)	Increased use of chemical fertiliser and synthetic amino acids (4.2)	Increasing the efficiency of cultivation and livestock farming (4.3)	Utilisation of residual flows (4.4)
Most important mechanism	Europe produces more of its own animal feed and less plant-derived food; imports of animal feed are replaced by imports of plant-based food products.	Less animal feed causes imbalances in other parts in the system, such as less available manure and lower feed efficiency; this response restores those balances.	Increased scarcity of land and animal feed stimulates production efficiency per hectare (thus closing the 'yield gap') and feed efficiency per animal; more fallow land is also taken into production.	Nutrient-rich by-products (meat-and-bone meal, swill and poultry manure) are upgraded for use as animal feed, while taking food safety into account.
Effects on consumption and production within Europe	Animal production and consumption is almost identical to the situation without the measure (consumption of animal protein is 10% below the baseline level).	Full recovery of plant production and consumption, limited recovery of animal production and consumption.	Full recovery of animal production and consumption is possible.	As a result, approximately half of the decrease in animal feed can be restored; the response is not sufficient to fully restore animal protein consumption.
Effect on production systems	Original balance is largely restored: availability of manure and magnitude of animal production largely restored; fewer co-products for animal feed due to lower plant production.	Restoration of fertiliser shortages and animal feed quality; this creates a new balance; contraction of animal production and consumption persists despite increased efficiency of animal production.	Restoration of balance (new equilibrium) through more intensive production, but considerably more chemical fertiliser is needed.	Other imbalances (due to shortage of fertiliser) are also restored; about half of the original decline is reversed.
Probability	Plausible trade response: existing livestock farming system continues to demand more animal feed, even when prices rise.	Fast trading response quickly eliminates shortages. Magnitude of use depends on other responses.	Partly an existing response, but closing the yield gap is major systemic change. The response will be reinforced by the measure when other responses fail (or are attenuated).	Slow response due to food safety risks; policy and innovation must eliminate those risks. High probability in the medium term; other supplemental responses needed.
Desirability based on circularity goals	No sustainability gain; economically less efficient.	Repairs the economic imbalance that has arisen; negative sustainability aspects due to the use of synthetic inputs.	Economically desirable; mainly negative impact on sustainability due to intensification and increased inputs.	Positive economic and sustainability effects, provided that food safety can be guaranteed.

Table 10b *Continuation of overview of response scenarios and their effects.*

	Increased imports (and reduced exports) of animal products (5.1)	Consumption of less animal protein, more plant protein (5.2)	Consumption of less meat, more fish (5.3)	
	Lower production of plants and animals in Europe. Imports therefore increase, exports decrease. For both animal and plant products for food.	Deploy more European land for plant production, so that Europe attains protein self-sufficiency. As a result, animal production contracts more than in the 'direct effects' scenario.	Current fish exports deployed for European consumption; supplemented with additional fishing or imports from outside Europe.	**Most important mechanism**
	Full restoration of animal and plant protein consumption is possible.	Shift from animal to plant protein; restore total protein consumption.	Nearly complete restoration of protein consumption possible; supplement with additional fishing if necessary.	**Effects on consumption and production within Europe**
	Lower availability of manure and smaller magnitude plant and animal production.	Contraction of animal production; shift in plant production from feed to food; no additional external inputs (chemical fertiliser, imported food) needed.	Lower availability of manure and smaller magnitude plant and animal production.	**Effect on production systems**
	Plausible trade response: when a shortage of animal protein arises, chains look for supply outside Europe.	Existing movement that is accelerated only slightly by this measure; there is no strong stimulus for behavioural change; other responses are faster and stronger.	Plausible trade response: when animal protein shortages arise, consumers and chains look for alternatives.	**Probability**
	Less pressure on European environment, land and water due to contraction of livestock farming, but overall a clear deterioration (displacement and amplification of side effects).	Positive sustainability effects also require behavioural change from consumers and transformation of the entire food system; time is needed for both.	Limited sustainability gain; less pressure on European environment, land and water (shifted outside Europe); slightly positive effect on climate; additional fishing will lead to overfishing.	**Desirability based on circularity goals**

6.1.5 Valuation of responses by stakeholders

During the final workshop the participants were asked to rate the response scenarios that had been identified. The aim of this question was to understand the various perspectives from which people looked at the results. Participants were asked to rank the described scenarios according to their own estimate of probability and desirability. They did this for the short term (0 to 5 years) and long term (10 to 15 years).

Despite the diversity of the group, there was a great deal of unanimity in the choice of responses that were deemed probable and desirable for the long term (10 to 15 years). Structural changes in the system, such as the larger-scale use of residual flows and a change in consumption pattern – less animal protein and more plant protein – were deemed likely and desirable in the long term by almost everyone.

However, the estimates for the short term (0 to 5 years) differed between the participants. Representatives from business viewed these major changes as undesirable and improbable due to their major economic impact. They considered repair responses such as increasing the amount of chemical fertiliser and synthetic amino acids to be more probable and desirable for the shorter term. Representatives from civil society organisations and (to a lesser extent) government agencies differed in their estimates for the short term and long term. In their assessments of desirability and probability in the short term, they appeared to take less account of the direct economic impact of the measure and the responses.

6.2 Focusing on the effects

In the current study, the effects of the responses were determined mainly for Europe as a whole and for the livestock sector as a whole. In many cases, however, these effects will not be equally distributed: different regions, sectors and types of farms and businesses will be affected to varying degrees. These differences were discussed in the workshops, but have not been calculated in the model. A number of these differences and a more detailed estimate of the effects are elaborated below. These estimates are based on a combination of expert views of researchers and input from participants of the workshops. A complete picture of the details requires an extensive model study. The estimates described below illustrate what the scenarios can mean in practice, while at the same time providing more insight into the complexity.

Piglets and poultry are very sensitive to the quality of the protein and the presence of certain amino acids. With an increased scarcity of animal feed, piglet and poultry production is still possible, but at higher cost (the required protein is more expensive), or lower efficiency (accepting the consequences of lower-quality protein). The question is to what extent this is still competitive with producers outside Europe; the price is still determined on the world market. To remain competitive, farms will have to reduce their costs per animal; further intensification is then an obvious choice. At the same time, this is an incentive to look for distinctiveness and new production concepts. Farms that cannot compete will be forced out of business.

The above applies to a much lesser extent to dairy farming: this sector is not as dependent on high-quality protein, and dairy cattle perform well on feed that consists largely of grass. In addition, farms with sufficient land are less affected; they are less dependent on the market and have more opportunities to anticipate the new situation. Countries and regions with a high degree of self-sufficiency in animal feed will also be less affected by the measure.

In many of the elaborated scenarios products from arable farming become more expensive. Arable farmers can count on a higher price for their products. At the same time, there may be a shortage of manure and the price of land will rise, which leads to higher costs.

The overall competitive position of European food production deteriorates. This applies in particular to intensive livestock farming. Costs increase but the price remains the same – it is determined on the world market – so profit margins are shrinking. At the same time, the measure stimulates innovation. This can benefit Europe in the long term because expertise about utilising residual flows, closing regional nutrient cycles and other aspects of sustainable agriculture have value internationally.

Whether something substantial changes for the European consumer strongly depends on the interaction between the responses. As long as food can be imported from outside Europe, animal protein will be available and the price of meat, dairy products and eggs will hardly rise. This is different if supporting policy makes Europe more self-sufficient, or if the response is triggered in which more plant protein and less animal protein is consumed. In that case, food prices will indeed rise. It does not appear that major food shortages will arise, or that animal protein will become unaffordable for a significant part of the population. However, groups of consumers who are disproportionally affected by small price increases must be taken into account.

Although the measure may have far-reaching consequences for certain sectors, farms and regions, the overall picture is a relatively minor shift in the equilibrium between production and consumption. Because the measure is implemented for Europe as a whole, there is a lot of scope to mitigate the more abrupt effects – such as a contraction of livestock farming or uncertainty about the availability of animal proteins for consumption. However this scope also means that the desired responses do not just occur by themselves. If the same measure were to be implemented at national level – e.g. if the Netherlands banned animal feed and its raw materials that originate from outside its borders – the effects would be much more drastic.

7 Conclusions

This study used the NCAT to explore what happens when European countries no longer import animal feed and its raw materials from outside Europe. This was done in workshops with a diversity of stakeholders from practice, supplemented by scientific calculation of the direct effects of the measure and of the effects of various responses to the measure.

In the previous chapters, the direct effects of the measure on nutrient cycles have been described and calculated, followed by seven response scenarios. For each scenario, the effect has been described on the N cycle, the N balance (N import, N export, N losses, animal and plant N production and N consumption) and how the response scores on the broader circular agriculture criteria of the Ministry of Agriculture, Nature and Food Quality.

Each scenario contributes to understanding the cascade of effects resulting from the measure. However, to provide a final answer to the initial question – 'what are the consequences if European livestock farming bans imports of animal feed raw materials from outside Europe?' – the scenarios must always be viewed in mutual interaction. The probability with which each response occurs and the extent to which the response is actively directed determine the final answer to the initial question. To answer the initial question on the basis of this study, we can draw the following conclusions:

1. **Determining the consequences of a measure to ban imports of animal feed raw materials from outside Europe requires in-depth understanding of the highly complex nutrient cycle of the European agricultural and food system.**
   Reducing a single input does not automatically lead to improved circularity. The results show how the intervention at a single point of the cycle (banning imports of raw materials from outside Europe) affects the entire European agricultural and food system. The NCAT shows how a ban on imports of animal feed leads to decreased availability of animal feed, a decline in animal production, reduced availability of animal food products, and less animal manure – which in turn leads to a decline in plant production and plant-based foods. Production efficiency and absolute nitrogen losses also decrease.

2. **The consequences of the measure can only be assessed if the diversity of responses that occur within the chain as a result of the measure is taken into account.**
   The study shows how a shift in the cycle leads directly to very different responses. At locations in the chain where shortages arise, pressure automatically increases to eliminate shortages. This occurs by shifting trade flows, shifting production and increasing the use of co-formulants in feed. The shifts in the cycle can also lead to changes in consumption patterns. Each of these responses has its own effects on the production system and the cycle.

3. **If demand remains the same, decreases in the available amount of animal feed raw materials and food products lead to rapid trade responses. These responses attenuate the decline in production and result in less circularity of nutrient cycles.**
   Rapid trade responses compensate for the shortages that have arisen. A shortage of animal feed raw materials stimulates animal feed production in Europe at the expense of the production of plant-based food products. As a result, the availability of plant and animal products for human consumption declines. If demand remains the same, this leads directly to increased imports of food products from outside Europe. These responses attenuate the downward effect on production capacity (animal and plant). At the same time, imports shift from animal feed raw materials to food products. The intended effects of the measure – improving circularity – are thus attenuated.

4. **If policy remains the same, shortages of manure and specific amino acids lead to the use of additional chemical fertiliser and synthetic amino acids. This attenuates the**

decline in production and improves production efficiency, but leads to negative sustainability effects.
Due to the shortage of manure, the pressure to use chemical fertiliser is increasing. This leads to additional external input in the cycle. The decline in production efficiency as a result of the measure leads to additional input of synthetic amino acids. Increased use of chemical fertiliser and synthetic amino acids attenuates the decline in production (plant and animal), improves production efficiency, but also leads to additional environmental pressure.

5. **Utilisation of residual flows enhances circularity and attenuates the decline in production. The extent to which this response can occur is determined by safeguarding food safety through technology and regulations.**
   At present, the use of swill, meat-and-bone meal and poultry manure is forbidden due to food safety concerns. When animal feed becomes scarcer, the business community will invest more in innovation to do this safely. The pressure on politicians will also increase to allow this under certain conditions. If food safety can be guaranteed, the use of residual flows has a positive effect on circularity and other sustainability aspects.

6. **Shifting the consumption pattern from animal protein to more plant protein amplifies the intended circularity effects of the measure. At the same time, it causes a larger contraction in animal production and an increase in plant production. Without additional policy, implementing the measure does not accelerate this shift in the consumption pattern.**
   Due to price effects, lower availability of animal products within Europe can lead to a shift towards increased consumption of plant-based products. This shift would contribute to the intended circularity effects of the measure. It would lead to an increase in European plant production and a further decrease in animal production. However, if the policy remains the same, it is unlikely that the availability of animal products will actually decline. European shortages are offset by increased imports from outside Europe. The direct effect of the measure on a shift in consumption is therefore relatively small.

7. **To estimate the actual effect of the measure, the effect of all responses together must be considered. Calculations of the separate effects of individual responses say little about this.**
   The direct effect of the measure is a major intervention in the nutrient cycle and in animal and plant production, but does not lead to the intended circularity. The measure automatically evokes a variety of responses, each of which attenuates or amplifies the effects of the measure in its own way. The ultimate effect of the measure can only be measured as a sum of the direct effect of the measure and the effects of the various responses.

8. **More insight into the market and price effects (direct and indirect) of the measure is needed to estimate the degree to which the various responses will interact autonomously.**
   The degree to which various responses occur is driven especially by market and price effects on the global market for food and feed. These market and price effects have not been included in this study. Insight into these effects is needed not only for an assessment of the total effect of the measure, but also regarding the desirability of possible supporting policy.

Significance for sector and government policy

What is the actual effect of introducing the measure? This question cannot be answered unambiguously. One thing is clear: implementing the measure without paying attention to the total variation of responses does not ensure improved circularity in the European agricultural-food cycles and has a major impact on the vitality of the agriculture and food system in Europe.
The results described in this study provide in-depth understanding of the direct effects of the measure and of the individual responses. It shows which responses inhibit or reinforce the realisation of the intended circularity goals. It also shows which responses amplify or attenuate the impact on the vitality of the production sectors.

During the workshops, the stakeholders' appreciation of the desirability and probability of the various scenarios in the long term turned out to be relatively unanimous, but this varied widely regarding short-term responses. To achieve the long-term goals, cooperation is also essential in the short term. Short-term cooperation is hampered by the major impact of the measure on the European agricultural system.

The results of this study can help the sector, government agencies and NGOs to discuss how they can achieve the intended circularity together in a way that does not unduly impact the vitality of plant and animal production. The results of this study and economic exploration by Wageningen Economic Research, as described by Silvis et al. (2021), can provide a broad basis for this discussion.

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