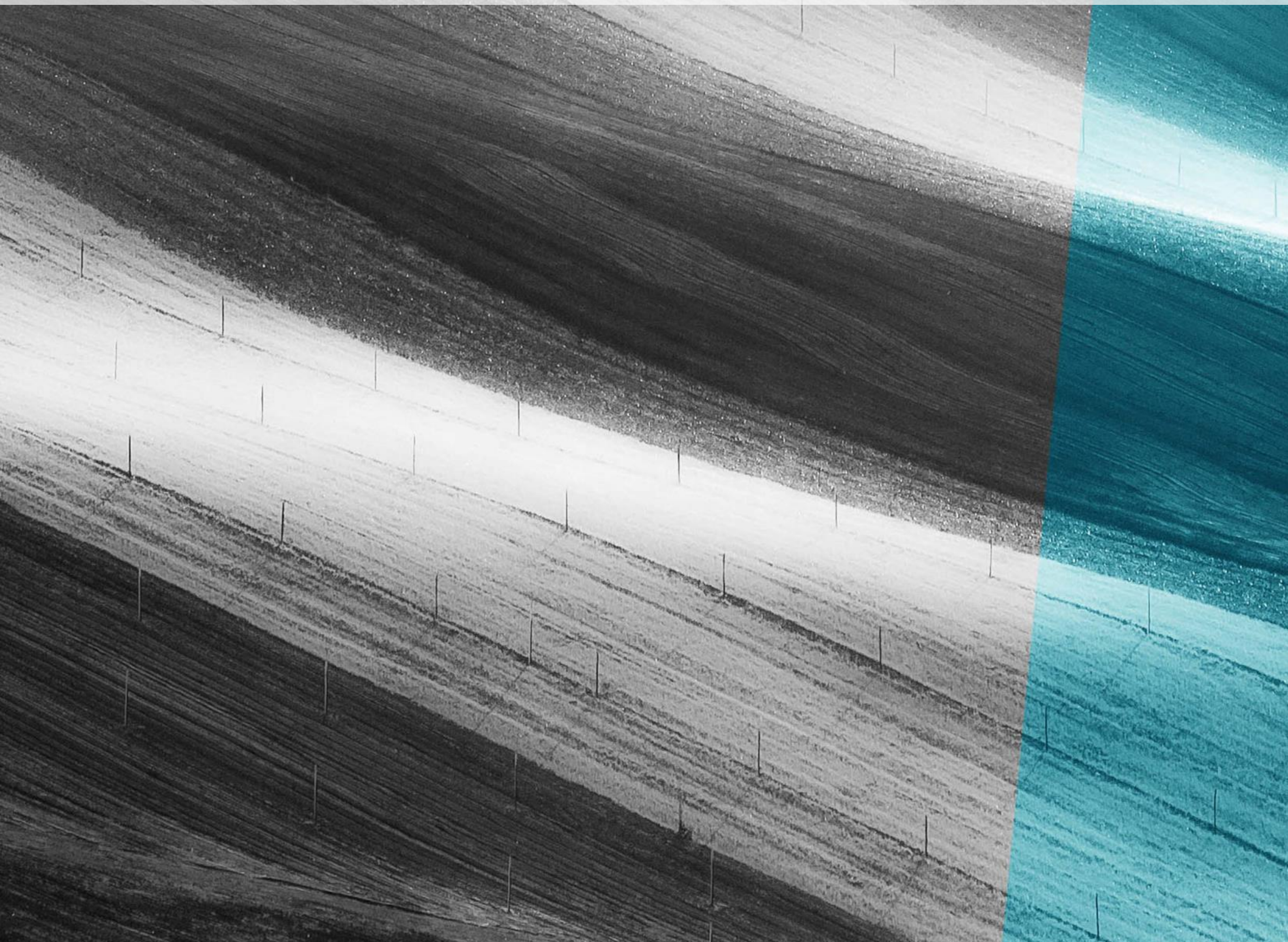
The applicability of LCA guidelines to model the effects of feed additives on the environmental footprint of animal production

The study is a joint methodological investigation by Blonk and DSM Nutritional Products



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DSM Nutritional Products. DSM is a global science-based company operating in the fields of Nutrition, Health and Sustainable Living. The animal nutrition and health division offers a broad portfolio of vitamins, enzymes, eubiotics, carotenoids, lipids and minerals. DSM is committed to providing tangible and measurable solutions to the biggest challenges facing society and the animal protein sector.

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Foreword

This study report is a methodological investigation of the applicability of the sector Life Cycle Assessment guidelines (FAO LEAP and/or EC PEF) to modelling nutritional interventions through feed additives, assessing their influence on the environmental footprint of animal production. The case studies have been specifically chosen to test the key aspects of the available sectorial guidelines.

The impact assessments are illustrative of the methodology used and representative only for the selected scenarios. It is not intended to provide generic LCA results for each nutritional intervention; changing inputs and assumptions will change the results. It is also not the intention of this study to provide comparative assertions.

Summary

Robust assessment of the environmental footprint of animal products is essential to support and monitor efforts to reduce both the emissions intensity and resource demands associated with their production. With its strategy to provide harmonized methods to assess the environmental footprints of livestock, the Food and Agriculture Organization (FAO) Livestock Environmental Assessment and Performance (LEAP) Partnership elaborated specific guidelines applicable to feed additives, as feed additives have the potential to confer environmental benefits in their use to support animal productivity, animal health, lifetime performance or even direct environmental benefits. This guidance document, combined with the corpus of other FAO LEAP documents and European Commission (EC) Product Environmental Footprint (PEF) category rules, offers a set of resources to enable conducting rigorous Life Cycle Assessment (LCA) when focusing on nutritional interventions in farm systems.

The main purpose of the current study was to explore, from a methodological standpoint, the applicability of the sector LCA guidelines (FAO LEAP and/or EC PEF) to modelling nutritional interventions (specifically, the use of feed additives). To that end, the effects on animal performance of a diverse set of nutritional interventions (n=14 in total) including the use of feed enzymes, vitamins, carotenoids, and eubiotics have been documented via an extensive literature review (along with the FAO LEAP Guidelines for feed additives) and further translated into potential effects observable at farm level. Three terrestrial target species were studied: broiler chickens, dairy cows, and fattening pigs. The reference systems were Dutch and Belgian. The methodological exploration was reviewed by external experts with respect to ISO 14044 requirements for LCA.

The study confirms the applicability of the available sector LCA guidelines as implemented in the APS-footprint tool, to evaluate nutritional interventions for improving animal productivity, animal health, lifetime performance or emissions. Nevertheless, more detailed guidance and more consistence between the guidelines would be helpful.

The road testing allowed identifying areas where the existing guidelines should be made more specific in order to confer more robustness to the LCA outcomes. This was the case, in particular, for the accounting of the variability and uncertainty when translating complex zootechnical dynamics in an LCA model. It was also true with respect to accounting for changes in the production and composition of manure leaving the farm and for the modelling of nutritional interventions that act on product quality and subsequent stages in the value chain. The study also highlights the pivotal role of feed formulations in determining estimated impacts. The way these dilemmas are manged by LCA experts may affect the outcome to a large extent, hence the need for clearer guidance.

The study also confirmed that the use of feed additives has a positive environmental impact over the entire lifecycle. Except in one case (for a product with a high inclusion rate), the environmental impact of the production of feed additives is confirmed to be relatively negligible compared to the positive impacts delivered, which can amount to up to a 10% improvement (cumulative effect for some impacts and some species) as per our assessment.

Improvement in productivity and specific reduction of emissions confirm feed additive concrete prospects with regards to the reduction of livestock footprint and are relatively easy to model. Environmental benefits provided by feed enzymes on feed formulation requires extended information on feed recipes to be properly generalized. Our study provides evidence for the need to integrate the footprint of ingredients as an optimization criteria, rather than as a calculated outcome, to fully capture the potential of feed enzymes to minimize environmental impact. It also confirms the significance of the contribution of phytase to abate phosphorus and nitrogen related impacts on farm. Finally, feed additive solutions supporting the lifetime performance of the animals (longevity, fertility, health status) also indicate a potential for environmental impact mitigation, although requiring sophisticated modelling of herd/flock dynamics.

The study confirms the important role that feed additives can play at farm level in conducting sustainability improvement plans. The multiple LCA case studies (multi-species, multi-interventions) are an opportunity to detect and discuss paths for improvements for livestock sectorial guidelines, while verifying the actionability of systematic foot-printing approaches, including when applied to nutritional interventions.

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1 Introduction

The need to assess in a robust manner the environmental footprint of animal products is essential to support and monitor their required reduction in both emissions intensity and resource demands. In its effort to provide harmonized methods to assess environmental footprint from livestock, the FAO LEAP Partnership elaborated specific guidelines applicable to feed additives [1], as feed additives have been identified to deliver environmental benefits, in their use phase, via support on animal productivity, animal health or even direct environmental benefits.

This guideline document, combined with the corpus of other FAO LEAP documents, and the earlier published EC PEF category rules offers a dense and up to date set of resources to conduct rigorous Life Cycle Assessment, when focusing on nutritional interventions in animal farming systems.

The main purpose of the study is then to explore from a methodological standpoint, the applicability of those authoritative sector LCA guidelines (FAO LEAP and/or EC PEF) to the nutritional interventions of feed additives.

To this end, a diverse set of nutritional interventions, based on the implementation of feed enzymes, vitamins, carotenoids and eubiotics, has been documented with an extensive bibliography further translated into effects observable at farm level.

Three terrestrial target species were studied: broiler chickens, dairy cows, and fattening pigs, while the reference systems are designed from Dutch and Belgium references.

The methodological exploration is reviewed by external experts.

1.1 Context and background

The UN FAO has set up the Livestock Environmental Assessment and Performance (LEAP) Partnership, a multi-stakeholder initiative that seeks to improve the environmental sustainability of the livestock sector through harmonized methods, metrics, and data. A key deliverable of this initiative is a set of LCA guidelines for each livestock species and various sustainability topics relevant for animal production. In total 10 LCA guidelines have been released in the period of 2013-2020 for diverse animal production systems. The current first version of the LEAP guidelines requires validation by stakeholders of the livestock sectors. This is the purpose of the so-called LEAP road testing steered by the LEAP Secretariat.

The present study contributes to the methodological efforts by providing insights on the concrete implementation of the FAO LEAP and/or PEF guidelines. While data are collected and documented for the possible reduction in environmental impact attributable to feed additives, the main purpose of the study is a testing of the methodology. Furthermore, the study is not designed nor documented to support comparative assertions.

This study is not a comparative assertion and the use of the results outside the context of this study would require additional assessments on uncertainty, variability and adaptation of system boundaries.

1.2 Involved parties

Blonk Consultants. Blonk Consultants is an international leader in the field of environment, sustainability, nutrition and health, advising businesses, governments and other organisations on environmental and sustainability issues faced by the agri-food sector. Blonk Consultants developed the APS (Animal Production System) footprint tool based on best available LCA methods, guidelines, standards, and databases, such as the FAO LEAP guidelines, EC PEF method and compliant databases.

DSM Nutritional Products. DSM is a global science-based company operating in the fields of Nutrition, Health and Sustainable Living. The animal nutrition and health division offers a broad portfolio of vitamins, enzymes, eubiotics, carotenoids, lipids and minerals. DSM is committed to providing tangible and measurable solutions to the biggest challenges facing society and the animal protein sector.

1.3 Commissioner and executors

The study has been commissioned by DSM Nutritional Products and is executed by a team of DSM and Blonk LCA and nutrition experts. The main authors of this document are:

- Björn Kok, Blonk Consultants, Pigs LCA and reporting;
- Nicolò Braconi, Blonk Consultants, Overall LCA modelling and reporting, Dairy LCA;
- Henk Bosch, Bosch Sustainability Consultant, Broilers LCA and reporting;
- Hans Blonk, Blonk Consultants, Overall reporting;
- Sabine Van Cauwenberghe, DSM, Coordination and overall reporting;
- The scientific input for establishing the effects to be modelled in the LCA (Annex 8.1) was delivered by DSM experts in animal nutrition among which (in alphabetic order) are Aaron Cowieson, Peter Fischer, Luc Levrouw, Gilberto Litta, Luis Tamassia and Nicola Walker.

The supporting LCA tool (Animal Production System Footprint, APS-footprint) was developed by Blonk Consultants.

1.4 Review process

This report and LCA was reviewed by a panel of experts.

The panel consisted of:

- Nathan Pelletier, University of British Columbia – CA, Chairman for the review; Dr. Pelletier is an Assistant Professor and NSERC/EFC Industrial Research Chair in Sustainability at the University of British Columbia, Canada. He has considerable methodological expertise in LCA and its application to assessment of crop and livestock production systems. He has previously conducted and published LCA studies of conventional and alternative beef, pork and broiler production systems in the United States, egg production systems in the US and Canada, and a broad array of crop production and processing systems globally.
- Greg Thoma, University of Arkansas – US; Dr. Thoma is currently lead investigator for a number of life cycle initiatives in the food and agriculture sector including studies on fluid milk, cheese, milk delivery systems, and is project director for a recently completed 5-year, $5M USDA multi-university project focused on greenhouse gas mitigation for US swine production. Dr. Thoma also consults on other LCA work at the University of Arkansas focusing on rice, cotton, corn, and sweet corn. He was the scientific lead for the LEAP Partnership on the Environmental Benchmarking of Livestock Supply Chains technical advisory group for poultry which produced guidance in the application of LCA for assessment of sustainable poultry and egg production.
- Theun Vellinga and Pim Mostert, Wageningen University – NL; Dr. Vellinga works at Wageningen University and Research (WUR), at Wageningen Livestock Research. As senior researcher, Dr. Vellinga has 30 years of experience in agricultural research, ranging from grassland management, grazing, environmental impacts, modelling farming systems, life cycle assessments, feed chain analysis and manure management. He is experienced in cooperation with policy workers, farmers and industry and is skilled in developing solutions to apply developed knowledge in practical tools for stakeholders. Dr. Pim Mostert is a researcher at WUR, Wageningen Livestock Research. He is working on modelling livestock systems, developing LCA methods, and conducting LCA studies about feed production and livestock systems. He has published several LCA studies about dairy production and greenhouse gas emissions.

The reviewers evaluated the ISO compliance of the road testing LCAs, involving the choices for and implementation of LCA methods, the results and the recommendations on the applicability of the sector LCA guidelines (FAO LEAP and/or EC PEF) to given nutritional interventions related to feed additives.

Multiple rounds of reviews allowed accounting for the recommendations from the panel.

- Version 0.1 had been submitted to the panel on September 23, 2020;

- Version 0.2, accounting for comments made by the 1st review round, had been submitted to the panel on November 27, 2020;
- Version 1.0 has been finalized on January 29, 2021; acknowledged by the reviewers on February 25, 2021.

A further description of the review process and the final critical review statement by the panel are made available in Annex 8.7.

1.5 Structure of the report

This report starts with the explanation of the goal and the scope of the study, together with the main methodological choices made in the LCA in chapter 2. Then the LCA impacts of feed additive interventions are explored per animal type: pigs in chapter 3, dairy cows in chapter 4 and broilers in chapter 5. Chapter 6 summarizes the generic observations on the impact of feed additives and the applicability of industry standards, and chapter 7 contains the overall conclusions. The substantiations for the effects of the nutritional interventions are detailed in Annex 8.1.

2 Methodology

2.1 Modelling LCA impacts of feed additives use

Feed additives[1] have many functions, from technological to biologic. Some of them support animal health and performance and others reduce emissions and some do both at the same time. The FAO LEAP Guidelines on feed additives [1] mentions the below parameters as being possibly influenced by feed additives supplementation, while having an environmental impact:

- Change in feed composition;
- Improved feed conversion efficiency – due to modification of the feed consumption and/or of animal performance (milk, meat, egg, wool);
- Reduction of feed losses – through, for example, improved preservation during handling and storage;
- Mitigation of environmental emissions – due to changes in the excreta composition and/or directly as a result of emission reduction (such as methane for enteric fermentation or ammonia from manure due to manure acidification).

The support to the improvement of the lifetime performance of the animals (higher longevity, higher fertility, health status) and the improvement of the animal product quality (e.g. by improving its shelf life) are not listed in the FAO LEAP Guidelines on feed additives [1] but we assessed such effects for the dairy and pig cases. The study of the impact on the lifetime performance is in line with the consideration laid in the EU methane strategy[2] which points that "The most-effective ways of reducing emissions from enteric fermentation include *improving the health and fertility of the herds*, improving animal diets (mix of feed materials), feed additives, and feeding techniques.". We then took the option to also try modelling the impact of feed additives on

- the modified lifetime performance of the animals

Often the use of feed additives influences multiple flows in animal value systems. To capture the full LCA impacts, we apply a four-step approach, which we detail in the following paragraphs:

Step 1. defining the system where changes might occur;
Step 2. identifying the spots and mechanisms of change;
Step 3. defining the likely change scenarios (if possible, including some uncertainty);
Step 4. conducting the LCA calculations.

2.1.1 Step 1. Defining the system where changes might occur

Use of feed additives affects the product flows, consisting of substances (C, N, P K and micronutrients) and energy flows (carbohydrates related) going through the animal value system (*Figure 1*). The effects can be relatively isolated at one specific activity, changing only one specific flow, but can also be complex and 'long distance', affecting feed material flows in the supply chain or waste flows during consumption. Potential changes due to feed additives use may occur in all flows (quantity and composition), emissions and waste fractions. Also, the input of energy, materials (including packaging) and transport may be ultimately affected by changes.

[1] In this document, as in the FAO LEAP Guidelines on feed additives, the term «feed additives» is considered in the broad sense, as micro-ingredients added to the feed with the intent to achieve a given purpose, independently of any regulatory consideration.

[2] COM(2020) 663 (Oct 2020) COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS on an EU strategy to reduce methane emissions

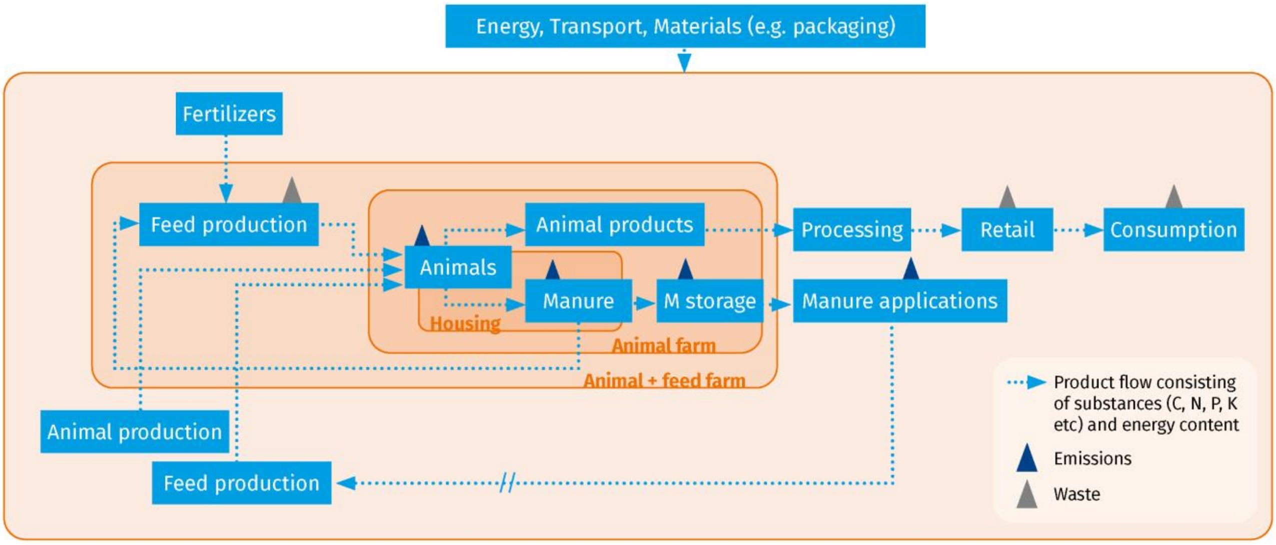

Figure 1 LCA view of the animal value chain

For the LCA of feed additives it is important that the overall animal value chain is defined in such a way that all potential impacts are included. A minimum requirement on system boundaries, according to the Leap Feed additive guidelines [1] is 'cradle to animal farm exit gate' connected to the reference units as produced at farm (litre milk etc.). For some additives that we will analyse here, this is a too narrow approach because impacts happen further on in the value chain at use of products, co-products, or manure.

Animal production can take place at a farm where the feed is completely imported, such as at the broiler and fattening pig farms that we studied here. It can also take place at a combined cultivation animal farm system, such as the dairy system where a major part of the ration (grass and other roughage) is grown on the farm. At an animal farm, there can be potential substance flow loops such as manure being used at cultivation of feed stuffs or by grazing on grassland. These feedback loops need consideration if the application of feed additives affects the composition of manure and hence changing the lifecycle impact at cultivation. Such loops may also exist when manure is leaving the farm and used at an arable farm that produces the feed again. Both feedback loops should be modelled consistently which needs ample consideration because the lifecycle calculations may also interfere with allocation rules. In section 2.5 we will explain how we dealt with this in this study.

In general, how the flows go through the system (conversions, division over co-products/waste and emissions) differs per region. This means that for defining the impact of feed additives the time and regional specificity needs to be considered. In this study we focused on current farm systems in the Netherlands and Belgium.

2.1.2 Step 2. Defining the changed flows and mechanisms of change

Feed additives have a zootechnical effect and hence influence the substance flows in the animal value system by a certain mechanism of change. In this study we analysed the potential impact of 14 feed additives applications. Table 1 summarizes the zootechnical effects and flows that are changed in the animal value system. A further elaboration of how the flows are modelled can be found in 8.1.

Table 1 Changes of flows as a result of feed additives

Additive	*Zootechnical effects*	*Changed flows and mechanisms of change*
Broilers		
Vitamin (25(OH)D3)	Muscle and bone development support via enhanced mineral homeostasis. More info in 8.1.5.4	Reduction in mortality. Higher amount of breast meat leading to more valuable product sales at slaughterhouse.
Eubiotics (acid and phytogenic compounds)	Gut functionality support via acidification of the digesta, gut flora modulation and stimulation of the	Improvement in FCR. This can be modelled as an increase in liveweight output, reduction of feed input, shorter production cycle or a combination of the approaches.

	digestive enzymes. More info in 8.1.5.5	
Enzyme (Phytase*)	Improved digestion of phytates. More info in 8.1.5.1	Change in feed materials composition because of lower needs for phosphorus and nitrogen input.
Enzyme (Protease)	Improved digestion of proteins. More info in 8.1.5.2	Change in feed composition (reduced nitrogen content) with higher overall feed digestibility. Same animal performance.
Enzyme (Xylanase)	Increased hydrolysis of arabinoxylans. More info in 8.1.5.3	Change in feed composition (higher level of wheat, lower levels of fat) with higher overall feed digestibility.
	Dairy cows	
Carotenoid (beta-carotene)	Fertility support via its antioxidant effects. More info in 8.1.4.1	**Fertility** Cows get pregnant more frequently, this gives a reduction of the dry period (shorter calving interval or longer lactation period) so that dairy cows can be more in lactation, this probably results in more milk production and more feed intake per year although shorter dry period might affect productivity at cow level. **Longevity** Better fertility could reduce culling of dairy cows. Increased longevity of dairy cows reduces the demand for youngstock and provides more calves liveweight output. The lower culling rate gives less liveweight output from mature cows culled. The amount of milk produced is also related to the age of the cow, so improved longevity will also influence milk productivity.
Vitamin (25(OH)D3[3])	Support of milk production, support of fertility, support calcium metabolism, support udder health, via enhanced mineral homeostasis. More info in 8.1.4.2	**Support of milk productivity** Higher milk output with the same feed input. **Improved udder health** means lower prevalence of mastitis and subclinical mastitis. This will impact animal performance, and possibly milk production, feed intake and **longevity**. Support against hypocalcemia means increase of level of calcium in blood, reducing prevalence of milk fever. This will affect animal performance, possibly on milk production, feed intake and **longevity**. Also, the **improved fertility** could lead to higher **longevity** due to less culling. All in all, milk production increases with a lower replacement ratio, changing the balance in milk, culled cow and calf's production.
Vitamin (Vitamin E)	Support of fertility, support udder health, via antioxidant effect. More info in 8.1.4.3	Mechanisms are described above.
Vitamin (Biotin)	Support of hoof health and locomotion and thus milk production. More info in 8.1.4.4	**Support of locomotion** means lower prevalence of lameness, this will have an impact on animal performance, possibly on milk production, feed intake and **longevity**. **Support of milk productivity.** Higher milk output with the same feed input.
Enzyme (Amylase)	Increased digestion of starch and fibers. More info in 8.1.4.5	Increase **milk** production and of overall feed digestibility
	Pigs for fattening	
Vitamin (Vitamin E)	Enhanced meat quality, lower meat losses. More info in 8.1.3.4	Lower meat losses related to spoilage results in less liveweight needed for the same consumed meat: direct reduction in impact
Eubiotic (Benzoic acid)	Gut function support via acidification of the digesta and gut flora modulation. Urine acidification via featuring of hippuric acid. More info in 8.1.3.3	Improvement in FCR. This can be modelled as an increase in liveweight output, reduction of feed input, shorter production cycle or a combination of the approaches. Lower ammonia emission from manure.

[3] The active form of Vitamin D. Existing synonyms: 25-hydroxyvitamin D3, HyD, hidroferol, calcifediol, calcidiol, Ampli-D, the two latter names being used for food applications.

Enzyme (Phytase*)	Increased digestion of phytates. More info in 8.1.3.1	Change in feed composition (reduced phosphorus and nitrogen content) with higher overall feed digestibility. Same animal performance.
Enzyme (Xylanase)	Increased hydrolysis of arabinoxylan. More info in 8.1.3.2	Change in feed composition (improves digestible energy from wheat) with higher overall feed digestibility. Allowing the use of feed materials with an overall lower digestible energy. Also shifting the sources of protein and therefore allowing use of different specific amino acids. Same animal performance.

The efficacy of feed additives is commonly studied by performing trials at livestock farms, exposing groups of animals to dietary treatments which differ only by the inclusion of the additive. Elaborated statistical analysis is carried out in the design of the trials and the interpretation of the results, in order to make sure that the observed differences are statistically significant and therefore reliable conclusions on the efficacy of the interventions can be drawn. These results are also sometimes required for the registration and subsequent marketing of these feed additives. In our present study, we use such results as a starting point for estimating the environmental impacts of the use of feed additives. This is also the rationale behind the LEAP guideline for feed additives. In Annex 8, paragraph 8.1.6 we give an overview of the literature that we used to derive average feed additive efficacy values.

As can be seen in Table 1, the translation of feed efficacy to LCA interventions is sometimes relatively straightforward. For instance, the use of amylase in the dairy ration is only affecting milk production. Such feed conversion changes can mostly be relatively easily converted to LCA interventions. Although it should be noted that improved feed conversion can be the result of two parameters, the pace of growth and the feed consumption per unit of time. There are slight differences in environmental impact between these two that will therefore be investigated in this study (see Figure 10).

Feed additives that change the nutritional requirements for the rest of the supplied feed are more complex to analyse because (changed) feed composition is related to prices of raw materials in a certain period and region. Also, complex to define are the interventions related to the feed additives that change health of dairy cows which can generate a combination of improved milk yields and increased longevity. Change in longevity may change the herd dynamics at the farm and so the balance in outputs of milk, culled cows, and calves. But increased longevity may also negatively affect milk yields of the herd again because older cows give less milk on average.

2.1.3 Step 3. Defining the likely change scenario and variability and uncertainties in the scenario

In step 3 a likely change scenario is defined, and alternative scenarios are defined to capture the variability and uncertainty in the effect mechanisms and related changes in the lifecycle flows.

The likely change scenario is defined for the LCA study in terms of changes of the flows going through the system and leaving the system in the form of:

- Product flows (their composition and ratio of co-products produced);
- Emissions;
- Waste flows.

During this step also alternative scenarios and uncertainties are defined. The rigor required in the sensitivity and uncertainty assessment depends on the goal of the LCA assessment. The more generic conclusions are intended to be drawn the more effort is needed in this step.

The uncertainty in the LCA results of feed additives use depends on several factors, such as:

1. The uncertainty in the environmental impact of the feed additives production;
2. The variability and uncertainty of the efficacy of feed additives;
3. The different possible scenarios for translating efficacy to changed inventory flows at the animal farm;
4. The variability of changes in supplying systems (feed, animals, bedding materials);

5. The variability of changes in downstream systems (manure application, retail, etc.).

In this study we applied a semi quantitative assessment of uncertainty and variability connected to the four places where the changes occur in the system that defines the impact. So, we combined 2 and 3.

- Environmental Impact of **feed additive production;** ΔFAI
- Changed environmental impact due to **emissions and resource use at animal farm;** ΔAFI
- Changed environmental impact of the **upstream supply chain;** ΔUPI
- Changed environmental impact in the **downstream value chain;** ΔDSI
- Changed environmental impact in the **total system.** ΔTOT

The total uncertainty / variability of the LCA results is then the sum of these four. This means that small changes with high uncertainty have less impact on the total.

Since the road testing was only targeted at getting preliminary insight in impacts of the feed additives, we were selective in implementing additional calculations.

2.1.4 Step 4. Defining the LCA method and conducting the LCA calculations

The LCA methodology to be applied (and the data sources used) for feed additive LCA should be capturing the full range of relevant impacts of the feed additives, sufficiently accurate, consistent and complete, should consider variability and uncertainty well in relation to the conclusions to be drawn.

The full range of environmental impacts relates to the system boundaries and the selection of environmental impact categories that are used in the assessment. In this study we explored if the limited cradle to grave system boundaries as being used in most guidelines and PEFCR's and the PEF EF2.0 Impact methodology suffice for feed additive LCA's.

Accuracy relates to the precision of modelling of the product flows, emissions, and waste flows and the changes in them. Most critical for drawing conclusions on the changed impact of the animal production system due to use of feed additives is how accurate the *direct* changes are modelled and if the *indirect* changes of product flows (quantities and composition) and emissions flows are accurately modelled including all likely changes.

Consistency relates to the application of LCA methodological choices in allocation, system boundaries and cut offs, through all animal production systems and secondary data used. The consistency requirement is also relevant for the secondary data used for feed materials since changed feed compositions can affect the results considerably.

Completeness is relevant here in two contexts. Completeness of modelling (are all mechanisms of change sufficiently captured) and completeness of secondary data. Lacking data will result in the use of proxies that affect the robustness of results.

The methodology that we used in the Road testing is further elaborated in section 2.2.

A final note on using attributional LCA

Although a change is studied, attributional LCA methodology can be used if the scale of change is relatively limited, such as comparing the impact of an animal farm system with or without the use of certain feed additives. This gives an indicative estimation of the actual change of impact when applying the feed additives on farm level. However, if large scale changes would be studied, other changes induced by using feed additives should also be considered. This is especially relevant for large scale changes that affect the use of co-products in feed. There is a group of feed ingredients for which the supply is limited because this is determined by the market of the main product, such as beet pulp, spent grain or soybean hulls. If additives would increase the use of these on a large scale, the analysis would have to take market limitations and reactions into account. This would also affect the economic allocation, which is an additional reason to apply more consequential LCA modelling, expanding system boundaries.

2.2 Road testing LCA methodology for feed additives impact

2.2.1 Road testing approach

We conducted a road testing LCA of nutritional interventions, based on feed additives supplementation, to explore if the current LCA methodology and available background data are sufficiently developed to conclude on the magnitude and certainty of lifecycle impact of the use of feed additives. Additionally, we also explored how LCA studies can deal with the use of multiple feed additives as one intervention, the so-called combined effects.

The primary aim of this study is to draw conclusions on adequacy of current LCA guidelines and standards that would support the LCA practitioner in conducting LCAs of nutritional interventions based on feed additives use. The secondary aim of the study is to explore the likely impact of the use of feed additives (multiple type of additives, applied to different target species) and how this impact could be further substantiated depending on the goal of the LCA study. We do not aim to assert the impact of use of feed additives for certain farm systems in given region and timeframe.

2.2.2 Test interventions

The guidelines were tested by studying a large number of diverse nutritional interventions (14) based on feed supplementation with additives leading to zootechnical changes. The study is conducted on three different target species (broiler chickens, pigs for fattening and dairy cows) with one reference system for each species. The dietary interventions are only applied to the selected life stages, although the effects can also be relevant for the level of replacement and thus the extent of the replacement herd, in case of dairy farming.

2.2.2.1 Substantiation of the interventions

The nutritional interventions are based on expert know-how and are substantiated by bibliographic information (developed in section 8.1).

More specifically we proceed in two steps illustrated in Figure 34.

1) The additive is documented (at least with one peer review paper, a review or several concurring ones, in the majority of cases) has having the potential to support a production parameter. A sample of the representative literature available is quoted with its intrinsic conclusions. From there an estimated effect when applied to the reference system is set.

2) The extent of the possible improvement when applied to the reference system is derived from the benefits shown in the literature and capped at level known to be reasonably achieved with nutritional management on the field, which may differ from what is revealed in experimental studies. The effect is integrated within our model, along other improvements resulting from other nutritional interventions. All the working hypotheses are transparently laid in the text. This second step mostly relies on expert knowledge.

A quality assessment for the substantiation of the effects accounted for in the LCA is provided in Annex 8.1, paragraph 0, along the criteria defined by the FAO Guidelines on feed additives [1] and point at a suitable level of substantiation. Indeed, in line with the FAO Guidelines on feed additives [1], we systematically based the effect of the nutritional intervention on peer-reviewed publications from reputable journals ("Peer-reviewed publication in reputable journals is favoured" [1]). Whenever possible, we refer to reviews and/or meta-analysis and/or regulatory assessment (also named "opinion" in the EU acceptation) to substantiate the effect on more than one study ("One study is considered to be a limited level of substantiation, while a minimum of three studies could be considered a suitable level of substantiation" [1]). Reviews and meta-analysis represent close to 45% (34/75) of the papers considered for the effects consists of reviews, meta-analysis or regulatory opinions.

The documented beneficial zootechnical gains are further translated into flow effects observable at farm level (listed in Table 1) along the process described in Figure 34 in section 8.1. In our study, the beneficial effects of each nutritional intervention included in the LCA are based on a conservative approach likely to have such an effect in a Netherlands or Belgium baseline farm system.

2.2.2.2 Modelling several nutritional interventions

For the three species, the nutritional interventions (Table 1) have been selected to have independent modes of action, to allow the consideration of a cumulative effect. No synergies among dietary measures have been considered. The impacts of the interventions have been calculated independently (one by one) and then cumulatively (when all applied to the reference system).

However, in the case of dairy, despite having different modes of action, some nutritional interventions share a common productivity end point (for example milk production or longevity). The approach elaborated (developed in Annex 8.1, and also described in section 4.1.4) is to set maximum achievable effect and to allocate the benefits to given pathways. By doing so, we avoid unrealistic overestimation of the cumulative additive use effects. The defined parameters (maximum effects and contribution factors) were based on educated estimation from nutrition experts, substantiated by available scientific literature collected in Annex 8.1.

2.3 LCA standards, guidelines tools and background data used in the road test

2.3.1 Methodology compiled from several standard and guidelines

The standard considered as a basis for this study is the ISO 14044. It describes the basic requirements for performing an LCA study. This includes directions on how to define the functional unit of a product, how to determine which processes need to be included or excluded, and how to deal with co-production situations where elementary flows need to be allocated to the different products. However, the ISO standard can still lead to different methodological decisions, depending on the LCA practitioner's interpretation. This means that applying the ISO standards properly may still result in different approaches and different quantitative results.

To solve this, the LCA methodology that we applied in this LCA is a compilation of best practices as defined in FAO LEAP guidelines and Product Environmental Footprint guidelines:

- The LEAP Guidelines are handbooks developed by FAO, with the aim of guiding livestock industries in the measurement of their life-cycle impact. These guidelines focus on animal production systems and/or on impact categories. The guidelines of main interest are:
  - Greenhouse gas emissions and fossil energy use from poultry supply chains (LEAP, 2016 [*9*]);
  - Environmental performance of large ruminant supply chains (FAO LEAP, 2016 [10]);
  - Environmental performance of pig supply chains (FAO LEAP, 2016 [11]);
  - Environmental performance of animal feeds supply-chains (FAO LEAP, 2016 [*8*]);
  - Nutrient flows and associated environmental impacts in livestock supply chains (FAO, 2018 [12];
  - Environmental performance of feed additives in livestock supply chains (FAO, 2020 [1]).
- The Product Environmental Footprint (PEF) framework gives general requirements and principles to calculate the environmental impact of products and services (Fazio et al, 2018 [13]). It was developed by the European Commission with the aim of defining Category Rules (PEFCRs) for specific product groups. The PEFCRs provide detailed guidance in terms of emission models and methodological choices like functional unit, system boundaries and selection of background databases. The FAO LEAP guidelines give room for interpretation and are not completely up to date for some aspects. So, in this study we use the following three documents developed in the EC PEF pilot phase with the industry sectors as main reference documents for dairy and pigs:
  - The PEFCR for feed for food producing animals (European Commission, 2018 [6]);
  - the PEFCR for dairy products (European Commission, 2018 [4]);
  - The PCR for Red meat (Technical Secretariat for the Red Meat Pilot, 2019 [7]).

For poultry we used the FAO LEAP guidelines [9] as a basis and added missing elements from other well-established sources.

We choose not to restrict ourselves by the recommendations of the FAO LEAP feed additive guidelines when performing this study because our aim was to explore the LCA methodology by defining first what we think which approach is adequate and practical. In practice however many elements of the way of working is the same. In chapter 6.2 we will compare our findings on how to perform feed additives LCAs adequately with feed LEAP guidelines.

2.3.2 LCA tools

This LCA is mostly run in APS-footprint, a specific LCA software developed by Blonk Consultants, meant to evaluate interventions in farming systems. The methodology and the background data in the tool are to a very high level compliant with PEFCR guidelines and aligned with FAO LEAP guidelines. A further explanation of the tool, methodology and data is given in the following documents:

- “APS-footprint tool general methodology” describes the overall concept and generic description of the tool [14];
- “APS-footprint methodology dairy”, specifically describes the dairy APS module [15];
- “APS-footprint methodology for pig”, specifically describes the pig APS module [16];
- “APS-footprint methodology for broiler and laying hens”, specifically describes the broiler APS module [17].

2.3.3 Feed additive LCA data

The Life Cycle Inventories of the feed additives were provided by the DSM LCA team and added as ingredients in the APS-footprint tool. End of life emissions of carbon dioxide for fossil carbon were included in the additives in these inventories. We chose for this approach to highlight which additional impact is inherent to the feed additive production, despite the recommendation of the Feed PEFCR to account for the emission of fossil carbon in the additive at the point where it really occurs, so after digestion of the feed in the animal or digestion of the fossil carbon in the animal products. Information on the approach applied to calculate the footprints for the manufacturing of the additives can be found in section 0.

2.3.4 LCA background data

We used the Agri-footprint 5.0 database as the main source for feed materials data and other background data [2]. The Agri-footprint database is the main underlying source database for the EF2.0 feed database and the GFLI database. Both databases are referred to in the Feed PEFCR as main sources for feed data. There are small differences between the EF2.0 data and the GFLI database. One main difference concerns the transport and energy data being used. In the GFLI database the Agri-footprint data are used and in the EF2.0 database, EF2.0 energy and transport data are used. This gives only small differences in the main LCA impacts (mostly < 2%). The reason for the choice of using Agri-footprint data in this study is related to license rights.

When ingredients were not available in Agri-footprint, they have been developed based on other background databases (Ecoinvent and LCA Food database). This is usually connected to premix es and chemicals used as feed ingredients (Vitamin premix, mineral premix, choline chloride, coccidiostat, sodium bicarbonate and monocalcium phosphate).

2.4 System boundary settings and dealing with manure loops

In our baseline calculations we chose to define the system boundary from cradle to farm gate. It includes all activities starting from extraction of fossil fuels and minerals from the earth, through production of electricity, fertilizer and other inputs for crop production, crop production processes, feed milling and the animal husbandry operation itself. The system and its boundaries are illustrated in Figure 3. In this system the focus point is the animal farm and its production of animal farm products.

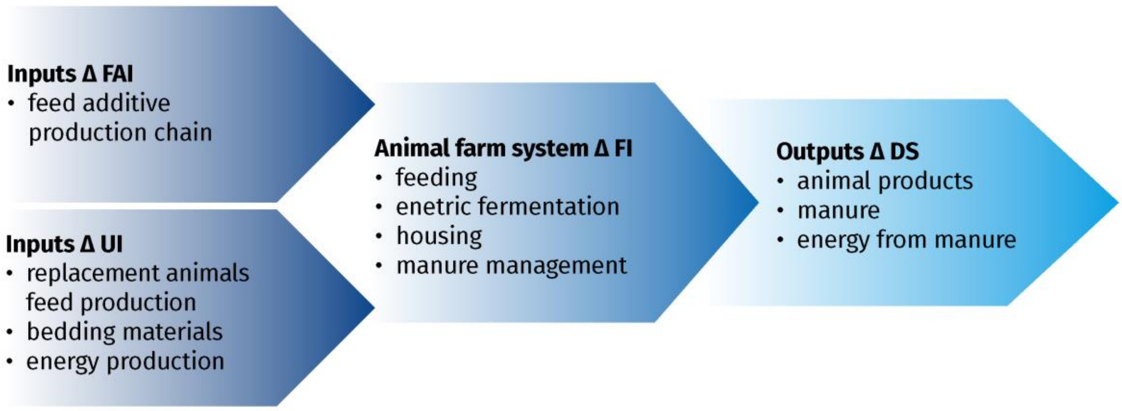

Figure 2 The animal farm system and its inputs, and outputs

We chose these system boundaries to limit the complexity of our LCA which has mainly an explorative character. Also, the different guidelines and PEFCRs are inconsistent on how to model the "after-farm" impacts.

The choice for these restricted boundaries implies that the "after farm" impact of some feed additives is not or incompletely modelled. In the sensitivity assessment we will explore "after-farm gate effects" related to the changes at use of the animal products or manure.

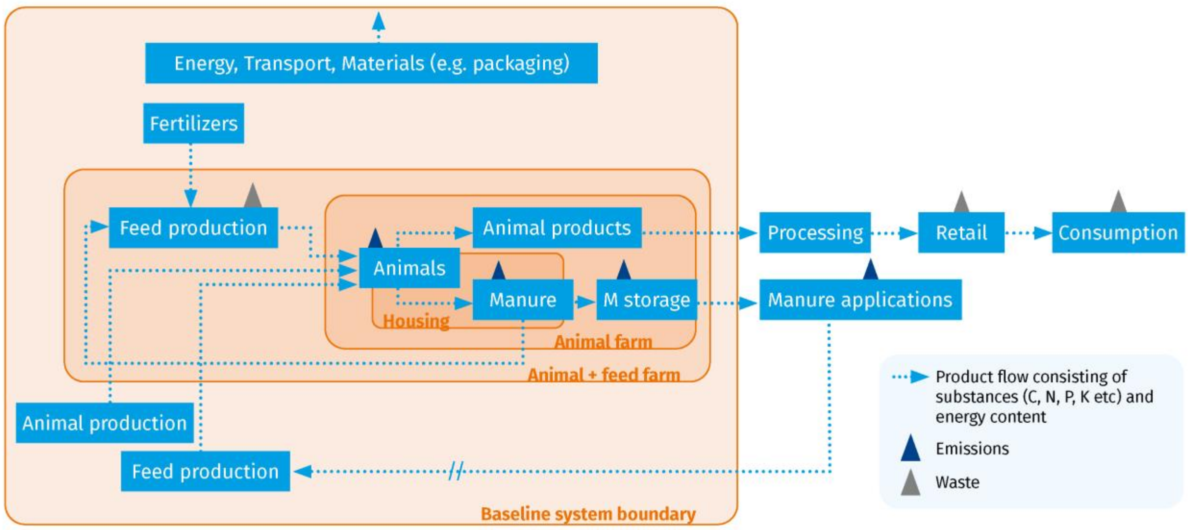

Figure 3 System boundary of the baseline calculations

Table 2 summarizes which processes and activities are included or excluded from our study.

The choice for inclusion or exclusion of the processes is based on the recommendations in PEFCR's or LEAP guidelines. The process of determining inclusion or exclusion in PEFCR's was based on impact contribution (significance) and data availability. This led to a lifecycle stage consistent approach. Between the lifecycle stages there can be inconsistencies, as for example for depreciation of capital goods, which is only included at cultivation since less data are available for the animal production lifecycle stage. The cut-off applied (excluded processes in Table 2) are considered to have a negligible effect on the overall LCIA results.

Table 2 System boundaries: included and excluded activities and or processes

Activities/ Processes	Included	Excluded
Crop cultivation	• Fuels use • Electricity use • N, P, K Fertilizer use • Organic fertilizer (manure and others) use • Lime use • Use of organic fertilizers or soil improvers • Use of Pesticides on the field and at storage • Use of irrigation water • Seed use • Depreciation of capital goods for machinery and storage • Packaging of fertilizers and pesticides	• Other consumables used during cultivation, such as foils, mineral oils for lubricating machinery • Activities related to living at the farm • Activities related to other business (e.g. producing wind energy) • Non-agricultural activities related to the producing company (e.g. accounting department).
Processing of feed materials, including	• Crop input mix of originating countries • Transport (distance per transport means) • Fuels use • Heat/ Electricity use • Water use • Wastewater treatment only for wet processes • Organic waste & losses • Auxiliary materials (processing aids)	• Some auxiliary materials adding up to less than 1% of mass contribution • Consumables used at the plant not used as a raw material or auxiliary material • Depreciation of capital goods • Non-agricultural activities related to the producing company (e.g. accounting department).
Animal farm (no cultivation or manure treatment and application)	• Youngstock (replacement animals) • Feed materials • Transport (distance per transport means) • Fuels use • Electricity use • Use of water	• Other Consumables used at the farm than animals and feed • Depreciation of capital goods • Production of semen for artificial insemination • Antibiotics and other veterinary product and services • Non-agricultural activities related to the producing company (e.g. accounting department).

2.4.1 Manure leaving the animal farm

The LEAP guidelines for animal husbandry (pigs, broiler, dairy and nutrient flows), PEFCR guidance document 6.3 and the dairy PEFCR distinguish between manure as a co-product, a residual stream and a waste stream [4,5,*9*,10,11,12]. The pig LEAP and the PEFCR guidance document 6.3 recommend as the baseline option considering manure leaving the farm as a residual stream [5,11]. This means that the outbound transport and application impacts are not included in the scope of the animal production system. The LEAP Guideline for nutrient flows is in contradiction with this because it considers manure as a co-product for all cases, especially when used as a fertilizer [12]. If manure is considered as a co-product the LEAP guidelines suggests a biophysical allocation, with economic allocation as a fallback option. The PEFCR guidelines suggests using system expansion or economic allocation for co-produced manure [4,5,*9*,10,11,12]. The large ruminants and poultry LEAP guidelines and the dairy PEFCR do not suggest a default approach, the choice depends on if manure brings a revenue or not to the farm.

For pigs, the red meat PCR stipulates that the consequential effects of application should be included, and that these consist of replacement of inorganic fertilizer [7]. This means that the impact of manure applied after leaving the farm needs to be considered, but also N and P inorganic fertilizers substitution is accounted for. Substitution of inorganic N and P should be based on realistic data or defaults may be used, 50% for N and 100% for P.

In our baseline calculations we considered manure as a residual product, not giving any revenue to the animal farm. This decision was made for several reasons:

- The geographical location in scope (Belgium and Netherlands region) is characterized by an exceptionally high density of animal system. Combined with the fact that environmental laws restrict use of manure, makes the removal of manure a cost for animal farmers. Therefore, in line with LEAP and PEFCR guidance (except for the LEAP nutrient flows, annex 8.6 summarizes guidelines indications on manure consideration): “if manure has no revenue for the farmer, it should be considered as residual” (this is also common practice in LCA studies for the Netherlands and Belgium).
- Practical reasons connected to tool and database limitations. The APS-footprint tool, used in this study as LCA modelling tool, currently only considers the residual scenario for manure. The Agri-footprint database that is used for feed ingredients also considers manure as an input with no upstream burden from the animal farm. Including manure effects would ideally be reflected at feed production too, to make the results comparable to other animal products where manure is treated as a residual product.
- The guidance documents that we use are mostly oriented towards attributional analysis, but not all, such as the additives Guideline and the nutrient Guidelines, which also enter the consequential LCA domain. How to interconnect this, is not developed yet in the LEAP framework (8.6 summarizes guidelines indications on manure consideration).

We realize the limitations of choosing such approach, when trying to account for changes that can also affect the amount (or nutritional content) of manure available for spreading to land. The LEAP additive guideline [1] states that an LCA that studies the changes induced by feed additives should study the full implications of the use of additives, thus also related to the manure leaving the animal farm. There is yet no indication on how to account for this. One option is to consider manure as a useful output, therefore considering allocation. Allocation method used should be able accounting for changes in manure nutritional content. This would be possible by following LEAP guidelines suggestion of using biophysical allocation based on energy used for nutrient digestion. Following the PEFCR guidelines suggestion of using economic allocation would be more complicated, in terms of price setting. Another option is to follow the PCR red meat approach. It consists in a boundary expansion, where emissions from applying manure leaving the farm are considered. Partial substitution of production and application emissions of inorganic fertilizers are also considered. We decided to investigate only the latter approach in various sensitivity analysis for scenarios that we considered more influenced by the manure off-farm methodological choice (section 3.3.5.2 and 5.3.3.2)[4]. The sensitivity analysis is meant to make the first step in the exploration of this methodological issue.

2.4.2 Manure application at the animal farm

In our baseline methodology the application of manure in the production of roughage is included as a background process, and manure applied on-farm is considered as a residual output. This means that a country average process for roughage production is used, rather than the farm specific one. This is especially important during intervention, since changes in manure composition are usually highly affecting the roughages (e.g. grass silage) mineral quality. This usually is closely considered by farmers, and might influence fertilization management or different feeding regimes.

A sensitivity has been performed to explore the influence of using the red meat PCR approach for accounting for manure nutrient changes.

Emissions from manure deposited while grazing are considered as foreground, and not included in the background dataset.

2.5 Allocation

We used background data from Agri-footprint for the processes energy production, feed ingredients production and animal breeding farms [2] This database applies the LEAP feed guidelines and the PEFCR feed requirements

[4] It should be noted that manure use is included at cultivation of feed crops in the background dataset starting with no impact of the producing lifecycle. Impacts from transportation and application are included.

for allocation. In the LEAP feed guidelines, economic allocation is set as the default option, since allocation on physical characteristics would not capture easily the variable functionality connected to the co-products produced by processing facilities. For comparative assertions sensitivity on allocation options shall be performed (FAO LEAP 2016). In the Feed PEFCR this requirement is not set anymore since the steering committee of the commission “forced” the choice for one allocation method for feed PEF compliant studies. In this study we did not perform any alternative allocation options in the sensitivity assessment because of the scope of the study and the fact that economic allocation for feed materials is seldomly challenged likewise the allocation used at energy production systems.

Also, allocation between piglet and sows and allocation between spent hen and breeding egg are based on economic allocation. Since the pig and broiler production are single output processes and manure is treated as a residual product, allocation at the farm is only relevant for dairy, where biophysical allocation is applied, as indicated by the Dairy PEFCR [4], and based on International Dairy Federation [27]:

$$AF = 1 - 6.04\, x\, \frac{M_{meat}}{M_{milk}},$$

Were AF is the Allocation Factor of milk, M_{meat} is the mass of live weight of all animal sold including bull, calves and culled mature animals per year, and M_{milk} is the mass in FPCM sold per year. The allocation for Meat can be calculated as 1 - AF. This equation is limited to a meat / milk ratio less than 4%.

Similar as for inclusion or exclusion of processes the allocation approach is following the standards and guidelines and therefore not consistent between the lifecycle stages in case of dairy.

Table 3 Summary of allocation used in the background dataset and in the APS-footprint tool

	Pig	*Dairy*	*Broiler*
Type of allocation of background processes (cultivations/breeding)	Economic allocation	Economic allocation	Economic allocation
Type of allocation at animal farm	Not applicable	Biophysical allocation [4]	Not applicable

2.6 Emission calculations

The excretions and emissions calculations used are based on IPCC and EMEP/EEA guidelines [*18*,*33*]. The emissions at cultivation can be consulted in the background dataset documentation [2,5]. The emissions calculated at animal farm are based on the APS-footprint tool and can be consulted in the APS methodological documents [14]. Here a summary of the tier level used for different emissions at the animal farm is given.

The emissions modelled at animal farms are:

- Methane (CH_4) from enteric fermentation;
- CH_4 from manure;
- Direct dinitrogen monoxide (also called nitrous oxide) (N_2O) from manure;
- Indirect N_2O from leaching of manure;
- Indirect N_2O from volatilization of ammonia (NH_3) and nitrogen oxides (NO_x);
- Non-methane volatile organic compounds (NMVOC) from manure;
- Particulate matter (TSP, $PM_{2.5}$ and PM_{10}) from manure.

Leaching of nitrate (NO_3^-) and phosphorus (P) (at animal farm, not cultivation), and emissions of heavy metals (e.g. Cu, Zn) are currently not modelled.

Some of the listed emissions first need estimation of excretions. Nitrogen, Total Ammonia Nitrogen (TAN) and Volatile Solids excretion are included in the calculations. P excretion has not been estimated due to tool limitation.

Table 4 summarizes the models used for excretion and emissions calculation in this study.

In general, IPCC Tier 2, is applied for N excretion (N balance approach), VS excretion (based on digestibility of feed), CH_4 from enteric fermentation (CH_4 conversion factor Ym multiplied by Gross energy), CH_4 from manure (based on VS excretion and manure management type), direct N_2O emissions (based on N excretion and manure management type) and indirect N_2O emissions (based on N excretion, volatilization and leaching factor, and indirect EFs). Exceptions are made for the dairy emission calculations: the N excretion does not account for a full mass balance, but uses a fixed retention factor and the CH_4 from enteric fermentation is based on the Tier 3 approach proposed in the Dutch NIR (feed emission factors (EF) as implemented in the Kringloopwijzer tool [19]). The limitation of using a fixed retention factor will be tested in sensitivity scenarios. Also, various enteric methane CH_4 modelling are investigated in a sensitivity scenario.

Non-greenhouse gas emissions are calculated with EMEP/EEA [*18*]. In general, Tier 2 approaches are used for NH_3 emissions (based on N excretion to TAN conversion factor and NH_3 EF), NO_x emissions (based on N excretion and NO_x EF) and NMVOC (based on VS excretion and NMVOC EF). TSP, $PM_{2.5}$ and PM_{10} emissions are calculated with a Tier 1 approach (the number of average annual animals present on farm is multiplied by a fixed EF).

Table 4 Tier model and sources for the excretion and emissions modelling at animal farms

Excretions and emissions	*Animal species*	*Baseline emission calculations*
N excretion (N_E)	Pig	IPCC Tier 2
	Dairy	IPCC Tier 2 (fixed retention factor)
	Broiler	IPCC Tier 2
TAN[1] excretion (TAN_E)	All	EMEP/EEA (conversion from N to TAN)
VS[2] excretion (VS_E)	All	IPCC Tier 2
CH_4 enteric	Pig	IPCC Tier 2 (Ym based on GLEAM)
	Dairy	IPCC Tier 3 (EF from Dutch NIR)
CH_4 manure	All	IPCC Tier 2
Direct N_2O emissions	All	IPCC Tier 2
Indirect N_2O emissions	All	IPCC Tier 2
NH_3 emissions	All	EMEP/EEA Tier 2
NO_x emissions	All	EMEP/EEA Tier 2
NMVOC emissions	All	EMEP/EEA Tier 2
TSP, $PM_{2.5}$ and PM_{10} emissions	All	EMEP/EEA Tier 1

Once the total N, TAN and VS excretion amounts are quantified, it is necessary to account for the shares of excreta deposition at the different locations on the farm. For the emissions calculated with the EMEP/EEA (2016) guidelines, this is done by defining the time spent on grazing, spent on open yard areas, and spent inside the housing (this is relevant only for dairy):

- Time spent on grazing is defined as the period spent by the animal on grassland or other pastures;
- Time spent on open yards is defined as the period spent by the animal on feedlot (or drylot) or spent on open areas while waiting for milking;
- Time spent on housing is defined as the period spent by the animal in the housing system where feed, water and protection from relevant environmental conditions are provided. Housing systems vary greatly worldwide, from shed to barns.

The time spent in each of the three locations is expressed as a fraction of the overall year (therefore summing up to 1), and has to be set by the user. These parameters are used to define the amount of manure excreted at each location. The assumption taken is that excretion behaviours of animals is not influenced by their location.

In the current version of APS-footprint tool, emissions calculated according to IPCC only consider one manure management per animal type: the housing management as defined by the user. This means that for N_2O and CH_4 emissions, N and Volatile Solids (VS) excretion are assumed to take place only at housing, with one type of manure management system in place.

Details on the equations and emission factors implemented in APS-footprint are available the APS methodological documents [14].

2.7 Impact method and impact categories

We used the EC PEF EF 2.0-method (Table 5) and calculated all 16 environmental impact categories. The climate change score is broken down to climate change without land use change and climate change of land use change.

Not all impact categories are considered equally robust. Three categories were defined and dare classified according to their quality into three levels: “Level I” (recommended and satisfactory), "Level II” (recommended but in need of some improvements) or "Level III” (recommended, but to be applied with caution). Impact categories defined as level I and II does not generally give potential limitation during interpretation stage. Level III impact categories, on the opposite, needs to be cautiously examined during interpretation stage, since inherently limitation in the method might influence the results.

Table 5 Impact categories with their methods

Impact category	*Indicator*	*Unit*	*LCIA method*	*Robust-ness*
Climate change	Radiative forcing as Global Warming Potential (GWP100)	kg CO_2 eq	Baseline model of 100 years of the IPCC (based on IPCC 2013)	I
Ozone depletion	Ozone Depletion Potential (ODP)	kg CFC-11eq	Steady-state ODPs as in (WMO 1999)	I
Ionising radiation, Human Health	Human exposure efficiency relative to U^{235}	kBq U^{235}	Human health effect model as developed by Dreicer et al. 1995 (Frischknecht et al, 2000)	III
Photochemical ozone formation, Human Health	Tropospheric ozone concentration increase	kg NMVOC eq	LOTOS-EUROS (Van Zelm et al, 2008) as applied in ReCiPe 2008	III
Respiratory inorganics	Human health effects associated with exposure to small particulate matter ($PM_{2.5}$)	Disease incidences	PM model recommended by UNEP (UNEP 2016)	I
Non-cancer human health effects	Comparative Toxic Unit for humans (CTUh)	CTUh	USEtox model (Rosenbaum et al, 2008)	II
Cancer human health effects	Comparative Toxic Unit for humans (CTUh)	CTUh	USEtox model (Rosenbaum et al, 2008)	II
Acidification terrestrial and freshwater	Accumulated Exceedance (AE)	mol H+ eq	Accumulated Exceedance (Seppälä et al. 2006, Posch et al, 2008)	II
Eutrophication freshwater	Fraction of nutrients reaching freshwater end compartment (P)	kg P eq	EUTREND model (Struijs et al, 2009) as implemented in ReCiPe	II
Eutrophication marine	Fraction of nutrients reaching marine end compartment (N)	kg N eq	EUTREND model (Struijs et al, 2009) as implemented in ReCiPe	II
Eutrophication terrestrial	Accumulated Exceedance (AE)	mol N eq	Accumulated Exceedance (Seppälä et al. 2006, Posch et al, 2008)	II
Ecotoxicity freshwater	Comparative Toxic Unit for ecosystems (CTUe)	CTUe	USEtox model, (Rosenbaum et al, 2008)	III
Land use	Soil quality index (Biotic production, Erosion resistance, Mechanical filtration and Groundwater replenishment	Dimensionless	Soil quality index based on LANCA (Beck et al. 2010 and Bos et al. 2016)	III
Water scarcity	User deprivation potential (deprivation-	kg world eq. deprived	Available water remaining (AWARE) in UNEP, 2016	III

	weighted water consumption)			
Resource use, energy carriers	Abiotic resource depletion (ADP ultimate reserves)	kg Sb eq	CML Guinée et al. (2002) and van Oers et al. (2002)	III
Resource use, mineral and metals	Abiotic resource depletion (ADP ultimate reserves)	MJ	CML Guinée et al. (2002) and van Oers et al. (2002)	III

We calculated all impact categories despite the fact that the impact models underlying the calculations are not equally robust.

In the main text we will focus on the following focus impact categories:

- Climate change (with and without LUC);
- Respiratory inorganics;
- Eutrophication marine;
- Eutrophication freshwater.

They are considered as relatively robust (category I or II), and add up to more than 80% of the weighted impact according to the EF2.0 methodology [40] which is a relevance criterium in the PEFCR guidance document for selecting relevant impacts [5]. For the sake of not duplicating interpretations and discussions, between various ammonia driven impacts (important for Respiratory Inorganics, Marina and Terrestrial Eutrophication) we choose only to focus on Respiratory Organics because this is related to human health directly. To get insights in the P related impacts we choose to include eutrophication freshwater.

Table 6 Impact categories contributions to single score, for the baseline systems

Impact categories	*Recommendation level*	*Pigs*	*Dairy*	*Broiler*
Climate change	I	25%	24.8%	30.6%
Ozone depletion	I	0%	0.0%	0.0%
Ionising radiation, HH	III	0%	0.0%	0.2%
Photochemical ozone formation, HH	III	2%	2.1%	2.1%
Respiratory inorganics	I	16%	19.6%	15.3%
Non-cancer human health effects	II	0%	0.0%	0.0%
Cancer human health effects	II	0%	0.0%	0.0%
Acidification terrestrial and freshwater	II	17%	20.9%	13.7%
Eutrophication freshwater	II	1%	0.5%	1.8%
Eutrophication marine	II	6%	6.5%	5.7%
Eutrophication terrestrial	II	14%	17.2%	11.2%
Ecotoxicity freshwater	III	0%	0.0%	0.0%
Land use	III	7%	4.0%	7.7%
Water scarcity	III	3%	1.2%	5.3%
Resource use, energy carriers	III	6%	3.0%	6.0%
Resource use, mineral and metals	III	0%	0.1%	0.3%

Land use, water scarcity and fossil energy use are also important impacts for animal production systems. Improved and more robust methodology is highly needed.

2.8 Baseline systems

2.8.1 Farm systems

The baseline farm systems defined for each species are meant to depict a Western European type of production system. For this, we used a mix of Dutch and Belgian data for the farm and feed systems. Table 7 summarizes the definition of the baseline animal production systems. The optimization level of the feed and the animal management systems can be considered as high in such reference farms.

The impact of the use of additives is evaluated for farms that are in a steady state, meaning that the youngstock (replacement animals) compensate the animals leaving the farm.

Table 7 Definition of the baseline animal production systems

	Pig	*Dairy*	*Broiler*
Typical region and period	Netherlands, Belgium 2015-2020	Netherlands, Belgium 2015-2020	Netherlands, Belgium 2015-2020
Reference data for the farms	NL, from Agri-footprint describing 2015 system parameters	NL, developed as a average reference system for APS-footprint [14]	NL, from Agri-footprint describing 2015 system parameters
Ration and feed design	Phase feeding with complete feed. Least cost Formulation (LCF) Executed in June 2020 by DSM nutritionist and reflecting key traits of the BE market	Roughages and concentrate feed (APS-footprint default ration). Concentrate feed composition recalculated with DSM BE LCF to get the total set of nutritional levels)	Phase feeding with complete feed. Least cost Formulation (LCF) Executed in June 2020 by DSM nutritionist and reflecting key traits of the BE market
Origin of feed ingredients	As indicated by DSM BE	Trade mix NL	As indicated by DSM BE
Feed composition	Table 43	Table 44	Table 45
Detailed feed composition	Annex 8.2		
Feed additives in baseline feed	Feeds in this area contain by default a standard commercial vitamin and mineral premix. They also contain amino acids and other typical nutritional additives. Phytase is in the baseline (the no phytase case is studied as a historical case)	The concentrate feed contains by default a standard commercial vitamins and mineral premix.	Feeds in this area contain by default a standard commercial vitamins and mineral premix. They also contain amino acids and other typical nutritional additives. Phytase is in the baseline (the no phytase case is studied as historical)

2.8.1.1 The case of phytase

In our present report, for pigs and broilers, we handle the phytase differently from the other additives. Supplementation of monogastric feeds with basal levels[5] of exogenous phytases, initiated in the early 1990s, is now a common practice. Therefore, in our intent to explore the possibilities of conducting LCAs of additive supplementation in practice, we express the impacts of the other additive supplementation in reference to a baseline that includes phytase.

However, to keep track of the reduction of environmental impact enabled by phytase supplementation, in the past decades, we also conducted a non-phytase use to a phytase use scenario to explore the contribution of using this enzyme to reducing environmental impacts.

[5] It should be noted that our report does not study the recent practice consisting in supplementing the feeds with notably high levels of phytase, an emerging nutritional practice.

2.8.2 Feed rations and recipes

The feed recipes were designed to have several key traits of typical feeds in the Netherlands and Belgium. They were all least cost formulated by a DSM nutritionist expert in feed formulations, based in Belgium (on Libra software by Actenium). The feeds considered per system are the following:

- Pig system: 3 phase fed diets for pigs for fattening (25-50kg, 50-80kg, 80-100kg) further averaged into one feed based on feed intake per growth stage.
- Dairy system: one dairy feed concentrate (fed in addition to the roughages).
- Broiler system: 4 phase fed diets (0-10d, 10-20d, 20-35d, 35-42d), further averaged into one feed based on feed intake per growth stage.

The feed design criteria are listed below:

- nutritional requirements and concepts applicable to advanced feeding programs for Belgium and/or Netherlands (for example in the case of pig and broiler diets: balanced digestible amino acids, metabolizable or net energy, digestible phosphorus, stepwise adjustment by phase feeding),
- typical raw materials (including several by-products from the food industry), sourced locally or on the global market. For the origin of the raw materials, 2 distinct incidental approaches have been taken for the dairy and the monogastric species:
    - Pig and Broiler feed: origins of the raw material are the effective ones (no consideration of a trade mix).
    - Dairy concentrate feed: origins of the raw materials are along a Dutch trade mix.
- a unique price list assessed as typical of the year 2020 with no notable specific price pattern.

Some interventions based on enzymes (phytase, protease, xylanase) affect the feed composition. Upon evaluation, the reference feeds were then altered accordingly implementing the approach above, as impacted by the intervention. All the other interventions do not interfere with the design of the feed.

The feed recipes defined for our systems have thus a limited representativity, while having several key traits of a typical Benelux feeds.

The averaged feed compositions can be read in Annex 8.2 (paragraph 8.2.1). The detailed formulas, before weighting, can be read in the same Annex in paragraph 8.2.2.

2.9 Feed additives "likely" change scenarios for baseline calculations

The effects accounted for in the 14 nutritional interventions are derived from expert know how and grounded on bibliographic information (collected in Annex 8.1), largely based on reviews and meta-analysis. All the publications considered are peer reviewed articles.

Furthermore, the beneficial effects of each intervention studied in the LCA are defined on the basis of a conservative approach, not taking the maximum effect but the average one derived from the literature, having some likelihood to exhibit an effect for a Netherlands or Belgium reference farm system.

Each intervention with its effect is further described in chapter 3, 4 and 1, for each of the species.

Table 8 Likely change scenarios after intervention

Additive	*Zootechnical effects*	*Likely change scenario's*
	Broiler	
Vitamin (25(OH)D3)	Muscle and bone development support	Mortality reduction of 0.5%-point. Breast meat yield increase of 4%
Eubiotic (CRINA Poultry Plus)	Gut functionality support	Feed Conversion Ratio reduction of 3%
Enzyme (Phytase)*	Improved digestion of phytates	Lower mineral phosphate requirement
Enzyme (Protease)*	Improved digestion of proteins	Lower crude protein requirement

Enzyme (Xylanase)*	Increased hydrolysis of arabinoxylan	Lower gross energy requirement
Dairy cows		
Carotenoid (beta-carotene)	Fertility support	Dry period (-6d), longevity as number of calving per cow (+15%)
Vitamin (25(OH)D3)	Support of milk production, fertility, udder health, (longevity)	Milk +0.5kg/d, Dry period -2d, Milk fever -25% prevalence, clinical udder health -7.5% prevalence, subclinical udder health -12.5% prevalence, longevity as number of calving per cow +5%
Vitamin (Vitamin E)	Support of fertility, udder health, (longevity)	Calving interval -2d, udder disorders -7,5 points, longevity as number of calving per cow +5%
Vitamin (Biotin)	Support of locomotion, milk production, (longevity)	Milk +0.5kg/d, lameness -50% prevalence
Enzyme (Amylase)	Increased digestion of starch and fibers	Milk +1kg/d
Pigs for fattening		
Vitamin (Vitamin E)	Enhanced meat quality, lower meat losses	-5% meat losses
Eubiotic (Benzoic acid)	Gut function support and urine acidification	FCR -3% support, NH3 emission -20%
Enzyme (Phytase)*	Increased digestion of phytates	Feed reformulation with lower mineral phosphate
Enzyme (Xylanase)*	Increased hydrolysis of arabinoxylan	Feed reformulation with more energy extracted from wheat

*Effects read on feed formulation.

2.10 Sensitivity assessments

Because our primary goal is to evaluate the fitness for purpose of the guidelines by testing an extended set of interventions (14 distinct interventions and 3 combined ones), the sensitivity appraisal for each individual intervention was only dealt with at a secondary level in our study. A discussion on the variability and certainty for the zootechnical effects is proposed in Annex 8.1.

A sensitivity analysis for the most influential hypothesis of the modelling is proposed in each species chapter.

2.11 Concluding on the LCA effects of feed additives

Although, the main objective of the road testing LCAs is not to come to definitive conclusions, we still attempted to derive conclusions on the potential effects of the additives considering all the limitations of the LCAs that we performed. We do this by reporting the quantitative results together with all the qualitative and quantitative considerations on the applied methodology and data as well as necessary improvements. We consider systematically all potential changes and LCA effects in the system: production of feed additives; at animal farm; at the supply chain and downstream. This approach leads us to consider and report (in section 6) all methodological issues and potential implications on the results.

As we explained in 2.1.4, an adequate LCA methodology should capture the full range of impacts of the feed additives; be sufficiently accurate, consistent, complete, and should consider variability and uncertainty well in relation to the conclusions to be drawn.

We specifically reflected on the need of defining a sound approach in relation to the goal and scope of feed additive LCA studies. This aspect is not well covered in any LCA guidance document yet. All the methodological considerations that we think are meaningful to consider in further development of animal production system LCAs are summarized in section 6.3.

2.12 Limitations and key assumptions

Biogenic GHG emissions are only quantified for methane, because biogenic CO_2 emissions in this lifecycle have such a short cycle that their impact can be considered zero (most uptake and release happen within several years). Non-biogenic emissions in the generation of electricity and other inputs are included, of course.

No carbon storage or delayed emissions are included in this study, since the methodology on this is still in development. We also think that in this study they are not relevant, because they don't change between the various scenarios.

3 Fattening pigs

3.1 Scope

3.1.1 The baseline pig production system

A baseline pig farm has been considered as a starting point for the evaluation of the interventions. The modelled system is representative for a modern (Belgian / Dutch) intensive pig production system as described in the LEAP guidelines [11]. Pigs are produced under very similar conditions in many places (mainly intensive systems), so this baseline is similar to many production systems in Western Europe, with the exception of emission mitigation technologies and feed composition, which are determined locally.

3.1.2 System description

A Dutch fattening farm produces pigs with an average target liveweight of 117 kg. The pigs are transported for slaughtering, where they undergo a quality check regarding carcass quality and diseases in organs (liver, lungs, etc). A farmer is paid for carcass weight and carcass quality. Data for farm design and performance are based on statistics collected by Wageningen UR and are representative for a typical Dutch farm (Wageningen UR, 2017 [*21*]) as well as for the Belgian situation.

A production cycle lasts 114 days on average, during which pig are grown from 25 kg up to 117 kg. The inventory is based on 100 animal places and 100 animals present, on average throughout the year, on the farm. We are assuming no empty periods and mortality happening at the end of the cycle. We estimate such assumptions to have a small effect on the overall results. This means that 320 piglets are bought every year and 313 pig are slaughtered (including a 2.3% mortality rate). A 2.07 kg compound feed/day/AAP is considered. The manure management system is a slatted floor with pit below, where manure is stored for more than 1 month on average.

Table 9 Pig farm baseline parameters as expressed in the APS-footprint tool. All values expressed per 1 year.

	Unit	*Value*	*Source*
Average annual temperature	degrees Celsius	10	
Geography		NL	
Pigs total live weight	kg	36599	Calculated based on [*21*]
Pigs nitrogen content	%	2.5	[30]
Diesel	MJ	36	[*21*]
Electricity	MJ	14188	[*21*]
Water	kg	70000	[*21*]
Natural Gas	MJ	4874	[*21*]
Saw dust	kg AAP^{-1}	0	Due to manure management
Straw for bedding	kg AAP^{-1}	0	
Number of rounds per year	#	3.2	[*21*]
Purchased piglets total animal live weight	kg	8000	Calculated
Purchased piglets nitrogen content	%	2.4	[*23*]
Purchased piglets average live weight	kg	25	[*21*]
Number of purchased piglets	#	320	Calculated
Animal type		Pig	
Average number of animals present	#	100	Assumed
Mortality	%	2.3%	[*21*]
Manure management system		Pit storage (> 1 month)	

Percentage of manure stored on farm before spreading	%	100	Expert judgment
Feed intake	kg AAP^{-1}	755	[21]
Digestibility	% of GE	85	[33]
Feed nitrogen content	%	2.77	[26]
Gross energy intake	MJ AAP^{-1}	12815.67	

The compound feed formulation has been specifically determined for this study, based on least cost formulation, and considering ingredients commonly used in Belgian and Dutch feed markets. The approach for designing the feed formulation is described in paragraph 2.8.2.

The averaged composition of the pig feed is summarized in Table 43, section 0.

3.1.3 Functional unit and reference flow

The functional unit is 1 kg live weight pig with average quality as delivered to the slaughterhouse at the farm gate. Carcass yield is assumed to be 79%, and the fresh meat fraction 67% based on Agri-Footprint database [2].

We assume that interventions do not modify the average quality of the animal, when slaughtered (no change in carcass yield or subsequent carcass quality).

3.1.4 Feed additive interventions

3.1.4.1 The interventions for pigs

The effects of additives in pig systems are first calculated individually based on zootechnical effects substantiated by recognised scientific literature as described in chapter 2. The cumulative effect is calculated by summing the zootechnical effects together, assuming the absence of any form of interaction between the individual additives. Consideration of such assumptions are discussed in the results section (3.3.7.2).

The set of dietary interventions considered for pigs for fattening is listed in Table 10. The full substantiation for the effects can be found in section 8.1.

Table 10 Dietary interventions considered for pigs for fattening with their effects

Principle	***Dose intervention***	***Zootechnical effect (qualitative)***	***Zootechnical effect (quantitative)***	***Change in LCA (inventory) flows (quantitative)***
Vitamin E	200 mg/kg finisher feed **	Enhanced meat quality, lower meat losses	5% less meat loss at consumer	Out of boundary (1.02% avoided liveweight production modelled in the sensitivity analysis)
Benzoic acid*	5000 mg/kg DM feed	Gut function support and urine acidification	FCR -3% support, NH3 emissions -10%	Larger growth (1.34%) and lower feed intake (1.34%), NH3 emission -10%
Benzoic acid*	10000 mg/kg DM feed	Gut function support and urine acidification	FCR -3% support, NH3 emission -20%	Faster growth (1.34%) and lower feed intake (1.34%), NH3 emission -20%
Phytase	30 mg/kg feed	Increased digestion of phytates	Feed reformulation with lower mineral phosphate	Change in feed formulation
Xylanase	100 mg/kg feed	Increased hydrolysis of arabinoxylan	Feed reformulation with more energy extracted from wheat	Change in feed formulation
All	Benzoic acid: 10000 mg/kg DM feed Xylanase: 100 mg/kg feed	Gut function support and urine acidification and increased hydrolysis of arabinoxylan	FCR -3% support, NH3 emission -20% Feed reformulation with more energy extracted from wheat	Faster growth (1.34%) and lower feed intake (1.34%), NH3 emission -20% and change in feed formulation

*Two doses are considered for benzoic acid. ** from 80 to 100kg.

Because of the modern practice of systematic phytase supplementation, the present study considers a baseline with phytase addition. However, to exemplify the benefit of a nutritional solution made available in the 90s, the footprint of pig feeding without phytase addition is also assessed.

3.1.4.2 Mode of action, efficacy and change in inventory flows

The mode of action of the respective interventions has been substantiated by scientific literature, as described in section 8.1. The translation into LCA (inventory) flows changes can be summarized as follows:

- Phytase allows digesting the phosphorus from the plant-based material present in the diets, reducing the need for addition of mineral phosphorus. It also enhances the digestibility of proteins. This allows a reformulation of the compound feed (Table 43). Least cost formulation, based on nutritional parameters, was performed similarly to the baseline compound feed formulation (section 2.8.2). The increase in protein digestibility is modelled through a reduced N content of the new reformulation, while the animal performances remain unvaried.
- Xylanase allows improving the digestion of carbohydrates present in cereals containing high levels of arabinoxylans, therefore allowing the animal to take up more energy. In this case also, this allows a reformulation of the compound feed (Table 43). Even though the reformulated feed has a higher protein content, it is assumed that the growth of the animal is not influenced by this. This results in higher N excretion and consequently higher N emissions from manure management.
- Benzoic acid dietary supplementation acidifies the digesta, modulates its biochemistry and microbial environment. It also stimulates digestive enzymes. The activation of the digestion process supports an enhanced feed efficiency. A reduction of 3% of the FCR has been modelled. This was applied to the system by considering a reduction in feed by 1.34% and a faster growth of the animal by 1.34%. This was decided upon consultation with nutritional experts, based on common management practices when introducing the additive in finisher diets. Since we assumed that the length of the production cycle remains unvaried, we modelled a higher target weight. An implicit assumption is that the functionality of the carcass is not changed by a higher weight of the animal at slaughtering.
  Furthermore, benzoic acid is metabolised into hippuric acid, which when excreted decreases the urinary pH leading to lower ammonia emissions. A reduction of ammonia emissions by 10% and 20% is considered for 5 and 10 g/kg dm feed intake doses, respectively. This also reduced indirect N2O emissions coming from ammonia volatilization.
- Vitamin E is a lipid-soluble antioxidant, delaying meat rancidity. This modification to the system is happening outside the boundaries considered in this study, therefore it is not possible to assess the impact of this additive. In the discussion section (3.3.6), a sensitivity analysis has been performed where the effect of such an intervention at farm level has been estimated. Considering a consumer loss of 17% for the baseline [5], this results in 83% of meat consumed for the baseline and 83.85% meat consumed after the intervention (5% reduction in meat losses, as defined in section 8.1). This is an increase of 1.02% in meat availability, which can be modelled as a 1.02% avoided production of liveweight.

3.2 Lifecycle Impact results

Table 11 summarizes the lifecycle impacts of the feed additive interventions for the pig case study. The Vitamin E case was not possible to assess since the effect of the additive modifies LCI flows outside the boundaries (additional discussion in section 3.3.6). The LCIA results are relative expressions and do not predict impacts on category endpoints, the exceeding of thresholds, safety margins or risks.

Table 11 Lifecycle Impact Assessment Results for the pig interventions

Impact Category	Unit (per kg of liveweight)	Without Phytase	Baseline	Xylanase	Benzoic Acid (5*)	Benzoic Acid (10*)	All
Climate change excl. LUC	kg CO_2 eq	$2.88\ 10^{0}$	$2.85\ 10^{0}$	$2.82\ 10^{0}$	$2.83\ 10^{0}$	$2.88\ 10^{0}$	$2.85\ 10^{0}$
Climate change	kg CO_2 eq	$4.16\ 10^{0}$	$4.08\ 10^{0}$	$4.07\ 10^{0}$	$4.03\ 10^{0}$	$4.08\ 10^{0}$	$4.07\ 10^{0}$
Ozone depletion	kg CFC11 eq	$8.14\ 10^{-8}$	$7.81\ 10^{-8}$	$7.55\ 10^{-8}$	$7.77\ 10^{-8}$	$7.92\ 10^{-8}$	$7.66\ 10^{-8}$
Ionising radiation	kBq U-235 eq	$1.30\ 10^{-1}$	$1.28\ 10^{-1}$	$1.24\ 10^{-1}$	$1.26\ 10^{-1}$	$1.27\ 10^{-1}$	$1.23\ 10^{-1}$
Photochemical ozone formation	kg NMVOC eq	$5.66\ 10^{-3}$	$5.54\ 10^{-3}$	$5.58\ 10^{-3}$	$5.48\ 10^{-3}$	$5.54\ 10^{-3}$	$5.58\ 10^{-3}$
Respiratory inorganics	disease inc.	$5.08\ 10^{-7}$	$5.03\ 10^{-7}$	$5.03\ 10^{-7}$	$4.65\ 10^{-7}$	$4.44\ 10^{-7}$	$4.43\ 10^{-7}$
Non-cancer human health effects	CTUh	$4.55\ 10^{-6}$	$4.55\ 10^{-6}$	$4.53\ 10^{-6}$	$4.45\ 10^{-6}$	$4.45\ 10^{-6}$	$4.43\ 10^{-6}$
Cancer human health effects	CTUh	$1.12\ 10^{-7}$	$1.08\ 10^{-7}$	$1.08\ 10^{-7}$	$1.05\ 10^{-7}$	$1.06\ 10^{-7}$	$1.06\ 10^{-7}$
Acidification terrestrial and freshwater	mol H+ eq	$6.85\ 10^{-2}$	$6.78\ 10^{-2}$	$6.78\ 10^{-2}$	$6.24\ 10^{-2}$	$5.93\ 10^{-2}$	$5.92\ 10^{-2}$
Eutrophication freshwater	kg P eq	$4.09\ 10^{-4}$	$3.88\ 10^{-4}$	$3.94\ 10^{-4}$	$3.81\ 10^{-4}$	$3.83\ 10^{-4}$	$3.89\ 10^{-4}$
Eutrophication marine	kg N eq	$2.72\ 10^{-2}$	$2.72\ 10^{-2}$	$2.66\ 10^{-2}$	$2.65\ 10^{-2}$	$2.64\ 10^{-2}$	$2.58\ 10^{-2}$
Eutrophication terrestrial	mol N eq	$3.02\ 10^{-1}$	$3.00\ 10^{-1}$	$3.00\ 10^{-1}$	$2.76\ 10^{-1}$	$2.62\ 10^{-1}$	$2.62\ 10^{-1}$
Ecotoxicity freshwater	CTUe	$1.98\ 10^{1}$	$1.97\ 10^{1}$	$2.00\ 10^{1}$	$1.93\ 10^{1}$	$1.93\ 10^{1}$	$1.95\ 10^{1}$
Land use	Pt	$5.31\ 10^{2}$	$5.29\ 10^{2}$	$5.23\ 10^{2}$	$5.17\ 10^{2}$	$5.17\ 10^{2}$	$5.11\ 10^{2}$
Water scarcity	m^3 depriv.	$2.04\ 10^{0}$	$1.79\ 10^{0}$	$1.83\ 10^{0}$	$1.75\ 10^{0}$	$1.76\ 10^{0}$	$1.81\ 10^{0}$
Resource use, energy carriers	MJ	$2.20\ 10^{1}$	$2.16\ 10^{1}$	$2.13\ 10^{1}$	$2.18\ 10^{1}$	$2.24\ 10^{1}$	$2.21\ 10^{1}$
Resource use, mineral and metals	kg Sb eq	$6.90\ 10^{-7}$	$3.57\ 10^{-7}$	$3.61\ 10^{-7}$	$3.55\ 10^{-7}$	$3.62\ 10^{-7}$	$3.65\ 10^{-7}$

*5 stands for 5000 mg/kg DM feed intake dose, while 10 stands for 10000 mg/kg DM feed intake dose.

Table 12 Lifecycle Impact Assessment Results for the pig interventions, relative to baseline

Impact Category	Unit	Without Phytase	Xylanase	Benzoic Acid (5*)	Benzoic acid (10*)	All
Climate change excl. LUC	kg CO_2 eq	0.9%	-1.0%	-0.7%	0.9%	-0.1%
Climate change	kg CO_2 eq	1.9%	-0.2%	-1.2%	-0.1%	-0.3%
Ozone depletion	kg CFC11 eq	4.3%	-3.4%	-0.6%	1.4%	-2.0%
Ionising radiation	kBq U-235 eq	1.6%	-3.3%	-1.6%	-0.7%	-3.8%
Photochemical ozone formation	kg NMVOC eq	2.1%	0.7%	-1.2%	-0.0%	0.7%
Respiratory inorganics	disease inc.	0.9%	0.0%	-7.5%	-11.8%	-11.9%
Non-cancer human health effects	CTUh	0.0%	-0.4%	-2.2%	-2.2%	-2.7%
Cancer human health effects	CTUh	4.2%	0.1%	-2.1%	-2.0%	-2.0%
Acidification terrestrial and freshwater	mol H+ eq	1.1%	0.0%	-8.0%	-12.6%	-12.7%
Eutrophication freshwater	kg P eq	5.4%	1.6%	-1.8%	-1.2%	0.4%
Eutrophication marine	kg N eq	-0.1%	-2.3%	-2.8%	-3.1%	-5.4%
Eutrophication terrestrial	mol N eq	0.7%	0.0%	-8.1%	-12.7%	-12.8%
Ecotoxicity freshwater	CTUe	0.4%	1.4%	-2.3%	-2.3%	-0.9%
Land use	Pt	0.4%	-1.1%	-2.4%	-2.4%	-3.5%
Water scarcity	m^3 depriv.	14.0%	2.4%	-1.9%	-1.4%	2.5%
Resource use, energy carriers	MJ	2.0%	-1.3%	0.7%	3.8%	2.4%
Resource use, mineral and metals	kg Sb eq	93.4%	1.1%	-0.5%	1.3%	-0.8%

3.3 Interpretation

3.3.1 Baseline

The carbon footprint of the baseline scenario is 4.08 kg CO_2 eq./kg liveweight. The main contribution comes from the production of the pig feed (60.1%). The impact of the housing (including manure emissions) contributes 15.4% to the total carbon footprint. The contribution due to piglets (both due to ration and emissions) and energy use within the manure management system are 22.3% and 2.2%, respectively.

If we exclude the impact of Land Use Change, the carbon footprint is 2.85 kg CO_2 eq./kg liveweight (Figure 4). The contribution of LUC is 30.2% of the total carbon emissions, which is almost half of the feed contribution and is mostly related to the use of soybean products from South America. If we exclude land use change emissions then the contribution is still dominated by feed production (52.4%), followed by housing emissions (22.4%), piglet production (22.1%) and energy use (3.1%).

The overall respiratory organics impact of the baseline is 5.03 10^{-7} disease inc./kg liveweight. The main contribution comes from housing (54.1%) and is related to ammonia and particulate matter emissions, and 24.5% is due to the feed production, mostly from ammonia.

The total eutrophication potential in the baseline is 2.72 10^{-2} kg N eq./kg for marine eutrophication and 3.88 10^{-4} kg P eq./kg for freshwater eutrophication. The impacts of both freshwater and marine eutrophication are dominated by feed production with 78% and 77.7% of baseline for freshwater and marine eutrophication, respectively. The remaining source is the feed production for piglet production. Housing of pigs has a relatively small contribution to marine eutrophication, caused by ammonia emissions.

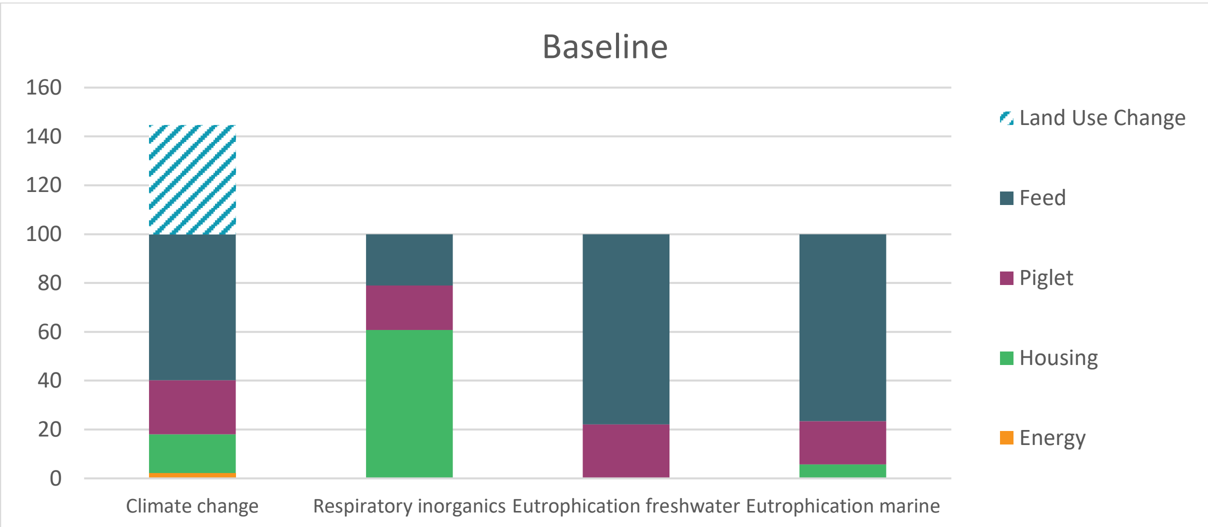

Figure 4 Contribution analysis of the fattening pigs baseline for the four focus impact categories

The breakdown of environmental impacts of the pig system can differ depending on the type of feed ingredients used, the housing system and the manure management system. Pig farms where a high share of feed stuffs or wet co-products are used have a considerably lower feed impact (less than 30% is possible). Also, the contribution of climate change due to land use change can vary a lot depending on the amount of soy products from South America in the feed mix. This can vary a lot through the year related to the global cycles in availability of soy and cereals. The contribution of housing in the Respiratory inorganics impact score can be much lower depending on housing system and use of air scrubbers that reduce the ammonia emissions. Feed conversion rate can also differ 10% between the low and best performing farms. Also, different consideration of manure leaving the farm can influence the breakdown of environmental impacts (a sensitivity assessment is performed in section 3.3.5.2.4, and discussion of the implication can be found in section 6.2.5.1).

3.3.2 Effect of interventions

The interventions considered in this study have different effects on the environmental impact of pig fattening, as discussed in the following paragraphs. In the figures below we compare the effect of the interventions on the four focus impact categories for each intervention or combination of interventions. These comparisons shown how much each scenario affects each of the impact category results in total, and how this effect is broken down over the contributing elements. Also, all the sources of variability and uncertainty are discussed qualitatively and, in some cases, with additional quantitative analysis.

3.3.3 Phytase

3.3.3.1 Main results

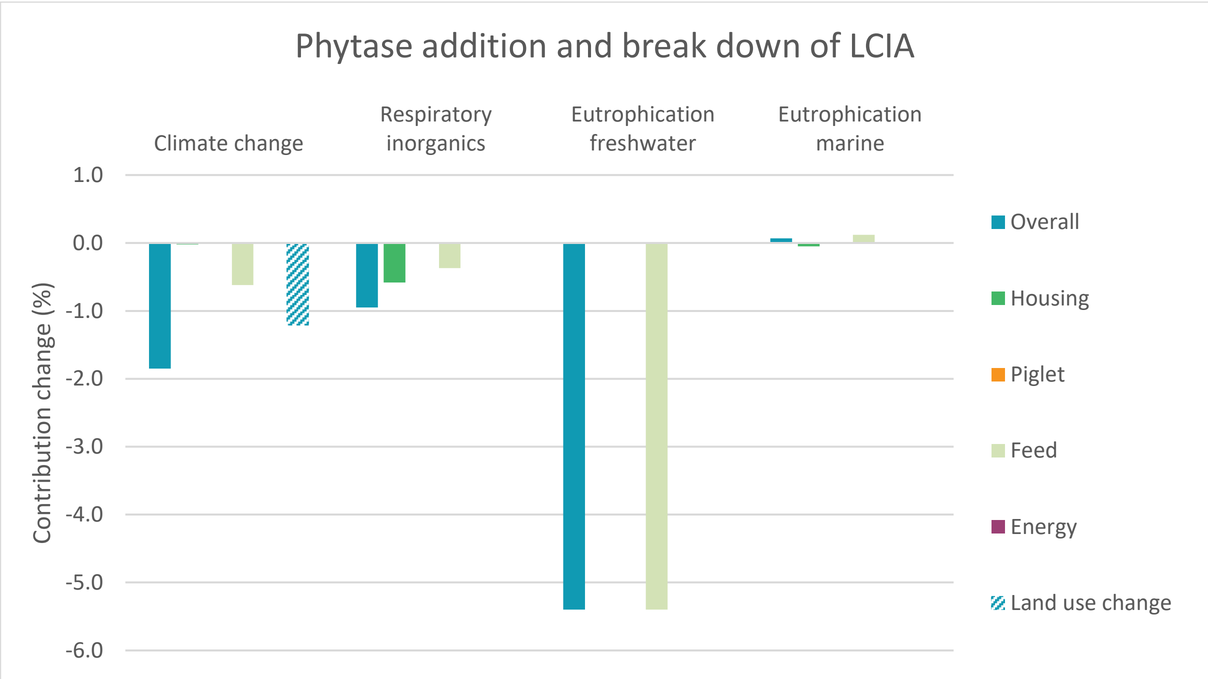

Figure 5 Phytase intervention effect for pigs

The reduction in climate change (-1.9%) is related to changes in compound feed formulation, which influences the contribution of feed production at farm and LUC contribution. The same can be said for eutrophication freshwater reduction (-5.4%).

Respiratory inorganic reduction (-0.9%) is partially caused by changes in the compound feed reformulation (-0.4%) and partly due to lower ammonia emissions at manure management (-0.6%). This is caused by lower N excretion, connected to a higher N efficiency of the animal (lower N content of feed, with same performance).

Marine eutrophication impact is also slightly reduced by a higher N efficiency at the animal farm, but this effect is counterbalanced by a higher N leaching associated with the production of the reformulated feed compound feed. This results in a small increase in impact (+0.1%).

3.3.3.2 Discussion and sensitivity analysis

3.3.3.2.1 Baseline performance

The variability in the baseline can influence the overall results. Since the intervention is related to feed formulation and most of the reduction is connected to this changed feed formulation. As feed formulations are inherently geographically and temporally variable due to market conditions there is a significant variability in the baseline.

3.3.3.2.2 Variability of the zootechnical effect

There is significant variability in the achievable changes in feed composition due to improved digestibility of phytates and protein. They may depend on the genetics of the pigs, the composition of the feed, and other conditions on the farm. The effects have been shown consistently in trials and application under practical conditions has been widely adopted without negative effects being observed. Still, the origin of the feed and the background dataset as defined in the baseline (previous chapter) might affect the results with large uncertainty.

3.3.3.2.3 Nutrient balance and manure application

Nitrogen balance is fully modelled, and a reduction of impact due to reduction of N input is modelled (small reduction of 0.8% in N content of feed input).

The improved digestion and uptake of organically bound Phosphorus should influence the excretion of P. Since a P balance is not performed in this study (not implemented in the APS-footprint tool), such changes are not estimated. This should not affect the emissions of P at housing, since leaching of manure is not taking place in enclosed systems, as used in the Netherlands [19].

The manure loop approach of this study is discussed in section 2.4. For the Dutch Belgian situation, the most valuable element of manure is organic matter. P content is often limiting the use and the farmer steers on the N-content. Following the Product Category Rule (PCR) for red meat [7] the default approach is that manure leaving the system for application should be considered as an avoided production of N (50%) and P inorganic fertilizers (100%). Such modelling will affect the results, potentially in opposite directions for different impact categories. To exactly quantify, we suggest performing a sensitivity assessment; an example can be found at section 3.3.5.2.4.

3.3.3.3 Conclusion

The main environmental effects of the addition of phytase can be partially assessed using the methodological framework. The main limitation is the unclarity on which methodology on how to handle manure loops from animal farm to application should be used. The reduction of N and P emissions connected to production of feed inputs are quantified, and are directly relatable to the zootechnical effect of the additive. Still, the uncertainty should be assessed to improve the reliability of this conclusion. There is no clear guidance on how to assess the variability of zootechnical efficacy, even though this is probably low since the additive is largely used in practice and its efficacy is publicly recognized. On the other hand, focus should be put on the uncertainty connected to the baseline compound feed formulation, the origin of ingredients and the background data used, since these might influence the results strongly.

Tool limitations are related to the lack of a P balance in the APS-footprint tool, and the capacity to perform systematic uncertainty analysis. Also, the background database used should be improved in order to give an indication on data quality and uncertainty.

3.3.4 Xylanase

3.3.4.1 Main results

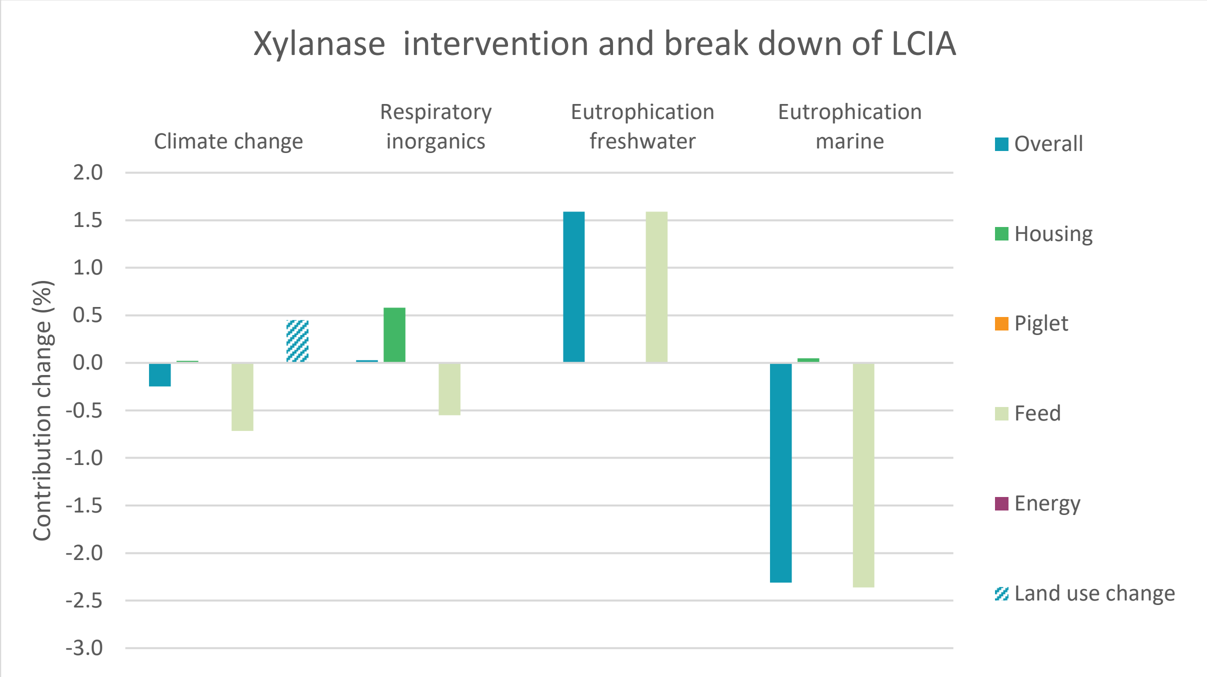

Figure 6 Xylanase intervention effect for pigs

Xylanase enhances the digestion of carbohydrates and allows for a higher inclusion of grains and by-products. This shift does not lead automatically to an overall better environmental performance.

For the four impacts we see various trends. Climate change impact is slightly (-0.2%) reduced thanks to a lower overall impact of the feed ingredients selected (-0.7%), even though the LUC attached to the feed ingredients is higher (+0.4%). This is connected to the introduction of soybean hulls from South America in the reformulated compound feed.

For respiratory inorganics there is a negligible net effect increase. The fact that the nitrogen input of the feed is higher results in higher excretion, and therefore higher ammonia emissions (+0.6%). This is equally counterbalanced by the lower impact of the feed (-0.5%).

The freshwater eutrophication impact increases (+1.6%) due to a lower phosphorus efficiency of the feed ingredient production in the new least cost formulation.

The opposite trend is observed for marine eutrophication (-2.3%). The reduction due to the use of less nitrogen leaching-intensive cultivation is only slightly counterbalanced by the lower nitrogen efficiency of animals (higher ammonia emissions).

3.3.4.2 Discussion and sensitivity analysis

3.3.4.2.1 Baseline performance

The baseline feed intake considered and the baseline feed formulation can influence the results of the intervention.

The choice for soybean hulls and its origin is driven by prices for feed ingredients used in the formulation. If soybean hulls would be sourced from another country with low deforestation (e.g. US), the results would largely differ (Figure 7. In such a scenario the impact connected to LUC would also show a reduction, and the overall climate change would be -2% lower when implementing Xylanase. The origin of feed is therefore relevant in determining the efficacy of an additive used for feed formulation changes. Please note, that if this is relevant in a fully attributional model, in a consequential approach would play a small to negligible role (depending on the use of the original source of soybean hulls). A further sensitivity assessment on this aspect is performed for the *All* scenario (chapter 3.3.7).

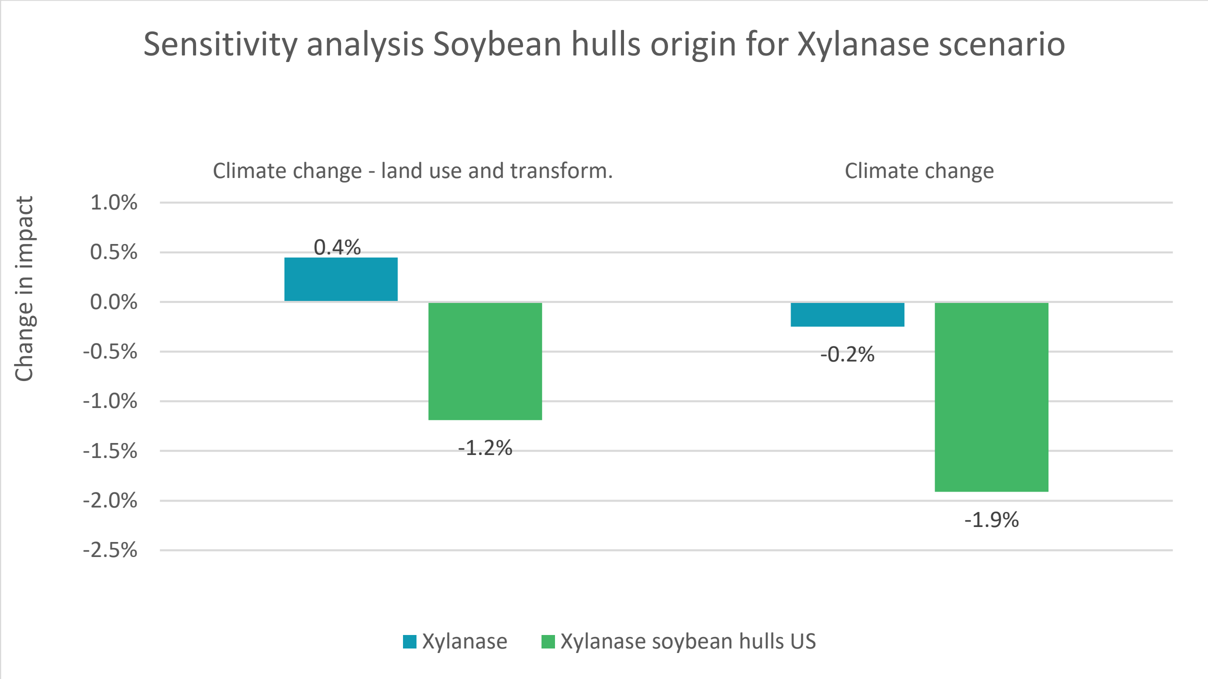

Figure 7 Sensitivity assessment of the climate change (only LUC and including LUC) impact reduction when using soybeans from US in Xylanase feed formulation

3.3.4.2.2 Variability of the zootechnical effect

The sensitivity of the changes in impacts can be analysed in a way very similar to the way it was done for phytase. For xylanase, the efficacy of the additive is less substantiated, therefore considering the variability of efficacy during the least cost formulation is more relevant and should be systematically applied. This is not adequately addressed in the LEAP guidelines for additives, this is further discussed in section 6.2.3.2.

3.3.4.2.3 Nutrient balance and manure application

As for the phytase case, nutrient balance changes are considered for N, but not for P due to APS-footprint tool limitations. This should not affect the emissions at housing since no P leaching is taking place in an enclosed manure management system.

The change in manure composition should still be accounted for in the subsequent manure application at farm. The currently applied methodological framework is not able to consider the impact changes due to manure application after leaving the farm and there is not a widely accepted methodology.

3.3.4.3 Conclusion

The conclusions for xylanase are very similar to those for phytase. The effect of the intervention can only be partially assessed, mainly due to the lack of consideration of changes in manure composition, which alter the farm application emissions. Also, the variability of efficacy of the additive on being able to alter the compound feed formulation should be assessed in a systematic way. The same goes for the variability of the baseline compound feed formulation, ingredient origin (before and after the intervention) and background dataset used.

3.3.5 Benzoic acid

3.3.5.1 Main results

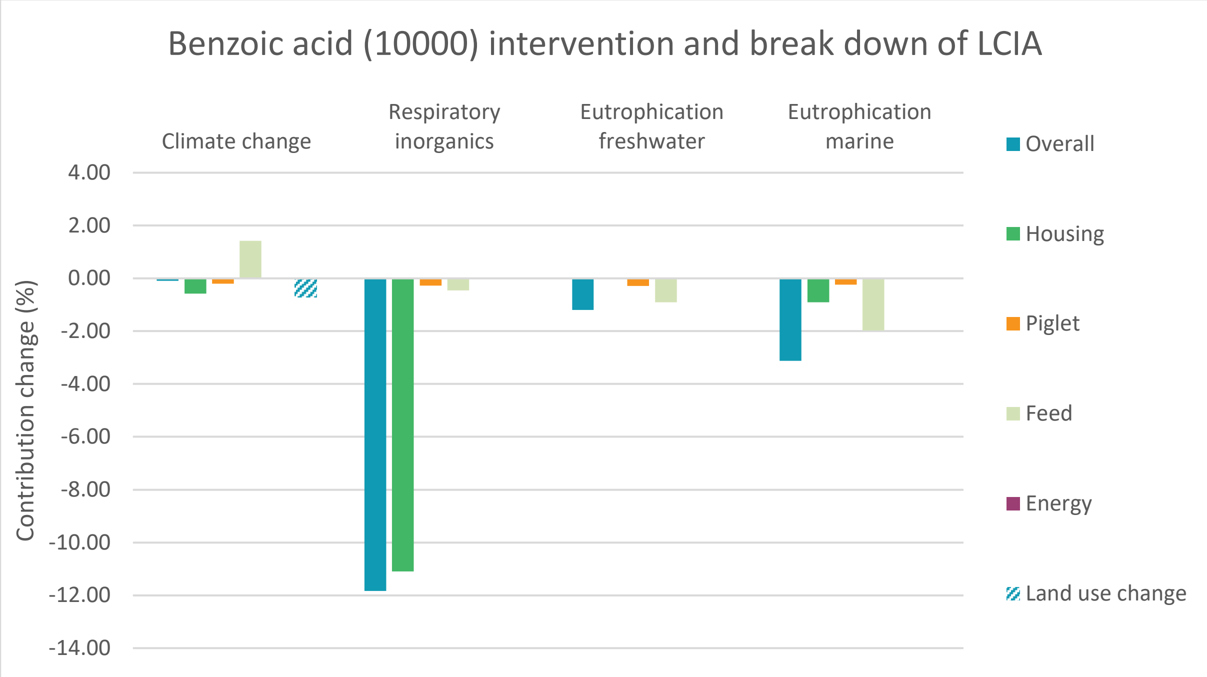

Figure 8 Benzoic acid (10000 ppm) intervention effect for pigs

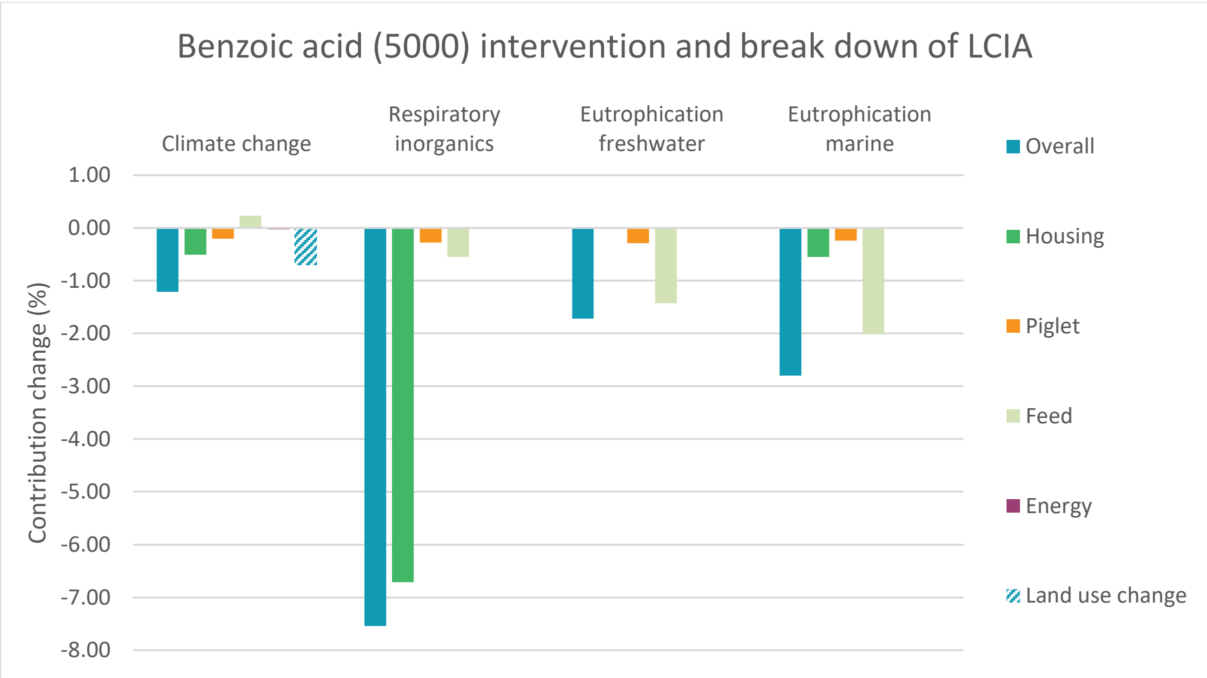

Figure 9 Benzoic acid (50000 ppm) intervention effect for pigs

This is the only case analysed in the overall study where the production of the additive (included in the feed contribution) is visibly increasing the impact.

In the 5000 mg scenario, the climate change impact is reduced from 4.08 to 4.03 kg CO_2 eq./kg pig liveweight including LUC and from 2.85 to 2.83 kg CO_2 eq./kg pig liveweight excluding LUC. The overall change in climate results are -1.2% for the 5000 mg scenario and -0.1% for the 10000 mg scenario. Various dynamics reduce the climate change impact: higher meat output reduces all contribution equally, lower indirect N2O emissions further reduces the housing contribution, and lower feed input reduces the contribution of feed and of LUC. These benefits are counterbalanced by the impact of the additive production. This increases the overall impact due to feed, and in the 10000 mg almost outweighs completely the benzoic acid benefit.

The respiratory inorganics impact category shows larger percentage reductions (-7.5% for the 5000 mg scenario and -11.8% for the 10000 mg scenario). The ammonia reduction due to manure acidification is the main driver of reduction of impact at housing.

Marine eutrophication reduced by -2.3% for the 5000 mg scenario and -3.1% for the 10000 mg scenario. The improved FCR is mainly driving the reduction, even though the ammonia reduction has a visible role. This can be seen by the fact that between the two scenarios (same FCR effect but higher ammonia reduction) there is a reduction of 0.8 points.

Freshwater eutrophication decreases by -1.7% for the 5000 mg scenario and -1.2% for the 10000 mg scenario. Reduction are only attributed to the FCR benefit, and the higher dose is visibly influencing the overall results.

3.3.5.2 Discussion and sensitivity analysis

3.3.5.2.1 Baseline performance

The baseline can influence the results due to system parameters and feed production impact (background dataset) variability. To increase rigour of the results we suggest accounting for variability ranges using uncertainty analysis. Still, since this intervention does not cope with feed reformulation, we expect the baseline variability as having a smaller influence on the relative impact change compared to the phytase and xylanase scenarios.

3.3.5.2.2 Variability of zootechnical effect on FCR

Variability in the feed conversion ratio can be affected by many factors, such as animal genetics and type of compound feed used. Applying a variability generic range of ± 50% (section 8.1.7.3.1), results in an equal variability in the results. This was tested to actually check the linearity of the results compared to the input changes. To increase the reliability of this scenario, a variability range (or standard deviation) of zootechnical parameters changes should be defined in a systematic way.

Another aspect to consider is the translation of the zootechnical improvements into LCI flows changes. A FCR change can be modelled as a reduction of feed input, a higher target weight for slaughtering (higher liveweight output) or a shorter production period. We are modelling the system on an annual basis, therefore a shorter period will still be modelled as an annual higher liveweight output. The extremes are therefore to fully model the FCR improvement as an increase in liveweight (calculated as 2.41% for a 3% increase in FCR) or a reduction of feed intake of 3%. The two FCR modelling extremes were compared with the taken approach, and only slight changes in the results were observed (Figure 10).

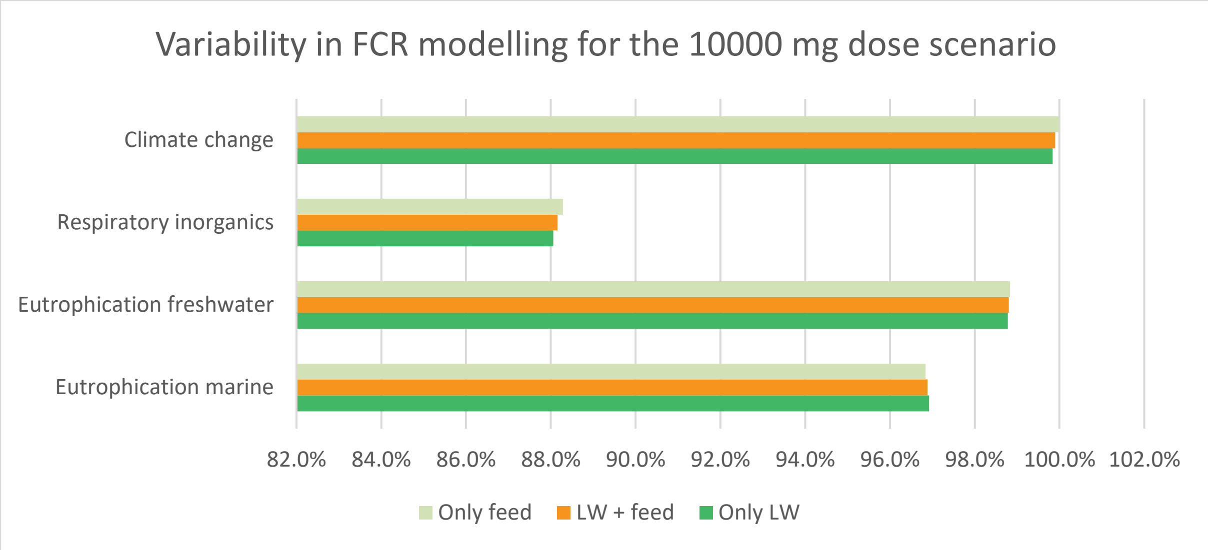

Figure 10 Variability of the results by changing the approach in modelling FCR

3.3.5.2.3 Variability of zootechnical effect on ammonia emissions

Ammonia emissions can vary due to farming practices, manure management systems in place and compound feed used. Ammonia emissions are determining for the respiratory inorganics impact category, and also play an important role in the marine eutrophication impact category. To increase the reliability of the calculated results in these impact categories, systematically determining the variability of ammonia reduction and an uncertainty analysis should be performed.

Also, acidification of manure might also reduce emissions of ammonia during manure application. Since this has not been proven in the scientific literature, we stress here the necessity to investigate further this relation. Manure loops and how to account for changes in manure properties when leaving the farm are discussed in the next chapter.

3.3.5.2.4 Nutrient cycle and manure application (exploring PCR Red Meat manure approach)

The reduction in ammonia emissions will also result in higher N content of manure. Methodology on how to account for this is inconsistently indicated in guidelines and might influence the overall results.

Here, implementing the Product Category Rule (PCR) for Red Meat [7] is investigated with a sensitivity analysis. The PCR for red meat suggests a boundary expansion, where the emissions from manure are included and nutrient application from manure substitutes inorganic fertilizers (100% of production and 50% of emissions). This is valid for both the baseline and the intervention scenario. When the manure is spread on farm, higher N availability in manure for the benzoic acid scenario will be in this way accounted for. In Figure 11 we show the effect of implementing such modelling in the results. It is assumed that Nitrogen in manure substitutes the production of the same N amount of a Dutch inorganic fertilizer mix (based on Agri-footprint). The Nitrogen in manure also constitutes 50% of the emissions from such inorganic fertilizers mix (default suggested in the PCR Red Meat, [7]). Since more Nitrogen is retained in the manure (calculated as N excreted – N emissions at housing), the use of Benzoic acid would cause an increase in the impact of applying the manure, counterbalanced by the substitution of inorganic fertilizer production and use. Since emissions from inorganic fertilizer production is important for climate change, the emissions from manure are counterbalanced by inorganic fertilizer substitution. This is not the case for eutrophication marine and respiratory inorganic impact categories. For them, the benefit of the additive is strongly reduced, showing the importance of accounting for manure changes in composition when leaving the farm.

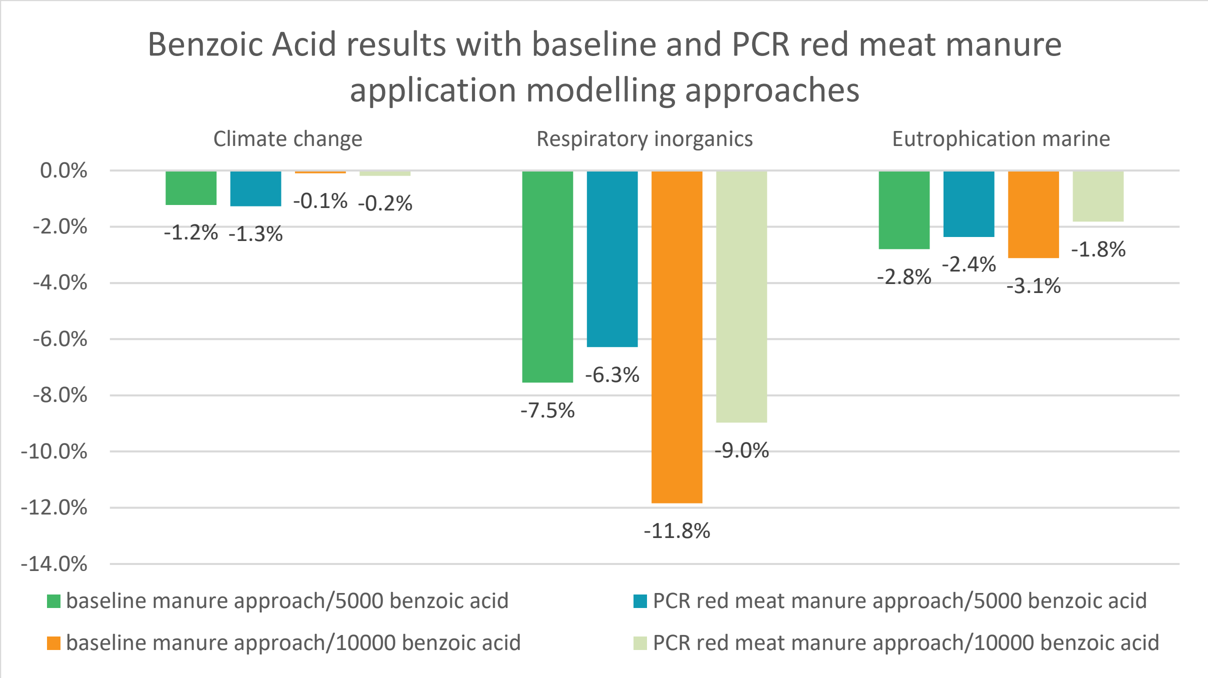

Figure 11 Benzoic Acid improvement with and without modelling of the manure application as defined by the PCR Red Meat

3.3.5.3 Conclusion

The main environmental effects of the addition of benzoic acid can be partially assessed using the guidelines and the tool based on them. The main limitation regards the conflicting guidance on how to account for the impact of changing nutrient content of manure on subsequent application. We have shown that they have a relevant magnitude and that the approach indicated by the PCR for red meat would be able to model such changes. Other approaches might also be explored in the future.

To improve the results reliability, variability regarding PCR reduction and ammonia emissions reduction should be estimated and uncertainty analysis should be performed.

FCR changes and ammonia emission changes can be modelled and different way of modelling FCR change resulted to have a small influence on the results. Suggestion has been made to investigate the effect of manure acidification on the ammonia emissions during application.

3.3.6 Vitamin E

3.3.6.1 Main results

The intervention with Vitamin E improves meat quality and leads to reduced food loss further at retail and consumer stages. The boundaries considered in this study do not allow to model the changes to the system from this additive use. No guidance is available on how to consider meat quality improvements caused by the use of additives.

Also, meat quality is in general not a factor taken into account in any of the standard or guidelines except for being stated as a qualifier for accepted meat. If the quality of the product is not the same, the requirement for functional equivalence according to the ISO standard is not fulfilled.

Solving the methodological limitation for this specific case would only be possible by expanding the boundary of the analysis.

3.3.6.2 Discussion and sensitivity analysis

3.3.6.2.1 Attempt to partially account for Vitamin E effect at farm gate level

Below we conducted a sensitivity calculation to make a partial estimation of the additive use effect on the considered impact category. As explained in section 3.1.4.2, a reduction of 5% in meat loss translates to a 1.02% avoided production of animal liveweight at farm. This means that at animal farm gate, the impact of 1 kg of liveweight pig is 1.02% lower (Figure 12).

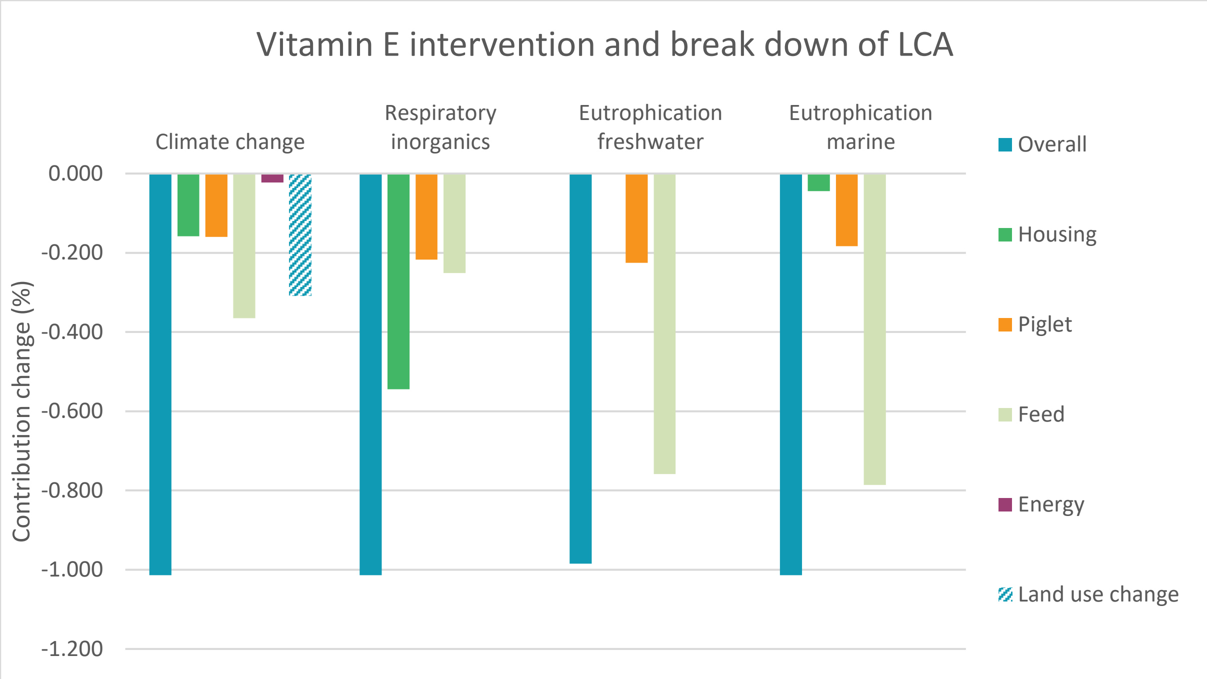

Figure 12 Vitamin E intervention effect for pigs

The reduction of 1.02% in impact equally distributes to the different impact categories, and the various contributions. Production of the additive slightly reduce the benefit for freshwater eutrophication.

The system change in impact can be only partially estimated. This is because the change of impact after the farm gate (slaughtering, packaging, retail and at consumer) is not considered. Still, considering that meat product contributions is usually dominated by the farm stage, the main reduction in impact is considered in this attempt. Still, the variability of the considered reduction in meat losses should be determined to increase the reliability of the attempted results.

3.3.6.3 Conclusion

The guidelines include no specifications for assessing the impact of meat quality changes. The methodological framework is not able to assess the impact change due to Vitamin E use. To consider the effect of Vitamin E on the system, the boundaries should be expanded to cradle-to-preparation. Also, the variability of the considered reduction in meat losses should be determined to increase the reliability of the results.

3.3.7 All

3.3.7.1 Main results

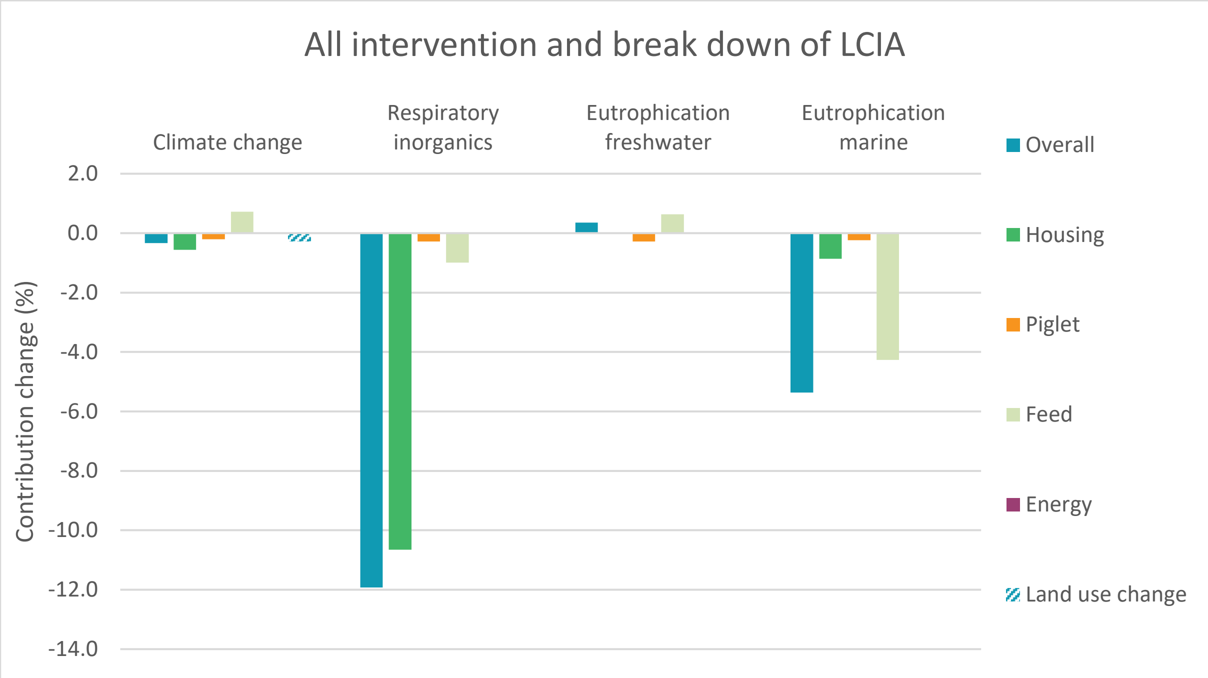

Figure 13 All intervention effect for pigs

The “all" scenario is the combination of xylanase and 10000 mg dose benzoic acid. The Vitamin E was not included, and phytase is already considered in the baseline.

Climate change impacts are only slightly reduced (-0.3%), partly due to improved FCR and partly due to Xylanase feed reformulation. The benefits in impact are almost completely counterbalanced by the impact of Benzoic Acid production.

Respiratory inorganics change in impact is dominated by the reduction of ammonia emissions due to benzoic acid supplementation.

For freshwater eutrophication, we see a net increase of impact because of the compound feed reformulation.

Both benzoic acid and xylanase have strong reducing effects on marine eutrophication, resulting in a 5.4% reduction.

3.3.7.2 Discussion and sensitivity analysis

3.3.7.2.1 Baseline performance

Various characteristic of the baseline can have a large influence on the results. Main ones are: FCR, baseline compound feed formulation, ingredient origin and background dataset used.

In the Xylanase scenario, we showed the effect of feed material origin (when introducing a new ingredient) on climate change results. For the “all " scenario we performed two sensitivity analyses: one where the origin for every soy products in the feed were changed to the US (US soy), and another where the origin for every grain product in the feed were changed to Belgium (BE grain). These origins applied to both the baseline and the intervened scenario. Figure 14 shows the results of this sensitivity analysis.

Changing the origin of soy products can affect climate change due to LUC. The overall climate change impact slightly reduces when soy products are imported from US, and slightly increases when Belgian grain products are used.

Respiratory inorganics is also influenced by opting for Belgian grain products (from -11.9% reduction in the default origin to -11.5%).

For both sensitivity assessments, the intervention effect on freshwater eutrophication is increased, indicating that at least a part of the negative effect in the xylanase scenario can be influenced by the source of feed materials. Eutrophication (marine) also reduces in the Belgian grain products scenario (from -5.4% reduction in the default origin to -5.7%).

This sensitivity calculation shows that the % of change due to an intervention can be influenced by the origin of feed inputs. The influence can be large (e.g. eutrophication freshwater), and the results can be completely overturned. This shows how variability in feed formulations and its connection to background dataset is extremely relevant and probably the largest source of uncertainty. This is especially relevant when scenarios compound feed reformulation (e.g. Xylanase addition). Guidelines does not provide specific information on how to properly account for feed formulation variability. Discussion on this can be found on chapter 6.2.3.2 and 6.2.3.1.

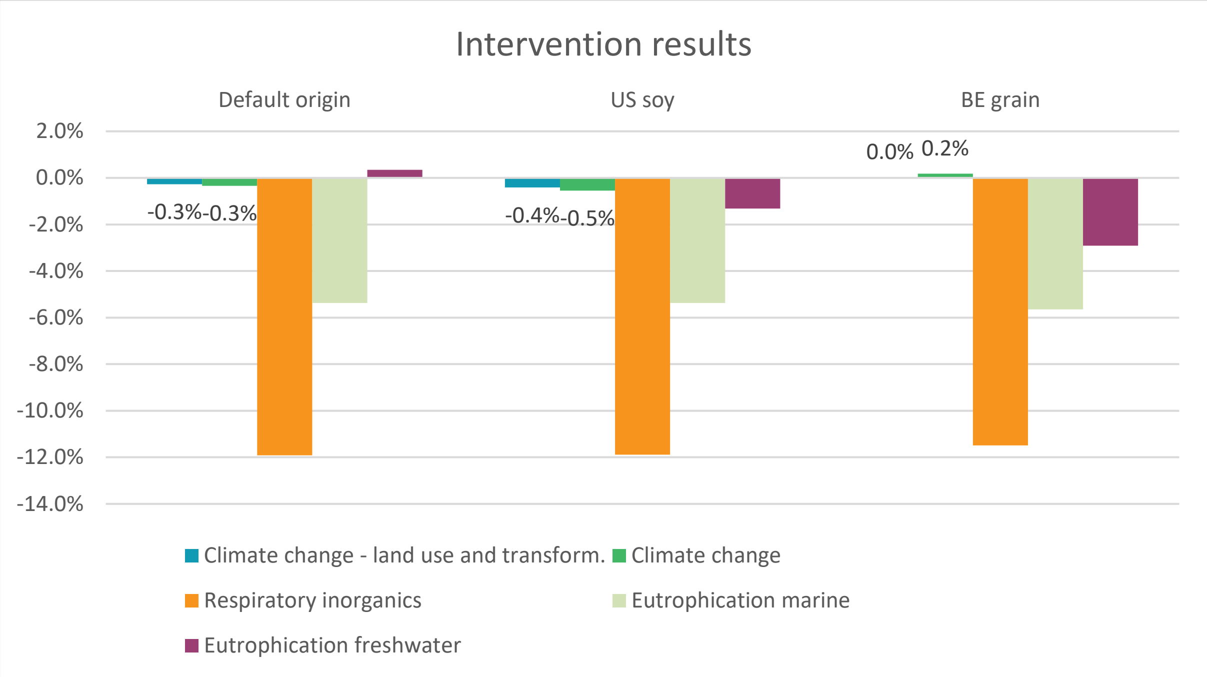

Figure 14 Sensitivity analysis of changing the origin of feed ingredient, both in the baseline and in the All intervention

3.3.7.2.2 Variability of the zootechnical effect

Even though the effect of the additives has been proven and analysed in trials, and the current reformulations are representative for a practical case, the least cost formulation could result in many different formulations depending on local and temporal variable market conditions. The variability of such processes is extremely large, difficult to model and will probably highly influence the results. Therefore a single representative feed formulation is not sufficient to prove the direction and magnitude of the effect of additives that influence feed composition. The LEAP guidelines for feed additives does not cover this in sufficient detail.

3.3.7.2.3 Additionality of impacts

The impacts on feed composition of the enzymes (phytase and xylanase together) are not additive, so this has been accounted for in the feed formulation, based on nutritionist expertise. The mechanism and effects of benzoic acid and of the enzymes might potentially interact, but since their mode of actions are affecting animal performance outcomes that are not strictly related, additionality can be expected. Further investigation is needed to check this assumption.

3.3.7.2.4 Nutrient cycle and manure application

If the changes to the nitrogen balance due to changes in FCR and feed input are accounted for, the effect on the phosphorus balance are not modelled. This is an APS-footprint tool limitation (i.e. the tool does not allow to consider changes in P content of manure before spreading).

As for the previous scenarios, the lack of accounting for changes in manure composition for subsequent manure spreading does not allow to fully account for the effect of the additives.

3.3.7.3 Conclusions

The effect of using a combination can be only partially assessed through the current methodological framework. Main limitation is the contradicting guidance on how to consider manure composition changes when manure is further applied on the land (manure loops).

The results are highly influenced by the FCR of the baseline, feed formulation of the baseline, the approach during compound feed reformulation, origin of ingredients and background dataset. To increase reliability of the results, variability of the listed parameters (when not based on primary data) should be considered and a thorough uncertainty analysis is needed.

If it seems acceptable assuming additionality, further investigations are suggested.

Tool limitations are not with respect to including P balance at animal farm and adding uncertainty analysis functionality. Background datasets should also be improved with DQR and variability ranges.

3.4 Summary of conclusions

The conclusions of the various scenarios are here summarized (Table 13), based on the approach explained in section 2.1.3. The summary will be used to systematically analyse and group the scenarios for the various animal specific chapters, and to identify trends to be discussed in section 6.

Table 13 Summary of the conclusions from the pig section scenarios, per life cycle influence

	Feed additive production	*Changed impact at animal farm*	*Changed impact upstream (feed, youngstock, bedding materials etc)*	*Changed downstream impact*	*ΔTOT*
Phytase	Between 0% and 0.02% of total impact baseline	Reduction of 0% to 0.6% due to reduced protein and consequently nitrogen content of the feed.	Change of +0.1% to -5.4% due to change in feed composition. Results highly uncertain due to feed origin, formulation strategies and background dataset.	No downstream impact changes are expected. Inconsistent guidance on how to model application of manure leaving the farm.	Overall reduction of 0% to 5.4%. Farm and upstream production reduction outweigh additives production. Inconsistent guidance on how to account for manure application. Certainty of the results relies on the solidity of the data related to feed origin, formulation strategies and background dataset.
Xylanase	Between 0% and 0.03% of total impact baseline	Increase of 0% to 0.6% due to higher protein and consequently nitrogen content of the feed.	Change of +1.6% to -2.4% due to change in feed composition. Results highly uncertain due to feed origin, formulation strategies and	No downstream impacts are expected. Inconsistent guidance on how to model application of manure	Change of +1.6% to - 2.3%. inconsistent guidance on how to account for manure application. Certainty of the results relies on the solidity of the data related to feed origin, formulation strategies

			background dataset.	leaving the farm.	and background datasets.
Benzoic acid	Between 0.04% to 1.2% and 0.08% to 2.4% for the 5000mg and 10000mg dose, respectively.	Reduction of 6.7% and 11.1% in the impact category respiratory inorganics for the 5000mg and 10000mg dose, respectively. Climate change and eutrophication are less effected with a reduction of 0% to 0.6% and 0% to 0.9% for the 5000mg and 10000mg dose, respectively. Ammonia emissions reduction and FCR variability should be included to improve reliability of the results.	Change of -0.8% to -2.3% and -0.9% to -2.3% for the 5000mg and 10000mg dose respectively, due to improved FCR.FCR variability should be included to improve reliability of the results.	No downstream impacts are expected. Inconsistent guidance on how to model application of manure leaving the farm.	Reduction of 1.2% to 7.5% and 0.1% to 11.8%. for the 5000mg and 10000mg dose respectively. For climate change, the reduction in impact is partially counterbalanced by the production of the additive. Respiratory inorganics impact category reduces largely. Inconsistent guidance on how to account for manure application. Ammonia emissions reduction and FCR variability should be included to improve reliability of the results.
Vitamin E	Not possible to estimate. Attempt to partially account for impact at farm gate resulted in a 0% and 0.03% of total impact baseline.	Not possible to estimate.	Not possible to estimate.	Influence on meat losses at retail and consumer. Not possible to estimate due to boundaries selected.	Impact reduction could not be evaluated, because additive effect is happening outside of the boundaries. Boundaries expansion is needed to estimate this scenario.
All	Between 0.09% and 2.4% of total impact baseline	Reduction of 0% to 10.7%. Ammonia emissions reduction and FCR variability should be included to improve reliability of the results.	Reduction of 0.6% to 4.4% Results highly uncertain due to feed origin, formulation strategies, background dataset and FCR variability.	No downstream impacts are expected. Inconsistent guidance on how to model application of manure leaving the farm.	Reduction of 0.1% to 11.8%. Inconsistent guidance on how to account for manure application. Certainty of the results relies on the solidity of the data related to feed origin, formulation strategies, background datasets and FCR variability. Additionality is increasing the uncertainty.

4 Dairy cows

4.1 Scope

4.1.1 The baseline dairy system

A typical Belgian Dutch baseline dairy farm has been considered as the starting point for evaluation of the interventions. The system assumes a steady state, meaning that the herd composition and productivity is constant over the years. Reference data for energy consumption, animal handling and the manure system are typical for a 2016 average Dutch reference system (average of north and south regions of the Netherlands), considered to be typical also for Belgium. Reference data of the farm system have been reviewed by WUR except for the feed concentrate, specifically developed for this study, to account for both the Belgian and Dutch feed market [15].

The dairy cow ration is mainly roughage based (72% of dry matter intake), with the herd having access to pasture in the summer months. Roughages are fresh grass, grass silage and maize silage. The other 28% of the ration is assumed to be a concentrate feed as described in Table 44. The use of wet co-products (e.g. spent brewers' grain) has not been considered in the reference system.

The emission calculations are described in the dairy methodological documentation of the APS-footprint tool [15]. The guideline followed is the dairy PEFCR [4]. This is on its turn based on IPCC and EMEP/EEA guidelines. The LEAP and dairy PEFCR guidelines [10, 4] require use of more advanced country-specific methodologies (TIER 3), if available and possible to implement. Therefore, we used the results from the Dutch TIER 3 method (emission factors as implemented in *Kringloopwijzer* tool) for enteric methane emissions as the baseline approach [19]. The emission factors were implemented externally from the APS-footprint tool (in Excel).

There are three possible approaches to implement for enteric methane emissions: IPCC Tier 2 with Y_m (methane conversion factor) 5.5%, IPCC Tier 2 with Ym 6.1% (based on Belgian National Inventory Report) and the Dutch National Inventory Report Tier 3 method [19]. In the section 4.3.8.2.5 we will further explore the impact of the differences.

4.1.2 System description

In this study we consider the cow milk production as main product and main driver for the design of the farm system, we applied allocation to account for the co-production of the calves and culled cows.

Most of the data are based on KWIN 2017-2018 [*21*], while other sources are FADN *Agrimatie* [*22*] and *Dierljike mest en mineralen* 2016 [*23*].

The herd composition in the APS-footprint tool is expressed in Annual Average Population (AAP). AAP is the number of animals in average present at farm, for a considered period of one year. The heifer animal type is defined as female calves that are raised from 2 year of age up to calving age. The latter is the age at which it gives birth to a calf for the first time, followed by its first lactation period. This means that the Heifer is the only animal type that has a shorter time span than one year.

The AAPs of the herd is as follows: dairy cows (103), heifers (5), calves from 1 to 2 years of age (31) and calves below 1 year of age (35). The number of heifers is calculated based on a replacement rate of 27.1%, a heifer mortality of 1.5% (expert judgment) and an average age of first calving of 788 days [*23*]. Other data used for determining the AAP are heifer and calves 1-2 year mortalities of 1.5 % (based on expert judgment), calves from 1 month up to 1 year mortality of 5% and 9% mortality of calves younger than 1 month [*23*]. The amount of 64 sold calves was derived from *Agrimatie* [*22*]. Milk yield per dairy cow is 8328 kg of raw milk every year. Other outputs of the system are liveweight of mature cows for slaughtering (17500 kg) and sold calves (3008 kg). These are based on a weight for dairy cow of 625 kg and 45 kg for sold calves [*23*].

The technical parameters of the system as implemented in the APS-footprint tool are summarized in the Table 14.

Table 14 Dairy farm baseline parameters as expressed in the APS-footprint tool. All values expressed per 1 year.

Parameters	***Unit***					***Source***
Average annual temperature	degrees Celsius	10				
Milk protein content	%	3.51				[23]
Fat content	%	4.39				[22]
Milk produced	Kg	857784				[23]
Liveweight co-product	Kg	20508				Calculated
Water consumption	Kg	4302532				[21]
Electricity use	MJ	167359				[24]
Gas use	MJ	41145				
Diesel use	MJ	0				
Animal type – Housing		Dairy cows	Calves <1 year	Calves 1-2 year	Heifers	
Straw for bedding	kg animal^{-1}	250	0	0	0	[21]
Saw dust for bedding	kg animal^{-1}	125	0	0	0	[21]
Average annual population of animals	#	103	35	31	5	[22]
Manure management system type		Pit storage (> 1 month)	Pit storage (> 1 month)	Pit storage (> 1 month)	Pit storage (> 1 month)	Expert judgment
Percentage of manure stored on farm before spreading	%	50	50	50	50	Expert judgment
Feed intake	kg as is animal^{-1}	18288.44	3905.95	11221.67	11221.79	Calculated
Compound feed	kg as is animal^{-1}	2297	0	0	0	[23]
Milk powder	kg as is animal^{-1}	0	49.6	0	0	[21]
Grass grazed	kg as is animal^{-1}	5287.5	1540.55	7390.67	7390.67	[23] for dairy cows.
Grass silage	kg as is animal^{-1}	5644.68	1893.6	3545.7	3545.8	
Maize silage	kg as is animal^{-1}	5059.26	422.2	285.3	285.3	[25] for other animals.
Digestibility of the ration	% of GE	70	80	70	70	[33]
Gross energy intake of ration	MJ animal^{-1}	106835.5	23250.5	52268	52268	[26]
Crude protein in ration	% of DM	17.6	19.3	20.4	20.4	
Percentage of silage in feed	% of GE	66.4	76.1	58.8	58.8	Calculated
Percentage of time spent grazing	%	11.4	10.9	26	26	[23]
Percentage of time spent in buildings	%	88.6	89.1	74	74	Calculated
Percentage of time spent in open yard areas	%	0	0	0	0	Expert judgment

The feed regime for dairy cows is:

- 15.5 kg grass silage as is/day (7.3 kg DM)
- 13.9 kg maize silage as is/day (3.8 kg DM)
- 14.5 kg fresh grass from pasture as is/day (2.3 kg DM)
- 6.3 kg compound feed as is/day (5.2 kg DM) – protein content 21.8% DM

The DM ration is based on *Dierljike mest en mineralen* 2016 [*23*], while the moisture content of each ingredient is based on CVB Feed table (*Veevoedertabel*) [26]. This diet represents an average yearly intake of feed between different regions of the Netherlands, between summer and winter, and between lactating and dry cows. This is not consistent with the Dairy PEFCR, where input should be distinguished between dry lactating cows. Still, the different aggregation of feed input used will not influence the results of the baseline. Limitations of this modelling during intervention scenario modelling will be discussed on section 4.1.4.3. For fresh grass, a dry matter content of 16% was assumed.

The total dry matter intake is 18.6 kg, 13.4 kg from forage and 5.2 kg from concentrate feed. This results in a dry matter ratio of 39% from grass silage, 20.4% from maize silage, 12.4% from pasture and 28% from concentrate. For the sake of simplicity, we assumed that concentrate is only fed to cows, while in reality, we know that the amount specific for cows also covered the compound feed consumed by youngstock.

4.1.3 Functional unit and reference flows

The functional unit is 1 kilogram of Fat-Protein Corrected Milk (FPCM) (corrected to 4% fat and 3.3% protein) as calculated in PEFCR dairy guidelines [4]:

$$FPCM\left(\frac{kg}{yr}\right) = Production\left(\frac{kg}{yr}\right) x\ (0.1226\ x\ True\ Fat\% + 0.0776\ x\ True\ Protein\% + 0.2534)$$

Where:

- FPCM is the amount of Fat-Protein Corrected Milk (kg $year^{-1}$);
- Production is the amount of milk produced (kg $year^{-1}$);
- True fat is the content of fat present in the produced milk (%);
- True protein in the content if protein in the produced milk (%).

0.1226 and 0.0776 are parameters calculated based on caloric content of fat and protein, respectively. 0.2534 is related to lactose content. More information on how these are calculated can be found on [27].

4.1.4 Feed additive interventions

4.1.4.1 The interventions for dairy cows

The feed additives effect on zootechnical performance and their qualitative translation to changes to the dairy system are introduced in section 2.1, step 2. The detailed scientific substantiation of the zootechnical effects are explained in section 8.1. Here, the likely changes to the system (step 3), and the subsequent modelling of LCA changes (expressed as changes in the APS-footprint parameters) is described.

The set of dietary interventions, their zootechnical effects (qualitative and quantitative) and LCA parameters changes are summarized in Table 15.

Table 15 Dietary interventions considered for dairy cows with their effects

Principle	*Dose intervention*	*Zootechnical effect (qualitative support)*	*Zootechnical effect (quantitative)*	*Change in LCA (inventory) flows (quantitative)*
Vitamin E	1000 mg/h/d vs 550 mg/h/d	Fertility Udder health	Dry period -2d Clinical mastitis -22.5% prevalence Subclinical mastitis -37.5% prevalence Culled cow parity +5%	+0.51% in milk production -6.44% n of youngstock AAP +0.07% feed intake -5.05% liveweight output
25(OH)D3	3/1 mg/h/d 25(OH)D3 (close-up/lact) vs 22000/21000 IU/h/d	Milk Fertility Udder health Calcium homeostasis	Milk +0.5kg/d, Dry period -2d Clinical mastitis -7.5% prevalence Subclinical mastitis -12.5% prevalence Milk fever -25% prevalence Culled cow parity +5%	+2.34% in milk production -5.48% n of youngstock AAP +0.08% feed intake -4.28% liveweight output
Amylase	12.5 g/h/d vs 0 g (1st 100d of lactation[6])	Higher digestion of starch and fibres	Milk +1kg/d	+3.96% in milk production
Biotin	20 mg/h/d vs 0 mg/h/d	Locomotion Milk	Milk +0.5kg/d Lameness -50% prevalence	+2.43% in milk production, -1.55% n of youngstock AAP -1.24% liveweight output -0.02% feed intake
Beta-carotene	500/300 mg/h/d (dry/lact) vs 0 mg/h/d	Fertility	Dry period -4d Culled cow parity +15%	+0.73% in milk production -15% n of youngstock AAP +0.3% feed intake -11.67% liveweight output
All	All previous	All previous	Milk +2kg/d, Dry period -10d Clinical mastitis -30% prevalence Subclinical mastitis -50% prevalence Milk fever -25% prevalence Lameness -50% prevalence Culled cow parity +25%	+10.19% in milk production -28.46% n of youngstock AAP +0.52% feed intake -22.12% liveweight output

h means head, ie 12.5 g/head/day

4.1.4.2 Mode of action, efficacy and change in inventory flows

The feed additives studied for dairy cows induce several interventions that have common end points (i.e. several solutions have the potential to increase milk production at the animal level). These interventions interact to a certain extent and are modelled relatively simplistically (Figure 15) assuming that the positive effects are limited to a certain maximum.

For each zootechnical effect a maximum change has been considered. The estimate of the maximum change is based on educated knowledge of DSM experts (more detail can be found on section 8.1.4.6.1). In this way we reassure that the cumulative effect of using multiple additives would not be unrealistic compared to the biological animal potential. This model is also used to calculate the cumulative effect ("All" scenario) assuming the absence of any type of synergistic or antagonistic effect.

[6] The amylase studied is only approved in Europe for the 1st 100d of lactation. Efficacy sustains beyond the 1st 100d but EU authorities deemed the submitted data set insufficient to grant the corresponding approval.

The extent of the possible improvement in zootechnical effects obtained with nutritional management (resorting to feed supplementation with additives) is estimated, based on expert knowledge as follows:

- Support of fertility. The maximum reduction of the dry period achievable with nutritional management is estimated at 10 days. The maximum increase of longevity is quantified at + 25% (expressed as cow parity from 3.5 up to 4.4).
- Support of milk production. The maximum increase of milk production achievable with nutritional management is quantified at 2 kg/d/cow. This correspond to a 7.92% milk increase (considering that the milk production of the baseline is 25.3 kg milk/d/cow).
- Support of udder health (clinical and subclinical). The maximum reduction of prevalence of clinical and subclinical mastitis achievable with nutritional management is quantified at - 30% and - 50%, respectively.
- Support of calcium homeostasis. The maximum reduction of prevalence of milk fever achievable with nutritional management is quantified at - 25%.
- Support of locomotion. The maximum reduction of prevalence of lameness achievable with nutritional management is quantified at - 50%.

The allocation of the maximum overall improvement to the various additives is also based on educated knowledge of DSM experts and grounded in the bibliography collected for the additives (more detail can be found on section 8.1.4.6.1). The mode of action and efficacy of the respective feed additives can be summarized as follows:

- Beta-carotene has shown a positive effect on cow fertility, via its antioxidant effects. It improves ovarian function and increases reproductive success:
  - Based on experimental results and field feedbacks, experts deem that ad hoc beta-carotene supplementation can help achieve 60% of the possible fertility improvement defined.
- 25OHD3 (25-hydroxycholecalciferol)7 is an advanced form of vitamin D. It supports the tissue function, which is important for udder health (25% of the maximum support) when exposed to milking stress factors. 25OHD3 also supports milk productivity (25% of the maximum support) and fertility (20% of the maximum support). Via its role on the calcium metabolism, it supports calcium homeostasis upon lactation onset:
  - Based on experimental results and field feedbacks, experts deem that ad hoc 25OHD3 supplementation can help achieve:
    - 25% of the possible udder health improvement defined;
    - 25% of the possible milk production improvement defined;
    - 20% of the possible fertility improvement defined;
    - 100% of the possible calcium homeostasis issues defined.
- Vitamin E, via its anti-oxidative properties, supports tissue function, which is important for udder health when exposed to milking stress factors and thereof supports udder health exposed to milking stress factors and therefrom help reduce the incidence of mastitis.
  - Based on experimental results and field feedbacks, experts deem that ad hoc Vitamin E supplementation can help achieve:
    - 75% of the possible udder health improvement defined;
    - 20% of the possible fertility improvement defined.
- Biotin supports horn tissue synthesis and thereof thus supports healthy hooves and improves mobility (100% of the maximum support). Also, biotin support milk productivity (25% of the maximum support).
  - Based on experimental results and field feedbacks, experts deem that ad hoc biotin supplementation can help achieve:
    - 100% of the possible hooves health improvement defined;
    - 25% of the of the possible milk production improvement defined.

[7] 25-hydroxycholecalciferol is not available yet for commercial dairy feeds in the EU market as the product is about to seek for authorization as a nutritional feed additive for dairy cows (while 25-hydroxycholecalciferol is already authorized in EU as a feed additive for pig and poultry).

- Amylase enhances the digestion of starch and thereof facilitates the overall rumen digestion processes, improving nutrient utilization leading to enhanced milk production (50% of the maximum support). Based on experimental results and field feedbacks, experts deem that ad hoc biotin supplementation can help achieve:
  - 50% of the possible milk production improvement defined.

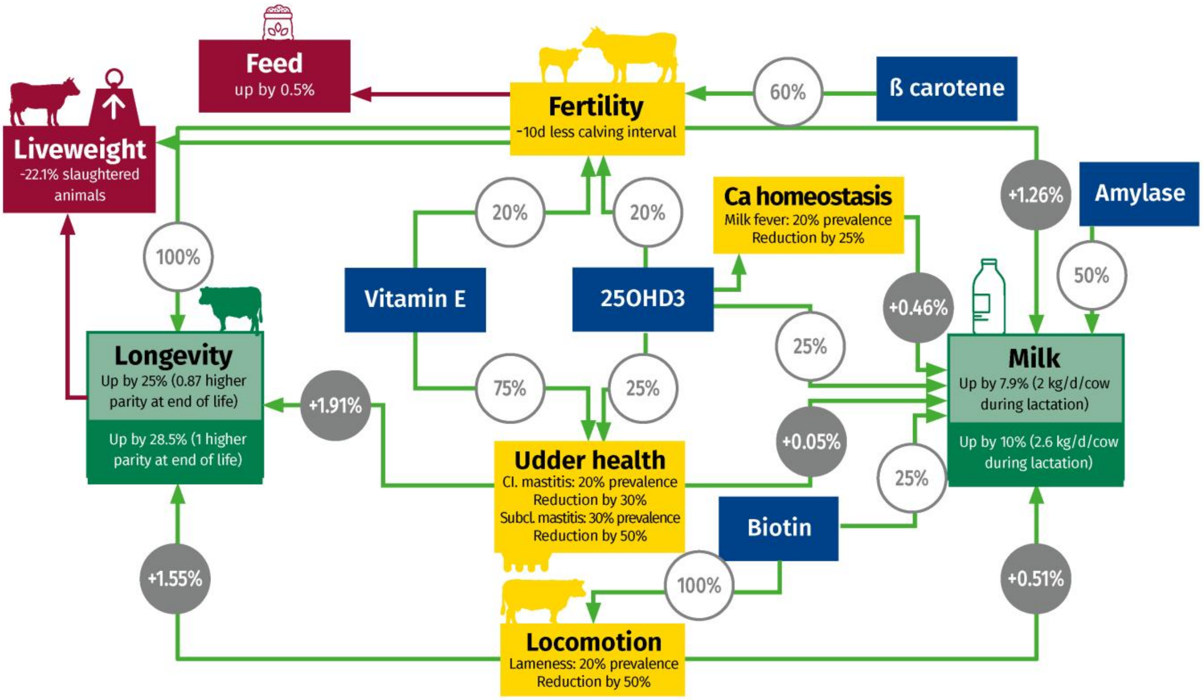

Figure 15 Overall view of nutritional measures and effects considered for dairy cows
Blue boxes: additive. Yellow boxes: intermediate effects with prevalence baseline and maximum change. White circles: direct contributions to the effect. Grey circles: additional indirect contributions to the effect. Green boxes: Final "positive" effects. Red boxes: Final "negative" effects

Each zootechnical effect has some consequences on the herd dynamics and directly and indirectly can affect overall productivity. To account for these interactions, the changes in animal herd composition needs to be considered. Aware that complex and extensive animal herd models has been developed on scientific research, we attempted here to create a simplified model to account only for some main dynamics, without entering in the details of e.g. lactation curves. When assumption has been taken, they will be noted and limitation that such simplifications carry will be described.

4.1.4.2.1 Support of udder health, calcium homeostasis and locomotion

Reduction of disorder prevalence have indirect effects on longevity and milk production (grey circle in Figure 15). This is modelled by estimating a percentage of disorder prevalence in the reference dairy cow herd and a longevity and milk production reduction due to the fact that the animal is ill in the considered period of 1 year (Table 16). Further substantiation of these parameters can be found on chapter 8.1.4.6.1. Potential effects on fertility are not considered.

For example, Vitamin E reduces the prevalence of clinical mastitis by -22.5% (75% share of udder health support, with a maximum potential of - 30% of clinical mastitis prevalence reduction) and subclinical mastitis by 37.5% (75% of -50%). The clinical and subclinical mastitis prevalence of the dairy cows is, after the intervention, 15.5% and 18.8% respectively (this results in 65.7% dairy cows not being ill). This translates to an overall increased milk production of 15.5%*(100-5%)+18.8%*(100-1%)+65.7%*(100%) = 99.04% compared to a reference milk production of 20%*(100-5%)+30%*(100-1%)+50%*(100%) = 98.70%. This results in a milk increase of 99.04/98.7 - 1 = 0.344%.

Table 16 Disorder prevalence, milk production reduction and longevity reduction

Disorder type	Baseline prevalence	Milk production reduction	Longevity reduction (expressed as cow parity)
Clinical mastitis	20%	-5%	-30%
Subclinical mastitis	30%	-1%	/
Calcium metabolism	20%[8]	-1%	/
Lameness	20%	-5%	-15%

Prevalence valid only on dairy cow animal type

4.1.4.2.2 Milk production support

The support of milk production is modelled as an increase of milk produced without accounting for the possible change in milk quality and assuming that all other animal performance remains constant (including replacement rate). Support of milk production is usually connected to an improvement in carbohydrates and starch digestion (e.g. amylase additive). This might result in lower volatile solids excretions (connected to methane and NMVOC emissions from manure) and in lower methane emissions from enteric fermentation. To account for these changes in the system, a complex biophysical model is needed. In this study we neglected these effects, and therefore potentially underestimating positive effects.

4.1.4.2.3 Support of fertility increases longevity and reduces dry period

The change in longevity is expressed as a change in average parity of culled dairy cows. The average parity of culled dairy cows of the baseline is 3.5, calculated with dairy cow replacement rate of 27.1% and mortality of 1.5% (section 4.1.2). The intervention implications are here simplified by only accounting for a reduction in youngstock AAP, by the same percentage as the longevity increase. This assumes optimal management practices, where the farmer decisions on calves kept are only influenced by actual replacement rates. In practice, such decisions might also be influenced by other factors that are not accounted for in this study.

In order to model the effect of a reduced dry period, a lactation period of 356 days, a dry period of 60 days and a short last lactation before culling of 264 days was considered in the reference system [*23*]. This results in a calving interval of 416 days (13.9 months). Considering the dairy cow average longevity, it is possible to calculate the average herd calving interval taking also in consideration the short last lactation before culling. For the reference this would be (416*(3.5-1)+264)/3.5 = 372.5 days. The same reasoning follows for the calculation of the average herd lactation period of (356*(3.5-1)+264)/3.5 = 329.7 days (including the last short lactation period before culling). Dividing the two results in a 329.7/372.5 = 88.5% of the time spent on lactation on average. Changes on longevity and on dry period, will influence the average time spent on lactation therefore increasing the milk production. For example, the Vitamin E use increases longevity by 6.44% (average parity of culled dairy cows of 3.72) and reduces the dry period to 58 days. A shorter dry period could result in a longer lactation period (constant calving interval) or in a shorter calving interval (constant lactation period). Since the first modelling option would require information on the lactation curve (to estimate the milk production increase), we decided to model a shorter dry period as a shorter calving interval. The dairy cow calving interval is therefore 414 days. The calving interval at herd level (including last short lactation before culling) is (414*(3.72-1)+264)/3.72 = 373.7 days. The lactation period at herd level is (356*(3.72-1)+264)/3.72 = 331.3 days. The average time spent on lactation by the dairy cow herd is 331.3/373.7 = 88.6% when Vitamin E is applied. This is a +0.17% more time resulting in the same increase in milk production.

Also, lactating cows needs more feed, therefore such change would affect feed intake too. We are here assuming that lactating cows are fed 1.8 times the feed given to cows on dry period [*28*] This means that the dairy cows

[8] Please note that contradicting reported incidences can be found on literature. The review by BERGE, A.C. and VERTENTEN, G., 2014. A field study to determine the prevalence, dairy herd management systems, and fresh cow clinical conditions associated with ketosis in western European dairy herds. Journal of dairy science, 97(4), pp. 2145-2154 mentions a much lower incidence of milk fever of 1.7%.

have on average a feed input of 1.8*88.5%+1*11.5% = 1.708 This means that on average dairy cows eat 1.708 times more feed compared to cows in the dry period. Changes in this parameter will directly affect feed input. For the Vitamin E example, this would be a 1.8*88.6%+1*11.4% = 1.709 (therefore a 1.709/1.708-1 = +0.07% increase in feed intake). The average compound feed (covering the yearly diet for the cow) has not been recalculated.

Changes in longevity (directly related to n of youngstock AAP) and dry period also influence the AAPs of the herd and the amount of liveweight co-product output from culled cows and sold calves. The culled cows change is directly related to the change in longevity. In the Vitamin E example, a longevity extension of 6.44% reduces the from 28 to 26.2 the number of culled cows. The sum of the AAP of calves taken for replacement with the calves sold (in the baseline 35 + 64 = 99 animals) is assumed to be inversely proportional to the herd calving interval of 372.5 days in the reference system (including the short last lactation before culling). Here we simplified the system by summing up an average population with a number of animals, therefore not taking into account mortalities. For example, the Vitamin E longer herd calving interval of 373.7 days reduces the sum of the AAP of calves for replacement with the calves sold to 99*372.5/373.7 = 98.7 animals. If we subtract the AAP of calves for replacement (32.7 due to an increased longevity of 6.44%) we calculate 98.7-32.7 = 65.9 sold calves. Considering the baseline animal weights as unchanged (625kg for culled cows and 47 kg for sold calves), the baseline liveweight output (625*28+47*64 = 20508 kg) reduces to 625*26.2+47*65.9 = 19473 kg (-5.05%).

Table 17 Summary of the change in herd model parameters in the various scenarios

	Refe-rence system	Vita-min E	25OHD 3	Amy-lase	Beta Caro-tene	Biotin	All
Dairy cows slaughtered (animals):	28.0	26.2	26.5	28.0	23.8	27.6	20.0
Born calves kept for replacement (animals):	35.0	32.7	33.1	35.0	29.8	34.5	25.0
Born calves slaughtered (animals):	64.0	65.9	65.7	64.0	68.9	64.4	73.5
Liveweight output (kg liveweight):	20508	19473	19629	20508	18115	20255	15972
Dry period (days):	60	58	58	60	54	60	50
Calving interval (days):	416	414	414	416	410	416	406
Lactation period including last (short) lactation period (days):	329.7	331.3	331.1	329.7	333.1	330.1	335.5
Calving interval including last (short) lactation period (days):	372.5	373.7	373.3	372.5	373.7	373.2	374.4
Milk period/calving interval (%):	88.5%	88.6%	88.7%	88.5%	89.1%	88.5%	89.6%
Feed Intake/feed intake dry cow (kg/kg):	1.708	1.709	1.709	1.708	1.713	1.708	1.717

An important consideration is that most of the parameters here modelled are interacting between each other. The actual situation at the animal farm is extremely complex, and the chosen approach is not able to fully grasp such complexity. A limitation is that, possibly, some changes in the system has not been accounted for. However, we assume that we captured the main changes in the system, which is sufficient for the road testing LCAs. A list of neglected effects is summarized in next section.

4.1.4.3 Change in inventory flows

The following LCA (inventory) flows have been considered in the road testing:

- Milk production increase;
- Average number of youngstock (replacement animals) reduction;
- The dairy cow feed input increases due to more cows longer in lactation;
- Liveweight of slaughtered animals' reduction.

Neglected effects that have not been modelled in order to simplify the overall complexity of this case are:

- Interaction between direct milk production increase and replacement rate;

- Effect of increased cow longevity or shorter dry period on milk production and feed intake;
- Disorder reduction effect on fertility and subsequently on dry period length;
- Increased feed intake due to higher daily milk production caused by disorder reduction;
- Changes in feed digestibility and enteric fermentation;
- Change in mortalities, due to longer cow longevity;
- Change in water and energy input;
- Change in dairy compound feed formulation due to different average time spent on lactation;
- Change in milk content (e.g. fat, protein, calcium) and that impact on N retention;
- Interactions between diseases on prevalence and production parameters.

We do not expect for most of these neglected effects to largely influence the LCA results, except for the effect of longer longevity and shorter dry period on milk production and feed intake because milk output and feed intake are the main parameters defining the overall results.

4.1.4.3.1 Vitamin E

The hypothesis is that Vitamin E is able to reduce the cases of clinical mastitis by 22.5% and of subclinical mastitis by 37.5% (substantiation can be read in chapter 8.1.4.3). The increase in milk production and longevity due to udder health support is +0.34% and +1.44%, respectively. The calculations for the Vitamin E scenario are used as example on how to calculate these changes in LCI flows in section 4.1.4.2.1.

The fertility benefit given by Vit E results in shortened dry period (-10 days*20% = -2 days of dry period) and a longer longevity (25% * 20% = 5%).

The overall effect on longevity is therefore +6.44% (1.44% due to udder health support and 5% due to a fertility benefit). This results in a reduction in the number of youngstock by – 6.44%.

Changes in longevity and a shorter dry period length means that cows are more in lactation therefore this requires a higher feed intake (+0.07%) and results in a higher milk production (+0.17%). Longer longevity also translates to lower replacement rates, therefore less culled cows and more calves available for sale (increased also by a shorter dry period). Since culled dairy cows have a much larger contribution to the living animals' output of the system by weight the overall living animal output reduces by –4.67%. The calculations for the Vitamin E scenario are used as example on how to calculate these changes in LCI flows in section 4.1.4.2.3.

The overall milk production increase is +0.51% (+0.34% due to udder health support and +0.17% due to a shortest dry period).

4.1.4.3.2 25-hydroxycholecalciferol (25OHD3)

The benefit on milk production is modelled as an increase of +7.92% * 25% = +1.98% in milk output.

The benefit to udder health is modelled in the same way as for Vitamin E. In this case, 25OHD3 has a contribution factor to the maximum achievable effect of 25% instead of 75% of Vitamin E. This results in -7.5% cases of clinical mastitis and -12.5% cases of subclinical mastitis. The increase in milk production and longevity due to udder health support is +0.11% and +0.48%, respectively. The calculations for the Vitamin E scenario are used as example on how to calculate these changes in LCI flows in section 4.1.4.2, based on Table 16.

The improved calcium homeostasis is modelled as a 25% lower incidence of metabolic syndrome (from 20% of the dairy cows to 15%). Since such syndrome reduce the milk production by approximately 1% the benefit on the overall milk production is low: +0.05%. The calculations for the Vitamin E scenario are used as example on how to calculate these changes in LCI flows in section 4.1.4.2.1.

Modelling of the fertility is similar as for the Vitamin E case. It results in a shortened dry period (-10 days*20% = -2 days of dry period) and longer longevity (+25%*20% = +5%).

The overall effect on longevity is therefore +5.48% (0.48% due to udder health support and 5% due to an improved fertility). This results in a reduction in the number of youngstock by –5.48%.

The interactions between changes in longevity, replacement rates and shorter dry period results in a higher feed intake (+0.08%), a higher milk production (+0.20%) and a live-weight co-product reduction (- 3.91%). The calculations for the Vitamin E scenario are used as example on how to calculate these changes in LCI flows in section 4.1.4.2.3.

The overall milk production increase is +2.34% (+1.98% due to direct milk production increase, +0.11% due to udder health support, +0.05% due to reduction of milk fever and +0.20% due to a shorter dry period).

4.1.4.3.3 Amylase

The benefit on milk production is modelled as an increase of +7.92% * 50% = +3.96% in milk output.

4.1.4.3.4 Biotin

The benefit on milk production is modelled as an increase of +7.92% * 25% = +1.98% in milk output.

The improved hoof health is modelled as a 50% reduction of dairy cows suffering of lameness, which means there is a higher proportion of cows easily accessing the feed which increases milk production. The increase in milk production and longevity due to hoof health support is +0.51% and +1.55%, respectively. The calculations for the Vitamin E scenario are used as example on how to calculate these changes in LCI flows in section 4.1.4.2.1.

Increased longevity results in a reduction in the number of youngstock by -1.55%. It also causes fewer dairy cows to be slaughtered per year and more calves available for sale. Since culled dairy cows have a much larger contribution to the meat output of the system, compared to sold calves, the overall meat output reduces by -0.86%. Changes in longevity also slightly reduce the average number of cows in lactation, reducing the milk production by 0.06% and feed intake by 0.02%. The calculations for the Vitamin E scenario are used as example on how to calculate these changes in LCI flows in section 4.1.4.2.3.

4.1.4.3.5 Beta-carotene

The fertility benefit from Beta-carotene results in a shortened dry period (-10 days*60% = -6 days of dry period. Also, better fertility tends to reduce the need for cow replacement, therefore a longer longevity (+25%*60% = +15%). This results in a reduction in the number of youngstock by -15%).

The combination a shortened dry period and a longer longevity results in a reduced average number of cow in lactation. This increase in the feed a higher intake (+0.30%) and increase a higher milk production (+0.73). Increased longevity also causes fewer dairy cows to be slaughtered per year and more calves available for sell (increased also by a lower dry period). Since culled dairy cows have a much larger contribution to the meat output of the system, compared to sold calves, the overall meat output reduces by -11.29%. The calculations for the Vitamin E scenario are used as example on how to calculate these changes in LCI flows in section 4.1.4.2.3.

4.1.4.3.6 All

The all intervention considers the use of all the previously described additives with the indicated doses.

The direct milk improvement is 7.92% (maximum direct change).

Clinical mastitis prevalence reduces by -30% and subclinical mastitis by -50%. This results in a higher milk production (+0.46%) and longer longevity (+1.91%). Lameness prevalence reduces by -50%. This results in a higher milk production (+0.51%) and longer longevity (+1.55%). Milk fever prevalence reduces by -25%. This results in a higher milk production (+0.05%). The calculations for the Vitamin E scenario are used as example on how to calculate these changes in LCI flows in section 4.1.4.2.1.

Fertility support reduces the dry period of 10 days and increase longevity by 25%.

The combination of a shortened dry period and a longer longevity results in a reduced average number of cows in lactation. This increases the feed intake (+0.52%) and increase milk production (+1.26%). Increased longevity also causes fewer dairy cows to be slaughtered per year and more calves available for sell (increased also by a lower dry period). Since culled dairy cows have a much larger contribution to the meat output of the system, compared to sold calves, the overall meat output reduces by -21.74%. The calculations for the Vitamin E scenario are used as example on how to calculate these changes in LCI flows in section 4.1.4.2.3.

The overall milk improvement is +10.2% (7.92% due to direct milk production increase, +0.46% due to udder health support, +0.05% due to reduction of milk fever, +0.51% due to locomotion support and +1.26% due to a shortest dry period and longer longevity).

Overall longevity improvement is +28.46% (25% due to fertility improvement, 1.91% due to udder health support and 1.55% due to support locomotion). This results in a reduction in the number of youngstock by –28.46%.

4.2 Lifecycle impact results

Table 18 summarizes the lifecycle impacts of the feed additive interventions for the dairy case study. The LCIA results are relative expressions and do not predict impacts on category endpoints, the exceeding of thresholds, safety margins or risks.

Table 18 Lifecycle Impact Results for the dairy interventions, absolute figures

Impact Category	Unit	Baseline	Vitamin E	25OHD3	Amylase	Biotin	Beta-Caro-tene	All
Climate change (excl LUC)	kg CO_2 eq	$1.22\ 10^{0}$	$1.21\ 10^{0}$	$1.19\ 10^{0}$	$1.18\ 10^{0}$	$1.20\ 10^{0}$	$1.20\ 10^{0}$	$1.11\ 10^{0}$
Climate change (incl LUC)	kg CO_2 eq	$1.41\ 10^{0}$	$1.41\ 10^{0}$	$1.39\ 10^{0}$	$1.37\ 10^{0}$	$1.40\ 10^{0}$	$1.40\ 10^{0}$	$1.29\ 10^{0}$
Ozone depletion	kg CFC11 eq	$3.64\ 10^{-9}$	$3.70\ 10^{-9}$	$3.62\ 10^{-9}$	$3.55\ 10^{-9}$	$3.60\ 10^{-9}$	$3.88\ 10^{-9}$	$3.76\ 10^{-9}$
Ionising radiation	kBq U-235 eq	$6.04\ 10^{-3}$	$6.07\ 10^{-3}$	$5.97\ 10^{-3}$	$5.89\ 10^{-3}$	$5.97\ 10^{-3}$	$6.14\ 10^{-3}$	$5.85\ 10^{-3}$
Photochemical ozone formation,	kg NMVOC eq	$3.18\ 10^{-3}$	$3.17\ 10^{-3}$	$3.12\ 10^{-3}$	$3.08\ 10^{-3}$	$3.12\ 10^{-3}$	$3.16\ 10^{-3}$	$2.92\ 10^{-3}$
Respiratory inorganics	disease inc.	$2.05\ 10^{-7}$	$2.03\ 10^{-7}$	$2.00\ 10^{-7}$	$1.98\ 10^{-7}$	$2.00\ 10^{-7}$	$2.00\ 10^{-7}$	$1.82\ 10^{-7}$
Non-cancer human health effects	CTUh	$1.16\ 10^{-6}$	$1.15\ 10^{-6}$	$1.14\ 10^{-6}$	$1.12\ 10^{-6}$	$1.14\ 10^{-6}$	$1.15\ 10^{-6}$	$1.06\ 10^{-6}$
Cancer human health effects	CTUh	$1.95\ 10^{-8}$	$1.94\ 10^{-8}$	$1.91\ 10^{-8}$	$1.89\ 10^{-8}$	$1.91\ 10^{-8}$	$1.94\ 10^{-8}$	$1.79\ 10^{-8}$
Acidification terrest. and freshwater	mol H+ eq	$2.74\ 10^{-2}$	$2.71\ 10^{-2}$	$2.67\ 10^{-2}$	$2.65\ 10^{-2}$	$2.68\ 10^{-2}$	$2.68\ 10^{-2}$	$2.43\ 10^{-2}$
Eutrophication freshwater	kg P eq	$7.01\ 10^{-5}$	$6.94\ 10^{-5}$	$6.84\ 10^{-5}$	$6.79\ 10^{-5}$	$6.87\ 10^{-5}$	$6.88\ 10^{-5}$	$6.31\ 10^{-5}$
Eutrophication marine	kg N eq	$9.61\ 10^{-3}$	$9.51\ 10^{-3}$	$9.38\ 10^{-3}$	$9.30\ 10^{-3}$	$9.40\ 10^{-3}$	$9.42\ 10^{-3}$	$8.57\ 10^{-3}$
Eutrophication terrestrial	mol N eq	$1.22\ 10^{-1}$	$1.20\ 10^{-1}$	$1.19\ 10^{-1}$	$1.18\ 10^{-1}$	$1.19\ 10^{-1}$	$1.19\ 10^{-1}$	$1.08\ 10^{-1}$
Ecotoxicity freshwater	CTUe	$3.35\ 10^{0}$	$3.35\ 10^{0}$	$3.30\ 10^{0}$	$3.24\ 10^{0}$	$3.29\ 10^{0}$	$3.36\ 10^{0}$	$3.12\ 10^{0}$
Land use	Pt	$1.04\ 10^{2}$	$1.04\ 10^{2}$	$1.02\ 10^{2}$	$1.01\ 10^{2}$	$1.02\ 10^{2}$	$1.04\ 10^{2}$	$9.56\ 10^{2}$
Water scarcity	m3 depriv.	$2.56\ 10^{-1}$	$2.57\ 10^{-1}$	$2.53\ 10^{-1}$	$2.48\ 10^{-1}$	$2.52\ 10^{-1}$	$2.63\ 10^{-1}$	$2.47\ 10^{-1}$
Resource use, energy carriers	MJ	$3.58\ 10^{0}$	$3.57\ 10^{0}$	$3.52\ 10^{0}$	$3.46\ 10^{0}$	$3.51\ 10^{0}$	$3.58\ 10^{0}$	$3.34\ 10^{0}$
Resource use, mineral and metals	kg Sb eq	$9.83\ 10^{-8}$	$9.94\ 10^{-8}$	$9.76\ 10^{-8}$	$9.54\ 10^{-8}$	$1.20\ 10^{-7}$	$9.93\ 10^{-8}$	$1.18\ 10^{-7}$

Table 19 Lifecycle Impact Results for the dairy interventions, relative to baseline

Impact Category	Vitamin E	25OHD3	Amylase	Biotin	Beta-Carotene	All
Climate change (excl LUC)	-0.7%	-2.1%	-3.2%	-2.0%	-1.1%	-9.2%
Climate change (incl LUC)	-0.5%	-2.0%	-3.2%	-2.0%	-0.8%	-8.6%
Ozone depletion	1.7%	-0.6%	-2.6%	-1.2%	6.6%	3.2%
Ionising radiation, HH	0.5%	-1.3%	-2.5%	-1.2%	1.6%	-3.2%
Photochemical ozone formation, HH	-0.5%	-2.0%	-3.2%	-2.0%	-0.7%	-8.4%
Respiratory inorganics	-1.1%	-2.5%	-3.2%	-2.2%	-2.2%	-11.0%
Non-cancer human health effects	-0.6%	-2.1%	-3.2%	-2.1%	-1.0%	-8.9%
Cancer human health effects	-0.4%	-1.9%	-3.2%	-2.0%	-0.4%	-8.0%
Acidification terrestrial and freshwater	-1.2%	-2.5%	-3.2%	-2.2%	-2.2%	-11.2%
Eutrophication freshwater	-0.9%	-2.3%	-3.0%	-2.0%	-1.8%	-10.0%
Eutrophication marine	-1.1%	-2.5%	-3.2%	-2.2%	-2.0%	-10.8%
Eutrophication terrestrial	-1.2%	-2.6%	-3.2%	-2.2%	-2.3%	-11.3%
Ecotoxicity freshwater	-0.1%	-1.7%	-3.2%	-1.9%	0.2%	-6.8%
Land use	-0.5%	-2.0%	-3.2%	-2.0%	-0.6%	-8.3%
Water scarcity	0.4%	-1.3%	-3.1%	-1.6%	2.6%	-3.4%
Resource use, energy carriers	-0.1%	-1.6%	-3.1%	-1.8%	0.2%	-6.5%
Resource use, mineral and metals	1.1%	-0.7%	-2.9%	22.3%	1.0%	19.8%

4.3 Interpretation

4.3.1 Baseline

Contribution analysis of the dairy baseline for the four selected impact categories shows the breakdown of the four selected focus impact categories as defined in section 2.7. The same breakdown is used along the interpretation of the results of the additive scenarios. Youngstock includes calves (under 1 year and between 1-2 years) and heifers. The ration includes the cradle-to-animal-farm impact connected with the production and transport of compound feeds, single ingredients and roughages (fed to youngstock in case of “youngstock ration” and fed to dairy cow in case of “dairy cow ration”). “Youngstock emissions” includes emissions from enteric fermentation and manure management (including storage) of youngstock. For dairy, emissions from manure management and enteric fermentation are separated in two categories. Energy includes electricity, gas and fuels use at animal housing. Water/bedding include water and bedding material use at animal housing.

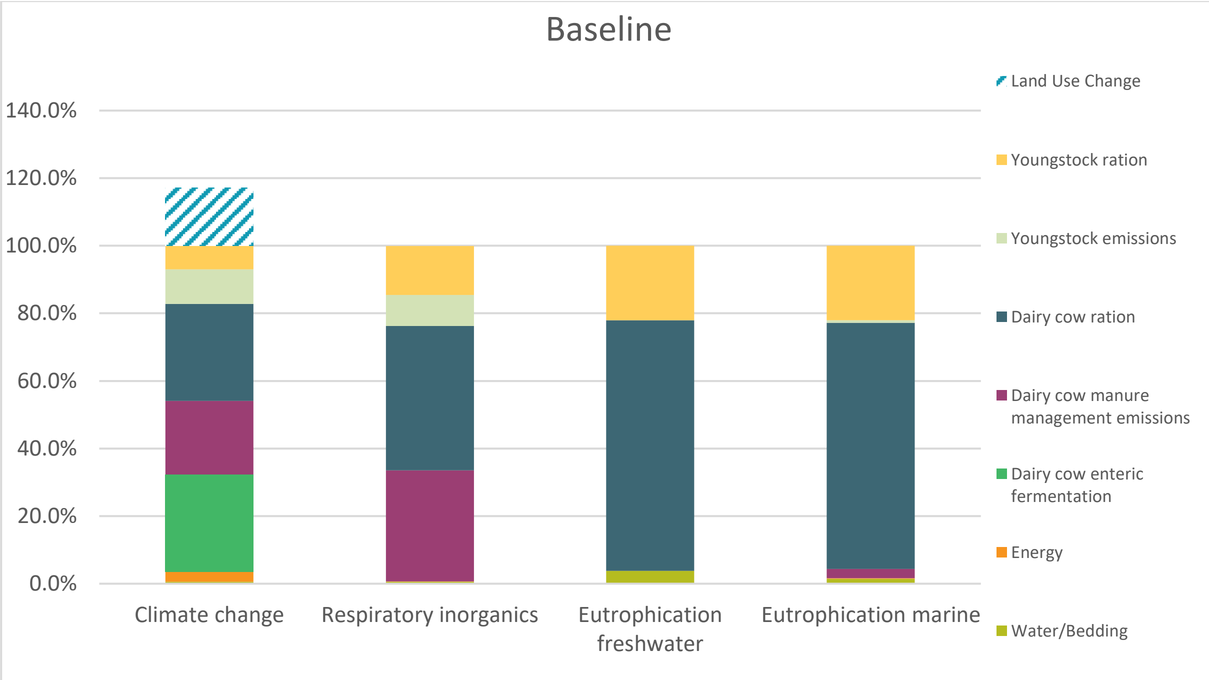

Figure 16 Contribution analysis of the dairy baseline for the four selected impact categories

The carbon footprint of the baseline scenario is 1.41 kg CO_2 eq./kg of FPCM. If we exclude the impact of Land Use Change, the carbon footprint is 1.22 kg CO_2 eq./kg FPCM. The main contribution comes from the dairy cow enteric fermentation (34.4% of the without-LUC-baseline) followed by the production of dairy cow's ration (28.7% of the without-LUC-baseline). The impact coming from young stock (both due to ration and emissions) is 17.2% of the without-LUC-baseline. The contribution due to dairy cow manure management system is 16.2% of the without-LUC-baseline. The contribution due to land use change is considered separately, and therefore would increase the 100% without-LUC-baseline to a theoretical 116.2%.

The overall respiratory inorganics impact of the baseline is 212×10^{-9} disease incidences/kg FPCM. The main contribution is coming from the dairy cow housing (75.7% of the baseline). The dairy cows ration production contributes for 41.3% of the baseline and emissions from dairy cows manure management contribute to 34.4% of the baseline. The rest of the impact is mainly due to youngstock (23.6% of the baseline). Respiratory inorganics impact category, like for acidification and terrestrial eutrophication, shows the largest contributions due to youngstock.

The impact contribution of both freshwater and marine eutrophication is similar and dominated by feed production. The dairy cow ration is more contributing (74.2% and 72.6% of baseline for freshwater and marine eutrophication, respectively) than the youngstock ration (22.0% of baseline for both freshwater and marine eutrophication).

Although the baseline impact and its breakdown is considered as typical there is considerable variation in the parameters of the dairy system in the Dutch Belgian area related to factors as, milk yields, soil type, land availability, ration and herd management. This variability impacts also the breakdown of the different contributors of the total impact of the farm system and therefore influence the calculations of the impact of the feed additives. When the variability of a baseline parameter is expected to have a relevant effect on the additive intervention scenarios, this is discussed in the specific scenario chapters, since dependent on the specific intervention dynamic. An overview, together with other limitations, can be found on Table 22. All these aspects are also systematically discussed in chapter 6.2.

Furthermore, simplification/aggregation of the baseline may influence the results. The choice for background data is also influencing the baseline results (and contribution) and therefore, might also change the efficacy of interventions.

We did not do any further assessments on the impact of this variability because of the road testing is not aimed to arrive at definitive conclusions. However, we highlight specific issues here at discussing the results per feed additive.

4.3.2 Effect of interventions

In the figures below we compare the effect of the interventions on the four focus impact categories. For each intervention, or combination of interventions it is shown how much it affects each of these impact categories in total, and how this effect is broken down over the contributing elements. For climate change 100% is the impact excluding land use change, and any change in the land use change impact is also weighed against this amount.

In general, three types of change are considered:

- Additive production impact increases the impact of the dairy cow ration for all impact categories. This is a limited effect for the focus impact categories but can be more relevant for impact categories that are not particularly relevant for agricultural production.
- Increase in milk production has the potential to reduce all impact categories, the extent of reduction depends on the other changes related to increased milk production. Especially connected changes in feed use, feed formulation and herd dynamics are relevant.
- An increase in longevity reduces the number of youngstock, and therefore acts on the impact specifically related to that part of the herd. On the other hand, since the liveweight-to-slaughter output reduces, more impact is allocated to the milk. This counterbalances the positive effect and can cause in several cases an increase of impacts connected to dairy cows or overall inputs.

4.3.3 Vitamin E

4.3.3.1 Main results

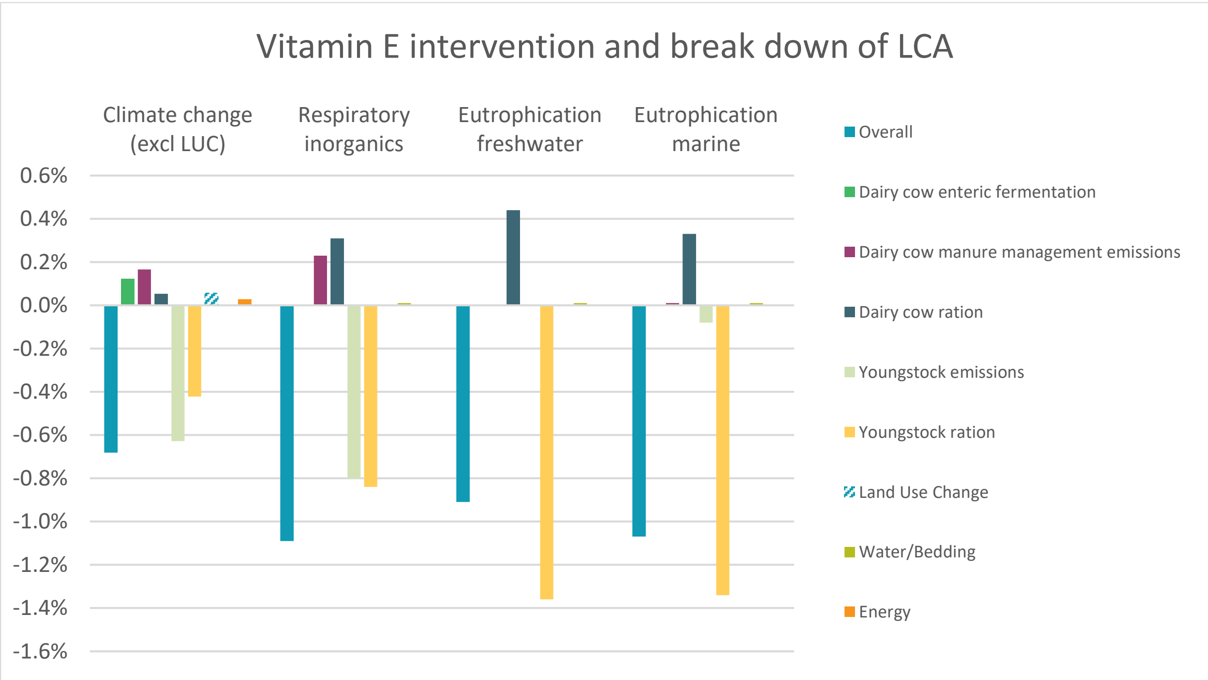

Figure 17 Vitamin E intervention effect on the four selected impact categories

In the Vitamin E scenario, we have a combination of milk increase (+0.51%), a reduction of youngstock AAP (-6.44%) and a decrease in liveweight output (-5.05%). The focus impact categories always show an overall reduction in impact ranging from -0.7% up to -1.1% compared to the baseline.

The youngstock related impacts ("Youngstock emissions" and especially the "Youngstock ration) are the most affected by the Vitamin E addition. This is mainly due to the increase in longevity and consequential lower number of youngstock.

On the other hand, the impacts related to the dairy cows herd ("Dairy cow enteric fermentation", "Dairy cow manure management emissions" and "Dairy cow ration") always increase. This is due to the increase in dairy cow feed input (+0.07%) and due to the reduced liveweight output. This can be explained by the fact that the reduction of slaughtered animals influences the allocation factors, resulting in a systematic higher allocation of all impacts to the milk. This is only partially counterbalanced by the increase in milk production.

In general, the two described trends ("smaller youngstock AAP + increased milk" and the "less liveweight output + increase dairy cow intake") counterbalance each other; still, the first one prevails on the second. An interesting aspect demonstrating this, is that the benefit of Vitamin E additive is higher for the impact categories with larger youngstock-related contributions in the baseline. For example, freshwater eutrophication baseline impact has a youngstock-related contribution of 22.1% (due to "Youngstock ration", Figure 16) while climate change (excl. LUC) has a youngstock-related contribution of 17.2% (due to "Youngstock ration" and "Youngstock emissions", Figure 16). Subsequently freshwater eutrophication has a higher improvement compared to climate change (excl. LUC).

4.3.3.2 Discussion and sensitivity analysis

4.3.3.2.1 Baseline performance

The simplification in the baseline (allocating all compound feed used in the farm to dairy cows) will influence the results. This is because the different impact caused by youngstock and by dairy cows follows two opposite trends. The impact caused by youngstock tend to reduce, due to the additive use; while the impact caused by dairy cows increases, due to the additive use. Such simplification is therefore underestimating the reduction in impact.

Variability in the feed materials impact and the selection of specific materials and origin could also be relevant (e.g. because the contribution of "Dairy cow ration" and "Youngstock ration" is altered) and needs further consideration if the aim is to come to more definitive conclusions.

4.3.3.2.2 Variability of the zootechnical effects

Even though the effects of Vitamin E are recognized, and no negative effects has been proven (see chapter 8.1.4.3 for substantiation), still many characteristics of the baseline (animal genetics, feed characteristic etc.) and the general high complexity of a natural system, makes zootechnical effect variability present, and difficult to estimate. More and better data would be needed about the impact of additives on production parameters for a better estimation of the environmental impact categories. Since in this study we want to explore methodology approaches, a generic variability range of ±50% was tested (more information can be found in chapter 8.1.7.3.1). Two scenarios were modelled, one with -50% zootechnical effects and another with +50% zootechnical effects (compared to the changes shown in chapter 4.1.4.1). The calculated reductions for the considered impact categories tend to vary with slightly enlarged deviation of the results from the baseline (±51% for eutrophication marine and respiratory inorganics, ±53% for climate change excl. LUC and ±58% for freshwater eutrophication).

Therefore, to quantify the environmental impact of the additive, the variability of the zootechnical effects should be quantified with a scientific and systematic approach. To fully test the impact of variability of zootechnical effect on the results, a more advanced method should be used (such as Montecarlo analysis).

4.3.3.2.3 Translating zootechnical effects in likely changes in the system

As introduced in chapter 4.1.4.2, the modelling of herd population dynamics can be rather complex. Various simplifications have been applied for the Vitamin E scenario modelling, that could potentially alter the results. These are:

- Effect of longer cow longevity on milk efficiency and feed intake. An increase of 6.44% in longevity (average culled cow parity of 3.72 instead of 3.50) will probably increase the production of milk of the dairy cow herd, and also require higher feed intake. This is because cow in 4th and 5th parity tend to have a higher milk production than cows at 3d parity [29]. Even though higher feed intake would counterbalance the benefit of a higher milk production, we expect the net effect to improve the modelled reduction of impact in the Vitamin E scenario.

- Effect of shorter dry period on milk efficiency and feed intake. Dry period is important for cows' recovery between lactation cycles. Reduction of it might negatively affect the subsequent lactation cycle. On the other hand, a 2-day reduction is rather small, and should not affect productivity largely. Actually, Dutch statistics report that from 2015 to 2019 the average dry period of *herdbookcows* was reduced by 5 days with an increase in milk production per day.
- Disorder reduction effect on fertility and subsequently on dry period length. The relation between disorder reduction and fertility was not modelled. Increase on fertility benefit would improve the modelled reduction of impact of the Vitamin E scenario, even though we expect it to be a small change.
- Change in mortalities, due to longer cow longevity. Support of udder health might be beneficial in reducing dairy cow mortalities. On the other hand, older cows might be more prone to other types of issues increasing mortality [29]. We expect the mortality rates to slightly change, and to have a negligible influence on the overall results.
- Change in water and energy input. Older cow and higher milk production will increase energy and water requirements. On the other hand, reduction of youngstock AAP would reduce these inputs. Considering the low contribution of these inputs to selected impact category (Figure 16), and the probably small extent of change, we expect this to create negligible changes on the results.

The effect of longer cow longevity on milk efficiency and feed intake has been identified as the main limitation and extending the approach with a complex herd model should improve the analysis. We expect this to result in an increase of the modelled benefit of the Vitamin E scenario due to higher milk production caused by longer longevity.

4.3.3.2.4 Nitrogen excretion and manure application

Changes in input and output will modify the animal nitrogen balance, therefore changing the nitrogen excretion. This can affect the N related emissions on farm and the N available in manure for spreading.

The current N balance implemented in the APS-footprint tool, considers a partial balance where the retention factor is fixed (section 2.6). This method calculated a total farm N excretion of 17799 kg N/year and 17527 kg N/year for the baseline and Vitamin E scenario, respectively. This is a 1.53% reduction in N excretion. Taking into consideration the actual N retention in milk and liveweight co-product (assuming a 2.25% protein content in culled cows and 2.94% protein content in sold calves [23]) will result in a N excretion of 16592 kg N/year and 16280 kg N/year for the baseline and Vitamin E scenario, respectively. This is a reduction a 1.88% reduction in N excretion. The N balance methodology applied in this study is not sufficient for modelling changes in efficiency of the system, and a full balance approach should be considered. In this specific case, the results give an underestimation of the intervention.

Another aspect to consider is that N available in manure for application will reduce after the intervention. The manure loop has been described in chapter 2.4. Since manure has been considered as residual this has currently no impact on the Vitamin E scenario. The LEAP guidelines on additive use, suggests to account for possible change in nutrient content of the manure after interventions, but do not suggest specific approaches. This could be dealt through allocation (discussed in the next chapter). Another approach could be to expand the boundary and consider the implication of lower N fertilization on on-farm cultivation, or the implication of substituting this N lack with inorganic fertilizers (as suggested by the PCR red meat [7]). A sensitivity scenario of this approach can be found on section 4.3.5.2.3.

4.3.3.2.5 Allocation

The allocation between milk, live weight production and manure plays an important role in the vitamin E case.

Allocating impact to manure, by considering it a co-product, will result in a lower reduction in impact in the Vitamin E scenario, since less N is available in manure for application after the intervention.

Allocation between milk and liveweight is highly relevant. This is proven by the fact that using alternative allocations would highly influence the results. In particular, the use of IDF allocation reduces the benefit of Vitamin E scenario, compared to other allocations. This is because a reduction in liveweight output is currently increasing the impact allocated to milk. For example, using economic allocation would result in a much less impact allocated to liveweight co-product in general (Table 20). The reduction of the liveweight output stream in the intervened scenario would therefore be less relevant, and the benefit of the Vitamin E scenario compared to the baseline would be higher.

Table 20 Different approaches to determining the allocation factors

Allocation types	*Milk*	*Liveweight aggregated*	*Culled cows*	*Sold calves*
IDF allocation	86.43%	13.57%	-	-
Mass allocation	93.30%	-	5.63%	1.07%
Energy allocation	92.29%	-	4.59%	3.11%
Economic allocation	92.91%	-	5.96%	1.13%

Mass, Energy and Economic allocation based on Agri-footprint (DM, GE and prices of the various output).

The main IDF allocation limitation is that does not distinguish between the biophysical burden of culled cows and sold calves. This is important to distinguish, since in the Vitamin E scenario the liveweight output of culled cows reduced but the liveweight output of sold calves increase. We do not have expectation about how this would affect the results. Please note that, being IDF higher on ISO 14001 allocation ranking and being the most recognized approach in dairy sector, we still consider it the best methodological choice; even though would be important expand it with more indications on how to distinguish between culled cows and sold calves.

4.3.3.3 Conclusions

The methodological framework gives a basis for conducting the LCA but is only partially capable to model the environmental changes (from -0.7% up to -1.1% on the selected impact categories) connected to the use of Vitamin E. Main limitations are:

- Lack of guidance on how to estimate variability in the considered zootechnical effects of the additive;
- Lack of guidance on how to model longevity, fertility and disorder changes at herd level (e.g. complex herd model able to estimate the change in milk production and feed output connected to a change in longevity);
- Lack of consistency on how to model effect connected to changes in manure compositions between the various guidelines;
- IDF allocation is not capable of distinguishing liveweight coming from culled cows and sold calves.

Other limitations connected to the APS-footprint tool are the lack of DQR and uncertainty for the cultivation background dataset used, lack of an uncertainty calculator functionality and lack of a complete N balance approach at herd level in the default emission calculation method of dairy APS module.

4.3.4 25OHD3

4.3.4.1 Main results

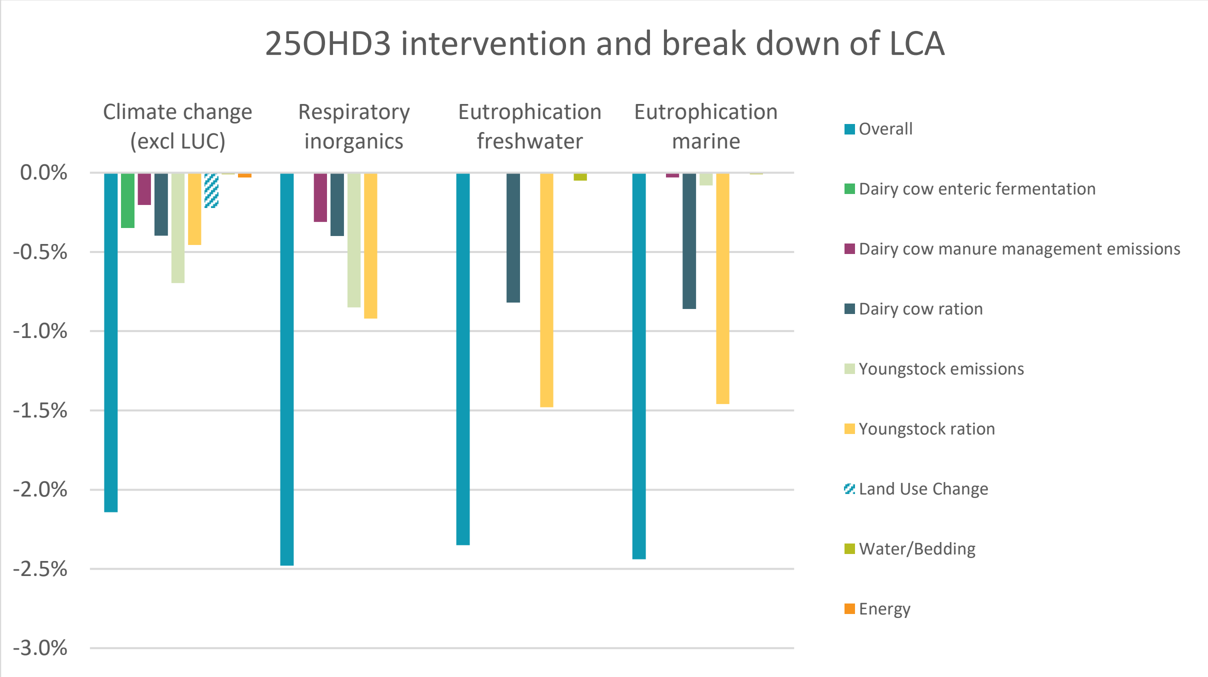

Figure 18 25OHD3 intervention effect on the four selected impact categories

The 25OHD3 addition results in an overall reduction ranging from -2.2% up to -2.6% compared to the baseline. The intervention consists of a combination of milk increase (+2.34%), a reduction of youngstock AAP (-5.48) and a decrease in liveweight output (-4.28%).

In this scenario also, most of the reduction is caused by reduced impact connected to youngstock contributions ("Youngstock emissions" and "Youngstock ration"). Such reduction is due to the reduced youngstock AAP.

Differently than in the Vitamin E scenario, the impact contributions related to dairy cows ("Dairy cow enteric fermentation", "Dairy cow manure management emissions" and "Dairy cow ration") reduced with the 25OHD3 intervention. This is because, even though the dairy feed input increases (+0.08%) and the liveweight output reduces (therefore increasing the milk allocation factor), the milk output increase is relatively high. Therefore, in this scenario the milk production improvement outweighs he reduction in youngstock AAP.

Since climate change is less sensitive to changes in longevity (due to the lower contribution of youngstock on the baseline), climate change impacts are mainly reduced by the milk yield improvements. Opposite is the situation for eutrophication, where a larger contribution of "youngstock ration" to the baseline, makes this impact category highly influenced by longevity improvement.

4.3.4.2 Discussion and sensitivity analysis

4.3.4.2.1 Baseline performance

As for the Vitamin E case, the baseline impact might vary due to the properties of the selected dairy system selected and the background data used. While, the first aspect is not relevant for the scope of this study, the quality and uncertainty on background data should be considered for estimating the reliability of the results. The lack of DQRs of the background dataset (Agri-footprint 5.0) and the lack of uncertainty functionality of the APS-footprint tool, can be considered a limitation of the background dataset and of the tool, respectively.

4.3.4.2.2 Variability of the zootechnical effects

The effect of 25OHD3 supporting udder health, calcium homeostasis, milk production and fertility can be characterized by variability. In particular its support on calcium homeostasis is characterized by high variability (due to variability in milk fever incidence in dairy cow population). Being the considered increase in milk production already really low (+0.05%), this would probably have a negligible effect the calculated results. As for Vitamin E, recognized and positive effects has been proven during addition of 25OHD3 (see chapter 8.1.4.2 for substantiation). Still, its zootechnical effect shows variability, that is difficult to estimate. Applying a generic variability range of ±50% (chapter 8.1.7.3.1), results in a slightly enlarged proportional variation of the deviation of the results from the baseline (±54% for eutrophication marine, respiratory inorganics and climate change excl. LUC and ±56% for freshwater eutrophication).

Similarly, to the Vitamin E, this shows that the results are not always linearly affected, therefore, improvements should be made on quantifying the zootechnical effect variability (such as applying a Montecarlo analysis).

4.3.4.2.3 Translating zootechnical effects in likely changes in the system

Simplifications applied for the 25OHD3 scenario, that could potentially alter the results are the same as the one described in the Vitamin E sensitivity discussion:

- Effect of longer cow longevity on milk efficiency and feed intake. Similarly to Vitamin E, an increase of 5.48% in longevity (average culled cow parity of 3.69 instead of 3.50) will probably improve the modelled reduction of impact in the 25OHD3 E scenario. This is expected to be the assumption mostly influencing the results.
- Effect of shorter dry period on milk efficiency and feed intake. As for Vitamin E, a shorter milk efficiency could influence milk production, even though it is unclear how this could be model on practice.
- Disorder reduction effect on fertility and subsequently on dry period length. As for Vitamin E, the relation between disorder reduction and fertility was not modelled, even though we expect it to be a small change.
- Change in mortalities, due to longer cow longevity. Support of udder health and calcium homeostasis might be beneficial in reducing dairy cow mortalities, even though we expect this to have a negligible influence on the overall results.
- Change in water and energy input. Older cow and higher milk production will increase energy and water requirement, even though we expect this to create negligible changes on the results.

From the results we identified how the support of milk improvement is in this scenario more relevant than in the Vitamin E scenario, and able to prevail on the reduction in liveweight output. The identified limitations are mainly connected to changes in longevity, fertility and disorder, while the support of milk production is prone to less modelling limitation. We can therefore consider the listed limitations as less influencing the overall results for the 25OHD3 scenario, compared to the Vitamin E scenario.

4.3.4.2.4 Nitrogen excretion and manure application

Similarly, for Vitamin E, using a fixed retention factor for the Nitrogen balance, calculates a total farm N excretion of 17799 kg N/year and 17570 kg N/year for the baseline and 25OHD3 scenario, respectively. This is a 1.28% reduction in N excretion. Taking into consideration the actual N retention in milk and liveweight co-product (assuming a 2.25% protein content in culled cows and 2.94% protein content in sold calves [*23*]) will result in a N excretion of 16592 kg N/year and 16238 kg N/year for the baseline and 25HOD3 scenario, respectively. This is a reduction a 2.13% reduction in N excretion. As for Vitamin E, this demonstrates that a full N balance approach should be used to avoid underestimating the increase in N retention. The underestimation is larger compared to the Vitamin E scenario, since increase in milk is larger.

As for Vitamin E, N available in manure for application will reduce after the intervention. This could be dealt through allocation (discussed in the next chapter) or thorough expansion of the boundaries. In both cases, this will result in a reduction in the benefit resulting from 25OHD3 use.

4.3.4.2.5 Allocation

The allocation between milk, liveweight and manure plays an important role in this example, as for the Vitamin E scenario. Changes in how manure is considered, will result in a lower reduction in impact in the 25OHD3 E scenario. The choice of IDF allocation also reduce the benefit of Vitamin E scenario, compared to mass, energy or economic allocation. Also, IDF allocation is not able to distinguish between the biophysical burden of culled cows and sold calves.

4.3.4.3 Conclusions

The methodological framework used gives a basis for conducting the LCA but is only partially capable of modelling the environmental changes (from -2.2% up to -2.6% on the selected impact categories) connected to the use of 25OHD3. The main limitations are exactly the same as for the Vitamin E scenario.

The main difference compared to the Vitamin E scenario is the direct support of milk production which, in this scenario, is the main cause for improvement. We also identified the direct support of milk as not connected to important simplifications that could potentially influence the results. Assuming that the variability and uncertainty of the zootechnical effects between the two additives is comparable, we can conclude that the results of this scenario would be more reliable compared to the one from the Vitamin E scenario.

4.3.5 Amylase

4.3.5.1 Main results

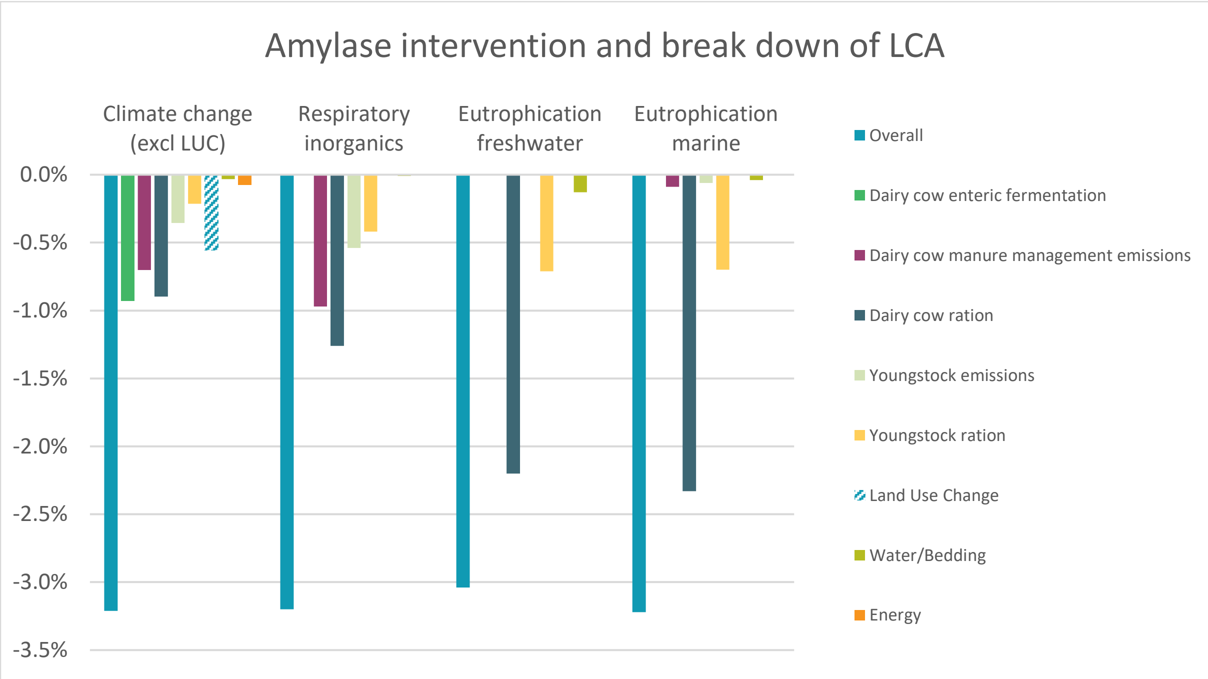

Figure 19 Amylase intervention effect on the four selected impact categories

Amylase scenario shows the largest changes compared to the other single-additive scenarios (between -3.0% and -3.0%). Amylase only affects milk production (-3.96%). Since the milk improvement is equally spread over the contributions, the extent of improvement is directly related to the contribution weight on the baseline impact (e.g. "Dairy cow ration" reduction is larger than "youngstock ration" reduction in eutrophication since their contribution to the baseline is 73% and 22%, respectively).

4.3.5.2 Discussion and sensitivity analysis

4.3.5.2.1 Baseline performance

In this intervention, the only relevant parameter in the baseline, that will influence the effect of the additive is the milk production. Intensive and extensive systems might respond differently during such an intervention. Therefore, in analysing a specific case, there is no methodological issue, but for more generic claims on the additive potential, such differences should be considered.

4.3.5.2.2 Variability of the zootechnical effects

The intervention considers an increase in milk production connected to improved digestibility of starch and fibres. Changes in digestibility might affect enteric fermentation emissions and volatile solids excretions. These effects are not substantiated and proven in scientific literature; therefore, such effects were not modelled.

The ration and its nutritional characteristics might influence the potential of the additive in increasing the Feed Conversion Rate. Applying a generic variability range for the effects of ±50% (Annex 8.1.7.3.1), results in an equal variation in the deviation of the results from the baseline of ±50%. This might be larger if changes in Nitrogen balance where considered.

4.3.5.2.3 Nitrogen excretion and manure application (exploring PCR Red Meat manure approach)

In the Amylase scenario, no reduction in Nitrogen excretion is modelled. This is an underestimation due to a limitation of the dairy APS module of the APS-footprint tool. Taking into consideration the actual N retention in milk and liveweight co-product (assuming a 2.25% protein content in culled cows and 2.94% protein content in sold calves [*23*]) will result in a N excretion of 16592 kg N/year and 16405 kg N/year for the baseline and Amylase scenario, respectively. This is a reduction a 1.13% reduction in N excretion. As for Vitamin E, this demonstrates that a full N balance approach should be used to avoid underestimating the increase in N retention.

As for Vitamin E, N available in manure for application will reduce after the intervention. This could be dealt through manure allocation (considering as a co-product) or thorough expansion of the boundaries (more detail on section 2.4).

Since this scenario shows the largest change in N excretion compared to the baseline, we e decided to investigate how the results will change by applying the manure approach as described in the PCR for red meat [7]. The PCR for red meat (not aligned with LEAP framework) suggests a boundary expansion, where the emission from manure are included and nutrients application from manure substitute inorganic fertilizers (100% of production and 50% of emissions). This is valid for both the baseline and the intervened scenario. When the manure is spread on farm, higher N availability in manure of the benzoic acid scenario will be in this way accounted. In Figure 20 we show the effect of implementing such modelling in the results. It is assumed that Nitrogen in manure substitutes the production of the same N amount of a Dutch inorganic fertilizers mix (based on Agri-footprint). The Nitrogen in manure also constitutes 50% of the emissions from such inorganic fertilizers mix (default suggested in the PCR Red Meat, [7]). Since less Nitrogen is retained in the manure (calculated as N excreted – N emissions at housing), the use of Amylase would cause a decrease of impact of applying the manure, counterbalanced by lower substitution of inorganic fertilizers production and use. Since emission from inorganic fertilizers production is important for climate change, this will reduce the benefit of the intervention. For respiratory inorganics and marine eutrophication, emissions from manure are more relevant compared to production of inorganic fertilizers, therefore the overall benefit brought by Amylase increases for these impact categories. Since the change in N excretion is not large (1.13%) this does not result in a large change in overall results (0.3 points for respiratory inorganics). Still, it shows that different methodological approaches can influence the results, and a larger change in N available for application might result in larger and more relevant changes.

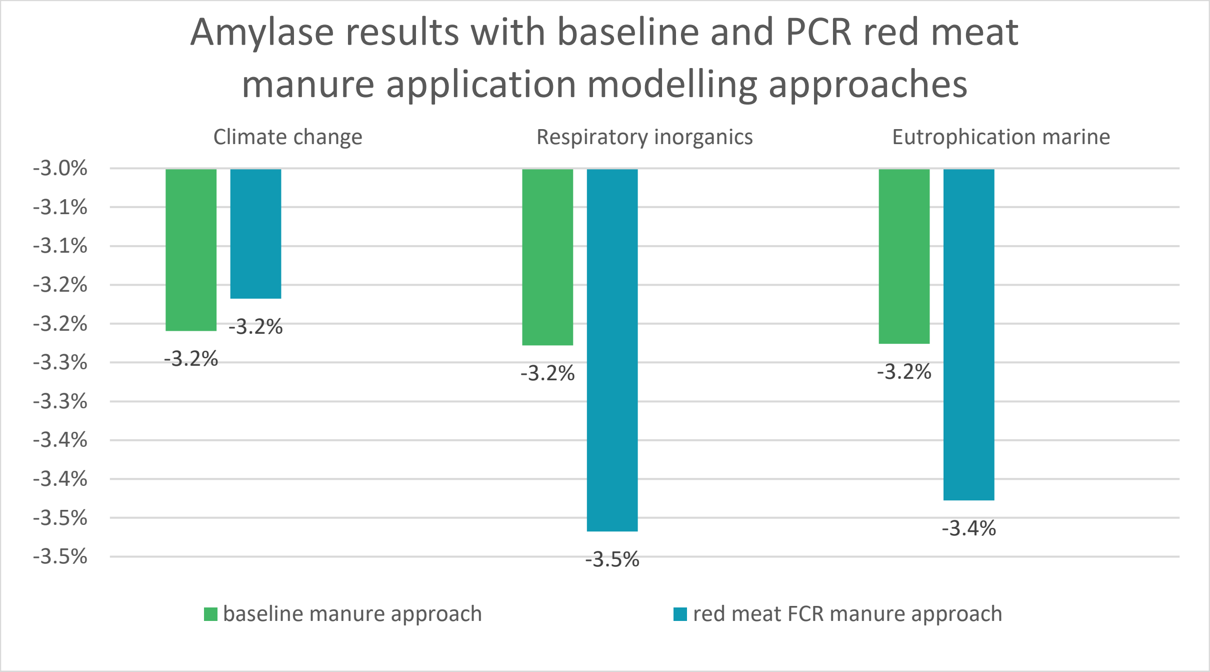

Figure 20 Amylase improvement with and without modelling of the manure application as defined by the PCR Red Meat

4.3.5.3 Conclusions

The methodological framework can be considered partially suitable to account for Amylase intervention. The only aspects where there is lack of guidance is in determining variability in the zootechnical effects, and inconsistent guidance on how to account for manure changes in composition.

APS-footprint tool limitations include the lack of an uncertainty calculator functionality and lack of a complete N balance approach at herd level in the default emission calculation method of dairy APS module.

4.3.6 Biotin

4.3.6.1 Main results

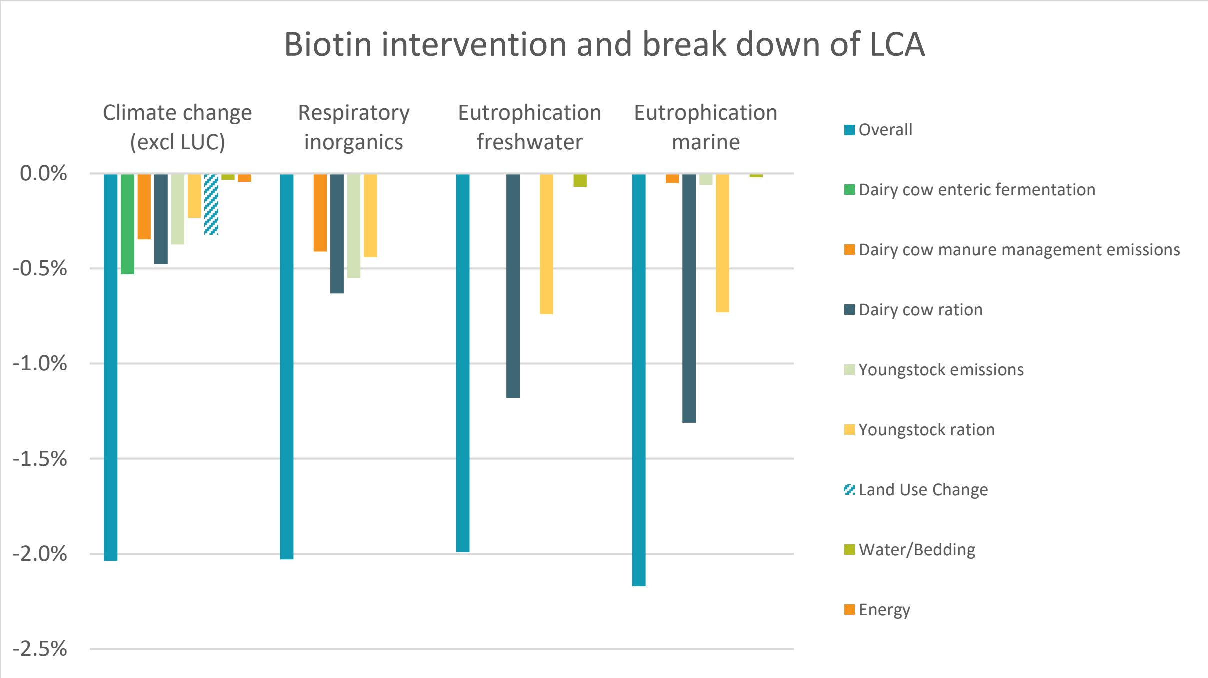

Figure 21 Biotin intervention effect on the four selected impact categories

In this scenario also, the impact reduces for all impact categories considered, ranging from -1.9% to -2.1%. This case is more dependent on the milk production improvement (+1.83%) than the 25OHD3 case, since milk benefit is coming mainly from health benefit, and not from fertility improvement. This is because fertility is also connected to higher feed intake and to fewer slaughtered animals. This intervention results in improvements for all contributions in the considered impact categories.

4.3.6.2 Discussion and sensitivity analysis

4.3.6.2.1 Baseline performance

Same considerations can be made as for the Vitamin E and 25OHD3 cases: the lack of DQRs of the background dataset (Agri-footprint 5.0) and the lack of uncertainty functionality of the APS-footprint tool, can be considered a limitation of the background dataset and of the tool, respectively.

4.3.6.2.2 Variability of the zootechnical effects

The effect of Biotin on support of hoof health and milk production can be characterized by variability. As for Vitamin E, biotin effects are recognized, and no negative effects has been proven (see chapter 8.1.4.4 for substantiation). Still, the zootechnical effects show variability, that is difficult to estimate. Applying a generic variability range of ±50% (chapter 8.1.7.3.1), results in a comparable variation of the deviation of the results from the baseline (±49% for eutrophication marine, ±50% for respiratory inorganics, ±51% climate change excl. LUC and ±54% for freshwater eutrophication). This means a systematic approach to determine additive effects should be determined, and advanced uncertainty analysis should be applied.

4.3.6.2.3 Translating zootechnical effects in likely changes in the system

Simplifications applied for the Biotin scenario, that could potentially alter the results are:

- Effect of increased cow longevity on milk efficiency and feed intake. An increase of 1.55% in longevity will probably improve the modelled reduction of impact. This is expected to not have a large influence on the results considering the small increase in longevity.

- Disorder reduction effect on fertility and subsequently on dry period length. As for Vitamin E, the relation between disorder reduction and fertility was not modelled, even though we expect it to be a small change.
- Change in mortalities, due to longer cow longevity. Support of hoof health might be beneficial in reducing dairy cow mortalities, even though we expect a negligible influence on the overall results.
- Change in water and energy input. Older cows and higher milk production will increase energy and water requirements, even though we expect this to create negligible changes on the results.

In general, since the intervention is mainly relying on milk increase, rather than longevity or other complex dynamics, we expect the uncertainty of the results to be lower compared to Vitamin E and 25OHD3 scenarios.

4.3.6.2.4 Nitrogen excretion and manure application

Similarly, for Vitamin E, using a fixed retention factor for the Nitrogen balance, calculates a total farm N excretion of 17799 kg N/year and 17734 kg N/year for the baseline and biotin scenario, respectively. This is a 0.36% reduction in N excretion. Taking into consideration the actual N retention in milk and liveweight co-product (assuming a 2.25% protein content in culled cows and 2.94% protein content in sold calves [*23*]) will result in a N excretion of 16592 kg N/year and 16046 kg N/year for the baseline and 25HOD3 scenario, respectively. This is a reduction a 1.12% reduction in N excretion. As for Vitamin E, this demonstrates that a full N balance approach should be used to avoid underestimating the increase in N retention.

As for Vitamin E, N available in manure for application will reduce after the intervention. This could be dealt through allocation or through expansion of the boundaries. In both cases, this will result in a reduction in the benefit resulting from Biotin use.

4.3.6.2.5 Allocation

The allocation between milk, liveweight and manure will be discussed also for this case, even though is influence is lower for this case (smaller longevity increase of 1.55%). Changes in how manure is considered, will result in a lower reduction in impact in the biotin scenario. The choice of IDF allocation also reduces the benefit of biotin scenario, compared to mass, energy or economic allocation. Also, IDF allocation is not able to distinguish between the biophysical burden of culled cows and sold calves. This is relevant for this intervention since the liveweight from dairy cows is decreasing while the liveweight from calves is increasing.

4.3.6.3 Conclusions

The methodological framework gives a basis for conducting the LCA but is only partially capable of modelling the environmental changes (from -1.9% up to -2.1% on the selected impact categories) connected to the use of biotin. The main limitations are the same as for the Vitamin E scenario.

Since this intervention is more dependent on milk improvement compared to Vitamin E and 25OHD3 interventions, the uncertainty and limitations connected to complex relations of the systems have less influence on the improvements.

4.3.7 Beta Carotene

4.3.7.1 Main results

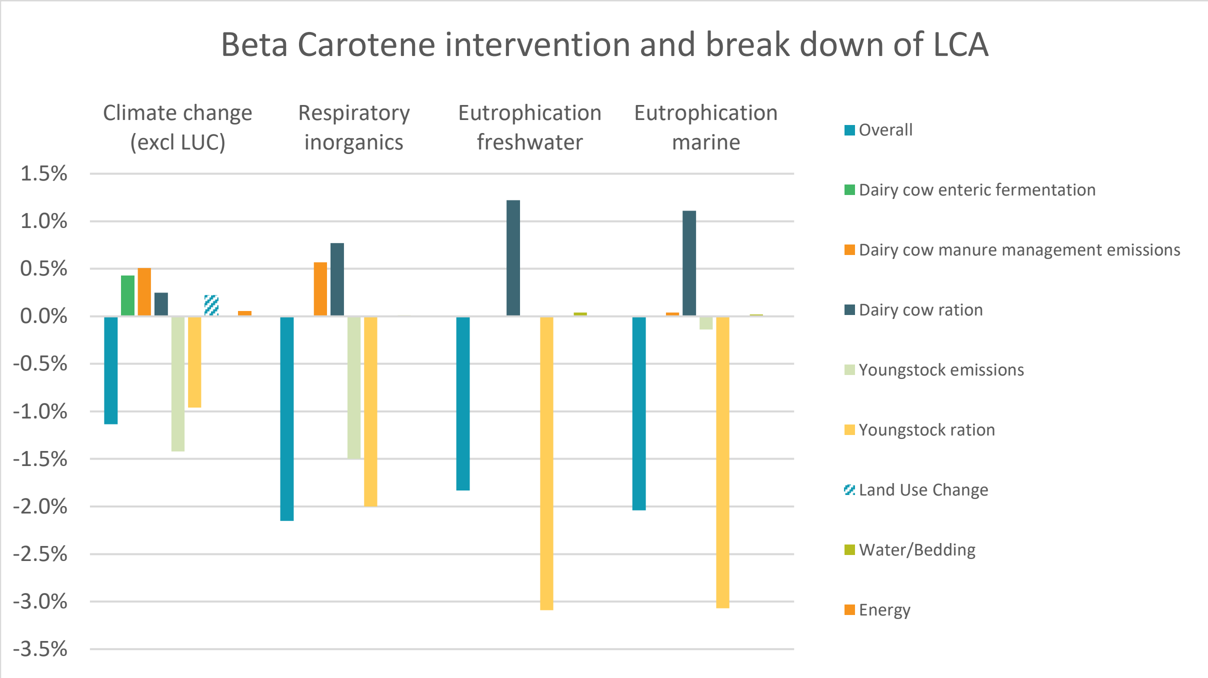

Figure 22 Beta carotene intervention effect on the four selected impact categories

Beta Carotene only influences fertility. The reduction of youngstock (due to a longer longevity) are counterbalanced by the dairy cows' feed consumption increase and by the reduced liveweight output. The overall results are still showing reduced impact, in a range of -1.1% up to -2.2%. Beta Carotene addition is more effective on respiratory inorganics, because this impact category is more dependent on youngstock contributions.

4.3.7.2 Discussion and sensitivity analysis

4.3.7.2.1 Baseline performance

Same considerations can be made as for the Vitamin E, 25OHD3 and Biotin cases: the lack of DQRs of the background dataset (Agri-footprint 5.0) and the lack of uncertainty functionality of the APS-footprint tool, can be considered a limitation of the background dataset and of the tool, respectively.

4.3.7.2.2 Variability of the zootechnical effects

The effect of beta carotene on support of fertility can be characterized by variability. As for other additives, beta carotene effects are recognized, and no negative effects has been proven (see chapter 8.1.4.1 for substantiation). Still, the zootechnical effects show variability, that is difficult to estimate. Applying a generic variability range of ±50% (chapter 8.1.7.3.1), results in a slightly enlarged variation of the deviation of the results from the baseline (±53% for eutrophication marine and for respiratory inorganics, ±56% climate change excl. LUC and ±57% for freshwater eutrophication). This again stresses the need for a systematic variability estimation of the additive effects.

4.3.7.2.3 Translating zootechnical effects in likely changes in the system

Simplifications applied for the beta carotene scenario, that could potentially alter the results are:

- Effect of longer cow longevity on milk efficiency and feed intake. An increase of 15% in longevity (average culled cow parity of 3.72 instead of 4.28) will probably increase the production of milk of the dairy cow herd [29], and also require higher feed intake.

- Effect of shorter dry period on milk efficiency and feed intake. Reduction of dry milk might negatively affect the subsequent lactation cycle (not clear how could be modelled). Even though, a 6 days reduction is not large, and should not affect productivity largely.
- Change in mortalities, due to longer cow longevity. Older cows might be more prone to other types of issues increasing mortality. We expect the mortality rates to slightly change, and to have a negligible influence on the overall results.
- Change in water and energy input. Older cow and higher milk production will increase energy and water requirements. Considering the low contribution of these inputs to selected impact category (Figure 16), and the probably small extent of change, we expect this to create negligible changes on the results.

In consideration of the listed simplification, we could not grasp the full complexity of the system and of the Beta-carotene effect. This makes the calculated results highly uncertain.

4.3.7.2.4 Nitrogen excretion and manure application

Similarly for Vitamin E, using a fixed retention factor for the Nitrogen balance, calculates a total farm N excretion of 17799 kg N/year and 17185 kg N/year for the baseline and beta carotene scenario, respectively. This is a 3.45% reduction in N excretion. Taking into consideration the actual N retention in milk and liveweight co-product (assuming a 2.25% protein content in culled cows and 2.94% protein content in sold calves [*23*]) will result in a N excretion of 16592 kg N/year and 15912 kg N/year for the baseline and 25HOD3 scenario, respectively. This is a reduction a 4.10% reduction in N excretion. This demonstrates that a full N balance approach should be used to avoid underestimating the increase in N retention, even though the underestimation is smaller compared to the other scenarios.

As for Vitamin E, N available in manure for application will reduce after the intervention. This could be dealt through allocation (discussed in the next chapter) or thorough expansion of the boundaries. In both cases, this will result in a reduction in the benefit resulting from beta carotene use.

4.3.7.2.5 Allocation

The allocation between milk, liveweight and manure play an important role in this example (14.63% in liveweight output). Changes in how manure is considered, will result in a lower reduction in impact in the 25OHD3 E scenario. The choice of IDF allocation also reduce the benefit of Vitamin E scenario, compared to mass, energy or economic allocation. Also, IDF allocation is not able to distinguish between the biophysical burden of culled cows and sold calves.

4.3.7.3 Conclusions

The methodological framework used is only partially capable to model the environmental changes (from -1.1% up to -2.2% on the selected impact categories) connected to the use of beta-carotene. Main limitations are the same as for Vitamin E, even though in this scenario they are increasing the uncertainty of the results largely. This is because the fertility benefit (only change to the system in this intervention) is highly influenced by the various limitations.

4.3.8 All

4.3.8.1 Main results

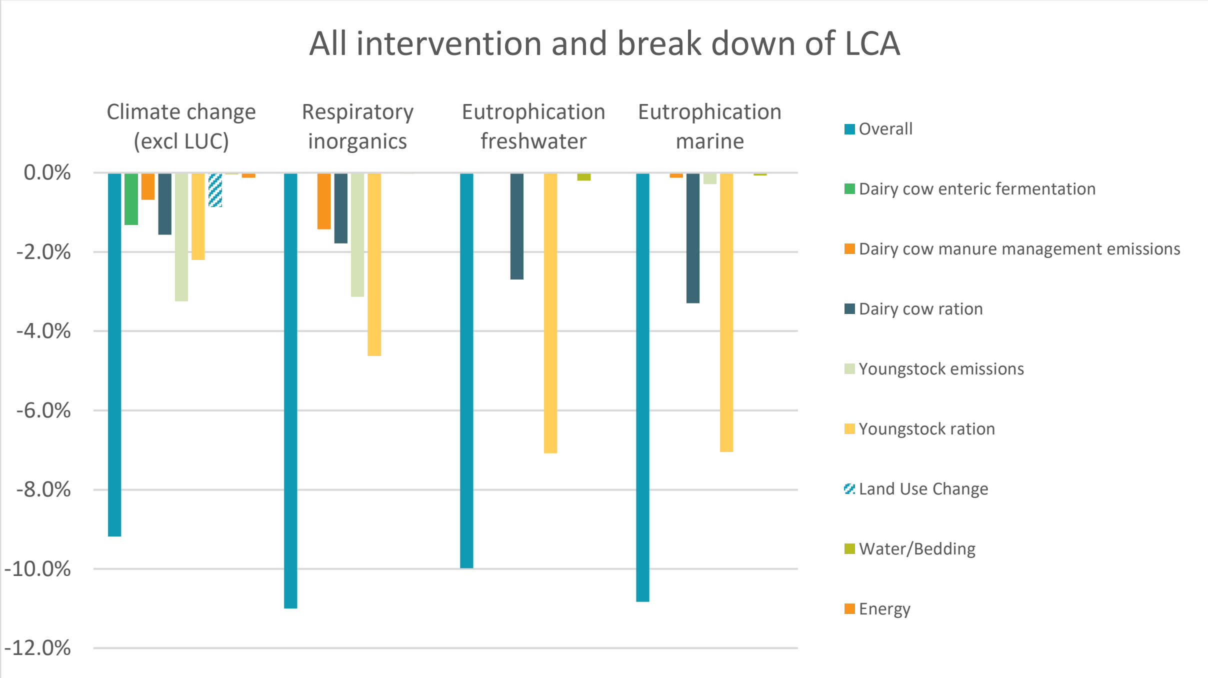

Figure 23 All intervention effect on the four selected impact categories

The “All" scenario is a sum of the previous analysed interventions. The overall benefit ranges between -9.2% and -11.0%, and all contributions show an improvement. For the All scenario, most of the benefit is connected to a reduced impact of youngstock. This is caused by a 28.5% increase in longevity. The increase of impact due to reduced liveweight output relative to milk is completely counterbalanced by the milk yield improvement. The various additives complement each other, and the All scenario shows benefit in every LCA contribution category.

4.3.8.2 Discussion and sensitivity analysis

4.3.8.2.1 Baseline performance

The baseline impact might vary based on the system selected and the background data used.

Some simplification/aggregation of the baseline, such us allocating all compound feed used in the farm to dairy cows will influence the results. This is because, as we seen in the results, the difference impact caused by youngstock and by dairy cows follows two opposite trends.

4.3.8.2.2 Variability of the zootechnical effects

The variability of the zootechnical effects can influence the results considerably. An important cause is the difference between the dairy system considered in trials and scientific papers, and the baseline dairy system that we considered. Furthermore, although a combination of additives is used in practice, trials are not commonly performed to estimate the effect of multiple additives. To avoid overestimation of benefits and to avoid considering the interaction between additives, we decided to account for additionality and generally opted for conservative modelling of the improvement factors. This was the reason to set maximum achievable improvements, and then allocate these improvements to the various additives. Still, this approach is inherently limiting this scenario, since based on educated assumptions, rather than on actual trial data. Also, there is no guidance available in any of the guidance documents that we used on how to account for the interaction between different additives.

The APS-footprint tool also not supported an analysis where variability of multiple additives could be systematically assessed in a sensitivity assessment.

4.3.8.2.3 Translating zootechnical effects in likely changes in the system

As introduced in chapter 4.1.4.2, the modelling of herd population dynamics can be rather complex. Various simplifications have been applied in translating zootechnical effects into likely changes to the system, as already previously described:

- Effect of longer cow longevity on milk efficiency and feed intake. An increase of 28.5% in longevity (average culled cow parity of 4.50 instead of 3.50) will probably increase the production of milk of the dairy cow herd [29] and also require higher feed intake.
- Effect of shorter dry period on milk efficiency and feed intake. A 10-day reduction of it might negatively affect the subsequent lactation cycle.
- Disorder reduction effect on fertility and subsequently on dry period length. The relation between disorder reduction and fertility was not modelled.
- Change in mortalities, due to longer cow longevity. Support of udder health and other disorders might be beneficial in reducing dairy cow mortalities. On the other hand, older cows might be more prone to other types of issues increasing mortality.
- Change in water and energy input. Older cow and higher milk production will increase energy and water requirements. On the other hand, reduction of youngstock AAP would reduce these inputs. Considering the low contribution of these inputs to selected impact category (Figure 16), and the probably small extent of change, we expect this to create negligible changes on the results.

Considering these simplifications, it is likely that we could not grasp the full complexity of the system, especially when the additives are applied all together.

4.3.8.2.4 Nitrogen excretion and manure application

The use of a fixed retention factor results in a N excretion of 17799 kg N and 16628 kg N every year for the baseline and the "all" scenario, respectively. This is a 6.58% of N excretion reduction. Taking into consideration the actual N retention in milk and liveweight co-product (assuming a 2.25% protein content in culled cows and 2.94% protein content in sold calves [*23*]) will result in a N excretion of 16592 kg N/year and 14869 kg N/year for the baseline and 25HOD3 scenario, respectively. This is a reduction a 10.38% reduction in N excretion. This demonstrates that a full N balance approach should be used to avoid underestimating the increase in N retention.

The N available in manure for application will reduce after the intervention. This could be dealt through allocation (discussed in the next chapters) or thorough expansion of the boundaries.

4.3.8.2.5 Emissions modelling

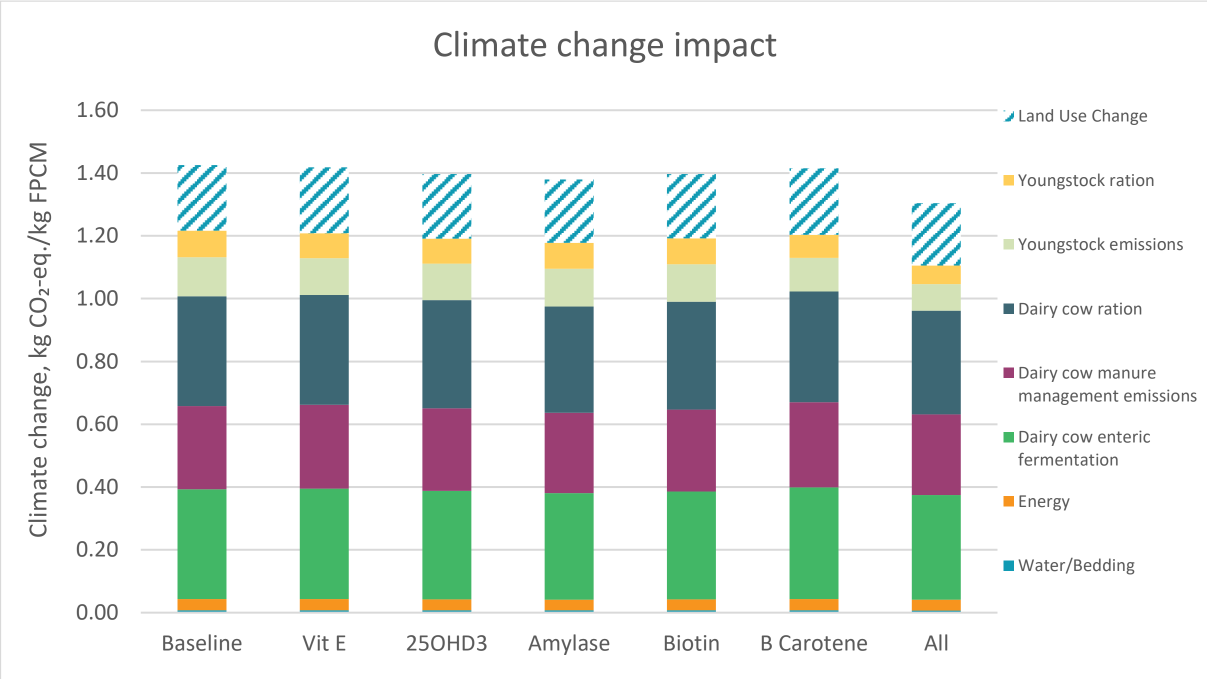

Figure 24 Contribution analysis of the climate change impact category

Different emission calculations play an important role on the results. All the emissions calculation implemented are based on international guidelines such as NIR, IPCC and EMEP/EEA. Even though such calculation rules (and emissions factors) contain assumptions and uncertainties, they are generally regarded as reliable and a consistent way of modelling emissions at the dairy farm, especially when analysing a theoretical national-average system.

To test the impact of using more specific modelling, the use of different emission models for enteric methane has been investigated:

- APS-footprint tool default methodology uses a Tier 2 IPCC with 5.5% Y_m, because Western Europe is considered a high-quality diet by IPCC, therefore lower Y_m range [4, 15],
- Belgian NIR: Tier 2 IPCC with 6.1% Y_m [38],
- Dutch NIR enteric emission factors (as implemented in *Kringloopwijzer* tool) were implemented [39, 19].

The lower tier level tends to reduce the estimation of enteric methane from dairy cows, therefore enhancing the impact from youngstock. This results in a negligible increase of the “All” additive scenario of 0.2 percentage point.

Table 21 Sensitivity analysis of the climate change (excluding LUC) impact and All scenario improvements of using various Tier level methodologies for enteric fermentation methane emissions

	Baseline (kg CO_2 eq.)	*All (kg CO_2 eq.)*	*All (%)*
Dutch NIR	1.22	1.11	-9.2%
Tier 2 Belgium	1.19	1.08	-9.3%
Tier 2 APS-footprint tool	1.15	1.04	-9.4%

4.3.8.2.6 Allocation

The allocation between milk, liveweight and manure plays an important role (22.22% in liveweight output). Changes in how manure is considered, will result in a lower reduction in impact. The choice of IDF allocation reduces the benefit of the "all" scenario, compared to mass, energy or economic allocation. IDF allocation does not distinguish between the biophysical burden of culled cows and sold calves, which also affects allocation.

4.3.8.3 Conclusions

The "all" scenario introduces the complexity of dealing with interactions between the additives. The chosen approach might be improved in future studies. Our models were not able to fully account for the underlying connections between additives. Also, the methodological and tool limitations found in the single interventions are also present (and probably enlarged) in the "all" scenario. Therefore, we conclude that the methodological framework used gives a basis to conduct the LCA but is only partially capable of modelling the environmental changes (from -9.2% up to -11.0% on the selected impact categories) connected to the use of a mix of additives. This makes the results very uncertain. The main methodological issues found are:

- lack of guidance on how to estimate variability in the considered zootechnical effects of the additive, and how to account for the interaction of multiple additive effects,
- lack of guidance on how to model longevity, fertility and disorder changes at herd level (e.g. complex herd model able to estimate the change in milk production and feed output connected to a change in longevity),
- contradicting guidance on how to model effect connected to changes in manure compositions,
- IDF allocation is not capable of distinguishing liveweight coming from culled cows and sold calves.

Other limitations connected to the APS-footprint tool limitations are the lack of DQR and uncertainty for the cultivation background dataset used, lack of an uncertainty calculator functionality and lack of a complete N balance approach at herd level in the default emission calculation method of dairy APS module.

4.4 Summary of conclusions

The conclusions of the various scenarios are summarized in Table 22, based on the approach explained in section 2.1.3. This summary is used to systematically analyse and group the scenarios of the various animal specific chapters, and to identify trends to be discussed in chapter 6.

Table 22 Summary of the conclusions from the dairy section scenarios, per life cycle influence

	Feed additive production	***Changed impact at animal farm***	***Changed impact upstream (feed, youngstock, bedding materials etc)***	***Changed downstream impact***	***ΔTOT***
Vitamin E	Between 0% and 0.13% of total impact	Reduction of 0% to 0.6% due to increase in milk, less youngstock Counterbalanced by less liveweight output and higher feed intake cows. Modelling is simplified and change is uncertain.	Reduction of 0.3% to 1.0% increase in milk, less youngstock. Counterbalanced by less liveweight output and higher feed intake cows. Modelling is simplified and change is uncertain.	Downstream impacts of milk production should not be influenced by the additive, but for the consideration of manure composition changes (contradicting guidance).	Overall reduction of 0.7% to 1.1%. Farm and production reduction outweigh additives production. Certainty of the results relies on the solidity of the data related to: variability of zootechnical parameters, modelling of herd dynamics, allocation influence, nitrogen balance limitations and consideration of manure composition changes.
25OHD3	Between 0% and 0.1% of total impact	Reduction of 0% to 1.2%. Similar considerations as for Vitamin E, but higher milk support increase reliability of results.	Reduction of 1.1% to 2.4%. Similar considerations as for Vitamin E, but higher milk support increases reliability of results.	Downstream impacts should not be influenced by the additive, but for the consideration of manure composition changes (contradicting guidance).	Reduction of 2.1% to 2.5%. Same conclusions as Vitamin E. Since results are more dependent on support of milk production, certainty is higher than for Vitamin E (assuming comparable uncertainty of zootechnical effects).

Amylase	Between 0.01% and 0.2% of total impact	Reduction of 0% to 2% due to higher milk output.	Reduction of 1.7% to 3.2% due to higher milk output.	Downstream impacts should not be influenced by the additive, but for the consideration of manure composition changes (contradicting guidance).	Reduction of 3.0% to 3.2%. Farm and production reduction outweigh additives production. Certainty of the results relies on the solidity of the data related to: nitrogen balance limitations and consideration of manure composition changes. The direct modelling makes the results more certain than for nutritional solutions affecting herd dynamic.
Biotin	Between 0.01% and 0.2% of total impact	Reduction of 0% to 1.3%. Similar situation as Vitamin E and 25OHD3, but higher milk support increase reliability of results.	Reduction of 1.1% to 2.2%. Similar situation as Vitamin E and 25OHD3, but higher milk support increase reliability of results.	Downstream impacts should not be influenced by the additive, but for the consideration of manure composition changes (contradicting guidance).	Reduction of 2.0% to 2.2%. Same conclusions as Vitamin E. Results being related to the support of milk production, the reliability appears higher than those for Vitamin E and 25OHD3 (assuming comparable uncertainty of zootechnical effects).
Beta carotene	Between 0% and 0.12% of total impact baseline	Reduction of 0% to 0.9% due to less youngstock AAP. Counterbalanced by less liveweight.	Reduction of 0.5% to 1.9% due to less youngstock AAP. Counterbalanced by less liveweight.	Downstream impacts should not be influenced by the additive, but for the consideration of manure composition changes (contradicting guidance).	Reduction of 2.1% to 2.5%. Same conclusions as Vitamin E. Results being mostly related to fertility support, they appear more uncertain due to modelling complexity (assuming comparable uncertainty of zootechnical effects).
All additives	Between 0.02% and 0.74% of total impact	Reduction of 0% to 5.2%. due to increase in milk, less youngstock. Counterbalanced by less liveweight output and higher feed intake cows. Modelling is simplified and delta are uncertain.	Reduction of 4.9% to 10.7%. due to increase in milk, less youngstock AAP. Counterbalanced by less liveweight output and higher feed intake cows. Modelling is simplified and delta are uncertain.	Downstream impacts should not be influenced by the additive, but for the consideration of manure composition changes (contradicting guidance).	Reduction of 9.2% to 11.0%. The certainty of the results is pending with the variability of zootechnical effects, the modelling of herd dynamics, allocation choices, nitrogen balance limitations and considerations of manure composition changes. Additionality is increasing the uncertainty.

5 Broilers

5.1 Scope

5.1.1 The baseline broiler system

The system studied is a typical modern broiler farm in the Benelux producing 60000 broilers per cycle of 42 days of growing and ten days of cleaning. The emission calculations are described in the LCA framework for broilers and laying hens (Blonk Consultants, 2019 [17]). It follows the LEAP guideline for calculating greenhouse gas emissions (FAO, 2016 [*8*]) augmented by the EMEP/EEA air pollutant emission guidelines (EMEP/EEA, 2016 [*18*]) and the IPCC (IPCC, 2006, [*33*]).

5.1.2 System description

The farm produces animals of approximately 2.5 kg starting from one day chickens in 6 weeks, with 10 days of cleaning, disinfection and maintenance work between cycles. The feed conversion ratio is approximately 1.6 kg feed/kg liveweight gain. Four different feeds are applied at different life stages, and 10 days before the end of a production cycle a part of the animals is removed to reduce the stocking density. The broilers are transported for slaughtering and the carcasses are checked for deviations. Non-conforming carcasses are condemned and disposed. A farmer is paid based on the remaining carcass weight.

In the Netherland, at the end of the cycle, the litter with manure is removed to be mainly used as fertilizer, although incineration with energy recovery is also quite common. In our baseline, it is not considered as a co-product to which impact is allocated because of the high density of intensive farming in the Benelux creating a manure oversupply, and a negative price for the animal farmer.

5.1.2.1 Flock management

We assumed practices representative for Benelux broiler farms, as reported by DSM poultry experts.

We assumed that the total production cycle is 52 days. On day 0 one-day chickens are brought into the shed. They are grown for 42 days in 4 feeding stages:

- Starter, day 1 to 10
- Grower 1, day 11 to 20
- Grower 2, day 21 to 35
- Finisher, day 36 to 42

On day 32, 28% by weight of the largest birds are transferred to the slaughterhouse to optimize usage of space and limit the final stocking density for final growth of the remaining animals. On day 42 the remainder of the animals is transferred. We assumed that for emptying the animal gut, they only get half of the feed at the day of removal to the slaughterhouse. After day 42 the barn is cleaned and on day 52 a new cycle starts.

5.1.2.2 Mortality

Mortality has been specified per day to calculate total feed consumption based on performance timetables (see section below). Sources for mortality specified per day are not available, so we have generated a daily mortality table for this study. The mortality in the baseline is set at 4.4% in line with the average literature data (Tallentire et al., 2019 [115]) and divided over early mortality until day 7 of 1.1%, late mortality during the remaining lifetime of 3.1% and dead upon arrival at the slaughterhouse of 0.2%. We applied these figures to the performance tables by assuming that there is an elevated mortality on the first day and on the day of slaughter, and using a linearly declining mortality rate in between, such that the figures for early, late and overall mortality match. The results are included in section 8.5.1.

5.1.2.3 Animal performance

We used animal performance tables for the commonly used Ross 308 broilers of both sexes, specifying daily feed intake and weight gain (AVIAGEN, 2019 [34]).

To facilitate the calculation of the intervention effects, we made regression functions describing feed intake and feed conversion ratio as a function of body weight based on the Ross/AVIAGEN tables, and we applied the mortality as described above, resulting in the performance tables of section 8.5. We assumed that the live weight delivered at the slaughterhouse is equal to the weight on day 41, the half daily ration fed on the last day compensating for the weight loss from emptying the gastrointestinal tract induced by fasting during the last half day.

5.1.2.4 Manure management

Litter and excreta are left in the barn until slaughter and then removed and temporarily stored on the farm and carried off at a suitable time, according to the normal practice in the area.

5.1.2.5 Feed composition

The approach taken to design the feeds is described in the paragraph 2.8.2. Annex 8.2 collects data on the feeds.

The averaged feed intake over the complete lifecycle is shown inTable 45, which compiles the feed compositions for each intervention scenario and the origin of the raw materials.

5.1.2.6 Miscellaneous inputs

We used data reported for north west Europe as reported in the SFIS study (IFIF-FEFANA, 2014 [*35*]) for electricity, water, fuel and bedding consumption.

The data that we used as input for the baseline farm system are summarized in the table below.

Table 23 Input data for the baseline broiler system per cycle

Parameter	*Unit*	*Value*
Average annual temperature	C	10
Broilers for slaughter	kg	151337
Water	kg	484277
Electricity	MJ	70418
Gas	MJ	281673
Straw for bedding	kg animal present^{-1}	1.656
One day chickens	#	61957
Number of animals	#	45704
Ash content of manure	%	8
Manure management system		Poultry manure with litter
Percentage of solid manure stored on farm before spreading	%	100
Feed nitrogen content	%	3.067
Digestibility	% of GE	88.3
Feed intake	kg animal^{-1}	5.21

The calculation of the average number of animals present is complicated by the variable mortality and the intermediate delivery to slaughter. It is calculated by taking the average number of the number of surviving animals in the performance tables of section 8.5.1, and correcting for the empty period between cycles.

5.1.3 Functional unit and reference flows

The intermediate product of live broilers is measured in kg live weight broilers arriving alive at the slaughterhouse. Carcass yield is assumed to be 72.5%, based on Agri-footprint database [2].

5.1.4 Feed additive interventions

5.1.4.1 The interventions for broilers

This report studies the effects of several interventions with feed additives independently and cumulatively. We selected 5 principles for intervention. The set of dietary interventions considered for broilers is listed in Table 24. The full substantiation for the effects can be read in Section 8.5.1.

Table 24 Dietary interventions considered for broilers with their zootechnical effects and changes in LCA inventory flows

Principle	Dose intervention	Zootechnical effect (qualitative)	Zootechnical effect (quantitative)	Change in LCA (inventory) flows (quantitative)
25(OH)D3	69 µg/kg feed replacing 3000 IU Vit D3/kg feed	Muscle and bone development support	Mortality reduction of 0.5%-point Breast meat yield increase of 4%	Increase in production per cycle (0.47%) with lower than proportional increase in feed consumption (0.20%) Breast meat yield effect investigated in sensitivity study
Eubiotics	300 mg/kg feed	Gut functionality support	Feed Conversion Ratio reduction of 3%	Faster growth (1.6%) and lower feed intake (1.6%)
Phytase	100 mg/kg feed	Improved digestion of phytates	Lower mineral phosphate requirement	Change in feed composition
Protease	200 mg/kg feed	Improved digestion of proteins	Lower crude protein requirement	Adapted feed composition Change in feed composition
Xylanase	75 mg/kg feed	Increased hydrolysis of arabinoxylan	Lower gross energy requirement	Adapted feed composition Change in feed composition

Because of the current systematic application of phytase supplementation, the present study considers a baseline with a basal phytase addition. However, to exemplify the benefit of phytase as a nutritional solution made available in the 90s, the footprint of broiler feeding without phytase addition is also assessed as a historical scenario See also Section 2.8.1.1.

5.1.4.2 Mode of action, efficacy and change in inventory flows

The mode of action and the efficacy of the interventions and the effect they have in terms of LCA input are discussed in this section.

Enzymes (Phytase, Protease and Xylanase) only have an effect on the feed composition which is determined with least cost formulation software. We accounted for enzyme effects by including the release of nutrients they liberate from the feed for digestion by the animal into account, using feed matrix values for the enzymes published by DSM. So, for the enzyme applications only the feed composition changes, and none of the other input parameters. The matrix values used for the enzymes are reported in 8.1, and the resulting feed formulations are made available in section 8.2.

The vitamins and eubiotics affect health and growth and not the composition of the feed.

5.1.4.2.1 Phytase

Phytase extracts the phosphorus from the plant-based material present in the diets, reducing the need for addition of mineral phosphorus. The primary change in the feed composition is therefore a reduction in the mineral phosphate content. Phytase also improves protein digestibility, and therefore the feeds with phytase contain less soya and more wheat and corn. Phytase is added as 0.1 kg per ton of feed.

5.1.4.2.2 Protease

Protease enhances the digestion of the protein present in feed ingredients, allowing a reduction of crude protein in the feed. This allows a further shift from soya to wheat in the feed. Protease is added as 0.2 kg per ton of feed.

5.1.4.2.3 Xylanase

Xylanase improves the digestion of energy present in the cereals containing high level of arabinoxylans, like wheat. This allows the replacement of some wheat by cheaper ingredients with lower energy content, like rapeseed meal, sunflower meal and wheat bran. Because these co-products contain more protein than wheat, the amount of soya bean meal is further reduced. Xylanase is added as 0.081 kg per ton of feed.

5.1.4.2.4 25(OH)D3

25(OH)D3 (short for 25-hydroxycholecalciferol) is an advanced source of Vitamin D with a higher potency than Vitamin D. Vitamin D supports bone and muscle development.

We assume that the superior bone health and resulting lower occurrence of lameness translate into a decrease in mortality. The mortality in the baseline is set at 4.4% in line with the average data published by Tallentire, et al. (2019), and a reduction by 0.5%-point is hypothesized (thus in our study cases mortality decreases from 4.4% to 3.9%). This reduction of mortality can only occur after the birds have consumed the product, so early mortality is not affected as much as late mortality. In our mortality curve we modelled this as an increase in the ratio between day 1 and day 42 mortality from 1.8 to 2.9, day 1 mortality remaining the same. The result is included in section 8.5.1.3.

The increase in breast meat yield does not affect the cradle to farm gate impacts, but it does affect product quality and therefore the requirement for functional equivalence in a comparative LCA is not obeyed. The effect of this quality change would show up in a slaughterhouse product LCA and is discussed in section 5.3.7.2.

25(OH)D3 is included as 5.52 g per ton of feed.

5.1.4.2.5 Eubiotics

In this study we investigate a eubiotic (product that support the gut functionality and its microbiome) which is a combination of benzoic acid and phytogenic aroma compounds. It acidifies the digesta, modulates its biochemistry and microbial environment. It also stimulates digestive enzymes. The activation of the digestion process supports an enhanced feed efficiency.

We included an overall improvement in feed conversion ratio of 3.5%. We modelled this benefit as both a lower feed consumption and a faster growth rate, as a function of body weight, in equal contribution. Since the birds grow faster, they also reach their target weight earlier. In this scenario, the weight on day 41 is closer to the target weight than the weight on day 42, so the cycle duration is reduced by one day. This change in scenario means that the improvements in weight gain and feed consumption do not follow a mathematical logic that would result in a 1.73% improvement in both. In the present scenario a 1.6% improvement in both results in an overall improvement of feed conversion ratio of 3.5%.

Eubiotics are included as 0.3 kg per ton of feed.

5.1.4.2.6 Combined solutions

The enzymes only affect feed composition through digestibility. Due to the many boundary conditions in the feed formulation, these effects are not additive Combination of enzymes changes the formulation in a similar direction as the addition of the individual enzymes, but to a different extent. The mechanisms and effects of the other two supplements are also independent from each other and of the enzymes, and can therefore be treated as additive.

5.2 Lifecycle Impact Results

The results are summarized in Table 25 giving the absolute numbers, and Table 26 giving the change compared to the baseline. The LCIA results are relative expressions and do not predict impacts on category endpoints, the exceeding of thresholds, safety margins or risks.

Table 25 Lifecycle Impact Results for the broiler interventions, absolute

Impact Category	Unit	Scenario							
		A	B	C	D	E	F	G	H
Climate change (excl LUC)	kg CO_2 eq	1.57 10^{0}	1.61 10^{0}	1.56 10^{0}	1.56 10^{0}	1.55 10^{0}	1.52 10^{0}	1.55 10^{0}	1.51 10^{0}
Climate change	kg CO_2 eq	4.00 10^{0}	4.21 10^{0}	3.91 10^{0}	3.85 10^{0}	3.78 10^{0}	3.67 10^{0}	3.77 10^{0}	3.65 10^{0}
Ozone depletion	kg CFC11 eq	5.00 10^{-8}	5.34 10^{-8}	4.99 10^{-8}	5.00 10^{-8}	5.01 10^{-8}	4.89 10^{-8}	5.00 10^{-8}	4.87 10^{-8}
Ionising radiation	kBq U-235 eq	7.18 10^{-2}	7.47 10^{-2}	7.16 10^{-2}	7.19 10^{-2}	7.20 10^{-2}	7.00 10^{-2}	7.18 10^{-2}	6.98 10^{-2}
Photochemical ozone formation	kg NMVOC eq	6.27 10^{-3}	6.53 10^{-3}	6.17 10^{-3}	6.18 10^{-3}	6.06 10^{-3}	5.70 10^{-3}	6.05 10^{-3}	5.70 10^{-3}
Respiratory inorganics	disease inc.	3.82 10^{-7}	3.94 10^{-7}	3.76 10^{-7}	3.82 10^{-7}	3.76 10^{-7}	3.63 10^{-7}	3.75 10^{-7}	3.61 10^{-7}
Non-cancer human health effects	CTUh	5.27 10^{-6}	5.32 10^{-6}	5.25 10^{-6}	5.23 10^{-6}	5.21 10^{-6}	5.16 10^{-6}	5.20 10^{-6}	5.14 10^{-6}
Cancer human health effects	CTUh	1.32 10^{-7}	1.38 10^{-7}	1.32 10^{-7}	1.31 10^{-7}	1.31 10^{-7}	1.30 10^{-7}	1.31 10^{-7}	1.30 10^{-7}
Acidification terrestrial/fresh water	mol H+ eq	4.33 10^{-2}	4.51 10^{-2}	4.24 10^{-2}	4.34 10^{-2}	4.25 10^{-2}	4.05 10^{-2}	4.23 10^{-2}	4.03 10^{-2}
Eutrophication freshwater	kg P eq	5.83 10^{-4}	6.23 10^{-4}	5.75 10^{-4}	5.67 10^{-4}	5.61 10^{-4}	5.47 10^{-4}	5.59 10^{-4}	5.45 10^{-4}
Eutrophication marine	kg N eq	1.91 10^{-2}	1.90 10^{-2}	1.92 10^{-2}	1.90 10^{-2}	1.90 10^{-2}	1.86 10^{-2}	1.90 10^{-2}	1.85 10^{-2}
Eutrophication terrestrial	mol N eq	1.91 10^{-1}	1.97 10^{-1}	1.87 10^{-1}	1.91 10^{-1}	1.87 10^{-1}	1.78 10^{-1}	1.86 10^{-1}	1.77 10^{-1}
Ecotoxicity freshwater	CTUe	1.85 10^{1}	1.86 10^{1}	1.84 10^{1}	1.85 10^{1}	1.83 10^{1}	1.79 10^{1}	1.83 10^{1}	1.78 10^{1}
Land use	Pt	4.57 10^{2}	4.68 10^{2}	4.52 10^{2}	4.48 10^{2}	4.45 10^{2}	4.37 10^{2}	4.44 10^{2}	4.32 10^{2}
Water scarcity	m^3 depriv.	2.51 10^{0}	2.66 10^{0}	2.48 10^{0}	2.52 10^{0}	2.49 10^{0}	2.44 10^{0}	2.48 10^{0}	2.43 10^{0}
Resource use, energy carriers	MJ	1.62 10^{1}	1.68 10^{1}	1.61 10^{1}	1.61 10^{1}	1.60 10^{1}	1.57 10^{1}	1.60 10^{1}	1.57 10^{1}
Resource use, mineral and metals	kg Sb eq	8.03 10^{-7}	1.16 10^{-6}	8.00 10^{-7}	7.91 10^{-7}	7.90 10^{-7}	7.77 10^{-7}	7.91 10^{-7}	7.69 10^{-7}

The scenarios in the headings of Table 25 and Table 26 are: A: Baseline, B: No phytase, C: A + protease, D: A + xylanase, E: A + all enzymes, F: E + eubiotics, G: E + 25(OH)D3, H: All solutions.

Table 26 Lifecycle Impact Results for the broiler interventions, relative to baseline

Impact Category	Unit	Value baseline	Scenario							
			B	A	C	D	E	F	G	H
Climate change (excl LUC)	kg CO_2 eq	1.57 10^{0}	2.3%	0.0%	-0.4%	-0.8%	-1.2%	-2.3%	-0.3%	-3.8%
Climate change	kg CO_2 eq	4.00 10^{0}	5.3%	0.0%	-2.2%	-3.8%	-5.6%	-2.9%	-0.3%	-8.6%
Ozone depletion	kg CFC11 eq	5.00 10^{-8}	6.9%	0.0%	-0.1%	0.1%	0.2%	-2.4%	-0.1%	-2.5%
Ionising radiation, HH	kBq U-235 eq	7.18 10^{-2}	4.1%	0.0%	-0.3%	0.2%	0.2%	-2.7%	-0.3%	-2.9%
Photochemical ozone formation	kg NMVOC eq	6.27 10^{-3}	4.2%	0.0%	-1.6%	-1.5%	-3.3%	-6.0%	-0.3%	-9.1%
Respiratory inorganics	disease inc.	3.82 10^{-7}	3.2%	0.0%	-1.6%	0.1%	-1.5%	-3.6%	-0.4%	-5.5%
Non-cancer human health effects	CTUh	5.27 10^{-6}	1.1%	0.0%	-0.4%	-0.8%	-1.1%	-1.0%	-0.3%	-2.4%
Cancer human health effects	CTUh	1.32 10^{-7}	4.4%	0.0%	-0.4%	-0.6%	-0.8%	-0.8%	-0.3%	-2.0%

Acidification terrestrial/freshwater	mol H+ eq	4.33 10^{-2}	4.1%	0.0%	-2.1%	0.2%	-1.9%	-4.8%	-0.5%	-7.1%
Eutrophication freshwater	kg P eq	5.83 10^{-4}	6.8%	0.0%	-1.5%	-2.8%	-3.9%	-2.4%	-0.2%	-6.6%
Eutrophication marine	kg N eq	1.91 10^{-2}	-0.5%	0.0%	0.1%	-0.6%	-0.5%	-2.5%	-0.3%	-3.3%
Eutrophication terrestrial	mol N eq	1.91 10^{0}	3.5%	0.0%	-2.1%	0.3%	-1.9%	-4.9%	-0.5%	-7.2%
Ecotoxicity freshwater	CTUe	1.85 10^{1}	0.6%	0.0%	-0.7%	-0.3%	-1.1%	-2.2%	-0.3%	-3.7%
Land use	Pt	4.57 10^{2}	2.4%	0.0%	-1.0%	-1.9%	-2.5%	-1.8%	-0.3%	-5.5%
Water scarcity	m3 depriv.	2.51 10^{0}	6.0%	0.0%	-1.5%	0.3%	-1.1%	-1.9%	-0.3%	-3.2%
Resource use, energy carriers	MJ	1.62 10^{1}	3.6%	0.0%	-0.5%	-0.9%	-1.3%	-1.9%	-0.3%	-3.6%
Resource use, mineral and metals	kg Sb eq	8.03 10^{-7}	44.6%	0.0%	-0.4%	-1.5%	-1.6%	-1.6%	0.1%	-4.2%

With only a few exceptions all additives reduce the impacts in all categories. The application of enzymes increases impact in some categories, because the changes in the feed composition (including the addition of the enzyme) replace ingredients with a lower impact by ingredients with a higher impact for these categories.

5.3 Interpretation

5.3.1 Baseline

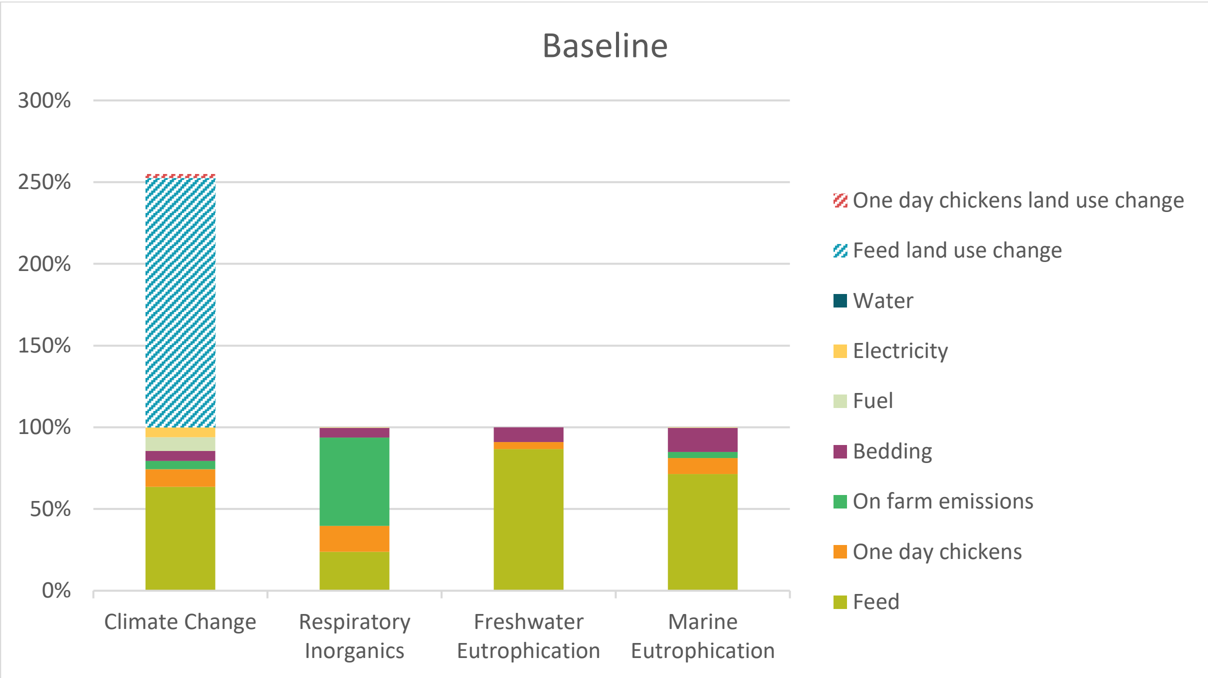

Figure 25 Contribution analysis of the broiler baseline for the four selected impact categories

The carbon footprint of the baseline scenario is 4.0 kg CO_2 eq/kg live weight broiler, with about 60% coming from land use change. These results are within the normal range found for broilers in the Benelux [17]. The land use change impact originates mainly from the historical deforestation for the creation of soy farms in Brazil. If we exclude the impact of land use change, the carbon footprint is 1.6 kg CO_2 eq/kg live weight. 64% of this footprint comes from the feed, 11% from one day chickens and about 5% each from on farm emissions, electricity, bedding material and the burning of fuel for heat generation.

The overall respiratory organics impact of the baseline is 382 10^{-9} disease incidences/kg live weight broiler. The respiratory inorganics impact category, similarly to acidification and terrestrial eutrophication, shows the largest contributions of on farm emissions, especially of ammonia. These three impact categories are therefore affected in very similar ways if ammonia emissions are reduced.

Freshwater eutrophication impact is 583 mg P eq/kg live weight, mainly related to feed production. However, the production of wheat straw and (feed for) producing one day chickens are also significant.

The marine eutrophication impact is 19 gr N eq/kg live weight for the baseline case. It is dominated by the production of feed. Just like for freshwater eutrophication, production of straw for bedding and (feed for) producing one day chickens is also significant.

The baseline results are sensitive for the choices about the type of farm and the assumptions about FCR and other input parameters, for assumptions about the origin of feed ingredients, the upstream processes as modelled in the databases, and for modelling assumptions inherited from the guidelines used to determine on farm and upstream emissions. This variability does not affect the impacts of the 2 feed additives that are only related to animal performance. The variability in the environmental impact of feed can be relevant for the enzymes change impact which will be shown below.

5.3.2 Effect of interventions

In the figures below we compare the effect of the interventions on the four focus impact categories. For each intervention, or combination of interventions it is shown how much it affects each of these impact categories in total, and how this effect is broken down over the contributing elements. For climate change 100% is the impact excluding land use change, and any change in the land use change impact is also weighed against this amount.

For each intervention we also discuss sensitivities to assumptions and uncertainties.

5.3.3 Phytase

5.3.3.1 Main results

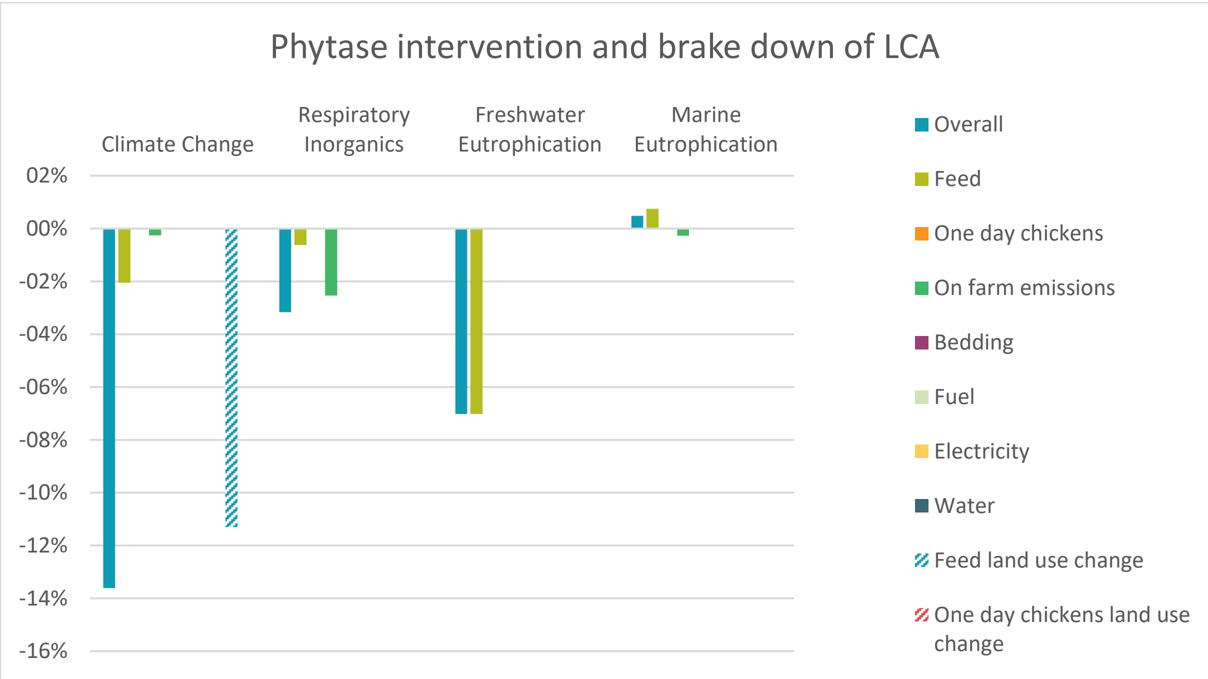

Figure 26 Phytase intervention effect for broilers

Phytase is now commonly applied in broiler feed, so we included it in our baseline. To give insight in the potential of enzymes we explore here the effect by applying it in a current diet with and without phytase. It should be noted that this is not the real historical effect because quite some parameters like FCR, feed composition and production of feed materials have been changed over time.

The main purpose of phytase is to reduce the dependence on mineral phosphate addition. This impact is not visible in the graph because resource use was not selected as a focus impact category. In Table 26 it can be seen that removing phytase form the baseline increases the "mineral and metal resource use" by 45%.

Phytase also improves protein digestibility, allowing a lower crude protein content and so reducing the dependence on soy invoking a shift to grains in the feed formulation. This gives a reduction in the land use change impact related to deforestation in Brazil. The climate change impact excl. LUC is also reduced by 2%, mainly through the lower carbon footprint of the alternative feed formulation.

Lower crude protein content also means that the nitrogen content in the manure is reduced and hence the on-farm emissions of ammonia. This reduces respiratory inorganics impact by 2% and has a similar effect on terrestrial eutrophication (even 3.5% in this case), which we did not select as a focus impact category, but is an essential environmental issue in some areas, and in the Netherlands in particular.

The shift away from soya also reduces freshwater eutrophication impact by 7%. This is caused by the phosphorus run-off from soy production being larger than from the production of the alternative other crops in the formulation, because of a high use of phosphorus fertilizer.

Marine eutrophication, which is driven by run-off of nitrogen compounds in agriculture is slightly increased, mainly because soya, being a legume, does not require much nitrogen fertilizer. This is compensated to some extent by the lower ammonia emissions on the animal farm.

Phytase (and the other enzymes) do not affect performance in our scenarios, but just feed composition, so only the contributions of feed and of the on-farm emissions, which depend on feed composition are affected by them, and the impacts of one day chickens, bedding, heat and electricity remain the same for all impact categories.

5.3.3.2 Discussion on robustness of the results

5.3.3.2.1 Variability of the zootechnical effect

There is significant variability in the increase in digestibility of phytates and protein. It may depend on the genetics of the birds, the composition of the feed, and other conditions on the farm. However, increased digestibility has been shown consistently in trials and the application under practical conditions has been widely adopted without any negative effects. So, our modelling of the zootechnical effect assuming no change in performance is supported by the results in practice.

5.3.3.2.2 Ingredient production

The ingredient production contributes very little to the footprint. For the focus impact categories, it contributes most to freshwater eutrophication at 0.02%. Overall, its contribution is largest for mineral resource use at 0.5%. As a fraction of the intervention effect, it is also small, with an overall maximum of 0.5% for climate change. The impact of producing the ingredient is therefore much smaller than its effect in use and the impact of broiler production.

5.3.3.2.3 Manure application

The application of phytase affects the composition of the manure. This means the condition of functional equivalence for a comparative LCA is not met. Therefore, the impact of not meeting this condition has to be discussed. As discussed in section 2.4, a reasonable way of studying the LCA effects, is to expand the system boundaries to include manure application. In this section we will discuss the main impacts of such a system expansion.

With phytase the amount of phosphorus in the feed is reduced with 2.7 gr/kg live weight produced. The phosphorus content of the manure is determined by the mass balance and therefore also reduced with the same amount. Approximately 5% of excess phosphate runs off. Therefore, freshwater eutrophication is reduced with 0.14 gr/kg live weight, which is 22% of the impact of the no phytase scenario. According to the PCR for red meat the impacts of replacing 50% of the reduced phosphorus with inorganic fertilizer has to be taken into account if the actual fertilization state of the application fields is not known. This would reduce the freshwater eutrophication impact of reducing the amount of phosphorus in the manure to about 11% instead of 22% of the no phytase scenario impact. The impact of producing the fertilizer is very small compared to the baseline impact in all categories and compared to reductions for the focus impact categories. This gives a good impression of the potential impact, but it depends on the phosphorus fertilization state of the application fields and the alternative fertilizers used how large the real effect is.

Likewise, the amount of nitrogen in the feed and excreta is reduced with 1.3 gr/kg live weight produced. Because part of the nitrogen is already emitted at the farm, the amount in the manure is reduced with 0.9 gr/kg live weight produced, which reduces leaching of nitrate and emission of ammonia after manure application. With the corresponding characterization factors this results in a decrease in marine eutrophication of 0.21 mgr N-eq/kg live weight produced, or 0.1% of the baseline. For respiratory inorganics the reduction of the impact of the manure application ammonia emission is 1.2%. So, reduction of nitrogen emissions during fertilization do not play an important role. Like for the phosphorus case, the impacts related to producing fertilizer are very small compared to the baseline in all categories and to the reductions in footprint for the focus impact categories.

So, the assessment of manure application impacts seems relevant for phosphate emissions and freshwater eutrophication, while nitrogen related issues do not have a large effect.

5.3.3.2.4 Housing system

The change in N emissions depends on the emissions characteristics of the housing system. We assumed a farm with no mitigation technology such as air scrubbers. Air scrubbers remove ammonia and dust from the exhaust ventilation air and therefore reduce impact in respiratory inorganics and marine eutrophication.

5.3.3.2.5 Soy origin

Environmental impacts of the feed are strongly dependent on the origin. If, instead of uncertified soy from Brazil, soy from a source with no deforestation was used in the baseline, the land use change effect would almost completely disappear. But there would also be other changes. If soy from Brazil was replaced by soy from the US climate change would increase slightly, the contribution of feed to respiratory inorganics would also increase and the contribution to marine eutrophication would increase less than for the present scenario. The freshwater eutrophication impact would be much lower in the baseline, but there would still be a reduction. This means that extrapolation of the effect of feed additives like phytase, allowing changes in feed composition without affecting animal performance to situations with a very different baseline feed composition should be done with care. This can already play a role with different price ratios between ingredients over time, resulting in a different optimized feed composition, but it is certainly the case for other geographies, with other price ratios, raw material availabilities and feeding preferences. Some conclusions can be easily extrapolated while others require a dedicated study with the new baseline feed.

5.3.3.2.6 Ingredient exchange and footprint of the ingredients

The effects of the substitution of high protein ingredients by lower protein ingredients is included in the results and discussed above. Some of these effects are inherent to the application of phytase. These include the reduced consumption of phosphate rock, the reduced deforestation and the reduced emission of nitrogen compounds from manure. Therefor the effects these have on mineral depletion, and respiratory inorganics can be generalized. This also applies to land use change, in as far as soy from farms where natural areas were recently converted is included in the baseline feed. Other effects of the substitution of high protein ingredients by lower protein ingredients are strongly dependent of the baseline feed composition and the ingredient replacement changes, which in turn are strongly affected by price patterns and ingredient availability. Generic conclusions on these effects can only be drawn after a thorough study including a representative range of price ratios and ingredient availability. For other situations a specific study is necessary to quantify these indirect effects.

5.3.3.2.7 Feed adjustment scenario

If phytase is applied without (completely) adjusting feed composition to achieve the same nutritional value, animal performance is likely to improve. This effect is harder to quantify accurately, but may be environmentally more beneficial than rebalancing the feed. There is a trend in feed formulation to apply phytase at higher doses, with complete or partial adjustment of the feed composition. This may also improve environmental benefits further. These arguments also apply to the other enzymes.

5.3.3.2.8 Baseline performance

In this study phytase is applied to a state-of-the-art production system and feed composition. The effects of phytase addition in less advanced systems will be different and may be even more substantial. This also means that the calculations here are not reflecting the historical benefits of phytase completely, because during the implementation 25 years ago the performance of broiler farms was lower.

5.3.3.3 Conclusions

The main environmental effects of the addition of phytase can be assessed using the guidelines and the tool based on them. The reductions in impact observed can be explained based on the detailed results and their link to the intervention scenario. For the target effects (reduction of N and P inputs) the quantification can be generalized. Indirect effects as result of changing feed composition and the related upstream impacts can't be generalized. The effects in manure application are not in the scope of the tool and this study, and the guidelines are not consistent about how this should be included. We have shown that they have a relevant magnitude and that they are case dependent.

5.3.4 Protease

5.3.4.1 Main results

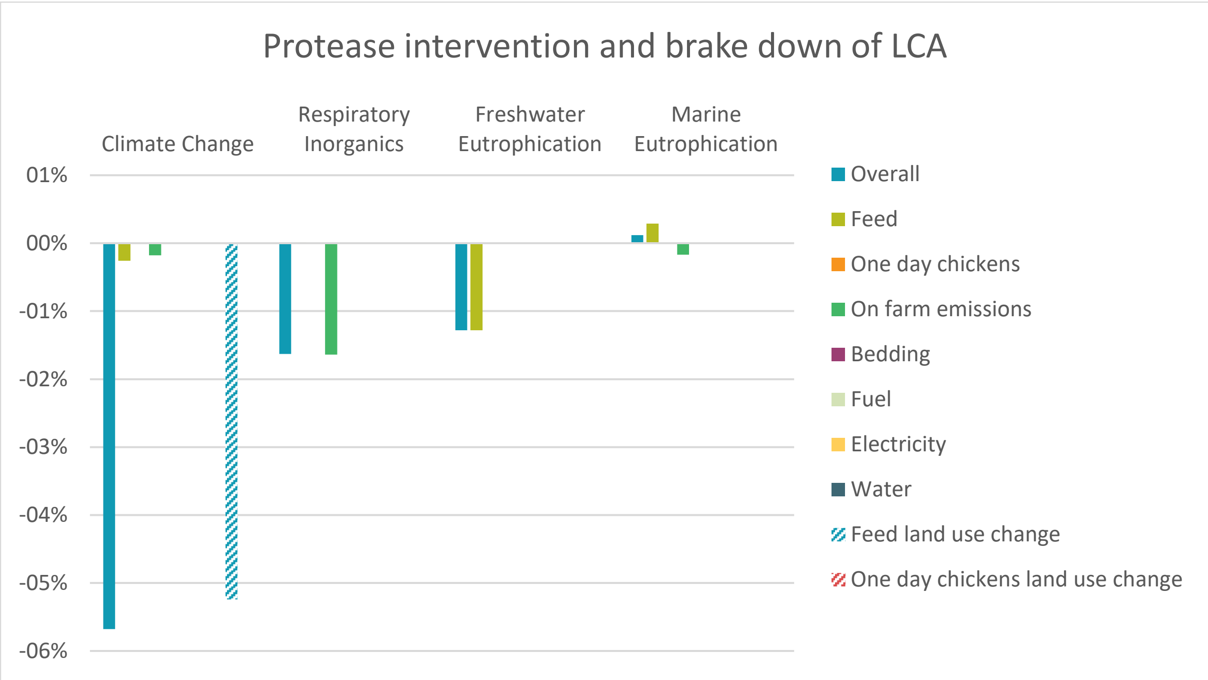

Figure 27 Protease intervention effect for broilers

The effects of the protease intervention look very similar those of the phytase intervention. This is because it is targeted at an improved protein digestibility, which was a collateral benefit of the phytase addition. Therefore, much of the explanation of Figure 26 also applies here. Quantitatively the effects of protease are about half as large as the phytase effects. Applied on a baseline feed without phytase, the protease effect would be much larger.

5.3.4.2 Discussion and sensitivity analysis

5.3.4.2.1 Variability of the zootechnical effect

The sensitivity of the changes in impacts can be analysed in a way very similar to the way it was done above for phytase. For protease, there is not such a wealth of trials and practical experience, so there is a larger uncertainty.

5.3.4.2.2 Ingredient production

The ingredient production contributes little to the footprint. For the focus impact categories, it contributes most to freshwater eutrophication at 0.1%. Overall, its contribution is largest for mineral resource use at 0.2%. As a fraction of the intervention effect, it is relevant, with an overall maximum of 67% of the reduction in other impact for ozone depletion and 20% for climate change in the focus impact categories. The impact of producing the ingredient is therefore smaller than its effect in use and much smaller than the impact of broiler production.

5.3.4.2.3 Other sensitivities

Very similar observations as for phytase about the sensitivity for other assumptions like the origin of the feed ingredients apply.

5.3.4.3 Conclusions

The conclusions for protease are very similar to those for phytase. The only difference is that for protease the reduction of phosphorus inputs is not a target effect, and therefore reduction of phosphate emissions in manure application is not relevant.

5.3.5 Xylanase

5.3.5.1 Main results

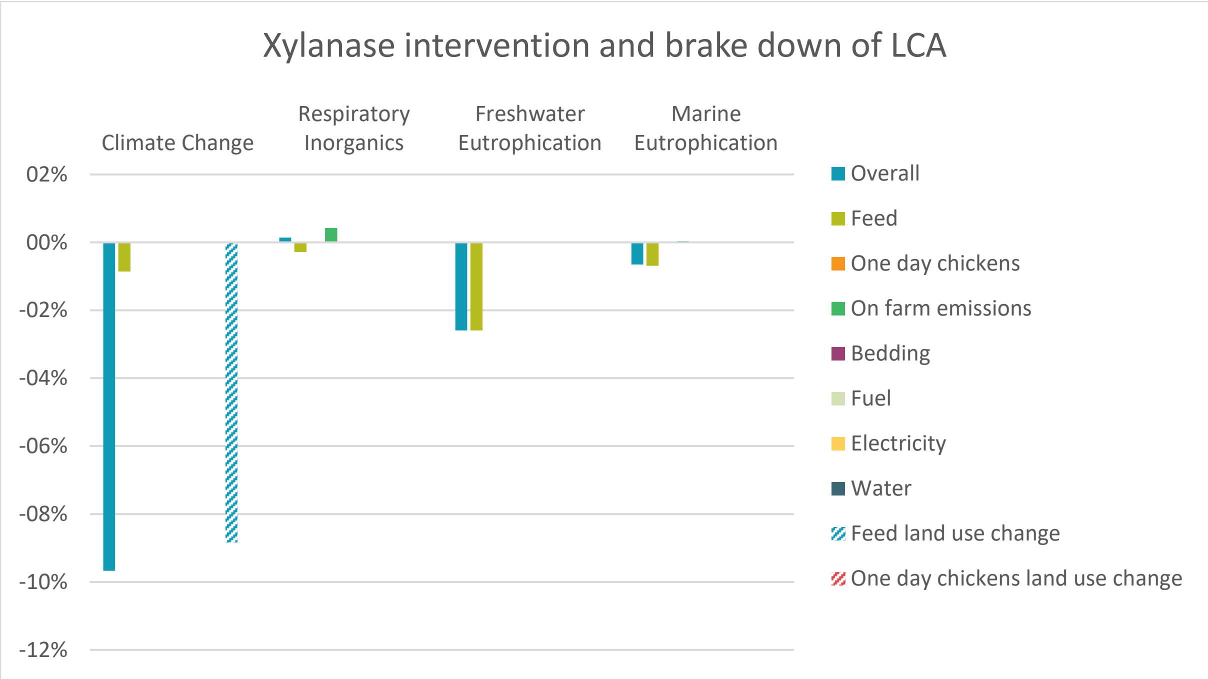

Figure 28 Xylanase intervention effect for broilers

Because xylanase improves the utilization of the energy in wheat, it allows a shift from wheat to co products with less energy and more protein, further reducing dependence on soy meal. Therefore, there are similarities with the effects for phytase and protease.

The on-farm emissions of nitrogen compounds increase a little because the digestibility of protein is not affected by xylanase, and the protein of the alternative sources is not digested as easily as soy protein and hence the crude protein content in the feed increases a little. This increases respiratory inorganics and marine eutrophication impacts a little.

Marine eutrophication impacts are reduced a little, because wheat has a relatively large contribution to this impact category due to leaching of fertilizer nitrogen.

5.3.5.2 Discussion and sensitivity analysis

5.3.5.2.1 Variability of the zootechnical effect

For the same reason as for protease, the uncertainty in the change in impacts is ± 50%.

5.3.5.2.2 Ingredient production

The ingredient production contributes very little to the footprint. For the focus impact categories, it contributes most for freshwater eutrophication at 0.001%. Overall, its contribution is largest for mineral resource use at 0.003%. As a fraction of the intervention effect, it is also small, with a maximum of 0.2% for climate change in the focus impact categories and an overall maximum of 3% for ozone depletion. The impact of producing the ingredient is therefore much smaller than its effect in use and the impact of broiler production.

5.3.5.2.3 Other sensitivities

Very similar observations as for phytase and protease about the sensitivity for other assumptions like the origin of the feed ingredients apply. The main difference is that for xylanase the primary objective, the release of more energy from wheat, affects environmental impact only through a complex feed ingredient replacement scenario. It is not a coincidence that the cheaper replacement ingredients have a lower footprint, because they are coproducts that get lower allocation of impacts than the main products of crops, but the results are more sensitive to the circumstances of these various productions.

5.3.5.3 Conclusions

The conclusions for xylanase are very similar to those for protease and phytase. Generalization of the results is more difficult, because the effects are circumstantial to a larger extent than for the other enzymes.

5.3.6 All enzymes

5.3.6.1 Main results

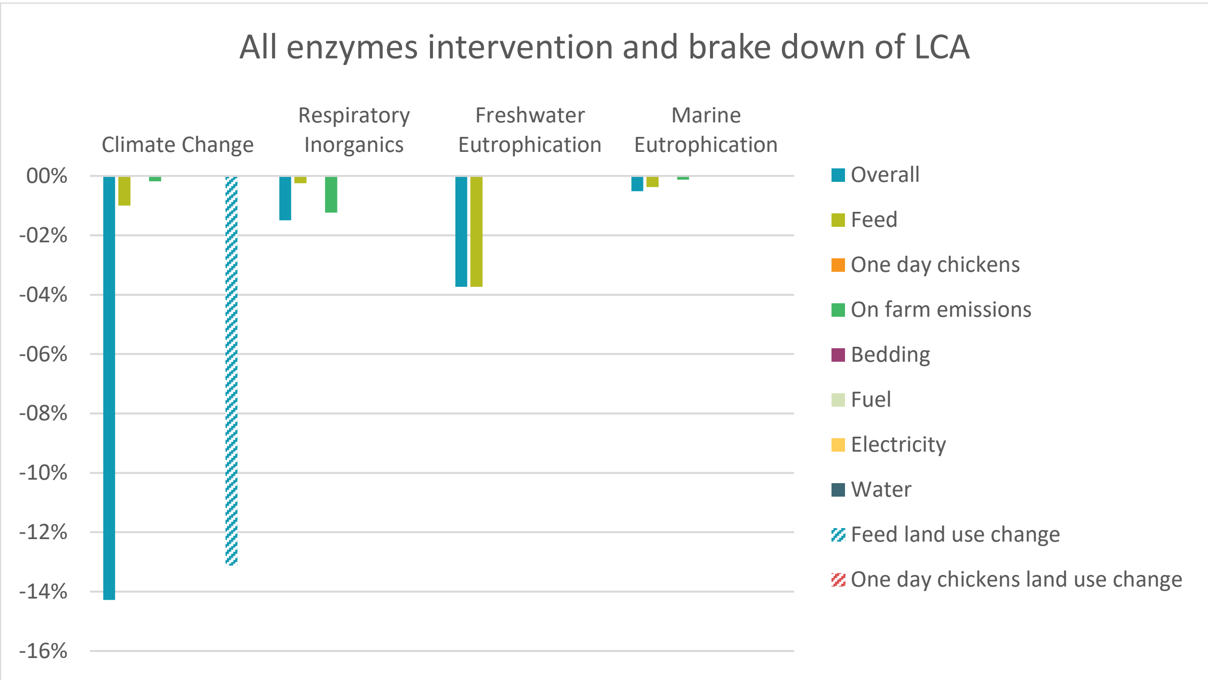

Figure 29 All enzymes intervention effect for broilers

It should be noted that this is the effect of the three enzymes compared to the baseline with phytase only. The combination does not add the effects of the two enzymes individually, because constraints are active in the optimization of the feed composition. The causes of the changes and the sensitivities remain the same as for the individual cases.

5.3.6.2 Discussion and sensitivity analysis

5.3.6.2.1 Variability of the zootechnical effect

For the same reason as for protease and xylanase, the uncertainty in the change in impacts is ± 50%.

5.3.6.2.2 Ingredient production

The ingredient production contribution is dominated by the protease, which still contributes little to the footprint. For the focus impact categories, it is highest for freshwater eutrophication at 0.1%. Overall, its contribution is largest for mineral resource use at 0.3%. As a fraction of the intervention effect, it is relevant, with an overall maximum of 67% of the reduction in other impact for ozone depletion and 17% for climate change in the focus impact categories. The impact of producing the ingredient is therefore smaller than its effect in use and much smaller than the impact of broiler production.

5.3.6.2.3 Other sensitivities

Same observations as individual enzymes.

5.3.6.3 Conclusions

The conclusions for the combination of all enzymes are similar to those for the individual enzymes. The impacts related to the target effects (N and P input) can be generalized, effects related to other shifts in feed composition can't be generalized easily.

5.3.7 25(OH)D3

5.3.7.1 Main results

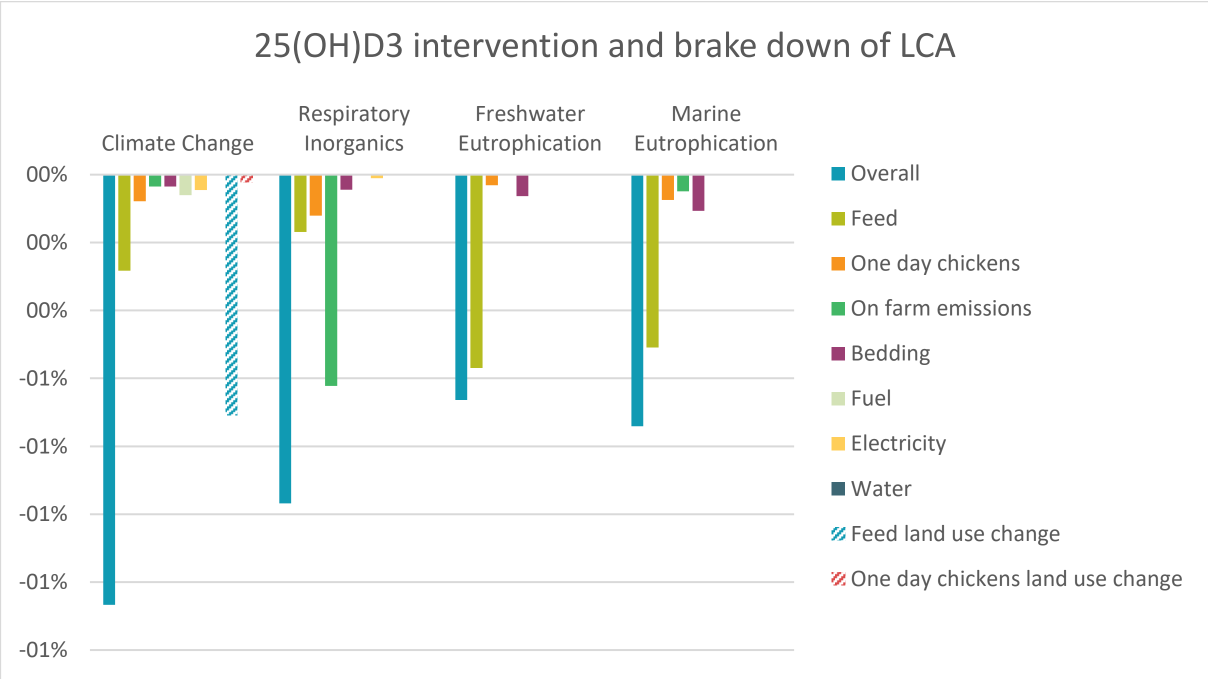

Figure 30 25(OH)D3 intervention effect for broilers

Since 25(OH)D3 primarily increases production, all impacts are reduced with a similar percentage, about 0.5% in total. There are some differences, because the reduced mortality results in non-linear effects.

The reduction in the contribution of on farm emissions to respiratory inorganics impact stands out. This is partially caused by the fact that respiratory inorganics is the only impact category that is not dominated by feed production impacts but by on farm emissions. On top of this, the higher production means that through the mass balances less nitrogen ends in the manure and this reduces ammonia emissions.

Climate change also seems to stand out overall, but this is because the 100% reference does not include land use change.

5.3.7.2 Discussion and sensitivity analysis

5.3.7.2.1 Variability of the zootechnical effect

The mortality effects are all linear. From the variability in the change in mortality of ± 50% we can therefore conclude that the uncertainty in the change of the impacts is also ± 50%.

5.3.7.2.2 Ingredient production

The ingredient production contributes very little to the footprint. For the focus impact categories, it contributes most to freshwater eutrophication at 0.06%. Overall, its contribution is largest for mineral resource use at 0.4%. As a fraction of the intervention effect, it is relevant, with a maximum of 30% for climate change in the focus impact categories. The impact of production is 40% larger than the impact reduction in application for mineral resource use. The impact of producing the ingredient is therefore smaller than its effect in use, except for the impact category mineral resource use. The impact of ingredient production is much smaller and the impact of broiler production.

5.3.7.2.3 Feed conversion ratio

The main effect of the intervention is an improvement of the overall FCR, or the ratio of consumed feed and produced live weight, and because the production in feed is a dominant factor in most impact categories, the prediction that this effect has on the environmental impact of the broilers is very reliable. However, the reduced mortality also has effects related to the change in the number of dead animals, which will be discussed in the next section.

5.3.7.2.4 Dead animals

To some extent the reduced ammonia emissions are artificial, because the mass balance does not account for dead animals. Fewer dead animals means that less nitrogen is exported this way, and more nitrogen remains in the manure. This effect increases the ammonia emissions per kg of live weight by about 0.4%, because ammonia emissions represent approximately one third of the total respiratory emissions impact, this increases the impact by 0.13%-points, taking away 1/3 of the calculated benefit of the on-farm emissions benefit. It can be concluded that for the proper prediction of mortality effect, dead animals should be included in mass balances.

The treatment of the dead animals is not included in the scope of this study. The impact this has depends a lot on the way of treatment. For predicting animal footprint if mortality changes this effect should be included.

5.3.7.2.5 Breast meat yield increase

The increase of 4% in breast meat yield as reported in section 5.1.4.2. violates the requirement of functional equivalence. It would show up in the calculation of the cradle to gate footprint of the slaughterhouse. The LEAP guideline for poultry is not meant for comparative LCA and does not consider functional equivalence and suggests that all edible meat should be treated in the same way, which means that mass allocation should be used, although the example given is about economic allocation. A mass allocation would still violate the functional equivalence principle. Economic allocation is a logical methodological choice to account for quality differences. In section 8.5.3 it is shown that by applying the LEAP Guideline economic allocation example a 4% increase in breast meat yield results in a 0.25% reduction of the footprint of all products. In the footprint of the slaughterhouse products, including the impacts at the slaughterhouse this reduction will also apply to the slaughterhouse impacts, so all slaughterhouse product footprints will decrease by 0.25%.

5.3.7.3 Conclusions

The main environmental effects of the addition of 25(OH)D3 can be assessed using the guidelines and the tool based on them, because they relate to the amount of product produced per kg of feed. The LEAP guideline includes the effect of dead animals on manure production, because they are based on retention and dead animals don't consume or retain feed. They also require the inclusion of the impacts of treating dead animals, which we did not do, since the APS-footprint tool does not include treatment of dead animals and it does not include the dead animals in the nitrogen balance. For the analysis of the impacts of mortality this means that the tool captures the main impact, but needs to be extended to give reliable results.

The guidelines do not allow an assessment of the impact of product quality. This means that the full impact of interventions that affect product quality cannot be assessed in a way that is compliant with the leap guidelines. The tool also does enable such an analysis, while it can be assessed by processing the tools results.

The observed effects can easily be generalized, provided the limitations are indicated.

5.3.8 Eubiotics

5.3.8.1 Main results

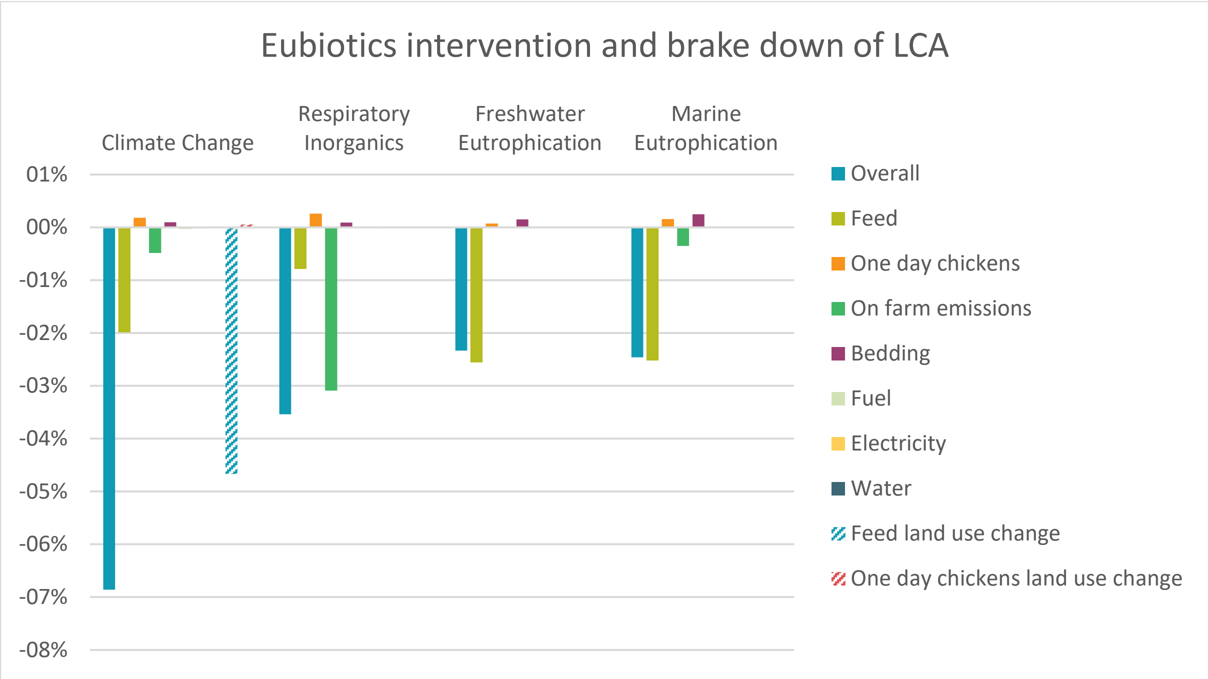

Figure 31 Eubiotics intervention effect for broilers

Because eubiotics affect mostly the feed conversion ratio, the reduction of impact is dominated by the reduction of the feed contribution. Other effects are very small. Like for 25(OH)D3, the effect of on farm emissions in respiratory inorganics visually stands out because the on-farm emissions dominate this impact category. Because of the increased utilization of nitrogen also the absolute ammonia emissions are reduced. Whereas for 25(OH)D3 this effect was partially superficial, in this case it truly occurs.

5.3.8.2 Discussion and sensitivity analysis

5.3.8.2.1 Variability of the zootechnical effect

The FCR effects are all linear. From the variability in the change in FCR of ± 50% we can therefore conclude that the uncertainty in the change of the impacts is also ± 50%.

5.3.8.2.2 Ingredient production

The ingredient production contributes little to the footprint. For the focus impact categories, it contributes most to climate change at 0.2%. Overall, its contribution is largest for mineral resource use at 1.2%. As a fraction of the intervention effect, it is small, with a maximum of 7% for climate change in the focus impact categories. The impact of production is 40% of the impact reduction in application for mineral resource use. The impact of producing the ingredient is therefore smaller than its effect in use and much smaller than the impact of broiler production.

5.3.8.3 Conclusions

The main environmental effects of the addition of eubiotics can be assessed using the guidelines and the tool based on them, because they relate to the amount of product produced per kg of feed. The results can easily be generalized.

5.3.9 All solutions

5.3.9.1 Main results

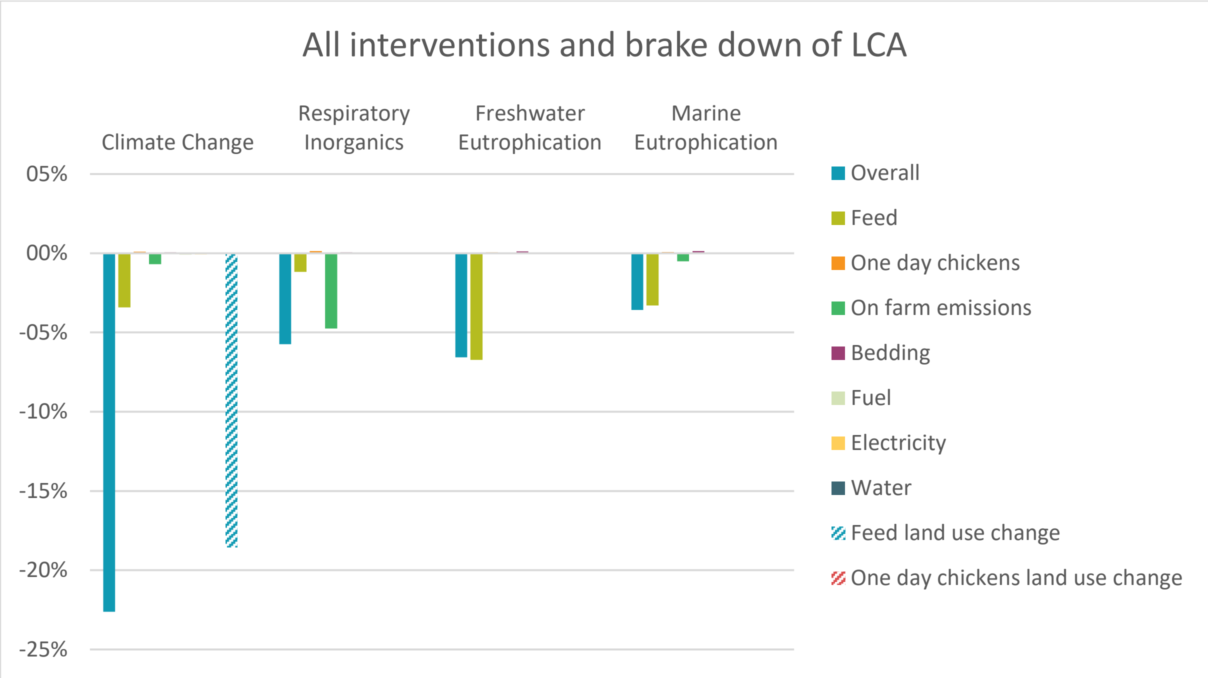

Figure 32 Effect of all intervention combined for broilers

The effect of all interventions combined is almost equal to the sum of the effect of all enzymes, 25(OH)D3 and eubiotics interventions. It is not the exact sum, because of the discontinuities induced by the mortality tables.

If you exclude land use change all impact categories are reduced by approximately 5% in total. Mostly coming from the feed.

5.3.9.2 Discussion and sensitivity analysis

5.3.9.2.1 Variability of the zootechnical effect

Since the effects on impact are independent, the combination of their uncertainties leads to a total uncertainty well below the uncertainty in the individual effects.

5.3.9.2.2 Ingredient production

By combining all solutions both the production impact and the effect impacts add up, while baseline broiler production impact remains the same. The ingredient production still contributes little to the footprint. For the focus impact categories, it contributes most to climate change at 0.3%. Overall, its contribution is largest for mineral resource use at 2%. As a fraction of the intervention effect, it is small, with a maximum of 12% for climate change in the focus impact categories. The impact of production is 40% of the impact reduction in application for mineral resource use. The impact of producing the ingredients is therefore smaller than its effect in use and much smaller than the impact of broiler production.

5.3.9.2.3 Additionality of impacts

The impacts on feed composition of the enzymes are not additive, but this has been accounted for in the feed formulation. The mechanisms and effects of 25(OH)D3 and eubiotics are independent of the use of enzymes and of each other, as discussed in section.

5.3.9.2.4 Analysis of the combined effects

For a better understanding of the relative improvements due to the interventions, the breakdown of the climate change impact excluding land use change and the effect of the additives are shown in Figure 33.

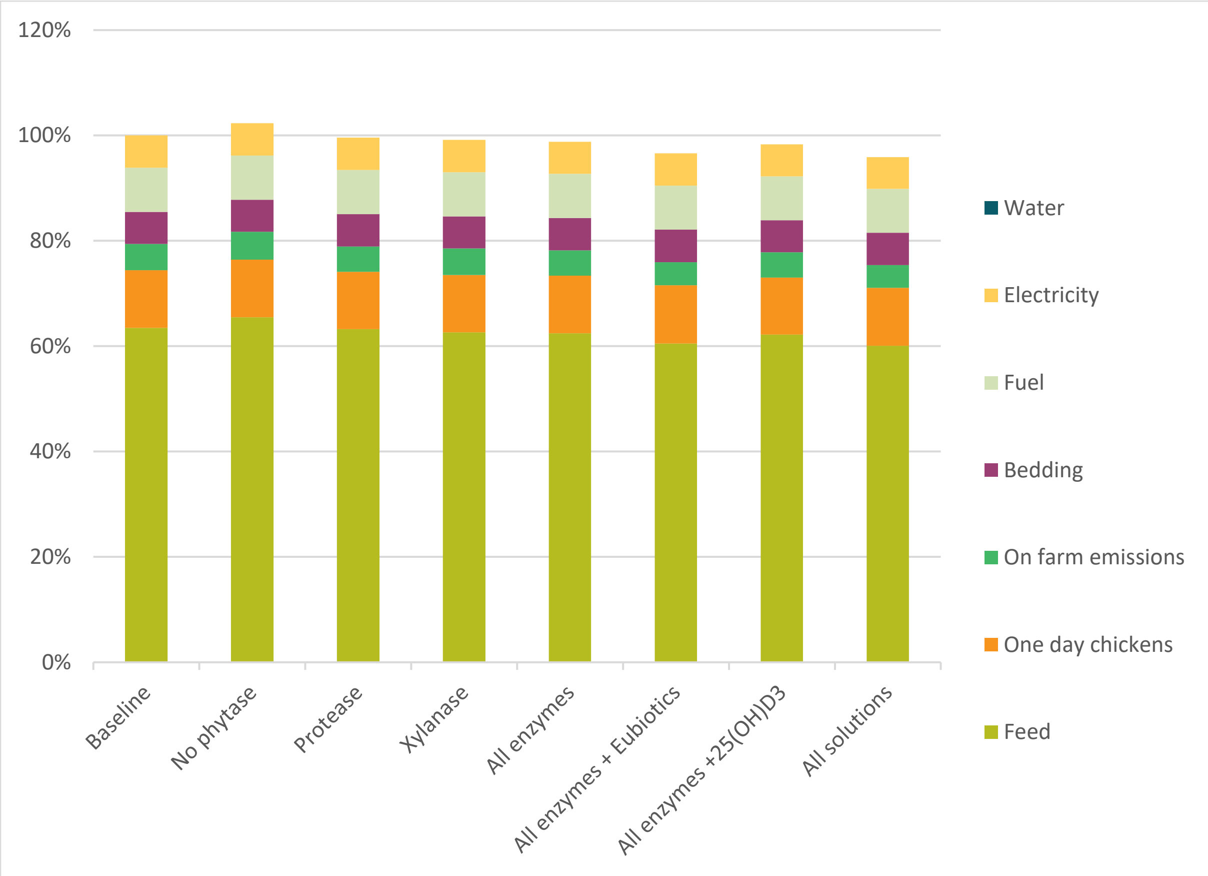

Figure 33 Climate change impact progression

The baseline impact excluding LUC is 1.57 kg CO_2-eq/kg live weight broiler. 64% comes from the feed, 11% from one day chickens and between 5% and 8% each from on farm emissions, electricity, bedding material and the burning of fuel for heat generation.

Removing phytase from this baseline increases the footprint by 2.3%, mainly caused by a higher need for soy, leading to more deforestation, and the release of large carbon stocks into the atmosphere. All other additives decrease the footprint by a half to two percent, through a general improvement in efficiency and/or a further shift from soy to other protein sources.

The impacts in other impact categories are included in Table 25 and Table 26. The contribution of feed dominates most impact categories, and hence improvements of feed efficiency dominate the improvement effects. There are some exceptions which were discussed in the sections about the individual interventions.

Farm emissions are a dominant factor in respiratory inorganics impact, and they are dominated by emissions of ammonia from manure. Ammonia emission is proportional to the amount of nitrogen in manure, and hence interventions that improve the overall nitrogen retention of the animals have a favourable impact. Phytase and protease stand out in this respect.

Xylanase increases the impacts in a few categories slightly, because the net effect of the changes in feed composition is slightly negative.

The remaining impact categories are generally regarded as being characterized by larger uncertainty (EC, 2018,3). In most cases these impact categories follow the general trends described above.

5.3.9.3 Conclusions

Feed additive interventions with different modes of action can be considered additive and if the environmental effects of the individual interventions can be calculated according to the guidelines and with the tool, the effects of combinations of interventions can also be calculated.

5.4 Summary of conclusions

We showed that the environmental impacts of feed additives applied at broiler farms can be demonstrated applying the LEAP Guidelines as implemented in the APS-footprint tool in a full LCA study and report.

We excluded the change in environmental impact related to application downstream in the basic analysis. Methodology rules for assessing this are not available in any poultry guidelines at the moment. Accounting for the change by system expansion is discussed in section 5.3.3. This analysis does not change any of the conclusions of this study, but it does highlight the case dependency.

We have two further considerations on this matter. First poultry manure leaving the poultry farm can have many applications which are quite specific for a region. In the Netherlands, a substantial fraction of poultry manure is incinerated with energy recovery, while this is not a common case in other Western European countries. Making very specific calculations on this was beyond the scope of the study. Secondly, the validity of the simple lifecycle extension approach for PCR red meat can be challenged because the default replacement scenarios are probably not applicable for poultry. And again, an in-depth analysis, estimating manure fate and fertilizer replacement scenarios was beyond the scope of the study. Nevertheless, in the interpretation of the phytase impact in section 5.3.3, we discussed the impact of a few scenarios.

We have shown that effects of interventions on meat quality exist and that the environmental impact can be quantified, although such an assessment is not supported by the guidelines or by the tool.

Feed additives can affect feed composition, growth, feed conversion ratio and mortality. Together these have a considerable effect on key environmental impact categories like climate change, respiratory inorganics and eutrophication.

Other impact categories tend to be more uncertain and shows less consistent improvements. In a few cases there is even a slight increase in impact due to the interventions.

The quantitative LCIA results obtained here should not be carelessly extrapolated to other baselines. For reliable predictions the actual production system should be studied in an LCA.

The conclusions per intervention are included in Table 27.

Table 27 Summary of results of the broilers study

	Feed additive production	Changed impact at animal farm	Changed impact upstream (feed, youngstock, bedding materials etc)	Changed downstream impact	ΔTOT
Broilers: Phythase	The impact of producing the additive is below 0.06% of the impact of the baseline	Better digestibility of protein reduces the impact categories dominated by on farm emissions by up to 2%.	Phosphorus use is reduced, but the effect on mineral resource use could not be interpreted. The target impact category land use change induced	Changes in the application of manure as fertilizer are only significant for phosphorus emissions, but	The reduction of environmental impact over the life cycle is much lower than the impact of producing the feed

	system for every impact category.		climate change is reduced by 7%. The magnitude of this change depends on the circumstances. Other changes in impact like in freshwater eutrophication (7%) are even more case dependent and the quantitative effect can't be generalized.	lower than impacts in the life cycle stages included in the scope.	additive. Upstream impact reduction other than reduction of phosphorus use and land use change are significant, but circumstantial and difficult to predict. Impacts in manure application are limited and can't be assessed conclusively due to limitations of guidelines and methodology.
Broilers: protease used on top of feed mix with phytase	The impact of producing the additive is below 0.3% of the impact of the baseline system for every impact category.	Better digestibility of protein reduces the impact categories dominated by on farm emissions by up to 2%.	The target impact category land use change induced climate change is reduced by 3%. The magnitude of this change depends on the circumstances. Other changes in impact like in freshwater eutrophication (1.5%) are even more case dependent and the quantitative effect can't be generalized.	Down-stream impact in manure application is very limited.	The reduction of environmental impact at farm is larger than the impacts of production of the feed additive. Upstream impact reduction other than land use change are significant, but circumstantial and difficult to predict. Impact in manure application are limited and cannot be assessed conclusively due to limitations of guidelines and methodology.
Broilers: xylanase	The impact of producing the additive is below 0.003% of the impact of the baseline system for every impact category.	Better digestibility of the wheat decreases allows shifts in fed composition reducing in farm emission impacts by up to 1% but these effects are strongly case dependent.	Impact changes due to the shift in feed composition are significant. For example, 9% in land use change and 3% in freshwater eutrophication. These changes are case dependent, and the quantitative effect can't be generalized.	Changes to manure composition are relatively small.	The contribution of the production of the enzyme to environmental impact is low, while reductions of the impacts in other parts of the value chain are circumstantial. Net effects must be assessed on a case-by-case basis.
All enzymes	The production impacts of the individual enzymes add up.	The effects of the enzymes are a combination of the effects of the individual enzymes. Compared to the baseline with phytase this means the impact on farm	The effects of the enzymes are a combination of the effects of the individual enzymes. Compared to the baseline with phytase this means the impact up stream is dominated by the effect of protease.	The effects of the enzymes on emissions in manure application are a combination of the effects of the individual enzymes, which are limited.	The effects of the enzymes are a combination of the effects of the individual enzymes. Compared to the baseline with phytase this means the overall effect is

		is dominated by the effect of protease (Phytase, being in the baseline).			dominated by the effect of protease.
Broilers: 25(OH)D 3 used on top of all enzymes	The impact of producing the additive is below 0.4% of the impact of the baseline system for every impact category.	All farm emissions are reduced by approximately 0.4%. Calculated nitrogen emissions are reduced even more because the dead animals are not accounted for in the nitrogen balance.	Because more live weight All upstream impacts are reduced by approximately 0.3%.	Because more live weight is produced with a lower than proportional increase in the amount of manure produced any downstream impact related to manure are also reduced.	The reduction of environmental impact at farm and upstream for feed production is larger than the impacts of production of the feed additive, except for the mineral and metal resource use impact categories, where these changes cancel out.
Eubiotics	The impact of producing the additive is below 1.2% of the impact of the baseline system for every impact category.	Because of the improved efficiency the amount of manure and the amount of nitrogen in it are reduced, resulting in reductions of on farm emission impact of up to 3% for respiratory inorganics.	A decrease in FCR results in a proportional reduction of feed production impact.	Reduction of the amount of manure and its nitrogen content led to reduced impacts downstream.	The reduction of environmental impact at farm and upstream for feed production is larger than the impacts of production of the feed additive.

6 Discussion

6.1 Road testing LCAs of feed additive interventions

6.1.1 Goal of the road testing LCA

We conducted a road testing LCA of feed additive interventions to explore if the current available LCA methodologies and background data are sufficiently developed to conclude on the magnitude and certainty of lifecycle impacts of the use of feed additives. This study as such is not a comparative assertion and the use of the results outside the context of this study would require additional assessments on uncertainty, variability and adaptation of system boundaries.

The starting point is a selection of additives that may have a positive environmental lifecycle impact. The efficacy of the feed additives is defined based on an extended set of literature including reviews, meta-analysis, and regulatory documentation (annex 8.1). The effects are defined conservatively per additive to not overestimate impacts and so to have realistic starting points for the road-testing lifecycle assessment studies for pigs, dairy and broilers. The evaluation of the potential zootechnical improvements is done for typical farms for Belgium and the Netherlands, based on the unequivocal potential of the products to be efficacious and expert judgement for the effects to be exerted in the farm system considered (Figure 34).

The road testing assessment brought quantitative results, commented in sections 3 for pig, 4 for dairy cows and 5 for broilers (with all data collected in Annex 0) which are further systematically discussed from a methodological stand point hereafter. This study identified areas of improvement for the harmonization of guidelines towards standardisation and accuracy.

6.1.2 LCA impacts per animal type for the nutritional interventions

6.1.2.1 Pigs

The modelled additives showed improved environmental impact, however in some cases (high dosage feed additive) the impact was counterbalanced by additive production impact, or due to increased impact related to a change in compound feed formulation. More generic conclusions on the full lifecycle of enzymes need further study on the impact of feed formulation (because of the variability on origins, prices and diversity in raw materials and formulation techniques). Changes in manure composition have an effect which is not well captured by the existing guidelines. To better assess the impacts on meat quality effect (Vitamin E) the system boundaries should be extended to include food preparation at consumer stage.

Table 28 Summary of the conclusions from the pig section scenarios

	*Change in focus impact categories**	*Considerations on change in focus environmental impact categories*
Phytase	CC inLUC: -1.9% CC exLUC: -0.9% RI: -0.9% FE: -5.4% ME: +0.1%	Farm and upstream production reduction outweigh additives production. Conflicting guidance on how to account for manure application and co-product allocation. Certainty of the results relies on the solidity of the data related to feed origin, formulation strategies and background dataset.
Xylanase	CC inLUC: -0.2% CC exLUC: -1.0% RI: 0.0% FE: +1.6% ME: -2.3%	Conflicting guidance on how to account for manure application and co-product allocation. Certainty of the results relies on the solidity of the data related to feed origin, formulation strategies and background datasets.
Benzoic acid 5000mg	CC inLUC: -1.2% CC exLUC: -0.7% RI: -7.5% FE: -1.8% ME: -2.8%	For climate change, the reduction in impact is partially counterbalanced by the production of the additive. Respiratory inorganics impact category reduces considerably. Conflicting guidance on how to account for manure application and co-product allocation. Ammonia emissions reduction and FCR variability should be included to improve reliability of the results.

Benzoic acid 10000mg	CC inLUC: -0.1% CC exLUC: +0.9% RI: -11.8% FE: -1.2% ME: -3.1%	For climate change, the reduction in impact is outweighed by the production of the additive. Respiratory inorganics impact category reduces considerably. Conflicting guidance on how to account for manure application and co-product allocation. Ammonia emissions reduction and FCR variability should be included to improve reliability of the results.
Vitamin E	Not evaluated	Impact reduction could not be evaluated, because additive effect is happening outside of the boundaries. Boundaries extension to include downstream food preparation at consumer is needed to estimate this scenario.
All	CC inLUC: -0.3% CC exLUC: -0.1% RI: -11.9% FE: +0.4% ME: -5.4%	Conflicting guidance on how to account for manure application and co-product allocation. Certainty of the results relies on the solidity of the data related to feed origin, formulation strategies, background datasets and FCR variability. Potential synergies among interventions increase the uncertainty of the results.

* Impact categories are: Climate Change including LUC (CC inLUC), Climate change excluding LUC (CC exLUC), Respiratory Inorganics (RI), Freshwater Eutrophication (FE), Marine Eutrophication (ME).

6.1.2.2 Dairy

All feed additives are generating a reduction of environmental impact at farm and in the supply chain to the farm that outweighs the impact of the production of the feed additive.

The more the additive is relying on fertility or health support, the more the results become uncertain because of the complex herd dynamics. When only increased milk production is involved (e.g. amylase), the results are more certain and can be more easily generalized.

Changes in manure composition have an effect which is not well captured by the existing guidelines.

Table 29 Summary of the conclusions from the dairy section scenarios

	*Change in focus impact categories**	*Considerations on change in focus environmental impact categories*
Vitamin E	CC inLUC: -0.5% CC exLUC: -0.7% RI: -1.1% FE: -0.9% ME: -1.1%	Farm and production reduction outweigh additives production. Certainty of the results relies on the solidity of the data related to: variability of zootechnical parameters, modelling of herd dynamics, allocation influence, nitrogen balance limitations and consideration of manure composition changes.
Vitamin (25OHD3)	CC inLUC: -2.0% CC exLUC: -2.1% RI: -2.5% FE: -2.3% ME: -2.5%	Same conclusions as Vitamin E. Since results are more dependent on support of milk production, certainty is higher than for Vitamin E.
Enzyme (Amylase)	CC inLUC: -3.2% CC exLUC: -3.2% RI: -3.2% FE: -3.0% ME: -3.2%	Farm and production reduction outweigh additives production. Certainty of the results relies on the solidity of the data related to: nitrogen balance limitations and consideration of manure composition changes. The direct modelling makes the results more certain than for nutritional solutions affecting herd dynamic.
Vitamin (biotin)	CC inLUC: -2.0% CC exLUC: -2.0% RI: -2.2% FE: -2.0% ME: -2.2%	Same conclusions as Vitamin E. Results being related to the support of milk production, the reliability appears higher than those for Vitamin E and 25OHD3.
Beta carotene	CC inLUC: -0.8% CC exLUC: -1.1% RI: -2.2% FE: -1.8% ME: -2.0%	Same conclusions as Vitamin E. Results being mostly related to fertility support, they appear more uncertain due to modeling complexity.
All additives	CC inLUC: -8.6% CC exLUC: -9.2% RI: -11.0%	The certainty of the results is pending with the variability of zootechnical effects, the modeling of herd dynamics, allocation choices, nitrogen balance limitations and considerations of manure composition changes.

	FE: -10.0% ME: -10.8%	Additionality is increasing the uncertainty.

* Impact categories are: Climate Change including LUC (CC inLUC), Climate change excluding LUC (CC exLUC), Respiratory Inorganics (RI), Freshwater Eutrophication (FE), Marine Eutrophication (ME).

6.1.2.3 Broilers

All feed additives are generating a reduction of environmental impact at farm that outweighs the impact of the production of the feed additive and feed production.

More generic conclusions on the full lifecycle of enzymes need further study on the impact of feed formulation (because of the variability on origins, prices and diversity in raw materials and formulation techniques).

Changes in manure composition have an effect which is not consistently captured by the existing guidelines.

Table 30 Summary of the conclusions from the broiler section scenarios

	*Change in focus impact categories**	*Considerations on change in focus environmental impact categories*
Phytase	CC inLUC: -5,3% CC exLUC: -2.3% RI: -3.2% FE: -6.8% ME: +0.5%	The reduction of environmental impact over the life cycle is much lower than the impact of producing the feed additive. Upstream impact reduction other than reduction of phosphorus use and land use change are significant, but circumstantial and difficult to predict. Impacts in manure application are limited and cannot be assessed conclusively due to limitations of guidelines and methodology.
Protease	CC inLUC: -2.2% CC exLUC: -0.4% RI: -1.6% FE: -1.5% ME: +0.1%	The reduction of environmental impact at farm is larger than the impacts of production of the feed additive. Upstream impact reduction other than land use change are significant, but circumstantial and difficult to predict. Impacts in manure application are limited and cannot be assessed conclusively due to limitations of guidelines and methodology.
Xylanase	CC inLUC: -3.8% CC exLUC: -0.8% RI: +0.1% FE: -2.8% ME: -0.6%	The contribution of the production of the enzyme to environmental impact is low, while reductions of the impacts in other parts of the value chain are circumstantial. Net effects must be assessed on a case-by-case basis.
25(OH)D3	CC inLUC: -0.3% CC exLUC: -0.3% RI: -0.4% FE: -0.2% ME: -0.3%	The reduction of environmental impact at farm and upstream for feed production is larger than the impacts of production of the feed additive, except for the mineral and metal resource use impact categories, where these changes cancel out.
Eubiotics	CC inLUC: -2.9% CC exLUC: -2.3% RI: -3.6% FE: -2.4% ME: -2.5%	The reduction of environmental impact at farm and upstream for feed production is larger than the impacts of production of the feed additive.
All additives	CC inLUC: -8.6% CC exLUC: -3.8% RI: -5.5% FE: -6.6% ME: -3.3%	The reduction of environmental impact at farm and upstream for feed production is much larger than the impacts of production of the feed additive. Impact in manure application are limited and cannot be assessed conclusively due to limitations of guidelines and methodology. Certainty of the results relies on the solidity of the data related to feed origin, formulation strategies and background datasets.

* Impact categories are: Climate Change including LUC (CC inLUC), Climate change excluding LUC (CC exLUC), Respiratory Inorganics (RI), Freshwater Eutrophication (FE), Marine Eutrophication (ME).

6.2 Observations on LCA methodology

The current industry guidelines for environmental foot-printing, such as FAO LEAP guidelines and the related PECRs as implemented in APS-footprint can serve as a basis for modelling the environmental impact of interventions introducing feed additives in modern animal farm systems. However, we identify various points requiring further consideration developed hereafter.

6.2.1 Modelling feed additive production

Models for feed additives are generally not available in databases, so we had to include our own. We could use models developed by DSM and import the LCIs into the tool. This can introduce inconsistencies in the background datasets, because the DSM policy is to use Ecoinvent models for these. There is no practical way to do this with Agri-footprint, because it was not developed for supporting LCA of chemical processes. These inconsistencies are not problematic because the contributions of the ingredients to the impacts are always low or even negligible (with one exception for benzoic acid in pig, where such limitations on the additive production LCI reduce the certainty of the results).

The LEAP guideline for feed additives contains rules for how to model processes for production of feed additives. We ignored these rules, because DSM applies the WBCSD guidelines for LCA of chemical processes [37], which are prevailing for this industry. However, it should be noted that the rules in the LEAP feed additives guideline and the WBCSD guideline for the chemical industry are very consistent. Furthermore, in any case the contribution of the additives to the total footprint is low. Hence our approach is not impacting the overall conclusions.

The guidelines do not contain generic rules for how to deal with fossil carbon embodied in ingredients which are metabolized by the animals. The LEAP guideline for feed requires that embodied fossil carbon in feed is reported, with the intention that LCA practitioners using such feeds as an input can add the emissions in their studies, but this is not mentioned in the guideline. The only guideline that contains ingredient specific guidelines is the EUPEFCR Dairy that says that the carbon dioxide produced from fossil carbon in urea and limestone in the feed should be included as CO_2 emissions in the inventory. We find that a good approach, and for a fair evaluation this should be done for any ingredient with fossil carbon embodied in it. To make sure it cannot be forgotten, and these emissions are effortless and correctly included, we included these emissions in the life cycle inventories of the ingredients, the way it is also done in Agri-footprint, see section 8.4.7. We recommend extending the feed and feed ingredients guidelines with this requirement.

6.2.2 Modelling animal farm interventions

6.2.2.1 Translating published efficacy into LC interventions

The starting point for the feed additive LCA is the definition of the feed additives efficacy. Based on this information, the change scenarios for inventory flows at the animal farm and the related changes in the supply chain “upstream” and downstream for the products leaving the animal farm can be defined.

The methodology used for compiling the additive effects, is described in Annex 8.1, paragraph 8.1.2 and especially in Figure 34. The translation of change in zootechnical parameters into LCI flows is also introduced in Annex 8.1, and detailed in the animal specific chapters (pig in section 3.1.4.2, dairy in sections 4.1.4.2 and 4.1.4.3, and broiler in section 5.1.4.2).

We identified tree main topics:

- **Translating animal health and lifetime performance to LCA interventions.** This is particularly critical when studying effects that change the lifetime performance of the animals. For example, beta-carotene is unequivocally documented to support fertility, but no publication documents specifically its effects on the reduction of the calving interval, while this is needed for the LCA model. As another example, we assumed that 25OHD3 supporting the skeletal strength also reduces mortality, while no publication documents, in a consensual way, the reduction in mortality it may deliver. We dealt with these information gaps by making assumptions, based on educated expert knowledge. Such indirect translation obviously deserves a sensitivity analysis or a more advanced modelling of e.g. herd dynamics.
- **Including the variability of experimental facts in an LCA study.** As elaborated in Annex 8.1, paragraph 0, “quality assessment for the effects”, we explain that we are indeed likely to encounter some variance in the expression of the effects as we deal with complex biologic systems (herd, age, feed, breed, management effects, to name few). Our proposal in the present study has been to consider a default large variance (CV50%) for the effects, to establish a rather wide confidence interval for effects to realise on a farm system meeting the predefined criteria. Such wide interval allows running illustrative

sensitivity analysis, but it remains centred on a mean value which drives the conclusions. If a well characterised corpus of data is available a more precise variability assessment can be done.

- **Degree of certainty for the change scenario to happen in the field.** This question is not specific to the LCA domain and prevails as well for techno-economical decision-making process. One way to increase the certainty of the effects (discussed in Annex 8.1, paragraph 0, on the quality assessment for the effects) consists in setting the effect at a conservative level vs the body of evidence (i.e. one standard deviation below the mean effect) to raise the chance to realise the effect (placing it at 85% instead of 50% when only taking the mean value). For several effects in the present study, we set a modest change scenario to increase confidence in its certainty.

6.2.2.2 Modelling changes in FCR

Animal performance improvement is often reported as improvement of Feed Conversion Ratio (FCR), without specifying whether it is the result of a reduction of feed input not changing production or the other way around, increasing production without changing the inputs. The difference between the two effects is that in case the animals grow faster; the cycle time is reduced and more can be produced on a farm in a year. Hence, the inputs which are fixed per unit of time, like energy consumption and some emissions are reduced per kg of product. In this study we chose to distribute improvements in FCR evenly between increased growth rate and reduced feed intake. This has a negligible impact on the LCA outcome.

In both cases the distribution of feed inputs between animal products and manure changes and the increased productivity goes along with reduced excretion, reducing farm emissions. Changes in manure production and composition have downstream effects which can be included by system extension. This may offset some of the reduction in impact on the farm.

6.2.2.3 Change in herd dynamics

On an animal farm, nutrition and feed additives use, can impact health, longevity and productivity of the animals. We saw this especially in the scenarios characterizing the dairy chapter. This may lead to multiple changes in the herd composition and the balance of products being produced by the farm.

The current LEAP guidelines for feed additives and large ruminants and the PEFCR for dairy do not give any guidance on how to model changes in the herd dynamics, related to changes in the health conditions and productivity of milking cows. As discussed in chapter 4 multiple impacts are related to this, changing the balance in inputs (feed, replacement animals) and outputs (milk, different animal types and manure).

Multiple scenarios can be derived to translate increased health, longevity and productivity to changes in herd composition and inputs and outputs depending on strategy decisions of farmers that can differ per region and type of farm. Methodological guidance on how herd dynamics should be addressed would be helpful to streamline the modelling of such changes.

6.2.2.4 Change in emissions of manure management

Manure management emissions refer to the total of emissions that can happen at an animal farm from excretion till removing the manure from the farm. It involves emissions in the field, in the housing system from the floors and the temporarily storage, from the longer-term storage outside the barns and from manure processing. All these emissions are calculated based on emission models from two main sources (IPCC and EMEP).

The main limitation is that such guidelines are meant to compile emissions estimation at country level, therefore not always adapt well to single farm case scenarios. Modelling manure emission mechanistically rather than empirically would accommodate the more context-specific situations. For this, further research on scientific literature for, or eventually development of, process-based model on manure emissions is recommended.

Another limitation is that IPCC and EMEP are not using the same definitions for the different steps/places of moving manure through the animal farm system.

- IPCC lists a series of manure management system, but do not systematically differentiate between liquid and solid manure management systems nor between housing, storage and "end-of-life" fate (e.g. manure spreading or manure burning).
- EMEP/EEA systematically divides between such categories, but do not differentiate between specific manure management systems (e.g. a liquid storage system might be an anaerobic or aerobic treatment, resulting in different emissions).

Main discrepancy between the two bodies above, is the connection between ammonia and indirect N_2O emissions. Ammonia is estimated by the two guidelines for different reasons: IPCC calculates ammonia to estimate N_2O indirect emissions, while EMEP/EEA aims to estimate ammonia LCI flow itself. Such contradictory modelling rules are especially relevant when modelling ammonia emissions reduction (Benzoic acid scenario in pig, in our study).

Following flows of N and P through the manure management system in a unambiguous way is critical to assure comparability of studies. Also, alignment would allow better capturing the effect of additives or other practices abating ammonia emissions.

6.2.2.5 Change in energy and materials use

In our modelling approach we neglected in many cases that energy use and other materials input can be affected by the FCR effects of the additive. Higher milk production will increase energy use at the farm little bit for milking and cooling. Faster growing broilers will change the ratio between production time and cleaning time slightly which will affect energy and bedding materials in a small extent.

We have not found strong evidence in our case studies that more advanced modelling is necessary, because the contribution of energy and additional materials is always low, and changes are negligible.

6.2.2.6 Lifecycle methodology and emissions modelling at farm level

As stated in chapter 2, the animal farm system should be modelled so that all lifecycle relevant substance flows entering the animal farm (feed, including additives and bedding material) going through the animals and the manure management system can be traced. This means that a balance can be made of ingoing and outgoing substance flows and emissions (to the exception of biogenic CO_2 and N_2 in most cases).

Especially the flow modelling of nitrogen is critical because it is the source of several emissions that contribute to Climate change, Eutrophication, Acidification and Respiratory Inorganic Diseases and it is highly reactive. It is also relevant because it represents fertilization value that can be evaluated by system expansion in the LCA. So, the overall N use efficiency of the system is very important and to define this and the related effects the Nitrogen flows should be modelled well in a balance approach where at every step is defined how much remains in a product and how much is emitted. This also holds for P, Zn and Copper which are much easier to follow because they are less reactive and are simply dispatched over manure and animal products without any losses.

In the LCA model that we applied and built upon the PEFCR for dairy, the PCR for red meat and several LEAP guidelines, N flow through the animals is fully modelled (at least for the pig and broiler, dairy uses a fixed retention factor). Still, other nutrients flows are not fully accounted. Also, the flows of nutrient through the manure management (discussed in previous chapter), through application of manure and connected crop cultivations are considered only indirectly.

This is mainly relevant for internal manure loops happening on dairy farms and their consequential effects. For example, additional N in milk will results in a decrease of N content in the manure. If manure is applied on own feed crop growing, then at some point an adaptation of the farmer can be expected; otherwise the N yields of cultivation will be affected. When and how this happens depends on several factors. For the Dutch and Belgian situation there is some room to not adapt because of the relative high levels of N inputs. This basically means that the nitrogen use efficiency of crop cultivation increases which gives an additional positive effect. However, if the farmer starts compensating with Nitrogen fertilization, the positive environmental impacts of milk production can be reduced again to the effects of the additional inputs. Help on how to model the consequences of the introduction of an additive on the internal manure loops should be added on current guideline, for completeness and consistency reasons.

6.2.3 Modelling of feed supply

6.2.3.1 Representativity of the feed set

In our study, we used a given set of feed recipes having several key traits of typical Belgian and Dutch least cost optimised feeds. These feeds have limited representativity. We used this set to depict a typical re-arrangement of feed ingredients and feed variables, triggered by the use of enzymes. For more robust quantitative conclusions on the contribution of enzymes an extended set of diverse recipes (differing by their nutritional levels and choice of ingredients), crossed with extended time series of price lists would be advisable.

6.2.3.2 Feed formulation without optimisation for environmental footprint

In our study, the least cost formulation was operated in a classical way, for nowadays practices, meaning with no accounting for the footprint of the ingredients in the optimisation algorithm.

The absence of environmental boundaries in the optimization allowed for the inclusion of ingredients not necessarily having a low environmental impact. This has been the case, for example, for the use of the xylanase in pigs which triggered the inclusion of feed ingredients with higher phosphorous emissions to water during cultivation, leading to an increased eutrophication impact (3.3.4). Another example is the low nitrogen benefit for the protease in our broiler study. While protease allowed a reduction of soy products leading to an improved climate change impact, its expected effect on the nitrogen impact is offset by the replacement of feed materials requiring higher nitrogen inputs upon cultivation (5.3.4). These two examples illustrate the importance of feed formulation changes for the LCA results. This needs more attention in future LCA studies on the impact of feed additives.

6.2.3.3 Feed materials origin

In our study, we took either a trade mix (dairy) or effective origin identified for our feed set (pig and broilers).

The FAO LEAP guidelines on feed additives provides examples based on effective origin of ingredients but do not recommend one or another practice. They recommend running a sensitivity analysis for the performance of the animals, in case they would be affected by the change of recipe despite the control of the key nutrients. This latter testing is not an option we took, because of the confidence we have in nutrient control with modern formulation techniques.

To the contrary we deem important to consider with sufficient details the origin of the raw materials as this is greatly impacting the overall footprint of the feed, especially because the origin not only implies transportation expenses but also often relates to a large variability on inventory data for the feed materials (

Table 31, based on Agri-footprint [2]). In some cases, especially for larger countries, country level data might be too generic, and would require distinguishing between different regions.

From a time perspective, having data that are representative for multiple years is important to avoid yearly variation (Agri-footprint cultivations processes are based on 5 years averages). Possibly, data should be based on a recent year range.

Table 31 Climate change of wheat grain, barley grain and soybeans from different origins

Product	Climate change - excl LUC kg CO_2 eq./kg product	Climate change – LUC kg CO_2 eq./kg product
Wheat grain/NL	0.51	0.0035
Wheat grain/DE	0.33	0.01
Wheat grain/CA	0.39	0
Wheat grain/BR	0.57	3.70

Wheat grain/AU	0.48	0.36
Soybeans/US	0.30	0.016
Soybeans/TR	0.39	0.015
Soybeans/IT	0.52	0.15
Soybeans/BR	0.35	5.25
Soybeans/AR	0.27	5.21
Barley grain/UA	0.50	0
Barley grain/RU	0.43	0
Barley grain/PL	0.45	0
Barley grain/NL	0.48	0
Barley grain/FR	0.35	0.14

6.2.3.4 Feed materials data (secondary data quality and proxies method)

The main data source for feed materials was Agri-footprint 5.0. Some ingredients in the feed formulations were not available in the background dataset, therefore were based on other recognized databases (e.g. Ecoinvent). On other occasions, additional data sets were developed, or proxies were made.

Generic indication of which databases can be used can be found in LEAP guidelines. Still, we suggest to always avoiding mixing different background datasets and align as much as possible with the GFLI database. In one specific example (phytase addition in pig), this resulted in a high overestimation of the reduction in mineral scarcity. This was in part due by different assumption on capital goods between Agri-footprint and Ecoinvent, but also due to the general more detailed approach on chemical processes of Ecoinvent.

For future studies, it would be meaningful to account for data quality rating (DQR) and uncertainty ranges of the background datasets and to connect this to a proxy methodology inspired on the Feed PEFCR method where the DQR is also leading for the qualification if the study is PEF compliant.

6.2.4 Modelling other upstream processes

Other upstream background processes than feed (piglets, 1d chicks, reared piglets, straw, water…) and their selection can affect the results. This is connected to the contribution of such upstream life cycles in the overall impact. High attention should be put on piglet rearing, or other animal systems connected to the considered animal farm. Straw input might also be characterized by large variability (as for the feed discussion), even though the contribution to the overall impact is generally low. Of less importance can be considered energy and water input, except for some specific impact category (fossil resource scarcity and water scarcity, respectively).

In general, expanding the analysis with DQR and uncertainty ranges of background dataset will help estimating the reliability of the results, and potentially indicate main source of uncertainty that require quality improvement. Furthermore, this should be performed to support comparative assertions[9].

6.2.5 Modelling downstream changes

Downstream the farm involves all the operations occurring with products coming from the farm. So, this involves in this study, manure, live and dead animals and dairy.

6.2.5.1 Manure usage outside animal farm

Manure that leaves the farm can have several fates. Quite common is transporting it, unprocessed, to nearby farms where it is applied for cultivation. In Belgium and the Netherlands this is indeed a regular practice and it is then for the greater part applied in open field farming. There are several other routes for manure that become increasingly important such as separation in a liquid and solid fraction, (co-)digestion, incineration with energy recovery.

To properly model the impacts of change for all these routes a system expansion approach is needed that includes several consequential steps. By using feed additives, the composition of manure can change which leads

[9] ISO 14044 - Environmental management — Life cycle assessment — Requirements and guidelines, ISO, 2006

to a change in emissions when converting manure (during separation or processing) and when applying the final products. The use and processing of manure also leads to avoidance of use of replacing products such as fertilizers, other organic matter sources, heat, gas and electricity. To capture these changes, methodology is needed on how to define replacement scenarios in a realistic and unambiguous way. The PCR for red meat gives some direction but more specific guidance on the definition of realistic manure fate scenarios is needed.

6.2.5.2 Changes at processing, retail and use related to changed product quality

Due to the use of additives the composition and the functionality of the animal products may change. This is partly captured by the reference unit of milk if the protein fat ratio changes. But changes in lactose, protein, vitamin and minerals content are not captured. For broilers and pigs there are no specific attributes added to the reference unit that includes nutritional or quality aspects.

As this study showed various improvement are needed to model additives that affect the product quality:

- Changes in wastage in the retail and consumer phases can be captured by full cradle to grave modelling or extended cradle to grave as long as it includes all changes.
- Changes in animal composition (e.g. more breast meat) can be captured through allocation. This can be done by biophysical allocation if able to account for changes in animal composition, or with economic allocation. Also, the current recommendations in the guidelines about this topic can be made more unambiguous.
- Changes in nutritional quality of animal products can be captured by accounting for nutritional quality in the functional unit, or through allocation. Still, since nutritional requirements of the diet can be modelled, consequential modelling of nutrients substitution or compensation should be considered. This needs a big extension of system boundaries because compensation scenarios can be defined in many ways.
- Changes in co-product output (such as liveweight reduction in case of dairy intervention) might require substitution of meat from culled cows or calves. To further investigate such implications, a consequential analysis should be considered.

6.3 Defining scenarios in relation to goal and scope of study

One of the main observations in our process of interpreting the results of the road-testing studies is the criticality of goal and scoping of the LCA study. Feed additives are produced to be applied for creating additional value in animal production. This value is now mostly targeted on improving performance at the farm or reducing costs in the feed production chain.

The case studies that we performed were based on the current way of feed additive application in the Dutch/Belgian situation. For several feed additive applications (especially enzymes) current use is targeted to maintaining performance at the farm and enabling the use of other sources of feed. This can reduce the cost price of the feed. However, such an approach is not necessarily consistent with maximizing the reduction of environmental impact. As we have discussed in section 6.2.3.2 the changed feed formulation will not automatically give better performance. If we would have started from the research question how the additive can be applied to reduce environmental impact and improving value chain performance other change scenarios would have been defined accordingly.

Another topic is the specificity of the system for which the feed additive application is evaluated. There can be two approaches defined which can be seen as complementary. One approach is related to substantiating an environmental claim for a certain way of farming in a certain region, e.g industrial pig farming in Western Europe or industrial Broiler farming in Thailand. The region and typology then define a certain animal performance, farm design and feeds being used including the variability therein. An LCA research question would then be “what is the likely minimal impact of applying a feed additive in a certain way in a region in the coming 2 years?”. If we look at the application of xylanase for pig production, such a research question would require estimating the variability connected to the farm systems in the time and region considered (including compound feed formulation variability), investigating uncertainty connected to background dataset and estimating the variability connected to the least cost reformulation (and to additive efficacy). The first requirement is particularly complex, and could be done by stratifying the farm systems and defining typical systems per stratum.

Then, we come close to the other approach which is targeted to the assessment on specific farms. The research question can then be phrased specifically targeted to a farm situation focusing on how one feed additive or multiple feed additives can be applied in combinations with other solutions to reduce environmental impact and improve a specific farm performance at the same time.

In the current available methodology documents, guidance on how to do such assessments is lacking still and we recommend expanding on this in future updates. This holds for the feed additives guidelines but also all other guidelines do not give any guidance on how to study improvements in relation to the system considered.

6.4 Further standard and guidelines development

6.4.1 Aligning of standards and guidelines

We experienced some discrepancies while implementing the various methodological guidelines available. In particular, we recommend alignment towards consistency between guidelines of the same framework, such as LEAP guidelines. This is needed to perform assessment of the whole life cycle of a product, without incurring in methodological discrepancies. Main issues of concerns are:

- **Emissions coverage**. For example, the LEAP poultry guideline only considers greenhouse gas emissions and energy consumption, whereas other species guidelines include more impact categories. For a specific species study this is not an issue but for stakeholders interested in several species this might create confusion.
- **Rules applicable to co-product allocation and manure as output**. For poultry for example the species guideline for GHG emission and energy says that manure should be treated as a residual product, whereas the nutrient flow guideline says it should be treated as a co-product.
- **LCA scope (databases, impact assessment methods).** Differences between LEAP and PEFCR include inconsistencies in allowed databases, use of primary versus secondary data, scope and impact assessment methods. To some extent these are related to the different objectives of the two types of guidelines. For LCA users in the field the existence of competing sets of guidelines is challenging.
- **Consideration/integration of sector specific guidelines.** In the case of additives manufacturing, an initiative of the chemical sector led to the elaboration of actionable consensual guidelines [37], applicable to additives manufacturing and other similar products. These guidelines fit more accurately to additives manufacturing than the LEAP ones [1] which give broader instructions and thus more room for interpretation. Stepping on sectorial guidelines and organising the subsidiarity, after expert evaluation, would allow leveraging existing work and upgrade thereof authoritative harmonised guidelines.

It would also be beneficial if, for feed materials, one secondary database would be assigned by the various guidelines. It should contain detailed and updated data on cultivation (with regional resolution when needed), with calculation rules that are compliant to guidelines. The recently established Global Feed Lifecycle Institute (GFLI) database would be a potential candidate because they aim to become the leading global LCA database for the sector.

6.4.2 Updating of standards and guidelines

The current PEFCR and the LEAP feed guidelines have a strong attributional focus meant to measure the impact of an existing animal system or for performance tracking over time when changes in the system are made. In this section we aim to discuss several elements that needs attention when updating the attributional calculation methods.

The emission calculation of NH_3, NOx, N_2O and CH_4 play an important role in the overall results. All emission calculations implemented are based on international guidelines such as NIR, IPCC and EMEP/EEA. Even though such calculation rules (and emissions factors) contain assumptions and uncertainties, they are generally regarded as reliable and a consistent way of approaching emissions at animal farms, especially when analysing a theoretical national-average system. As we showed for the dairy system, methane emissions can be calculated with different algorithms. This did not turn out to have a big impact in our case, but it can be significant in other cases. The current guidelines are ambiguous on the matter which specific (TIER) level of emission calculation should be used. The FAO LEAP guidelines for large ruminants prescribes the use of the highest available TIER level (used for national GHG monitoring) in a country. The dairy PEFCR leaves this intentionally open for the user. There the decision needs to be made in relation to the goal and scope of the study. The FAO leap guidelines for pigs is not saying anything about preferred TIER level to use.

Possibly, incongruent emission rules for the same emissions should be aligned (EMEP/EEA ammonia emissions and IPCC ammonia emissions used to estimate N2O indirect emissions). Also, manure management modelling between EMEP/EEA and IPCC is different and creates complexity and unclarity. Guidelines such as PEFCR and LEAP should give guidance on how to merge the two approaches.

Sometimes the examples do not match with the guidelines. For example, the LEAP Guideline for allocation at the broiler slaughterhouse state (not very clearly) that economic allocation between the products should be applied and that for this purpose average prices for the major product classes, including all edible part as one class should be used). The example given includes different prices and allocation factors for different edible parts and also mass allocation information.

6.4.3 Extension of standards and guidelines

As explained, the several LEAP guidelines and PEFCRs have an attributional orientation and give, apart from the feed additives guidelines, hardly any guidance on how to deal with the modelling and evaluation of changes in the animal farm system. It is our expectation that future LCAs in the animal sector will be more and more targeted on how to define interventions that improve the environmental performance of the system. This means that there is much more need for guidance on how to study changes. Our recommendations are focusing on feed additives, but similar considerations can be made for any other intervention at farm level that affects performance of animals.

The LEAP feed additive guidelines were the first in the series of guidelines that have the goal to evaluate changes, but they overlooked quite some details needed for decision-making in various situations and they do not cover the complete scope of potential changes in the system. For instance, they do not address the improvement of the lifetime performance of the animals (higher longevity, higher fertility, health status). We assessed such effects for the dairy case and showed that they could have significant environmental effects. Also, they do not address effect that may occur downstream at manure application and for the animal products at retail or consumption. We would recommend adding this in future updates of the guidelines.

In section 2.1 we introduced a more complete conceptual evaluation framework where the additional impact of producing and supplying feed additives is related to the summarized reduced impact at animal farm, upstream supply chain and downstream value chain. It would be beneficial for stakeholders if there was a more guided and uniform way of achieving such insights and have more detailed guidance on how to calculate impacts at the animal farm, upstream supply chain and downstream value chain.

For the production of feed additives, we recommend considering the following potential extensions:

- Add guidance on accounting for fossil carbon release of additives use at production of additives.
- Align with existing sectorial guidelines for producing chemicals [37].
- Generate a more extended secondary LCA database for feed additives, potentially in cooperation with GFLI.

For the animal farm we concluded that more detailed guidance is needed on:

- The efficacy definition of feed additives for the animal farm system in scope.
- Translating the efficacy to the LCI change scenarios at animal farm regarding inventory flows and inputs and outputs of products and their composition. This is especially relevant where herd dynamics are affected.

- Detail of emission calculations (which TIER level is appropriate), solve incongruence on ammonia emissions estimations and further guidance on bridging EMEP/EEA with IPCC manure management approaches.
- The use of substance flow analysis through the animal fam.
- How to model intervention that affect the balance between dairy animal farm and on-farm cultivation (on-farm manure loops).

For the upstream LCA impact modelling we concluded that a feed additive induced change in feed ingredients depends on availability and prices of the feed ingredients in a certain region and at a certain point in time.

- Guidance is needed how to conduct the assessment of change taking into account the (now price driven) feed formulation process considering the goal and scope of the LCA.
- Further guidance is also needed on the selection of origin of feed ingredients and how to deal with data gaps. The Feed PEFCR gives guidance on this but this needs improvement regarding impacts of feed additives.
- It is also recommended to generate a secondary database for replacement animals and other inputs (such as bedding materials) and energy and transport that contain a certain granularity with region and production system specific products.

For the downstream impact we concluded that:

- One recognized approach is needed on how to model changes in manure composition when leaving the farm.
- More guidance is needed on how to do the LCA when product quality is affected.

In the PEFCR framework, a guideline for poultry is missing. For consistently working on different species, it would be beneficial if there was one. On the other hand, it may introduce new inconsistencies with the LEAP guidelines. In any development the utmost should be done in cross referencing and consistency.

7 General conclusion

The study confirms that the available sector LCA guidelines as implemented in the APS-footprint tool, can be used to evaluate nutritional interventions improving animal productivity, animal health, lifetime performance or emissions. However, they can still be significantly improved.

The road testing allowed identifying spaces where the existing guidelines would deserve being more specific to confer more robustness to the LCA outcome. This is the case, in particular, for the accounting of the variability and uncertainty of the additive zootechnical effects and its translation in an LCA model; for the accounting for changes in production and composition of manure leaving the farm, and for the modelling of nutritional interventions that act on product quality and subsequent stages in the value chain. The study also highlights the pivotal role of feed formulations to derive robust conclusions. The way these dilemmas are managed by LCA experts may affect the study outcome to a large extent. Hence the need for a clear guidance on the quantification of uncertainties and variabilities as well as guidance on how to properly support comparative assertions.

The study also confirmed that the use of feed additives may have a positive environmental impact over the entire lifecycle. Except in one case (for a product with a high inclusion rate), the environmental impact of the production of feed additives is confirmed to be negligible compared to the positive impacts realized in animal production. The assessment indicated that the total impact reduction can amount to up to 10% (cumulative effect for some impacts and some species).

Improvement in animal productivity and specific reduction of emissions confirm the concrete effects of feed additives with regards to the reduction of livestock footprints and are relatively easy to model. Environmental benefits provided by feed enzymes on feed formulation requires extended information on feed recipes to be properly generalized. Our study evidences the need to integrate the footprint of ingredients as feed formulation optimization criteria, rather than as a calculated outcome, to fully capture the potential of feed enzymes to minimize resource use. It also confirms the significance of the contribution of phytase to abate phosphorus and nitrogen related impacts on farm. Finally, solutions supporting the lifetime performance of the animals (longevity, fertility, health status) also indicate a potential for environmental impact reduction although requiring sophisticated modelling of herd/flock dynamics.

These results confirm the important role that feed additives can play at farm level in achieving sustainability improvement plans and the multiple LCA case studies (multi species, multi-interventions) provide an opportunity to detect and discuss pathways for improvements for livestock sectorial guidelines, while verifying the actionability of systematic foot-printing approach.

8 Annex

8.1 Effects substantiations

8.1.1 Introduction

Several nutritional solutions have been selected for their diversity, their independency one from another, their known and peer reviewed track records in field applications and their actionability in a European context, with the aim to quantify their environmental impact using LCA and resorting to available guidelines.

Not all solutions available to feed formulators and zootechnicians have been considered, only some representative examples have been documented and the target species studied in the exercise are limited to broiler chickens, dairy cows, and pigs for fattening.

The nutritional interventions considered consist in practical inclusion of commercially available[10] additives into animal feed.

The present section gathers the types of average effects attributable to the additives: their dimensions, their articulations one with another and their bibliographical substantiations. The effects excerpted for the calculation of the environmental impact are not necessarily the maximum reported effect. To the contrary, a conservative approach has been adopted, capturing mild effects reasonably obtained in average field situations.

A quality assessment along the recommendations of the LEAP guidelines for feed additives [1] is proposed in Annex 8.1.

8.1.2 Methodology

8.1.2.1 Target species considered

Three terrestrial target species have then been considered for the exercise: chickens for fattening, dairy cows, and pigs for fattening. The solutions are only applied to given production stages of the whole life cycle of the animal systems. Not all phases could be considered for the interventions:

- In pigs, only interventions in the fattening phase (from about 25 kg until about 100 kg) have been considered. Nutritional solutions applicable to sows and piglets have not been considered.
- In dairy cows, only interventions on dairy cows (producing and dry) are considered. Nutritional solutions applicable to calves, young bulls, or heifers have not been considered.
- In broiler chickens, only interventions on the chicken fattening phase (day 1 to day 42 of age) are considered. Interventions in the breeding phase are not in scope.

8.1.2.2 Selecting and documenting the effects

The criteria for the selection of the nutritional solutions have been:

- diversity,
- independency one from another, known track records in field applications and
- actionability in a European context.

The number (n=14) and diversity of solution studied (digestibility enhancers, eubiotics, vitamins, carotenoids) allows defining a large basis for the testing of the LCA guidelines.

The independency one from another allows proposing a cumulative effect thereof further quantifying the potential of feed additives to help mitigating the emissions from livestock.

[10] Only one solution considered for dairy cows is not yet actionable for EU production systems as the corresponding feed additives is not yet registered in Europe for this purpose: 25OHD3 for dairy cow.

Each nutritional measure is documented with:

- Its mode of action (to justify for their independency one from another and their possible extrapolation beyond the reference systems defined). For the dairy case a specific model is proposed to handle the fact that several solutions can affect a common end point (i.e. several solutions impact the quantity of milk produced or cows longevity);
- Its conditions of use (required supplementation dose in feed to deliver the effect which is modelled) to allow including the additive LCI input in the LCA;
- A non-exhaustive set of peer reviewed publication substantiating the effects, gathering whenever possible reviews and/or meta-analysis and/or regulatory opinions.

Based on the literature which establishes unequivocally that the feed additives have the potential to be efficacious on the production traits considered, and, based on expert knowledge for applicability of the solution to the reference systems considered, including integration in multifactorial approach (in the case of dairy), a set of improvement factors is finally proposed (8.1.6), with a conservative approach, for their uptake in the LCA with the primary intent to test the applicability of the existing LCA guidelines to capture the effects attributed to feed additives.

The process applied to set the intervention is illustrated in Figure 34, starting from the grounding on a collection of peer reviewed publication:

- The extent of the zootechnical effects reasonably obtained in the reference farm considered (at herd/flock level) are set and articulated one with another, based on expert knowledge. The approach is documented and explained transparently. In the specific case of dairy, having had to accommodate interventions that have multiple impacts on the herd.
- The way the feed enzyme is accounted for in feed formulation is defined, is also based on expert knowledge as well and is documented transparently (matrix values for the enzymes and detailed feed recipes are available in the report).

In the following paragraphs, we elaborate on the solutions considered for each species.

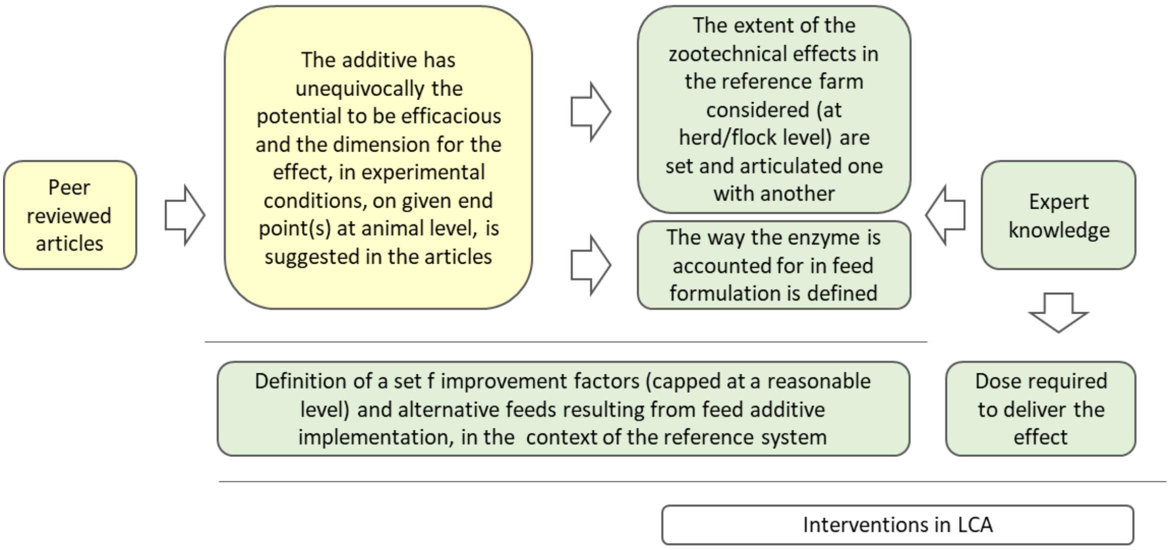

Figure 34 Definition of the improvement factors further evaluated in LCA

8.1.3 Solutions applicable to pigs for fattening

8.1.3.1 Phytase

Supplementation of monogastric feeds with exogenous phytases is current practice since the early 1990s. Adding the enzyme to the feed allows the release of the phosphorus present as phytic acid and phytate in all the plant raw materials within the feeds. Such supplementation improves the availability and digestibility of organically bound plant phosphorus and calcium, leading to reduced use of inorganic mined phosphorus in feed formulations and the subsequent decrease in phosphorus excretion to the environment. This formulation technique has been extensively reviewed in pigs [98] including for its environmental benefit [99, 100, 41, 42] owing to the sizable reduction of phosphorus excretion enabled.

An amino acid contribution has been attached to the phytase, based on the evidence gathered [43] on the release of extra amino acids taking place with phytase addition.

The feed formulation matrix values (i.e. the nutrient supply triggered by the enzyme upon feed formulation) for the phytase is proposed in Annex 8.1 (Table 40). In the present study, the phytase supplies extra phosphorus, calcium and amino acids. The effect on the feed formulation can be consulted in the feed recipes provided in Annex 8.2.

The dose required for the effect is 100, 50, 20 mg/kg feed in each of the phases from 25 to 100kg, averaging 30 mg/kg feed when weighting based on the feed consumed throughout this period[11].

Because of the industry's systematic phytase supplementation, the present study considers a baseline with phytase addition. However, to exemplify the benefit of a nutritional solution made available in the 1990s, the footprint of pig feeding without phytase addition is also assessed as a historical scenario.

Our study considered conventional doses of phytase. However, there is an emerging trend in both poultry and swine for phytase inclusion concentrations in feed to increase in order to generate more digestible nutrients and further reduce use of finite resources in feed. This trend deserves further attention in the near future to further improve precision in the magnitude of value created from this feed additive.

8.1.3.2 Xylanase

Xylanase (a carbohydrase feed enzyme) enhances the digestion of the complex carbohydrates present in the feedstuffs constituting the feeds. This is very relevant for wheat and barley-based diets, which are typical of European feed recipes.

A review [98] and a regulatory assessment [108] have been considered to justify the extra energy value conferred to the wheat used in the reference feeds, when the feed is supplemented with a carbohydrase. An earlier LCA study already assessed the environmental benefit of a pig diet supplemented with a xylanase [44].

The feed formulation matrix values (i.e. the nutrient supply triggered by the enzyme's effect on the feed formulation) for the xylanase is proposed in Annex 8.1 (Table 42). In the present study, the xylanase confers extra energy to the wheat. The effect on the feed formulation can be consulted in the feed recipes provided Annex 8.2.

The dose required for the effect is 100 mg/kg feed[12].

8.1.3.3 Organic acid, benzoic acid

In a similar manner as for broilers, various feed additive concepts have been proposed to improve nutrient utilization and support gut functionality in pigs, which ultimately can translate into increased production performance, enhanced resilience to diseases, and welfare. Probiotics, prebiotics, enzymes, organic acids and/or phytogenic components, a cluster of products that are referred to as eubiotics (as a result of their support to the digestive physiology as a whole), have been shown to support feed utilization, in addition to their specific benefits in certain health markers. The resulting improved feed conversion rate (FCR) reduces the amount of feed and the agricultural goods constituting them needed per kilo of live weight. This is of high value for the pigs in the fattening phase that have a high feed intake.

In our study we considered, as a eubiotic solution applicable to pigs for fattening, a supplementation with benzoic acid (composition in Table 39). Benzoic acid supports the functioning of the digestive tract via acidification of the digesta, as other organic acid would do [45, 46, 47, 48]. Its beneficial effect on feed utilization has been

[11] The reference product for the DSM authors is RONOZYME® HiPhos 20000 (GT)
[12] The reference product for the DSM authors is RONOZYME® WX 2000 (CT)

documented not only in piglets but in pigs for fattening, including at rather low dose and positively reviewed by the EU safety agency on additives, products or substances used in animal feed (EFSA Feedap, [49). Studies compiled in the EFSA opinion, dedicated to pigs for fattening, show an improvement of the FCR by 2% on average with 3000 mg/kg feed, while additional benefit (FCR +3%) are shown with 5000 mg/kg [50].

An additional trait, which is specific to benzoic acid, is it conversion to hippuric acid (its lead metabolite) in the urine [51, 52, 53] , which results in urine acidification and subsequent lower potential for ammonia emission from manure[13] [54, 55 and 56]. Overall, from the literature a reduction of ammonia emission by 20% is documented for a dietary dose of 10 000 ppm while 10% reduction is assessed when the dose is halved.

This solution had been evaluated by EIPPC as an available technique to abate ammonia emission from intensive rearing of pigs[14]. This solution has also been listed by the Belgian and Dutch authorities as practical measures to reduce ammonia emissions from pig farms [15].

In Europe, the product is authorized for both performance support and urinary pH decrease up to 10 000 ppm.

In our evaluation we study two interventions[16]:

- 5000 ppm, FCR -3%, ammonia emission -10%, depicting possible nowadays practice;
- 10000 ppm, FCR -3%, ammonia emission -20%, illustrating the ammonia mitigation potential of benzoic acid.

The benefit in FCR is modelled in the LCA study as both a lower feed consumption and a faster growth rate, in equal contribution. No information available today would substantiate a further reduction in FCR when setting the dose at 10 000 instead of 5 000 ppm.

8.1.3.4 Vitamin E

Oxidation of lipids is a major cause of deterioration in the quality of meat. Oxidative processes (measured via TBARS) lead to the deterioration of flavour, odour and colour of meat. The role of vitamin E, as a lipid-soluble antioxidant, has been investigated for several decades and shown to stabilize animal products. Several reviews and studies have been published for its specific effect on fresh pork meat [57, 58, 59, 60, 61, 62, 63, 64 and 65] at biochemistry level and for rancidity parameters. Many publications are also available for poultry and beef meat on the same topic with concurring elements. From the referenced publications and particularly from the data published in [63] and [65] that developed a shelf life extension approach, beyond biochemistry data, it is derived that the shelf life of pork meat from pigs that consumed high levels of Vitamin E is extended, by several days (possibly 4 to 6d) compared to pigs fed a basal level of Vitamin E. This is corresponding roughly to a doubling of the shelf-life duration, with minimal alteration of lipid oxidation, water holding capacity and meat colour.

Such improvement of meat quality is achieved by feeding high levels of vitamin E (100 to 400 mg/kg feed) in the finishing phase (compared to about 50 mg/kg[17]) for a basal diet.

Crossing those findings with data available on the meat losses occurring at household, food service and retailer (which have been assessed to amount about 17% of total meat available [66]) and assuming that 50% of those losses are due to rancidity reasons, while 10% of these would have been spared with an extended shelf life. The reduction of meat waste by the nutritional interventions can be assessed at about 5% (hyp. 1 in Table 32).

[13] AARNINK and NIJEBOER (2008) Ammonia emission factor for using benzoic acid (1% VevoVitall) in the diet of growing-finishing pigs. Report 133

[14] BREF. Best Available Techniques (BAT) Reference Document for the Intensive Rearing of Poultry or Pigs. Industrial Emissions Directive 2010/75/EU Integrated Pollution Prevention and control. 2017. EUR 28674 EN

[15]PAS “programmatische aanpak stikstofemissie” and “Stoppersregeling”.

[16] The reference product for the DSM authors is VevoVitall®

[17] DSM recommendation (OVN, 2016) for vitamin E is 60 to 100 mg/kg feed)

Table 32 Estimation of the meat losses sparing effect via action on the rancidity

	Hyp 1	*Hyp 2*	*Hyp 3*	*Hyp 4*
Meat waste at retailer and consumers level	17%	17%	17%	17%
Share of the waste allocated to rancidity/oxidation reasons (hyp)	**50%**	**50%**	**25%**	**25%**
Share of the waste not allocated to rancidity/oxidation reasons	50%	50%	75%	75%
Meat wasted for rancidity/oxidation reasons	9%	9%	4%	4%
Meat spared from rancidity/oxidation by Vit E (hyp)	**10%**	**20%**	**10%**	**20%**
Meat wasted for rancidity/oxidation reasons with intervention	8%	7%	4%	3%
Meat waste at retailer and consumers with Vit E	16%	16%	17%	16%
Meat sparing	5%	10%	2%	5%

In the present study, 200 mg Vitamin E[18] per kg feed, fed during the phase when the animal weighs between 80 to 100kg, is considered to reduce meat usually lost at household, food service and retailer for rancidity reasons, by 5%.

NB: this intervention has nowadays some limited applicability due to its high cost which restricts its application to very specific cases.

8.1.4 Solutions applicable to dairy cows

8.1.4.1 b-carotene

Beta-carotene is documented for its effect on cow fertility, via its antioxidant effects. Several publications have shown its contribution to the various aspects of optimal reproduction cycles [67, 68, 69, 70, 71 and 72] leading overall to a higher fertility rate. Furthermore, a recent study conducted in the Netherlands diagnosed plasma levels of beta-carotene in a dairy herd below estimated required levels, confirming the opportunity for supplementation [73].

An integrated approach on the beneficial effect on fertility delivered by supplemental levels of beta-carotene is dealt with in the paragraph 8.1.4.6.

The dose needed to deliver the effect described is 500 mg/head/d during the dry period and 300 mg/head/d during the lactation period[19]. This shall compare to a dose of 300 mg/head/d evenly given throughout all periods.

8.1.4.2 25-hydroxycholecalciferol

25-hydroxycholecalciferol (abbreviated as 25OHD3, the active form of Vitamin D) is considered for its documented positive effect on fertility [74], udder health [75, 76] and milk production [75, reporting a 10% higher milk production[20]]. Its contribution to peri-partum calcium homeostasis [74, 77, 78] is also accounted for based on the reduction of calcium metabolic syndrome occurring for some cows, upon the onset of lactation..

[18] The reference product for the DSM authors is ROVIMIX® E-50 Adsorbate.
[19] The reference product for the DSM authors is ROVIMIX® β-Carotene 10%.
[20] Additional papers (abstracts) pointing at a potential for 25OHD3 to support milk production (+13%, +5%,+10% milk) are:

- POINDEXTER M.B:, VIERA-NETO A., HUSNAIN A., ZIMPEL R:, FACCENDA A., SANCHEZ de AVILA A., SILVA A., CELI P., and CORTINHAS C. 2019. Effects of dose and source of Vitamin D on mineral homeostasis and performance iin transition cosw. Abstract. 2019 American Dairy Science Association Annual meeting.
- RIBEIRO I.C.O., SILVA R.B., RESENDE L.N., PEREIRA R.A.N., CORTINAS C.S., ACEDO A.C.C., LACRETA JUNIOR and PEREIRA M.N. 2019. Calcidiol increased milk yield and receduced somatic cell count of late lactation dairy cows. Abstract. 2019 American Dairy Science Association Annual meeting.
- SILVA A., CORTINHAS C.S., ACEDO T.S:, MORENZ M.J.F., LOPES F.C.F., ARRIGONI M.B., FERREIRA M.H., JAGUARIBE T.L. 2020. Effects of dietary 25-hydroxyvtamin D3 for prepartum dairy cows receiving acidogenic diets. Abstract. 2020 American Dairy Science Association Annual meeting.

An integrated approach to the extent of the beneficial effect on fertility, udder function, milk production and calcium homeostasis potentially delivered by supplemental levels of 25-hydroxycholecalciferol is dealt in the paragraph 8.1.4.6.

Doses considered to deliver the described effects are 3 mg/head/d during the dry period and 1 mg/head/d during the lactation period[21]. This compares to a Vitamin D dose of 20000 IU/head/d evenly given throughout all periods.

25-hydroxycholecalciferol is not available yet for commercial dairy feeds in the EU market as the product is about to seek for authorization as a nutritional feed additive for dairy cows (while 25-hydroxycholecalciferol is already authorized in EU as a feed additive for pig and poultry).

8.1.4.3 Vitamin E

Vitamin E is considered for its documented effect on fertility and udder health [79, 80, 81, 82), via its anti-oxidant effect. A meta-analysis on the potential of Vitamin E to support udder function [81] established a notable decrease in the risk of occurrence of udder disorders, when feeding high levels of Vitamin E. In this meta-analysis, vitamin E supplementation is associated with a 30% decrease in the risk of occurrence of mastitis.

An integrated approach to the extent of the beneficial effect on fertility and udder health to be possibly delivered by supplemental levels of vitamin E is dealt in the paragraph 8.1.4.6.

The dose needed to deliver the effect described is 1000 mg/head/d vs 750 mg/head/d for the base line[22].

8.1.4.4 Biotin

Biotin is considered for its effect on hoof health, via its role on horn tissue synthesis, and consequent influence on animal locomotion. A decrease in the incidence of lameness with biotin addition is documented [83, 84,] and inferred to lead to a slightly higher milk production thanks to an increased access to feed and enhanced welfare [86]. A direct contribution of biotin to milk production support is also documented [84, 85] and accounted for.

An integrated approach to the extent of the beneficial effect on milk production to be possibly delivered by supplemental levels of biotin is dealt in the paragraph 8.1.4.6.

The dose needed to deliver the effect described is 20 mg/head/d vs 15 mg/head/d for the baseline[23].

8.1.4.5 Amylase

An amylase allowing an enhanced digestion of starch from cereals present in the complementary feed provided to dairy cows (in addition to forages) is considered for its favourable effect on milk production: Its documented effect [87, 88, 89, 90], relies on an optimized energy metabolism of the rumen via production ad hoc volatile fatty acids without pH decrease.

An integrated approach to the extent of the beneficial effect on milk production to be delivered by addition of a amylase in the diet of dairy cows is dealt in the paragraph 8.1.4.6.

The dose needed to deliver the effect is 12,5 g/cow/day[24]. The baseline considers no enzyme addition.

Note 1. The efficacy of amylase would be conditioned by the presence of corn in the concentrate feed which is maximising the effect of the enzyme.

Note 2. The amylase studied is only approved in Europe for the 1st 100d of lactation. Efficacy is sustained beyond the 1st 100 days, but EU authorities deemed the submitted data set insufficient to grant the corresponding approval beyond 100d of lactation.

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[21] The reference product for the DSM authors is ROVIMIX® Hy·D® 1.25%.
[22] The reference product for the DSM authors is ROVIMIX® E-50 Adsorbate.
[23] The reference product for the DSM authors is ROVIMIX® Biotin HP.
[24] The reference product for the DSM authors is RONOZYME® RumiStar 600 (CT).

8.1.4.6 Compiling and defining the effects in dairy cows

8.1.4.6.1 Overall approach

As several interventions may have common end points (i.e. several solutions have the potential to increase fertility or milk production at the animal level), while the cow has a given limited potential to adjust towards maximum performance, the model illustrated on

Figure 35 (and copied as Figure 15, earlier in the document, to facilitate the reading), is proposed to capture the effect of the respective dietary measures, not necessarily all implemented at the same time.

- A reasonably achievable improvement in the key production parameters is defined. These improvements are defined based on expert knowledge on the potential change which can be achieved with nutritional measures, in view of the baseline defined. For example, for milk production a maximum increase of 7.9% is set corresponding to a 2 additional kg of milk per day. For fertility a reduction by 10d of the calving interval is defined as the improvement achievable. These parameters are listed in Table 33.
- An allocation of the beneficial effects is proposed (Table 34), also based on expert knowledge of the respective impact of the solutions considered and documented in the previous paragraphs.
    - At animal level, in our model, each solution would then not contribute more than allowed by the animal potential and by its share to the improvement.
    - At herd level some extra benefit may occur as a result of more animals moving to an optimal health status.

As for all the effects considered in this study, a conservative approach has been adopted, i.e. not considering the maximum documented effect, but accounting for mild effects reasonably obtained in average situations.

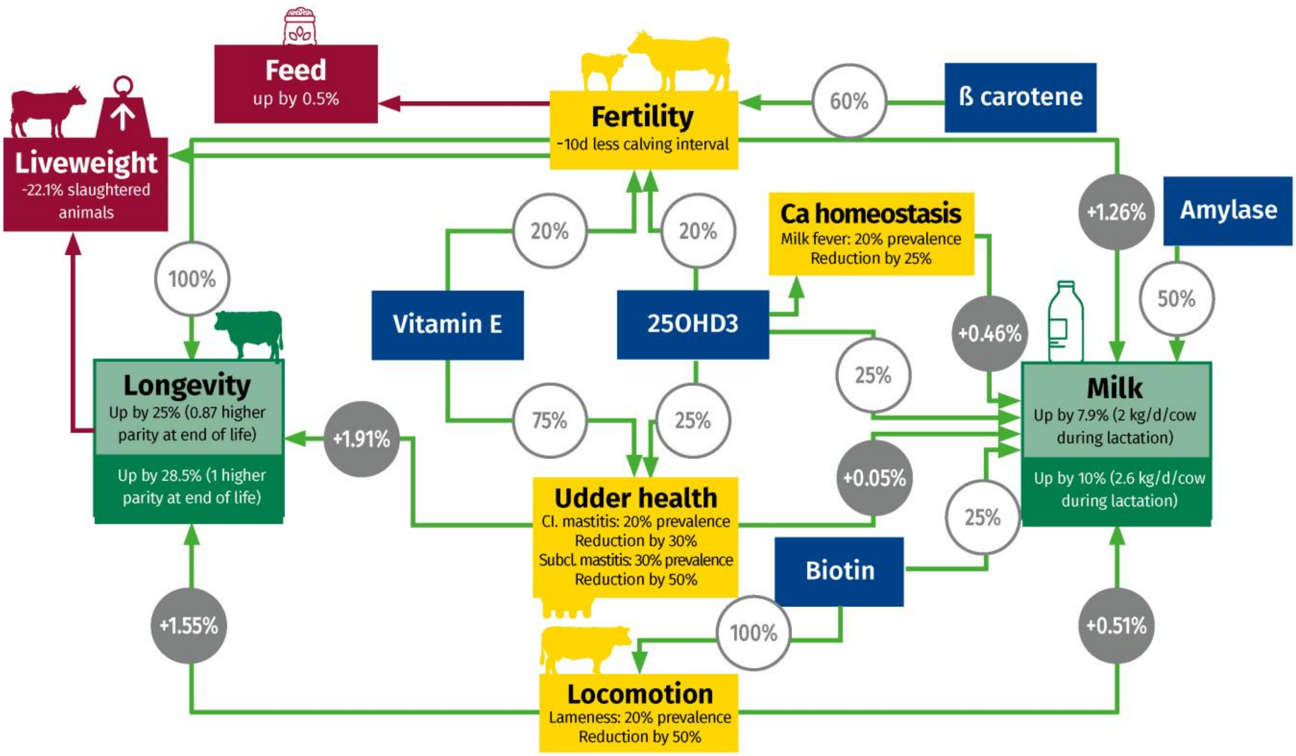

Figure 35 Overall view of nutritional measures and effects considered for dairy cows

8.1.4.6.2 Basal incidence and consequences of recurrent health disorders in dairy herds

To enable the modelling of the impact of nutritional solutions that help reduce the occurrence of recurrent health disorders in dairy herds, one should start by defining an average basal incidence in the reference system. The following hypothesis are considered.

Locomotion disorders. An estimation of the average occurrence of lameness in dairy herd is set at 20% along the figures in published in [84] and [91]. It is assumed that a cow not suffering from lameness produces 100% of the reference milk quantities, while a cow suffering from lameness would have its production impeded by 5% [92]. A cow suffering from lameness has a higher culling risk. The longevity of cows suffering from lameness is modelled to be 15% shorter than non-lame animals.

Udder function. An estimation of the proportion of cows in a dairy herd impacted by mastitis is set at 20% for clinical mastitis and 30% for sub-clinical mastitis, along the figures collected by [93], [94] and [95], which also indicate a reduction in milk production by 5% due to episodes of clinical mastitis (and we hypothesized a milk loss of 1% in case of subclinical mastitis fitting absence of detection by the farmer). A cow suffering from mastitis has a higher culling risk. The longevity of cows suffering from mastitis is modelled to be 30% shorter than non-lame animals.

Calcium homeostasis. An estimation of the average occurrence of calcium metabolism disorders in dairy herds is set at 20% along [96[25]]. The resulting impairment in milk production is set at 1.5%. Calcium metabolic syndrome is assumed not to impact the longevity of the cows.

The hypotheses are summarized in Table 33.

Table 33 Effects to be maximally attributed to the nutritional solutions in the dairy case

Yearly reference milk production	8328	kg milk/year with 103 cows	
Daily milk production in lactation	25.3	kg milk	
Potential delta in production traits	Potential improvement factor	Basal levels	Upgraded levels
Milk production, kg	7.9%	25.3	27.3
Fertility, as calving interval	2.5%	416	406
Longevity , as culled cow average parity, n	25%	3.6	4.4
Potential delta in incidence of disorders	Reduction of incidence	Basal incidence	Upgraded incidence
Udder disorders	-30%	20%	14%
Mild udder disorders	-50%	30%	15%
Lameness	-50%	20%	10%
Calcium metabolism (see footnote)	-25%	20%	15%
Production and longevity impairment with disorders	Reduction in production	Reduction in longevity	
Udder disorders	-5.00%	-30%	
Mild udder disorders	-1.00%	-30%	
Lameness	-5.00%	-15%	
Calcium metabolism	-1.50%	0%	

[1] Milk is expressed as fat-and-protein-corrected milk.

[25] The review by BERGE, A.C. and VERTENTEN, G., 2014. A field study to determine the prevalence, dairy herd management systems, and fresh cow clinical conditions associated with ketosis in western European dairy herds. Journal of dairy science, 97(4), pp. 2145-2154 mentions a much lower incidence of milk fever of 1.7%. This contradicting incidence spotted by the reviewers of the present report is considered in the LCA section.

Table 34 Allocation of the beneficial effects defined for each end point in the dairy case

Contribution to effect		Product	Effect	Milk	Fertility Longevity
25%	25OHD3	Udder health	0%		0%
100%	25OHD3	Calcium metabolism	0%		
25%	25OHD3	Milk potential	2-5%		
20%	25OHD3	Fertility		1%	5%
75%	Vit E	Udder health	0%		1%
20%	Vit E	Fertility		1%	5%
100%	Biotin	Locomotion	1%		2%
25%	Biotin	Milk potential	2%		
60%	b-carotene	Fertility		10-15%	15%
50%	Enzyme	Milk potential	5-8%		
		at herd level	8.2%	2.5%	28%
		at animal level	7.0%		

8.1.5 Solutions applicable to broiler chickens

8.1.5.1 Phytase

Supplementation of monogastric feeds with basal levels of exogenous phytases[26] is a current industry practice since the early 1990s. Adding a phytase enzyme to the feed enables the release of the phosphorus (P) present as phytic acid and phytate in all the plant raw materials in the feeds. Such supplementation improves the availability and digestibility of organically bound plant phosphorus, leading to a reduced use of mined phosphorus in feed formulation and subsequent decrease in phosphorus excretion. This formulation technique has been extensively reviewed in broilers [97, 98] including its environmental benefit [99, 100] owing to the sizable reduction of P excretion enabled.

An amino acid contribution has been attached to the phytase, based on the evidence gathered [101, 102] on the release of extra amino acids taking place with phytase addition.

The feed formulation matrix values (i.e. the nutrient supply triggered by the enzymes effect on the feed formulation) for the phytase is proposed in Annex 8.1 (Table 40). In the present study, the phytase supplies extra phosphorus, calcium and amino acids. The effect on the feed formulation can be consulted in the feed recipes provided in Annex 8.2.

The dose required for the effect is 100 mg/kg feed[27].

Because of the industry's systematic phytase supplementation, the corresponding life cycle assessment shall consider a baseline with phytase addition. However, to exemplify the benefit of a nutritional solution made available in the 1990s, the footprint of broiler feeding without phytase addition is also assessed as a historical scenario.

8.1.5.2 Protease

Protease enzymes have the potential to improve protein digestibility of chicken feeds and thus represent a key asset to reduce the nitrogen output of poultry farms [103]. Their effect on protein digestibility and broiler

[26] Our study considered conventional basal doses of phytase. However, there is an emerging trend in both poultry and swine for phytase inclusion concentrations in feed to increase in order to generate more digestible nutrients and further reduce use of finite resources in feed. This trend deserves further attention in the near future to further improve precision in the magnitude of value created from this additive.

[27] The reference product for the DSM authors is RONOZYME® HiPhos 20000 (GT).

performance have been documented by EFSA [104, 105] and reviewed extensively for its potential to support animal performance [106] and release of amino acids [102].

The feed formulation matrix values (i.e. the nutrient supply triggered by the enzyme's effect on the feed formulation) for the protease is proposed in Annex 8.2. In the present study, the protease supplies extra amino acids. The effect on the feed formulation can be consulted in the feed recipes provided in Annex 8.2.

The dose required for the effect is 200 mg/kg feed[28].

8.1.5.3 Xylanase

Xylanases (carbohydrases) enhance the digestion of the complex carbohydrates present in cereals. This is more relevant in wheat and barley-based diets, which are typical of European feed recipes, and which contain high amounts of fibrous polymers such as arabinoxylans and glucans.

A review [98], a meta-analysis [107] and a regulatory assessment [108] have been considered to justify the extra energy value conferred to the wheat when supplemented with a xylanase.

The feed formulation matrix values (i.e. the nutrient supply triggered by the enzyme's effect on the feed formulation) for the xylanase is proposed in Annex 8.1.8.4.. In the present study, the xylanase confers extra energy to the wheat implemented. The effect on the feed formulation can be consulted in the feed recipes provided in Annex 8.2.

The dose required for the effect is 75 mg/kg feed[29].

8.1.5.4 25-hydroxycholecalciferol

25-hydroxycholecalciferol (25OHD3[30], tradename HyD®) is an active form of Vitamin D [109][31]. The major biological function of vitamin D is to maintain normal blood levels of calcium and phosphorus. Vitamin D aids in the absorption of calcium, helping to form and maintain strong bones and skeletal development. In poultry, both experimental trials and commercial use have indicated that supplementing broiler diets with 25OHD3 can help improve bone and skeletal health, reduce the incidence of lameness and other bone disorders (e.g. tibial dyschondroplasia), modulate immune response; and improve performance, including support of on muscle development [109, 110, 111, 112].

The effect of 25-hydroxycholecalciferol on protein deposition in the muscle and in the filet in particular has then been documented in chickens for fattening [113]. A significant increase in the filet yield at 42d has been evidenced with a magnitude of about 4%. This observation is the one considered as hypothesis in our study (breast meat yield +4%).

The potential of 25-hydroxycholecalciferol to abate the occurrence of lameness, via enhance skeletal health, has been documented in a specific study [114], where the authors reported a 40% reduction in lameness occurrence, revealed in challenged conditions. In our study, we hypothesize that the superior bone health and resulting lower occurrence of lameness translate into a slight decrease in mortality. The mortality in the baseline is set at 4.4% in line with the average data published by [115] and a reduction by 0.5 point is applied when modelling the effect of 25-hydroxycholecalciferol.

[28] The reference product for the DSM authors is RONOZYME® ProAct (CT).

[29] The feed formulation presented in annex shows an inclusion rate twice bigger, but this is for a commercial product not in use anymore. The LCA calculations use 75 mg/kg as inclusion rate and the rest had been allocated to wheat inclusion rate. The reference product for the DSM authors is RONOZYME® WX 2000 (CT).

[30] Existing synonyms: 25-hydroxyvitamin D3, HyD, hidroferol, calcifediol, calcidiol, Ampli-D, the two latter names being used for food applications.

[31] Vitamin D (cholecalciferol) is essential to humans and animals. Vitamin D3, D3 being the form active in poultry, can be synthesized endogenously but, as this process has very low efficiency in this species, vitamin D3 must be supplemented via feed. To become active, vitamin D3 must be hydroxylated twice in the body: first in the liver to 25OHD3 and then in the kidney to the active, hormonal form 1,25(OH)2D3. By feeding 25-hydroxycholecalciferol directly, plasma levels are higher than when fed vitamin D3. This occurs even more clearly when intestinal diseases or stress impair vitamin D3 absorption. [53].

Such lower mortality rate represents a reduction of food losses occurring at primary production stage, in the sense of the EU platform of Food Losses and Food Waste. The reduction in lameness also represents an obvious gain in animal welfare.

The dose required for the effect is 69 µg/kg feed.

8.1.5.5 Organic acid and phytogenic compounds

Various feed additive concepts have been proposed to improve nutrient utilization and support gut functionality, which ultimately can translate into increased animal production performance, enhanced resilience to diseases, and welfare. Probiotics, prebiotics, enzymes, organic acids and/or phytogenic components, a cluster of products termed eubiotics as a result of their support of the digestive physiology as a whole, have been shown to support feed utilization, in addition to their specific input in given health markers. The resulting improved feed conversion rate (FCR) results in reduced feed quantities and the agricultural goods constituting them to grow a kilo of animal live weight.

In our study, we consider the impact of a blend of phytogenics and organic acids (trade name CRINA® Poultry Plus) proposed for supplementing poultry feed and chicken feeds in particular, at a dose rate of 300 mg/kg feed. It acts via acidification of the digesta, gut flora modulation and stimulation of the digestive enzymes. The improvement of the FCR obtained in chickens is documented [116, 117] and has been reviewed positively by the EU safety agency on additives, products or substances used in animal feed (EFSA Feedap) [117]. On average the improvement of FCR in the studies mentioned amounted 5%.

A conservative hypothesis of 3.5% (FCR -3.5%). is considered for application in the reference system considered.

The benefit in FCR is modelled in the LCA study as both a lower feed consumption and a faster growth rate, in equal contribution.

The composition of the product is provided in Annex 8.1.8.1.

8.1.6 Improvement factors attributed to the additives

A set of nutritional solutions was selected to be independent from one another and having some likelihood to deliver an effect in the identified reference systems.

The nutritional measures, specified by their mode of action and conditions of use, are substantiated with references to peer reviewed publications. Each effect is documented by several studies, and in a large number of cases by reviews and/or meta-analysis and/or regulatory opinions. The substantiation therefore meets the requirements defined by the LEAP Guidelines on feed additives for effects modelling.

8.1.6.1 From bibliography to average effect for LCA

For sake of extended transparency on how the effects were grounded on the feed additives all the bibliography gathered and discussed in the above paragraphs have been tabulated and related to the effect considered in the LCA. These effects are then modelled, studied individually and either cumulated (pig and broiler cases) or articulated and cumulated (dairy) along the pattern explained in each species section (Figure 34). Table 35 shows the key findings extracted from the bibliography (shaded in yellow) and the effect considered in our study (shaded in green).

Table 35 From bibliography to average effect for LCA

Species	Additive	Production parameter	Ref	Profil e	A and B counts	Key findings related to the additive	Key findings for our study	Primary improvement considered in the study (Table 40 or LCF data)

Pig	Phytase	P digestibility	98	A	2A, 3B	role is evidenced	role is evidenced	See matrix value proposed for the enzyme and feed formulation output
Pig	Phytase	P digestibility	99	B		role is evidenced	role is evidenced	
Pig	Phytase	P digestibility	100	B		role is evidenced	role is evidenced	
Pig	Phytase	P digestibility	41	A		Role is evidenced		
Pig	Phytase	P digestibility	42	B		role is evidenced	role is evidenced	
Pig	Phytase	P and protein digestibility	43	A		The effects of phytase on amino acid digestibility in swine is quantified (+1 to 3%)	Effect is evidenced and quantified	
Pig	xylanase	Wheat value	98	A	1A, 2B	role is evidenced	role is evidenced	See matrix value proposed for the enzyme and feed formulation output
Pig	xylanase	Wheat value	44	B		role is documented	role is evidenced	
Pig	xylanase	Wheat value	108	B		The efficacy of Ronozyme WX has been demonstrated in chickens, turkeys and ducks for fattening at a minimum proposed dose of 100 FXU/kg complete feed. Efficacy has also been demonstrated in piglets and in pigs for fattening at a minimum dose of 200 FXU/kg complete feed	role evidenced	
Pig	acid	feed utilisation	45	A	4A, 1B	role is documented	role evidenced	FCR -3% with 5000 ppm, -3% with 10000 ppm
Pig	acid	feed utilisation	46	A		role is documented	role evidenced	
Pig	acid	feed utilisation	47	A		role is documented	role evidenced	
Pig	acid	feed utilisation	48	A		role is documented	role evidenced	

Pig	Benzoic a	feed utilisation	49	A		EFSA concludes that VevoVitall® has the potential to increase the performance in pigs for fattening at the dose of 3,000 mg/kg complete feed.	1 to 3% with 3000 ppm	
Pig	Benzoic a	feed utilisation	50	B		Benzoic acid at the supplementation levels of 0.3% and 0.5% significantly improved the growth performance of in grower-finisher pigs	3% with 3000 ppm	
Pig	Benzoic a	NH3 reduction	51	B	1A, 5B	The addition of benzoic acid (10000 pm) reduced urinary pH by about one pH-unit in both feeding periods independent of the protein level of the diet (p<0.01) and increased the concentration of urinary hippuric acid markedly (p<0.01).	role is evidenced	20% reduction in NH3 emission with 10 000 ppm and 10% with 5 000 ppm
Pig	Benzoic a	NH3 reduction	52	B		Benzoic acid is metabilised in hippuric acid	role is evidenced	
Pig	Benzoic a	NH3 reduction	53	B		Benzoic acid was metabolized into hippuric acid which reduced urinary pH by 0.8 pH units (P<0.001), and dietary supplementation with 1% Met reduced urinary pH by 1.0 unit (P<0.001).	role is evidenced	
Pig	Benzoic a	NH3 reduction	54	A		Adding CaSO4 (1.7%), benzoic acid (1%) or adipic acid (1%) to the diet decreases urinary pH and thus, reduces in vitro NH3 emissions by 5%, 20% and 25% respectively (van Kempen, 2001; Velthof et al., 2005; Guiziou et al., 2006). […] Under practical conditions, the effect of benzoic acid (1–3%) was validated for growing-finishing pigs with NH3 emission reductions ranging from 16% to 57% (Hansen et al., 2007; Aarnink et al.,2008).	20% reduction in NH3 emission with 10000ppm	
Pig	Benzoic a	NH3 reduction	55	B		Ammonia nitrogen emission from the slurry, expressed as a proportion of the initial slurry nitrogen, was decreased (P=0.049) by the inclusion of benzoic acid in the diet: 35.2, 28.1, 26.2% for C, B05, B10, respectively.	25% reduction in NH3 emission with 10000ppm and 20% with 5000 ppm	
Pig	Benzoic a	NH3 reduction	56	B		Linear decrease in NH3 emission (P<0.001), as the dietary benzoic acid concentration increased (0, 10, 20 30 000 ppm)	30% reduction in NH3 emission with 10000ppm	
Pig	Vitamin E	Meat losses	57	B	6A, 4B	Vitamin E supplementation has a beneficial effect on the sensory data (freshness, tenderness, and juiciness and on the oxidative stability of pork as measured by induced TBARS values	Role is evidenced and quantified	Shelf life extended by 6d
Pig	Vitamin E	Meat losses	58	B		Dietary a-tocopheryl acetate supplementation significantly reduced lipid oxidation as measured by TBARS in both raw and cooked meat during storage at 4°C for 6 days	6d extra shelf life	
Pig	Vitamin E	Meat losses	59	A		Review	Role is evidenced	

Pig	Vitamin E	Meat losses	60	B		This study suggests that supplementation with 200 IU of Vit E/kg of feed for 6 wk before market is beneficial in improving lipid stability and pork quality.	Role is evidenced	
Pig	Vitamin E	Meat losses	61	A		Role evidence on drip losses	Role is evidenced	
Pig	Vitamin E	Meat losses	62	A		Modelling of Vit E intake and meat redness	Role is evidenced and modelled	
Pig	Vitamin E	Meat losses	63	A		Modelling of Vit E in tissue and TBARS	Role is evidenced and modelled	
Pig	Vitamin E	Meat losses	64	A		Modelling of Vit E accumulation in tissues and TBARS	Role is evidenced and modelled	
Pig	Vitamin E	Meat losses	65	B		Accumulation of Vit E in tissue and prevention of TBARS formation likely to carry over during the retail display for up to 6 days	6d extra shelf life	
Pig	Vitamin E	Meat losses	66	A		17% of total meat available is lost at household, food service and retailer	17% meat is lost	
Dairy	b-carotene	cows fertility	67	B	6B	Luteal function in the postpartum cows is related to plasma concentrations of b-carotene	role in fertility evidenced	Dry period - 10%, from 60d to 54d
Dairy	b-carotene	cows fertility	68	B		Lower b-carotene concentrations in plasma during the prepartum period is associated with anovulation during the first follicular wave postpartum.	role in fertility evidenced	
Dairy	b-carotene	cows fertility	69	B		Conception rate improved by carotene supplementation in younger cows: conception rates at first insemination were 0.70 vs 0.33 (P < 0-05); for all inseminations, conception rates were 0.71 vs 0.38 (P < 0.01)	role in fertility evidenced	
Dairy	b-carotene	cows fertility	70	B		For cows fed supplemental b-carotene for ≥90 d, pregnancy rate at 120 d postpartum was increased in 1 study (out of 3) (35.4% vs. 21.1%).	+70% pregnancy rate	
Dairy	b-carotene	cows fertility	71	B		Pregnancy rate was 22% for β-carotene-supplemented cows compared with 11% for control cows.	x2 pregnancy rate	
Dairy	b-carotene	cows fertility	72	B		Cows with higher concentrations of plasma beta-carotene at insemination had greater pregnancy rate (40 vs 19%) and lower pregnancy losses (16 vs 42%).	x2 pregnancy rate	
Dairy	25OHD3	cows fertility	74	B	1B	25OHD3 tended (P = 0.10) to increase the rate of pregnancy by 55% and reduce the median days to pregnancy by 19d.	+55% pregnancy rate	Dry period - 3%, from 58d to 60d

Dairy	25OHD3	udder health	74	B	2B	Feeding 25OHD3 improved the proportion of neutrophils with oxidative burst activity (60.0 vs. 68.7%)	Role in immunity evidenced	Clinical mastitis -7.5% (from an incidence of 20% of to 18.5%). Sub-clinical mastitis - 12.5% from and incidence of 30% to an incidence of 26.3%)
Dairy	25OHD3	udder health	76	B		Cows fed 25OHD3 had less severe mastitis at 60 and 72 h after challenge with S. uberis compared with cows fed Vitamin D.	Role in immunity evidenced	
Dairy	25OHD3	milk production	75	B	4B	Replacing VitD with 25OHD3 supplemented at 3 mg/d during the prepartum period improved the lactation performance (10%FCM (P<0.05))	+10% milk	Milk +2%
Dairy	25OHD3	milk production	Foot note	B		+13% (P<0.05)177 cows in study, dose testing with dose response	+13% milk	
Dairy	25OHD3	milk production	Foot note	B		+5% FCM (P<0.05) (30 cows in study)	+5% milk	
Dairy	25OHD3	milk production	Foot note	B		+10% FCM P<0.05, 40 cows	+10% milk	
Dairy	25OHD3	Ca homeostasis	77	A	2A	Vitamin D metabolites are essential for increasing the proportion of absorbed Ca when dietary Ca concentration is low or when the requirement for Ca is high. Vitamin D metabolites stimulate the synthesis of the proteins that control active intestinal Ca absorption. cows.	Role in Ca metabolism evidenced	Milk fever - 25%, from an incidence of 20% to an incidence of 15%
Dairy	25OHD3	Ca homeostasis	78	A		Evidence that 25OHD3 can induce metabolic adaptations that improve mineral homeostasis with the onset of lactation	Role in Ca metabolism evidenced	
Dairy	Vit E	udder health	79	B	3A, 1B	Clinical mastitis affected 25.0, 16.7, and 2.6% of quarters during the first 7 d of lactation for cows receiving the low, intermediate, and high vitamin E treatments, respectively.	Quarters with mastitis -90%	Clinical mastitis - 22.5% (from an incidence of 20% of to 16%). Sub-clinical mastitis - 37.5% from and incidence of 30% to an incidence of 19%)
Dairy	Vit E	udder health	80	A		Several studies shows that supplementation of Vit E reduces udder infections (-30% to -80%)	Significant role on udder health established	
Dairy	Vit E	udder health	81	A		Vitamin E supplementation was also associated with a reduction in milk somatic cell counts by 70% and a 30% decrease in the risk of occurrence of clinical mastitis.	Mastitis -30%	
Dairy	Vit E	udder health	82	A		Antioxidant role of Vit E	Antioxidants effect documented	
Dairy	Biotin	Lameness and milk prod	83	B	2A, 2B	The biotin-supplemented cows have better locomotion scores than the un-supplemented one (13 mo, 2700 cows, 20 farms).	Effect on locomotion documented	Milk + 2%
Dairy	Biotin	Lameness and milk prod	84	A		The biotin-supplemented cows (meta-analysis) have an increased in milk production by 1.29 kg/d (+4%) and the majority of the studies report a beneficial effect on hoof health	Milk +4%	
Dairy	Biotin	Lameness and milk prod	85	A		The biotin-supplemented cows (meta-analysis) have an increased in milk production by 1.66 kg/d (+3.5%).	Milk +3.5%	

Dairy	Biotin	Lameness and milk prod	86	B		The study shows an association between specific mobility scores and production and reproductive performance in spring-calving, pasture-based dairy cows scored during the summer grazing period	Milk and locomotion are connected	
Dairy	Amylase	milk production	87	B	4B	The addition of exogenous amylase enzymes to the diets of lactating dairy cows has the potential to improve animal productivity. Production of milk was greater in amysase fed cows	Milk +5%	Milk +4%
Dairy	Amylase	milk production	88	B		Amylase increased milk yield (32.3 vs. 33.0 kg/d, P<0.05) and reduced dry matter intake (20.7 vs. 19.7 kg/d), increasing feed efficiency (1.52 vs. 1.63)	Milk +2%	
Dairy	Amylase	milk production	89	B		Tendency to increase milk production (31.1 to 31.9 kg/d, NS)	Milk+2.5%	
Dairy	Amylase	milk production	90	B		Milk yield was numerically greater by 2.0 kg/d for cows fed amylase compared with control diet.	Milk+5%	
Dairy	Health issues	Lameness occurence	91	B	2B	In 21.2% of the lactations in the dataset one or more cases of clinical digital diseases were observed. Taking into account the total number of cases, the frequency was 34.7%.		Incidence rate lameness 20%
Dairy	Health issues	Lameness occurence	92	B		prevalence ranging from 0% to 70%		
Dairy	Health issues	Udder disorders	93	B	3B	incidence clinical mastitis 25%, sub-clinical mastitis 33% (SP)	incidence clinical mastitis 25%, sub-clinical mastitis 33% (SP)	Incidence rate 20% clinical mastitis and 30% sub clinical)
Dairy	Health issues	Udder disorders	94	B		cows treated for mastitis 20% (UK)	incidence 20%	
Dairy	Health issues	Udder disorders	95	B		Probability to develop a 1st mastitis is estimated from 17% to 30% along parity rate (1 to 5)	incidence 17 to 30%	
Dairy	Health issues	Ca disorders	96	A	1A	Milk fever incidence 21% (137 studies)	incidence 21%	Incidence rate milk fever 20%
Broiler	Phytase	Phosphorus digestion	97	A	4A, 2B	role is evidenced	role is evidenced	See matrix value proposed for the enzyme and feed formulation output
Broiler	Phytase	P digestibility	98	A		role is evidenced	role is evidenced	
Broiler	Phytase	P digestibility	99	B		role is evidenced and quantified	role is evidenced and quantified	

Broiler	Phytase	P digestibility	100	B		role is evidenced and quantified	role is evidenced and quantified	
Broiler	Phytase	Protein digestibility	101	A		Effect on amino acid digestibility is quantified	Effect quantified	
Broiler	Phytase	Protein digestibility	102	A		Effect on amino acid digestibility is quantified	Effect quantified	
Broiler	xylanase	Wheat value	98	A	3A	Role evidenced	Role evidenced	See matrix value proposed for the enzyme and feed formulation output
Broiler	xylanase	Wheat value	107	A		Role quantified	Role quantified	
Broiler	xylanase	Wheat value	108	A		Role evidenced and quantified	Role evidenced and quantified	
Broiler	25OHD3	Muscle and bone support	109	A	2A, 1B	Review on 25OHD3 biology	Role evidenced	Role evidenced on muscle and bone development
Broiler	25OHD3	Muscle and bone support	110	A		The results of several recent poultry studies have shown that 25-hydroxycholecalciferol (25OHD3) is more efficient in commercial poultry nutrition than the basic form of vitamin D3 (cholecalciferol)	Role evidenced and dose defined	
Broiler	25OHD3	Muscle and bone support	111	B		Stimulation of skeletal muscle cells activity	Role evidence	
Broiler	25OHD3	Muscle and bone support	112	B	2B	enhanced breast meat yield ($P < 0.05$) and protein synthesis with 25OHD3	Positive impact on breast meat yield	4% more breast meat yield
Broiler	25OHD3	Muscle and bone support	113	B		enhanced breast meat yield ($P < 0.05$, +4%) with 25OHD3	4% more breast meat yield	
Broiler	25OHD3	Muscle and bone support	114	B	1A, 1B	40% reduction in flock lameness score with 25OHD3 in challenging conditions	Role on lameness evidenced	Reduction of mortality b 0,5 point
Broiler		Mortality in chickens	115	A		mortality in the baseline is set at 4.4%		

Broiler	CPP	FCR	116	A	2A	Significantly improve performance of broiler chicks under various husbandry conditions (FCR −0.6%; P = 0.0414, BWG +2.0%; P = 0.0021)	Effect evidenced and quantified	FCR -3%
Broiler	CPP	FCR	117	A		Significantly improve performance of broiler in 3 distinct studies (FCR -4%, -7%, -2%)	Effect evidenced and quantified	

A: Review/Meta-Analysis/Regulatory opinion, B_Study report. Yellow shading: bibliographical info. Green shading: appraisal derived for the study as effect related to feed supplementation. Grey shading: epidemiologic information and assumptions.

8.1.6.2 Improvement factors considered

Based on the literature which establishes unequivocally that the feed additives have the potential to be efficacious on the production traits considered, and, based on expert knowledge for applicability of the solution to the reference systems considered, including integration in multifactorial approach (in the case of dairy), a set of improvement factors are finally proposed with a conservative approach, for their uptake in the LCA (Figure 1).

Table 36 Zootechnical effects considered for in the LCA

Principle	*Dose intervention*	*Zootechnical effect (qualitative)*		*Average improvement factor*	*Baseline*		*Improved baseline*
			Broiler				
25(OH)D3	69 µg/kg feed replacing 3000 IU Vit D3/kg feed	Muscle and bone development support	Mortality	-11%	4,4%	%	3,9%
			Breast meat yield	4%	19,5%	%	20,3%
Eubiotics	300 mg/kg feed	Gut functionality support	FCR	-3%	1,63	FCR	1,58
Phytase	100 mg/kg feed	Improved digestion of phytates	Adapted feed recipes				
Protease	200 mg/kg feed	Improved digestion of proteins	Adapted feed recipes				
Xylanase	75 mg/kg feed	Increased hydrolysis of arabinoxylan	Adapted feed recipes				
			Dairy				
beta-carotene	500/300 mg/h/d (dry/lact) vs 0	Fertility support (longevity)	Dry period	-10%	60	d	54,0
			Longevity (Fertility)	15%	3,5	cycle	4,0
25(OH)D3	3/1 mg/h/d 25(OH)D3 (close-up/lact) vs 22000/21000 IU/h/d	Support of milk production, fertility, udder health, (longevity)	Milk	2%	25,3	kg/d	25,8
			Dry period	-3%	60	d	58
			Udder disorders (cl)	-7,5%	20%	prevalence	18,5%
			Udder disorders (subcl)	-12,5%	30%	prevalence	26,3%
			Milk fever	-25%	20%	prevalence	15%
			Longevity (Fertility)	5%	3,5	cycle	3,7

Vitamin E	1000 mg/h/d vs 550 mg/h/d	Support of fertility, udder health (longevity)	Dry period	-3%	60	d	58
			Udder disorders (cl)	-22,5%	20%	prevalence	16%
			Udder disorders (subcl)	-37,5%	30%	prevalence	19%
			Longevity (Fertility)	5%	3,5	cycle	3,8
Biotin	20 mg/h/d vs 0	Support of hoof health, milk production	Milk	2%	25,3	kg/d	25,8
			Lameness	-50%	20%	prevalence	10%
Amylase	12.5 g/h/d vs 0 g (1st 100d of lactation)	Increased digestion of starch and fibers	Milk	4%	25,3	kg/d	26,3
			Pigs				
Vitamin E	200 mg/kg finisher feed vs 50 mg/kg	Enhanced meat quality, lower meat losses	Meat losses	-5%	17%	meat lost	16%
Benzoic acid	5 000 mg/kg vs 0	Gut function support and urine acidification	FCR	-3%	2,64	FCR	2,56
			NH3 from manure	-10%	4,3	kg NH3 /AAP yr	3,9
	10 000 mg/kg vs 0	Gut function support and urine acidification	FCR	-3%	2,64	FCR	2,56
			NH3 from manure	-20%	4,3	kg NH3 /AAP yr	3,4
Phytase	30 mg/kg feed (100, 50, 20 stepwise reduction) vs 0	Increased digestion of phytates	Adapted feed recipes				
Xylanase	100 mg/kg feed vs 0	Increased hydrolysis of arabinoxylan	Adapted feed recipes				

8.1.7 Quality assessment for substantiations

8.1.7.1 Recommendations from the LEAP guidelines

The FAO LEAP Guidelines on feed additives [1] specifies the following with regards to the quality standard to be met.

"To be regarded as suitable for LCA consideration, the effects of the additive on the nutrient level of the feed, on the feed efficiency or on the emission factors should be documented by ***robust state-of-the-art studies***. One study is considered to be a limited level of substantiation, while **a minimum of three studies could be considered a suitable level of substantiation**.

Peer-reviewed publication in reputable journals is favoured. However, if reports are not published, they should be made available, including raw data for scientific evaluation by qualified independent reviewers such as regulatory bodies, academia, third parties or certification bodies. In the case that extrapolation rules are applied from one type of animal to another (species, genotype) or from one kind of farm management to another (geography, climatic conditions, feed type), they should be explicitly documented. During the evaluation of the results, **the dosage of the additive should be taken into consideration and the LCA should be done on this basis**.

When carrying out an LCA, primary data are favoured (i.e. on-farm measurements).

The number of trials is not pre-defined but it should be indicated in the LCA report to enable scientific evaluation of the results (from one trial providing assumptions, to meta-analysis providing the possibility for further extrapolation). **Information providing a description of the mode of action** explaining the effect can be used to improve the potential extrapolation from one livestock system to another. For example:

- Time representativeness. Data relative to the mode of action are valid without limitation; data relative to the effect envisaged should be comparable to the current situation. More recent studies have a greater weight of evidence.
- Technological representativeness. Data relative to the mode of action shall be applicable to the type of diets and type of animals concerned; data relative to zootechnical results shall be obtained for similar rations (feed formulation) and similar strains of animals (e.g. fast-growing chickens vs slow-growing chickens).
- Geographical representativeness. Data relative to the mode of action shall be extrapolated with care regarding farm management; data relative to zootechnical results should be issued from similar farming practices, and in situations in which climatic conditions are possibly affecting performance (e.g. animals raised outside of barns) the conditions of the trials should be comparable to the practice.
- Cases where primary data on production with and without additives are available. If data are available for the farm(s) part of the LCA, the results from the farms before using the additives and after using them shall be considered.
- Cases where primary data are not available. The following secondary data considerations shall be evaluated: substantiation through regulatory bodies if available, meta-analysis and literature (peer-reviewed journals, data provided by reliable research groups to ensure scientific quality).

With regard to the above-mentioned qualitative aspects of the results (representativity of the zootechnical results), one trial could be considered to provide a limited level of substantiation and three trials a consensus (already used by different regulatory instances). In the case that the mode of action is demonstrated, a scientific peer review could be sufficient and its applicability to the particular case of the LCA should be provided. The practitioner is required to use feed additives according to the specification provided by the manufacturer and under the conditions substantiated by the data (e.g. same dose, same mode of application)".

8.1.7.2 Quality of the bibliographical substantiation

- Recent peer reviewed papers.

The effects collected in our study are all substantiated with peer reviewed papers. The vast majority of the bibliography refers to reputable journals (16 references point at the Journal of dairy Science, 8 to the Journal of Animal Science, 5 to the EFSA Journal, 4 to Animal Feed Science and Technology and 4 to Poultry Science).

69% of the references are less than 10 years old.

- A large number of reviews and/or meta-analysis

Care has been taken to identify reviews and/or meta-analysis whenever possible. In some cases, the effects are justified with a regulatory opinion. About to 45% (34/75) of the papers considered for the effects consists of reviews, meta-analysis or regulatory opinions (Table 37, directly derived from Table 35).

Table 37 Publications profile considered per species and per effect

	A	*B*	*Grand Total*
Broiler	**11**	**6**	**17**
25OHD3	**2**	**4**	**6**
Filet yield*		2	2
Muscle and bone support	2	2	4
CPP	**2**		**2**
Feed utilisation	2		2

Phytase	**4**	**2**	**6**
P digestibility	2	2	4
Protein digestibility	2		2
Xylanase	**3**		**3**
Wheat value	3		3
Dairy	**7**	**20**	**27**
25OHD3	**2**	**7**	**9**
Ca homeostasis	2		2
Cows fertility*		1	1
milk production		4	4
udder health*		2	2
Amylase		**4**	**4**
milk production		4	4
b-carotene		**6**	**6**
cows fertility		6	6
Biotin	**2**	**2**	**4**
Lameness and milk prod	2	2	4
Vit E	**3**	**1**	**4**
udder health	3	1	4
Pig	**16**	**15**	**31**
Acid	**4**		**4**
Feed utilisation	4		4
Benzoic a	**2**	**6**	**8**
Feed utilisation	1	1	2
NH3 reduction	1	5	6
Phytase	**3**	**3**	**6**
P digestibility	2	3	5
Protein digestibility	1		1
Vitamin E	**6**	**4**	**10**
Meat losses	6	4	10
Xylanase	**1**	**2**	**3**
Wheat value	1	2	3
Grand Total	**34**	**41**	**75**

A: Review/Meta-Analysis/Regulatory opinion, B_Study report. Effects marked with a * are substantiated with less than 3 study reports.

For each intervention, the effects modelled relies on several scientific articles, reporting given studies or consisting of meta-analysis, regulatory opinion or reviews.

This analysis allows confirming that the effects studied are suitable for LCA consideration, along the FAO LEAP Guidelines of feed additives, because they are documented:

- by robust state-of-the-art studies,
- made available as peer reviewed scientific articles,
- by at least three studies published individually or within a meta-analysis, a regulatory opinion or a review, except in the case of,
    - 25OHD3 x filet yield in broilers and
    - 25OHD3 x cows fertility and udder health in dairy,

where the substantiation can be deemed limited because leaning on less than 3 peer reviewed published study reports.

The modes of action for all the effects are systematically succinctly mentioned to justify their biological relevance and applicability to the reference systems considered.

The dose required for the feed ingredient to deliver the intended effect is systematically defined.

8.1.7.3 Sensitivity analysis for the zootechnical effects

The sensitivity analysis for each LCA conducted is covered in each species section (in chapters 3, 4 and 1), which has been assessed below for the variability and certainty in the zootechnical effects.

8.1.7.3.1 Exploring variability of the zootechnical effects

The variability is herewith approached as the dispersion in effects observation.

As, at animal level, we deal with a biological system, a variability in response to the dietary interventions is expected, both upon evidencing the effect in experimental studies and upon applying the solution on the field.

Causes of variance include factors involving the animals used e.g. breed, age, gender, health status; the diets that are fed e.g. nutrient density, primary cereal used, quality of ingredients used, particle size and feed form and finally the environmental conditions of the study e.g. temperature, stocking density, ventilation rates and so on. It is impractical to design a study that systematically explores the contribution of all sources of variance on the utility of a given feed additive for a particular species. However, in attempt to mitigate the effects of these experimental settings on efficacy responses we have selected peer-reviewed publications to support efficacy assumptions that include a wide diversity of diet types, environmental conditions, animal breeds, age and gender and so on. We therefore believe that the effects reported are representative of end user experiences and are resilient across a wide range of diet, animal and environmental settings.

In order to illustrate a possible practical variance, we propose considering a coefficient of variance of 50% for the realization of the effect (i.e. if the FCR is improved by 3% on average, there are some cases where the improvement will only be of 1.5% and some other cases of 4.5%).

The effects which pertain to least cost formulation (phytase, protease, xylanase) were excluded from the sensitivity assessment, because several other criteria supersede the zootechnical ones (origin, quality, price of the raw material to name few) and would require a stand-alone study.

Table 38 Variability assessments for the zootechnical effects (CV 50%)

Principle		*Average improvement factor*	*Improvement factor (low end)*	*Improvement factor (high end)*	*Baseline*	*Improved baseline (low end)*	*Improved baseline (average)*		*Improved baseline (high end)*
Chickens									
25(OH)D3	Mortality	**-11%**	-6%	-17%	**4.4%**	%	4.1%	**3.9%**	3.6%
	Breast meat yield	**4%**	2%	6%	**19.5%**	%	19.9%	**20.3%**	20.7%
Eubiotics	FCR	**-3%**	-1.5%	-4.5%	**1.63**	FCR	1.61	**1.58**	1.56
Dairy									
beta-carotene	Dry period	**-10%**	-5.0%	-15.0%	**60**	d	57.0	**54.0**	51.0
	Longevity (Fertility)	**15%**	8%	23%	**3.6**	cycle	3.9	**4.1**	4.4
25(OH)D3	Milk	**2%**	1%	3%	**25.2**	kg/d	25.5	**25.7**	26.0
	Dry period	**-3%**	-2%	-5%	**60**	D	59	**58**	57

	Udder disorders (cl)	**-7.5%**	-4%	-11%	**20%**	prevalence	19.3%	**18.5%**	17.8%
	Udder disorders (subcl)	**-12.5%**	-6%	-19%	**30%**	prevalence	28.1%	**26.3%**	24.4%
	Milk fever	**-25%**	-13%	-38%	**20%**	prevalence	18%	**15%**	13%
	Longevity (Fertility)	**5%**	3%	8%	**3.6**	cycle	3.7	**3.8**	3.9
Vitamin E	Dry period	**-3%**	-2%	-5%	**60**	D	59	**58**	57
	Udder disorders (cl)	**-22.5%**	-11%	-34%	**20%**	prevalence	18%	**16%**	13%
	Udder disorders (subcl)	**-37.5%**	-19%	-56%	**30%**	prevalence	24%	**19%**	13%
	Longevity (Fertility)	**15%**	8%	23%	**3.6**	cycle	3.9	**4.1**	4.4
Biotin	Milk	**2%**	1%	3%	**25.2**	kg/d	25.5	**25.7**	26.0
	Support hoof health	**-50%**	-25%	-75%	**20%**	prevalence	15%	**10%**	5%
Amylase	Milk	**4%**	2%	6%	**25.2**	kg/d	25.7	**26.2**	26.7
Pigs									
Vitamin E	Meat losses	**-5%**	-3%	-8%	**17%**	meat lost	17%	**16%**	16%
Benzoic acid	FCR	**-3%**	-2%	-5%	**2.56**	FCR	2.52	**2.48**	2.44
	NH3 emission from manure	**20%**	10%	30%	**10200**	kg NH3/yr	11220	**12240**	13260

8.1.7.3.2 Exploring the certainty of the zootechnical effects

The certainty is herewith approached as the ability to generalize the conclusions related to the zootechnical effects of the additives. It relates to the probability to observe similar positive impact upon additive implementation, in the field, for farms having similar characteristics than the ones described in our reference systems.

Whereas:

- the solutions herewith studied are already implemented by (some or many) users and
- our bibliographical data set (peer reviewed publications on large number of studies (Cf paragraph 8.1.7.2) evidencing unequivocally that each solution studied has the potential to be efficacious,

still, the certainty that our solutions will deliver systematically the quantitative effects described, in each farm system fitting our described parameters, is not 100%, because of the variability encountered on animal biology (exact physiological, nutritional and sanitary status, for example), animal management (quality of housing conditions, animal care level) and such other factors. In some cases, the effects will be lower and in some other cases the effects will be higher than the ones modelled in the present study, as we took a conservative approach upon setting the possible achieved benefits.

8.1.7.3.3 Conservative to realistic approach

The effects modelled were set (in a majority of cases) below (say about one standard deviation) the mean response collected from the literature. So that we can infer that the effect would be delivered in about 85% of the case (as opposed to 50% had we assumed the mean response).

This being said, we do not systematically hold statistically characterised information for each end point to be entered into the modelling. Beta-carotene unequivocally supports cows fertility but how does this translates into a given number of days saved for the calving intervals? For such cases transparent hypothesis have been made.

The product claims are in any case defined along those which would be realistically introduced upon technical dialog among nutritionists in the field.

8.1.8 Extra information related to effects

8.1.8.1 Composition of the eubiotic products

Table 39 Composition of the Phytogenic and acid blend and of the benzoic products

	Inclusion rate,% product	
VevoVitall [1]		
Benzoic acid	99.9%	
CRINA Poultry Plus [2]		
Benzoic acid	83.3%	
Thymol	1.9%	
Eugenol	1.0%	
Piperine	0.1%	
Iso amyl salicylate	0.1%	
Benzyl salicylate	0.3%	
Trans anethole	0.1%	
Butylated hydroxytoluene	0.1%	
Diatomaceous earth	6.8%	
Silicic acid	3.0%	
Monopropylene glycol total	1.5%	
Turmeric (rhizome)	0.3%	
Soyoil	1.5%	

[1] Inclusion rate in pig feed in our LCA study 5000 ppm, 2 inclusion rates in chicken feed in our LCA study 300 ppm.

8.1.8.2 Matrix value for phytase in the study case

Table 40 Matrix value for phytase (focus on P)

Spec	Monocalcium phosphate	Phytase
Phosphorus	22	-
P available Poultry	22	1800
P digestible Poultry	18	1450
P digestible Pigs	18	1440

8.1.8.3 Matrix values for protease in the study case

Table 41 Matrix values for protease (focus on protein and amino acids)

Nutrients	Protease
Crude protein	0.07
Lysine	-
SID Lysine Poultry	115
SID Methionine Poultry	35
SID Cystine Poultry	55
SID Met+Cys Poultry	90
SID Tryptophane Poultry	-
SID Threonine Poultry	120
SID Arginine Poultry	125

SID Leucin Poultry	130
SID Isoleucin Poultry	85
SID Valin Poultry	100

8.1.8.4 Matrix values for the wheat supplemented with a xylanase

Table 42 Matrix values for the wheat supplemented with a carbohydrase (focus on energy)

Spec	*Wheat*	*Wheat with carbohydrase*	*delta*
Crude protein	11	11	0%
Crude fat	1.5	1.5	0%
Crude ash	1.6	1.6	0%
Crude fiber	2.3	2.3	0%
Fermentable Carbodhydrates (pigs)	6.958	8.887	28%
Inert Carbohydrates (pigs)	6.817	4.888	-28%
NE pigs 2015 (MJ/kg)	10.5	10.7	2%
Nett Energy Pig 2015 (kcal/kg)	2515	2559	2%
EW Pig 2015 (x2100 kcal NE)	1.20	1.22	2%
NEv pigs 2004 (MJ/kg)	10.0	10.2	2%
NEtt Energy Pig 2004 (kcal/kg)	2398	2445	2%
EW Pig 2004 (x2100 kcal NE)	1.14	1.16	2%
ME Broilers (kcal/kg)	2902	3043	5%
ME Poultry (kcal/kg)	3124	3264	5%
ME Layers (kcal/kg)	3136	3224	3%

8.2 Feed compositions

This annex summarizes all feed compositions used in the baseline and feed additive scenarios. In 8.2.1, one can read the average feeds accounted for in the LCA. In 8.2.2, one can read the individual feeds which have been least cost optimised (reference price list can be read at the end).

8.2.1 Averaged feeds

Table 43 Feed composition (averaged) and origin of the ingredients for the pig case

Raw material	*Origin*	*No HiPhos, no WX*	*HiPhos only*	*HiPhos and WX*
beet by product		**3.0**	**2.9**	**4.1**
beetpulp france	France	1.8	1.8	1.8
molasses, beet	Belgium	1.2	1.1	2.2
cereal		**64.3**	**64.2**	**60.0**
barley	France	20.5	20.5	20.5
wheat 59% starch	France	28.8	28.7	24.5
yellow corn	France	15.0	15.0	15.0
cereal by product		**14.9**	**15.7**	**16.6**
maizegerm.ext.v	France	0.0	0.0	0.7
wheat bran (pellet) 8.5% cf	France	3.9	4.4	5.3
wheat gluten feed	France	2.1	2.3	2.3
milurex lestrem - wheat glute	France	8.9	8.9	8.4
fat		**1.7**	**1.7**	**1.7**
soybean oil	Brazil	1.7	1.7	1.7
mineral		**2.3**	**1.9**	**2.1**
limestone	Europe	1.3	1.6	1.7
monocalciumphos	Europe	0.6	0.0	0.0

salt	Europe	0.3	0.3	0.3
oil meal		**13.0**	**12.8**	**13.2**
arg. soybml. 49	Argentina	5.3	4.8	4.3
rapeseedmeal.vd	Germany	4.7	4.7	4.7
sunflow.meal 37	Germany	2.9	3.3	4.1
vit min aa et al.		**0.8**	**0.8**	**0.8**
cholin chloride 70% (cc)		0.0	0.0	0.0
dl-methionine	France	0.1	0.1	0.1
l-lysine hcl	France	0.5	0.4	0.4
l-threonine	France	0.2	0.2	0.2
l-tryptophane	France	0.0	0.0	0.0
ronozyme hiphos 2gt 0 - 2000 fyt	Denmark	0.0	0.0	0.0
ronozyme wx 2000 ct matrix	Denmark	0.0	0.0	0.0
trace elements		**0.1**	**0.1**	**0.1**
vitamins	Unknown	0.1	0.1	0.1
ronozyme hiphos 2gt 0 - 1000 fyt	Unkown	0.0	0.0	0.0
ronozyme hiphos 2gt 0 - 500 fyt	Unknown	0.0	0.0	0.0
soya by product		**0.0**	**0.0**	**1.6**
soybean hulls	Brazil	0.0	0.0	1.6
total		**100.1**	**100.1**	**100.1**

Table 44 Feed composition and origin of the ingredients for the dairy case

DSM ingredients	*APS ingredients (connected to Agri-footprint)*	*Origin*	*Amount (kg/ton)*
1000 BARLEY 20.000	Barley grain, dried	France	23
1001 BARLEY 20.000	Barley grain, dried	Germany	17.2
1002 BARLEY 20.000	Barley grain, dried	Netherlands	6.2
1003 BARLEY 20.000	Barley grain, dried	United Kingdom	3.6
1030 YELLOW CORN 17.500	Maize	France	50.6
1031 YELLOW CORN 17.500	Maize	Ukraine	45.8
1032 YELLOW CORN 17.500	Maize	Brazil	16.3
1033 YELLOW CORN 17.500	Maize	Germany	14
1034 YELLOW CORN 17.500	Maize	Hungary	11.7
1035 YELLOW CORN 17.500	Maize	Romania	11.7
1719 ARG. SOYBML. 49 15.879	Soybean meal (solvent)	Argentina	136.6
1750 RAPESEEDMEAL.VD 15.000	Rapeseed meal (solvent)	Germany	84.6
1751 RAPESEEDMEAL.VD 15.000	Rapeseed meal (solvent)	Netherlands	49.1
1752 RAPESEEDMEAL.VD 15.000	Rapeseed meal (solvent)	Belgium	16.3
1461 BEETPULP FRANCE 10.000	Sugar beet pulp dried	Netherlands	46.1
1241 MAIZEGLFD.ROQUE 8.801	Maize gluten feed dried	Netherlands	175
1510 MOLASSES, BEET 4.000	Sugar beet molasses	Netherlands	50
1028 WHEAT 59% Starch	Wheat grain, dried	France	23.2
1028 WHEAT 59% Starch	Wheat grain, dried	Netherlands	14
1028 WHEAT 59% Starch	Wheat grain, dried	Germany	12.9
2020 SOYBEAN HULLS 2.000	Soybean hull (solvent)	Argentina	50
2400 LIMESTONE 1.727	Limestone	Europe	16.4
1774 SUNFLOW.MEAL 37	Sunflower seed meal (solvent)	Netherlands	34.6
1774 SUNFLOW.MEAL 37	Sunflower seed meal (solvent)	Ukraine	24.8
1774 SUNFLOW.MEAL 37	Sunflower seed meal (solvent)	Argentina	19.1
2120 SOYBEAN OIL	Crude soybean oil (solvent)	Argentina	9.2
1171 WHEAT GLUTENFEED	Wheat gluten feed	Netherlands	30.6
2470 SALT 0.732	Salt	Europe	5.3
2459 MAGNESIUMOXYDE (50% Mg) 0.336	Vitamins and Minerals Premix	Europe	1.3
2390 VITAMINS 0.050	Vitamins and Minerals Premix	Europe	0.5
2391 TRACE ELEMENTS 0.050	Vitamins and Minerals Premix	Europe	0.5

Table 45 Feed composition and origin of the ingredients for the broiler case

Ingredient	Origin	Base-line	No phy-tase	Pro-tease	Xyla-nase	All enzymes	All enzymes + 25(OH)D3	All enzymes + Eubiotics	All solu-tions
Corn	FR	16.38	14.9	16.58	16.64	16.72	16.72	16.83	16.83
Soy bean meal	BR	17.62	18.06	16.81	16.67	15.66	15.66	15.82	15.82
Wheat	FR	49.04	47.4	49.74	46.22	47.14	47.15	46.86	46.86
Full fat soya	BR	6.26	7.81	5.98	5.75	5.75	5.75	5.77	5.77
Soy bean oil	BR	3.69	3.85	3.65	3.49	3.48	3.48	3.45	3.45
Peas	FR	3.08	3.08	3.08	3.08	3.08	3.08	3.18	3.18
Wheat bran	FR	0	0	0	1.76	1.83	1.83	1.79	1.79
Rapeseed meal	DE	0.25	0.24	0.51	1.58	1.58	1.58	1.54	1.54
Sunflower meal	DE	1	1	1	2.04	1.95	1.95	1.94	1.94
Animal fat	BE	0	0.23	0	0	0	0	0	0
Monocalcium phosphate	BE	0.22	1	0.22	0.2	0.21	0.21	0.22	0.22
Limestone	BE	1.21	1.16	1.21	1.32	1.37	1.37	1.37	1.37
DL-Methionine	FR	0.22	0.23	0.22	0.21	0.21	0.21	0.21	0.21
Biolys	FR	0.34	0.33	0.33	0.35	0.35	0.35	0.34	0.34
Salt	BE	0.21	0.21	0.21	0.2	0.2	0.2	0.2	0.2
L-Threonine	FR	0.11	0.14	0.1	0.11	0.1	0.1	0.1	0.1
Sodium bicarbonate	FR	0.13	0.14	0.12	0.13	0.12	0.12	0.12	0.12
Choline Chloride 70%	CN	0.083	0.083	0.083	0.083	0.083	0.083	0.083	0.083
Vitamin Premix	DE	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Mineral Premix	IT	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Coccidiostatic	FR	0.038	0.038	0.038	0.038	0.038	0.038	0.04	0.04
Protease	DK	0	0	0.02	0	0.02	0.02	0.02	0.02
Phytase	DK	0.01	0	0.01	0.01	0.01	0.01	0.01	0.01
Xylanase	DK	0	0	0	0.0081	0.0081	0.0081	0.0081	0.0081

8.2.2 Individual feed composition

Feed formulas

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Chickens for fattening

Bro 0-10 EXTREM	0-10d	Broiler recipe, no phytase, no protease, no carbohydrase
Bro 0-10 BAS HP	0-10d	Broiler recipe, with phytase, no protease, no carbohydrase
Bro 0-10 HP+PA	0-10d	Broiler recipe, with phytase and protease, no carbohydrase
Bro 0-10 HP+WX	0-10d	Broiler recipe, with phytase, no protease, with carbohydrase
Bro 0-10 ALL	0-10d	Broiler recipe, with all enzymes
Bro 10-20 EXTRE	10-20d	Broiler recipe, no phytase, no protease, no carbohydrase
Bro 10-20 BA HP	10-20d	Broiler recipe, with phytase, no protease, no carbohydrase
Bro 10-20 HP+PA	10-20d	Broiler recipe, with phytase and protease, no carbohydrase
Bro 10-20 HP+WX	10-20d	Broiler recipe, with phytase, no protease, with carbohydrase
Bro 10-20 ALL	10-20d	Broiler recipe, with all enzymes
Broil 20-35d AL	20-35d	Broiler recipe, with all enzymes
B 20-35 EXTR	20-35d	Broiler recipe, no phytase, no protease, no carbohydrase
B 20-35 Bas HP	20-35d	Broiler recipe, with phytase, no protease, no carbohydrase
B 20-35 HP+PA	20-35d	Broiler recipe, with phytase and protease, no carbohydrase
B 20-35 HP + WX	20-35d	Broiler recipe, with phytase, no protease, with carbohydrase
Bro 35-42 Extre	35-42d	Broiler recipe, no phytase, no protease, no carbohydrase
Bro 35-42 Bas H	35-42d	Broiler recipe, with phytase, no protease, no carbohydrase
Bro 35-42 HP+PA	35-42d	Broiler recipe, with phytase and protease, no carbohydrase
Bro 35-42 HP+WX	35-42d	Broiler recipe, with phytase, no protease, with carbohydrase
Bro 35-42 ALL	35-42d	Broiler recipe, with all enzymes

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Price list 104 LCA voeders

	Name	Bro 0-10 EXTREM	Bro 0-10 BAS HP	Bro 0-10 HP+PA	Bro 0-10 HP+WX	Bro 0-10 ALL
	Cost	282.941	276.502	276.859	274.051	274.407
	Grondstof	Aandeel (%)	Aandeel (%)	Aandeel (%)	Aandeel (%)	Aandeel (%)
1030	YELLOW CORN	35.427	37.753	38.842	38.490	39.579
1717	BRAZIL SOYBML50	27.930	27.008	26.115	26.937	26.045
1028	WHEAT 59% Starch	25.000	25.000	25.000	---	---
1605	FORTA	5.000	5.000	5.000	5.000	5.000
2120	SOYBEAN OIL	2.458	1.837	1.646	1.169	0.978
2410	MONOCALCIUMPHOS	1.604	0.815	0.823	0.813	0.822
2400	LIMESTONE	1.346	1.423	1.424	1.422	1.423
2200	DL-METHIONINE	0.285	0.260	0.250	0.259	0.249
2210	L-LYSINE HCL	0.229	0.216	0.216	0.217	0.217
2470	SALT	0.223	0.227	0.227	0.227	0.226
2220	L-THREONINE	0.131	0.099	0.086	0.098	0.086
2475	NA-BICARBONATE	0.124	0.109	0.096	0.101	0.088
2397	CHOLIN CHLORIDE 70% (CC)	0.093	0.093	0.093	0.093	0.093
2390	VITAMINS	0.050	0.050	0.050	0.050	0.050
2391	TRACE ELEMENTS	0.050	0.050	0.050	0.050	0.050
2750	COCCIDIOSTATIC	0.050	0.050	0.050	0.050	0.050
1029	WHEAT 59 ST ENZ	---	---	---	25.000	25.000
2379	RONOZYME PRO-ACT MX BENELUX	---	---	0.020	---	0.020
3218	Ronozyme HiPhos 2GT 0 - 2000 FYT	---	0.010	0.010	0.010	0.010
3021	Ronozyme WX 1000 (CT)	---	---	---	0.015	0.015

	Name	Bro 0-10 EXTREM	Bro 0-10 BAS HP	Bro 0-10 HP+PA	Bro 0-10 HP+WX	Bro 0-10 ALL
	Cost	282.941	276.502	276.859	274.051	274.407
	Nutriënt	gehalte (%)	gehalte (%)	gehalte (%)	gehalte (%)	gehalte (%)
101	Moisture (%)	11.869	12.050	12.094	12.140	12.184
102	Crude protein	21.429	21.097	20.724	21.116	20.743
103	Crude fat	5.711	5.166	5.004	4.528	4.367
104	Starch Ew.	39.439	40.872	41.518	41.339	41.984
107	Sugars + Starch	43.048	44.447	45.042	44.920	45.516
108	Crude ash	6.022	5.386	5.352	5.393	5.359
110	Crude fiber	2.696	2.723	2.721	2.740	2.738
119	Calcium av. poultry (incl. phytase)	0.900	1.001	1.001	1.001	1.001
120	Calcium	0.900	0.800	0.800	0.800	0.800
121	Phosphorus	0.708	0.539	0.537	0.539	0.538
124	P digestible Poultry	0.440	0.440	0.440	0.440	0.440
130	Sodium	0.130	0.130	0.130	0.130	0.130
131	Potassium	0.961	0.948	0.931	0.949	0.932
132	Chlorine	0.230	0.230	0.230	0.230	0.230
190	Xanthophylls (mg/kg)	7.341	7.605	7.753	7.571	7.719
300	Lysine	1.347	1.313	1.287	1.313	1.287
302	AFD Lysine Poultry	1.175	1.175	1.181	1.174	1.181
304	SID Lysine Poultry	1.200	1.200	1.200	1.200	1.200
310	Methionine	0.601	0.572	0.558	0.572	0.557
312	AFD Methionine Poultry	0.561	0.535	0.531	0.534	0.531
330	Methionine + Cystine	0.994	0.962	0.942	0.962	0.942
332	AFD Met+Cys Poultry	0.878	0.878	0.879	0.878	0.879

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	Name	Bro 0-10 EXTREM	Bro 0-10 BAS HP	Bro 0-10 HP+PA	Bro 0-10 HP+WX	Bro 0-10 ALL
	Cost	282.941	276.502	276.859	274.051	274.407
	Nutriënt	gehalte (%)	gehalte (%)	gehalte (%)	gehalte (%)	gehalte (%)
340	Tryptophane	0.266	0.261	0.255	0.261	0.255
342	AFD Tryptophane Poultry	0.231	0.231	0.231	0.231	0.231
350	Threonine	0.905	0.862	0.835	0.862	0.836
352	AFD Threonin Poultry	0.770	0.770	0.765	0.770	0.765
362	AFD Arginine Poultry	1.186	1.187	1.192	1.187	1.192
372	AFD Leucin Poultry	1.492	1.521	1.519	1.524	1.523
382	AFD Isoleucin Poultry	0.823	0.840	0.843	0.840	0.843
402	AFD Valin Poultry	0.970	0.990	0.991	0.990	0.992
490	ME Broilers (kcal/kg)	2800.000	2800.000	2800.000	2800.000	2800.000
500	ME Poultry (kcal/kg)	2981.591	2978.366	2975.969	2976.063	2973.665
587	6-Phytase - 4a18 (FYT/kg)	0	2000	2000	2000	2000
1006	Endo-1.4-betaxylanase EC 3.2.1.8 - 4a	0	0	0	150	150
9001	Ca/P total	1.270	1.485	1.489	1.483	1.486
9005	Ca/P digestible P	2.045	1.818	1.818	1.818	1.818
9031	AFD MET/LYS poultry	0.477	0.455	0.450	0.455	0.449
9033	AFD MET+CYS/LYS Poultry	0.747	0.747	0.745	0.748	0.745
9034	AFD TRYP/LYS poultry	0.197	0.197	0.196	0.197	0.196
9035	AFD THREO/LYS poultry	0.655	0.655	0.648	0.655	0.648
9036	AFD ARG/LYS poultry	1.009	1.011	1.010	1.011	1.010
9037	AFD LEU/LYS poultry	1.270	1.295	1.286	1.298	1.290
9038	AFD ISOLEU/LYS poultry	0.700	0.715	0.714	0.715	0.714
9040	AFD VAL/LYS poultry	0.825	0.843	0.839	0.843	0.840
9091	SID MET/LYS poultry	0.474	0.452	0.447	0.452	0.446
9093	SID METH+CYS/LYS poultry	0.730	0.730	0.730	0.730	0.730
9094	SID Tryp/Lys poultry	0.193	0.193	0.189	0.193	0.189
9095	SID THREO/LYS pluimvee	0.640	0.640	0.640	0.640	0.640
9096	SID ARG/LYS poultry	1.000	1.000	1.000	1.000	1.000
9097	SID LEU/LYS poultry	1.253	1.277	1.281	1.280	1.284
9098	SID ILEU/LYS poultry	0.691	0.705	0.705	0.705	0.705
9100	SID VAL/LYS poultry	0.820	0.837	0.838	0.837	0.839
9109	SID GLY + SER / LYS poultry	1.346	1.326	1.302	1.328	1.304

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Price list 104 LCA voeders

	Name	Bro 10-20 EXTRE	Bro 10-20 BA HP	Bro 10-20 HP+PA	Bro 10-20 HP+WX	Bro 10-20 ALL
	Cost	282.612	276.638	277.415	272.529	273.529
	Grondstof	Aandeel (%)	Aandeel (%)	Aandeel (%)	Aandeel (%)	Aandeel (%)
1028	WHEAT 59% Starch	41.431	43.910	44.958	---	---
1717	BRAZIL SOYBML50	23.058	22.089	21.187	20.168	19.245
1030	YELLOW CORN	20.000	20.000	20.000	20.000	20.000
1605	FORTA	5.000	5.000	5.000	5.000	5.000
2120	SOYBEAN OIL	3.842	3.253	3.109	2.500	2.500
1400	PEAS (EC)	3.000	3.000	3.000	3.000	3.000
2400	LIMESTONE	1.259	1.210	1.213	1.210	1.476
2410	MONOCALCIUMPHOS	1.246	0.446	0.451	0.419	0.425
2200	DL-METHIONINE	0.246	0.221	0.218	0.214	0.211
2470	SALT	0.217	0.222	0.222	0.206	0.206
2210	L-LYSINE HCL	0.210	0.197	0.196	0.230	0.230
2475	NA-BICARBONATE	0.130	0.114	0.101	0.125	0.112
2220	L-THREONINE	0.129	0.096	0.084	0.103	0.091
2397	CHOLIN CHLORIDE 70% (CC)	0.082	0.082	0.082	0.082	0.082
2390	VITAMINS	0.050	0.050	0.050	0.050	0.050
2391	TRACE ELEMENTS	0.050	0.050	0.050	0.050	0.050
2750	COCCIDIOSTATIC	0.050	0.050	0.050	0.050	0.050
1029	WHEAT 59 ST ENZ	---	---	---	44.161	44.726
1774	SUNFLOW.MEAL 37	---	---	---	2.407	2.500
2379	RONOZYME PRO-ACT MX BENELUX	---	---	0.020	---	0.020
3218	Ronozyme HiPhos 2GT 0 - 2000 FYT	---	0.010	0.010	0.010	0.010
3021	Ronozyme WX 1000 (CT)	---	---	---	0.015	0.015

	Name	Bro 10-20 EXTRE	Bro 10-20 BA HP	Bro 10-20 HP+PA	Bro 10-20 HP+WX	Bro 10-20 ALL
	Cost	282.612	276.638	277.415	272.529	273.529
	Nutriënt	gehalte (%)	gehalte (%)	gehalte (%)	gehalte (%)	gehalte (%)
101	Moisture (%)	11.563	11.721	11.742	11.760	11.730
102	Crude protein	20.276	20.023	19.685	20.022	19.656
103	Crude fat	6.724	6.161	6.022	5.415	5.413
104	Starch Ew.	40.571	42.013	42.595	42.174	42.468
107	Sugars + Starch	44.090	45.517	46.057	45.681	45.926
108	Crude ash	5.460	4.701	4.667	4.723	4.946
110	Crude fiber	2.649	2.672	2.664	3.030	3.027
119	Calcium av. poultry (incl. phytase)	0.800	0.851	0.851	0.851	0.953
120	Calcium	0.800	0.650	0.650	0.650	0.752
121	Phosphorus	0.627	0.456	0.455	0.469	0.468
124	P digestible Poultry	0.380	0.380	0.380	0.380	0.380
130	Sodium	0.130	0.130	0.130	0.130	0.130
131	Potassium	0.893	0.882	0.866	0.878	0.861
132	Chlorine	0.220	0.220	0.220	0.220	0.220
190	Xanthophylls (mg/kg)	5.060	4.913	4.877	4.725	4.725
300	Lysine	1.240	1.206	1.181	1.205	1.179
302	AFD Lysine Poultry	1.084	1.085	1.092	1.084	1.091
304	SID Lysine Poultry	1.100	1.100	1.100	1.100	1.100
310	Methionine	0.541	0.513	0.506	0.513	0.506
312	AFD Methionine Poultry	0.504	0.478	0.481	0.477	0.480

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	Name	Bro 10-20 EXTRE	Bro 10-20 BA HP	Bro 10-20 HP+PA	Bro 10-20 HP+WX	Bro 10-20 ALL
	Cost	282.612	276.638	277.415	272.529	273.529
	Nutriënt	gehalte (%)	gehalte (%)	gehalte (%)	gehalte (%)	gehalte (%)
330	Methionine + Cystine	0.928	0.899	0.888	0.904	0.891
332	AFD Met+Cys Poultry	0.817	0.821	0.831	0.823	0.832
340	Tryptophane	0.253	0.250	0.245	0.250	0.245
342	AFD Tryptophane Poultry	0.219	0.221	0.221	0.219	0.220
350	Threonine	0.843	0.800	0.773	0.801	0.775
352	AFD Threonin Poultry	0.716	0.716	0.712	0.717	0.713
362	AFD Arginine Poultry	1.091	1.093	1.098	1.094	1.099
372	AFD Leucin Poultry	1.337	1.360	1.355	1.344	1.338
382	AFD Isoleucin Poultry	0.761	0.779	0.783	0.773	0.776
402	AFD Valin Poultry	0.911	0.935	0.939	0.933	0.935
490	ME Broilers (kcal/kg)	2885.000	2885.000	2885.000	2885.000	2885.000
500	ME Poultry (kcal/kg)	3090.522	3091.204	3090.539	3089.020	3087.968
587	6-Phytase - 4a18 (FYT/kg)	0	2000	2000	2000	2000
1006	Endo-1,4-betaxylanase EC 3.2.1.8 - 4a	0	0	0	150	150
9001	Ca/P total	1.277	1.425	1.429	1.385	1.608
9005	Ca/P digestible P	2.105	1.711	1.711	1.711	1.980
9031	AFD MET/LYS poultry	0.465	0.441	0.441	0.441	0.441
9033	AFD MET+CYS/LYS Poultry	0.754	0.757	0.761	0.759	0.762
9034	AFD TRYP/LYS poultry	0.202	0.203	0.203	0.202	0.202
9035	AFD THREO/LYS poultry	0.661	0.660	0.652	0.662	0.654
9036	AFD ARG/LYS poultry	1.007	1.007	1.006	1.009	1.008
9037	AFD LEU/LYS poultry	1.233	1.253	1.241	1.240	1.227
9038	AFD ISOLEU/LYS poultry	0.702	0.719	0.718	0.713	0.712
9040	AFD VAL/LYS poultry	0.840	0.862	0.860	0.861	0.858
9091	SID MET/LYS poultry	0.463	0.440	0.440	0.440	0.440
9093	SID METH+CYS/LYS poultry	0.740	0.743	0.750	0.746	0.752
9094	SID Tryp/Lys poultry	0.200	0.201	0.197	0.200	0.196
9095	SID THREO/LYS pluimvee	0.650	0.650	0.650	0.650	0.650
9096	SID ARG/LYS poultry	1.000	1.000	1.000	1.000	1.000
9097	SID LEU/LYS poultry	1.226	1.247	1.249	1.232	1.232
9098	SID ILEU/LYS poultry	0.697	0.714	0.715	0.708	0.708
9100	SID VAL/LYS poultry	0.841	0.863	0.867	0.861	0.863
9109	SID GLY + SER / LYS poultry	1.368	1.350	1.325	1.343	1.317

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Price list 104 LCA voeders

	Name	Bro 35-42 Extre	Bro 35-42 Bas H	Bro 35-42 HP+PA	Bro 35-42 HP+WX	Bro 35-42 ALL
	Cost	277.724	265.920	266.965	264.258	265.379
	Grondstof	Aandeel (%)	Aandeel (%)	Aandeel (%)	Aandeel (%)	Aandeel (%)
1028	WHEAT 59% Starch	56.002	58.044	58.540	---	12.115
1717	BRAZIL SOYBML50	17.894	15.278	13.968	13.456	15.000
1030	YELLOW CORN	11.375	15.000	15.000	15.000	15.000
1605	FORTA	6.463	5.000	5.000	5.000	5.000
2120	SOYBEAN OIL	4.000	4.000	4.000	4.000	4.000
2400	LIMESTONE	1.362	1.437	1.431	1.385	1.385
2100	ANIMAL FAT (3-5 FFA)	1.012	---	---	---	---
2410	MONOCALCIUMPHOS	0.754	---	---	---	---
2210	L-LYSINE HCL	0.254	0.330	0.330	0.330	0.335
2200	DL-METHIONINE	0.209	0.220	0.216	0.209	0.204
2470	SALT	0.206	0.180	0.180	0.177	0.174
2475	NA-BICARBONATE	0.145	0.174	0.161	0.169	0.160
2220	L-THREONINE	0.141	0.145	0.132	0.137	0.125
2397	CHOLIN CHLORIDE 70% (CC)	0.082	0.082	0.082	0.082	0.082
2390	VITAMINS	0.050	0.050	0.050	0.050	0.050
2391	TRACE ELEMENTS	0.050	0.050	0.050	0.050	0.050
1750	RAPESEEDMEAL.VD	---	---	0.831	2.500	2.500
1135	WHEAT BRAN (pellet) 8.5% CF	---	---	---	2.500	2.500
1774	SUNFLOW.MEAL 37	---	---	---	1.185	2.011
3218	Ronozyme HiPhos 2GT 0 - 2000 FYT	---	0.010	0.010	0.010	0.010
1029	WHEAT 59 ST ENZ	---	---	---	53.745	54.265
2379	RONOZYME PRO-ACT MX BENELUX	---	---	0.020	---	0.020
3021	Ronozyme WX 1000 (CT)	---	---	---	0.015	0.015

	Name	Bro 35-42 Extre	Bro 35-42 Bas H	Bro 35-42 HP+PA	Bro 35-42 HP+WX	Bro 35-42 ALL
	Cost	277.724	265.920	266.965	264.258	265.379
	Nutriënt	gehalte (%)	gehalte (%)	gehalte (%)	gehalte (%)	gehalte (%)
101	Moisture (%)	11.283	11.553	11.558	11.554	11.541
102	Crude protein	18.699	17.435	17.121	17.738	17.433
103	Crude fat	8.014	6.797	6.809	6.880	6.879
104	Starch Ew.	42.300	45.636	45.919	43.690	43.970
107	Sugars + Starch	45.605	48.753	49.010	46.953	47.193
108	Crude ash	4.897	4.150	4.130	4.297	4.276
110	Crude fiber	2.476	2.468	2.534	3.029	3.139
119	Calcium av. poultry (incl. phytase)	0.750	0.849	0.850	0.850	0.850
120	Calcium	0.750	0.648	0.649	0.649	0.649
121	Phosphorus	0.508	0.337	0.339	0.376	0.379
124	P digestible Poultry	0.290	0.293	0.293	0.301	0.302
130	Sodium	0.130	0.130	0.130	0.130	0.130
131	Potassium	0.809	0.747	0.730	0.769	0.753
132	Chlorine	0.220	0.220	0.220	0.220	0.220
190	Xanthophylls (mg/kg)	3.500	4.050	4.050	4.050	4.050
300	Lysine	1.126	1.082	1.058	1.090	1.064
302	AFD Lysine Poultry	0.992	0.991	0.998	0.990	0.997
304	SID Lysine Poultry	1.000	1.000	1.000	1.000	1.000
310	Methionine	0.482	0.476	0.468	0.478	0.470

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	Name	Bro 35-42 Extre	Bro 35-42 Bas H	Bro 35-42 HP+PA	Bro 35-42 HP+WX	Bro 35-42 ALL
	Cost	277.724	265.920	266.965	264.258	265.379
	Nutriënt	gehalte (%)	gehalte (%)	gehalte (%)	gehalte (%)	gehalte (%)
312	AFD Methionine Poultry	0.447	0.445	0.448	0.444	0.447
330	Methionine + Cystine	0.857	0.833	0.824	0.848	0.838
332	AFD Met+Cys Poultry	0.753	0.766	0.777	0.771	0.781
340	Tryptophane	0.236	0.216	0.211	0.221	0.216
342	AFD Tryptophane Poultry	0.203	0.189	0.190	0.192	0.193
350	Threonine	0.776	0.724	0.699	0.733	0.707
352	AFD Threonin Poultry	0.660	0.658	0.654	0.660	0.656
362	AFD Arginine Poultry	0.948	0.871	0.876	0.892	0.903
372	AFD Leucin Poultry	1.173	1.130	1.125	1.136	1.130
382	AFD Isoleucin Poultry	0.679	0.647	0.650	0.649	0.653
402	AFD Valin Poultry	0.832	0.802	0.805	0.809	0.814
490	ME Broilers (kcal/kg)	3000.000	3000.000	3000.000	3000.000	3000.000
500	ME Poultry (kcal/kg)	3224.626	3212.181	3212.094	3219.390	3218.785
587	6-Phytase - 4a18 (FYT/kg)	0	2000	2000	2000	2000
1006	Endo-1,4-betaxylanase EC 3.2.1.8 - 4a	0	0	0	150	150
9001	Ca/P total	1.476	1.921	1.914	1.727	1.711
9005	Ca/P digestible P	2.586	2.212	2.216	2.156	2.152
9031	AFD MET/LYS poultry	0.451	0.449	0.449	0.448	0.448
9033	AFD MET+CYS/LYS Poultry	0.759	0.773	0.778	0.779	0.784
9034	AFD TRYP/LYS poultry	0.204	0.191	0.190	0.194	0.193
9035	AFD THREO/LYS poultry	0.665	0.664	0.655	0.667	0.658
9036	AFD ARG/LYS poultry	0.955	0.879	0.877	0.901	0.906
9037	AFD LEU/LYS poultry	1.182	1.141	1.127	1.147	1.133
9038	AFD ISOLEU/LYS poultry	0.685	0.653	0.651	0.655	0.655
9040	AFD VAL/LYS poultry	0.839	0.810	0.807	0.817	0.816
9091	SID MET/LYS poultry	0.452	0.450	0.450	0.450	0.450
9093	SID METH+CYS/LYS poultry	0.750	0.765	0.775	0.773	0.782
9094	SID Tryp/Lys poultry	0.203	0.191	0.187	0.193	0.189
9095	SID THREO/LYS pluimvee	0.660	0.660	0.660	0.660	0.660
9096	SID ARG/LYS poultry	0.950	0.873	0.871	0.890	0.895
9097	SID LEU/LYS poultry	1.190	1.150	1.150	1.150	1.150
9098	SID ILEU/LYS poultry	0.688	0.656	0.656	0.657	0.658
9100	SID VAL/LYS poultry	0.850	0.823	0.825	0.826	0.831
9109	SID GLY + SER / LYS poultry	1.354	1.247	1.220	1.263	1.237

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Price list 104 LCA voeders

	Name	Broil 20-35d AL	B 20-35 EXTR	B 20-35 Bas HP	B 20-35 HP+PA	B 20-35 HP + WX
	Cost	276.516	283.912	277.881	278.613	275.148
	Grondstof	Aandeel (%)	Aandeel (%)	Aandeel (%)	Aandeel (%)	Aandeel (%)
1029	WHEAT 59 ST ENZ	48.368	---	---	---	47.583
1717	BRAZIL SOYBML50	14.331	14.695	15.544	15.004	15.237
1030	YELLOW CORN	12.749	11.409	12.350	12.568	12.749
1605	FORTA	6.500	9.948	7.528	6.968	6.500
1400	PEAS (EC)	5.000	5.000	5.000	5.000	5.000
2120	SOYBEAN OIL	4.000	4.000	4.000	4.000	4.000
1135	WHEAT BRAN (pellet) 8.5% CF	2.500	---	---	---	2.377
1750	RAPESEEDMEAL.VD	2.000	0.473	0.496	0.630	2.000
1774	SUNFLOW.MEAL 37	2.000	2.000	2.000	2.000	2.000
2400	LIMESTONE	1.314	1.001	1.079	1.079	1.312
2210	L-LYSINE HCL	0.218	0.229	0.214	0.213	0.219
2470	SALT	0.211	0.208	0.213	0.213	0.211
2200	DL-METHIONINE	0.208	0.227	0.213	0.210	0.210
2410	MONOCALCIUMPHOS	0.127	0.936	0.142	0.146	0.122
2475	NA-BICARBONATE	0.107	0.143	0.125	0.112	0.120
2220	L-THREONINE	0.091	0.138	0.105	0.092	0.103
2397	CHOLIN CHLORIDE 70% (CC)	0.082	0.082	0.082	0.082	0.082
2390	VITAMINS	0.050	0.050	0.050	0.050	0.050
2391	TRACE ELEMENTS	0.050	0.050	0.050	0.050	0.050
2750	COCCIDIOSTATIC	0.050	0.050	0.050	0.050	0.050
2379	RONOZYME PRO-ACT MX BENELUX	0.020	---	---	0.020	---
3021	Ronozyme WX 1000 (CT)	0.015	---	---	---	0.015
3218	Ronozyme HiPhos 2GT 0 - 2000 FYT	0.010	---	0.010	0.010	0.010
1028	WHEAT 59% Starch	---	49.361	50.748	51.504	---

	Name	Broil 20-35d AL	B 20-35 EXTR	B 20-35 Bas HP	B 20-35 HP+PA	B 20-35 HP + WX
	Cost	276.516	283.912	277.881	278.613	275.148
	Nutriënt	gehalte (%)	gehalte (%)	gehalte (%)	gehalte (%)	gehalte (%)
101	Moisture (%)	11.510	11.335	11.481	11.503	11.505
102	Crude protein	18.965	19.599	19.285	18.941	19.314
103	Crude fat	7.131	7.767	7.273	7.160	7.127
104	Starch Ew.	41.356	40.648	42.027	42.576	40.907
107	Sugars + Starch	44.840	44.132	45.474	45.980	44.434
108	Crude ash	4.530	4.867	4.239	4.209	4.563
110	Crude fiber	3.273	3.000	3.000	3.000	3.276
119	Calcium av. poultry (incl. phytase)	0.850	0.650	0.751	0.751	0.850
120	Calcium	0.649	0.650	0.550	0.550	0.649
121	Phosphorus	0.419	0.574	0.403	0.402	0.420
124	P digestible Poultry	0.330	0.330	0.330	0.330	0.330
130	Sodium	0.130	0.130	0.130	0.130	0.130
131	Potassium	0.829	0.841	0.831	0.815	0.844
132	Chlorine	0.220	0.220	0.220	0.220	0.220
190	Xanthophylls (mg/kg)	4.000	4.000	4.000	4.000	4.000
300	Lysine	1.121	1.179	1.143	1.117	1.147
302	AFD Lysine Poultry	1.034	1.028	1.028	1.035	1.027
304	SID Lysine Poultry	1.040	1.040	1.040	1.040	1.040

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	Name	Broil 20-35d AL	B 20-35 EXTR	B 20-35 Bas HP	B 20-35 HP+PA	B 20-35 HP + WX
	Cost	276.516	283.912	277.881	278.613	275.148
	Nutriënt	gehalte (%)	gehalte (%)	gehalte (%)	gehalte (%)	gehalte (%)
310	Methionine	0.491	0.514	0.498	0.490	0.498
312	AFD Methionine Poultry	0.465	0.477	0.463	0.466	0.462
330	Methionine + Cystine	0.872	0.895	0.878	0.867	0.884
332	AFD Met+Cys Poultry	0.810	0.784	0.800	0.810	0.801
340	Tryptophane	0.236	0.244	0.240	0.236	0.241
342	AFD Tryptophane Poultry	0.211	0.209	0.210	0.211	0.210
350	Threonine	0.747	0.815	0.770	0.743	0.774
352	AFD Threonin Poultry	0.685	0.691	0.689	0.685	0.690
362	AFD Arginine Poultry	1.045	1.038	1.037	1.043	1.039
372	AFD Leucin Poultry	1.244	1.226	1.253	1.249	1.250
382	AFD Isoleucin Poultry	0.729	0.710	0.730	0.735	0.725
402	AFD Valin Poultry	0.885	0.855	0.884	0.889	0.882
490	ME Broilers (kcal/kg)	2957.453	2950.000	2950.000	2950.000	2950.000
500	ME Poultry (kcal/kg)	3181.483	3171.527	3169.601	3168.477	3174.170
587	6-Phytase - 4a18 (FYT/kg)	2000	0	2000	2000	2000
1006	Endo-1,4-betaxylanase EC 3.2.1.8 - 4a	150	0	0	0	150
9001	Ca/P total	1.549	1.132	1.363	1.367	1.545
9005	Ca/P digestible P	1.967	1.970	1.667	1.667	1.967
9031	AFD MET/LYS poultry	0.450	0.464	0.450	0.450	0.450
9033	AFD MET+CYS/LYS Poultry	0.783	0.763	0.778	0.783	0.780
9034	AFD TRYP/LYS poultry	0.204	0.203	0.204	0.204	0.204
9035	AFD THREO/LYS poultry	0.663	0.672	0.671	0.662	0.672
9036	AFD ARG/LYS poultry	1.010	1.010	1.010	1.008	1.012
9037	AFD LEU/LYS poultry	1.203	1.193	1.219	1.208	1.217
9038	AFD ISOLEU/LYS poultry	0.705	0.691	0.711	0.710	0.706
9040	AFD VAL/LYS poultry	0.856	0.832	0.861	0.859	0.859
9091	SID MET/LYS poultry	0.450	0.463	0.450	0.450	0.450
9093	SID METH+CYS/LYS poultry	0.776	0.750	0.766	0.774	0.769
9094	SID Tryp/Lys poultry	0.198	0.199	0.202	0.198	0.202
9095	SID THREO/LYS pluimvee	0.660	0.660	0.660	0.660	0.660
9096	SID ARG/LYS poultry	1.000	1.000	1.000	1.000	1.000
9097	SID LEU/LYS poultry	1.210	1.187	1.214	1.217	1.209
9098	SID ILEU/LYS poultry	0.703	0.687	0.707	0.709	0.702
9100	SID VAL/LYS poultry	0.863	0.834	0.863	0.868	0.860
9109	SID GLY + SER / LYS poultry	1.322	1.365	1.349	1.324	1.349

Feed formulas

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Pigs for fattening

GF Pig 25-50 AL	25-50kg	Pig for fattening, with both enzymes
Pig 25-50 basaa	25-50kg	Pig for fattening, without phytase, without carbohydrase
Pig 25-50 hipho	25-50kg	Pig for fattening, with phytase, without carbohydrase
GF Pig 50-80 EX	50-80kg	Pig for fattening, without phytase, without carbohydrase
GF Pig 50-80 HP	50-80kg	Pig for fattening, with phytase, without carbohydrase
GF Pig 50-80 AL	50-80kg	Pig for fattening, with both enzymes
GF Pig80-100 EX	80-100kg	Pig for fattening, without phytase, without carbohydrase
GF Pig80-100 HP	80-100kg	Pig for fattening, with phytase, without carbohydrase
GF Pig80-100 AL	80-100kg	Pig for fattening, with phytase, without carbohydrase

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23-06-2020 16:51

DSM linpro

Price list 104 LCA voeders

	Name	GF Pig 25-50 AL	Pig 25-50 basaa	Pig 25-50 hipho
	Cost	227.065	232.431	228.428
	Grondstof	Aandeel (%)	Aandeel (%)	Aandeel (%)
1028	WHEAT 59% Starch	24.742	30.421	29.441
1000	BARLEY	22.000	22.000	22.000
1030	YELLOW CORN	15.000	15.000	15.000
1171	MILUREX LESTREM - WHEAT GLUTE	9.000	8.113	9.000
1719	ARG. SOYBML. 49	8.265	10.516	10.333
1750	RAPESEEDMEAL.VD	4.000	4.000	4.000
1774	SUNFLOW.MEAL 37	3.000	1.356	0.214
1135	WHEAT BRAN (pellet) 8.5% CF	3.000	---	2.038
1260	MAIZEGERM.EXT.V	2.790	---	---
2400	LIMESTONE	2.017	1.497	1.791
1461	BEETPULP FRANCE	2.000	2.000	2.000
2120	SOYBEAN OIL	1.917	2.024	1.952
1510	MOLASSES, BEET	1.000	1.000	1.000
2210	L-LYSINE HCL	0.478	0.474	0.455
2470	SALT	0.300	0.300	0.300
2220	L-THREONINE	0.172	0.188	0.172
2200	DL-METHIONINE	0.093	0.099	0.104
2410	MONOCALCIUMPHOS	0.064	0.867	0.049
2390	VITAMINS	0.050	0.050	0.050
2391	TRACE ELEMENTS	0.050	0.050	0.050
2397	CHOLIN CHLORIDE 70% (CC)	0.024	0.024	0.024
2230	L-TRYPTOPHANE	0.018	0.021	0.017
3024	Ronozyme WX 2000 CT Matrix	0.010	---	---
3218	Ronozyme HiPhos 2GT 0 - 2000 FYT	0.010	---	0.010

	Name	GF Pig 25-50 AL	Pig 25-50 basaa	Pig 25-50 hipho
	Cost	227.065	232.431	228.428
	Nutriënt	gehalte (%)	gehalte (%)	gehalte (%)
101	Moisture (%)	11.482	11.508	11.592
102	Crude protein	15.593	15.498	15.307
103	Crude fat	4.000	4.000	4.000
104	Starch Ew.	40.566	42.484	42.493
108	Crude ash	5.298	5.357	4.968
109	Calcium av. pigs (incl. phytase)	1.087	0.857	0.994
110	Crude fiber	4.846	4.200	4.200
120	Calcium	0.930	0.857	0.837
121	Phosphorus	0.438	0.577	0.407
122	P inositol	0.303	0.278	0.284
127	P digestible Pigs	0.288	0.291	0.289
128	Phosphorus, std dig, pigs, pellet	0.285	0.283	0.283
129	Phosphorus, std dig, pigs, mash	0.310	0.310	0.310
130	Sodium	0.157	0.150	0.153
142	Na+K-Cl (meq/100 g)	15.620	15.288	15.778
180	Linoleic acid (C18:2)	1.805	1.817	1.809
214	Fermentable Carbohydrates (pigs)	12.629	11.901	12.136
215	Inert Carbohydrates (pigs)	8.867	7.729	7.979

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	Name	GF Pig 25-50 AL	Pig 25-50 basaa	Pig 25-50 hipho
	Cost	227.065	232.431	228.428
	Nutriënt	gehalte (%)	gehalte (%)	gehalte (%)
224	NSP digest. Pig (g/kg)	124.863	118.590	120.432
300	Lysine	1.030	1.039	1.017
301	AID Lysine Pig	0.896	0.896	0.896
303	SID Lysine Pig	0.930	0.930	0.930
313	SID Methionine Pig	0.307	0.307	0.307
333	SID Met+Cys Pig	0.581	0.577	0.582
343	SID Tryptophane Pig	0.177	0.177	0.177
353	SID Threonine Pig	0.614	0.614	0.614
470	NE pigs 2015 (MJ/kg)	10.008	10.008	10.008
471	Nett Energy Pig 2015 (kcal/kg)	2390.000	2390.000	2390.000
472	EW Pig 2015 (x2100 kcal NE)	1.137	1.137	1.137
479	NEv pigs 2004 (MJ/kg)	9.602	9.595	9.595
480	NEtt Energy Pig 2004 (kcal/kg)	2294.036	2292.334	2292.347
481	EW Pig 2004 (x2100 kcal NE)	1.092	1.092	1.092
587	6-Phytase - 4a18 (FYT/kg)	2000	0	2000
1006	Endo-1,4-betaxylanase EC 3.2.1.8 - 4a	200	0	0
9003	Ca/P dig. pigs	3.228	2.950	2.898
9051	AID MET/LYS Pig	0.332	0.332	0.332
9053	AID M+C/LYS Pig	0.618	0.613	0.618
9054	AID TRP/LYS Pig	0.184	0.184	0.184
9055	AID THR/LYS Pig	0.627	0.627	0.627
9060	AID VAL/LYS Pig	0.688	0.675	0.681
9071	SID MET/LYS Pig	0.330	0.330	0.330
9073	SID M+C/LYS Pig	0.625	0.620	0.626
9074	SID TRP/LYS Pig	0.190	0.190	0.190
9075	SID THR/LYS Pig	0.660	0.660	0.660
9077	SID LEU/LYS Pig	1.000	1.000	1.006
9078	SID ILE/LYS Pig	0.544	0.545	0.546
9079	SID HIS/LYS Pig	0.334	0.334	0.330
9080	SID VAL/LYS Pig	0.713	0.700	0.706

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DSM linpro

Price list 104 LCA voeders

	Name	GF Pig 50-80 EX	GF Pig 50-80 HP	GF Pig 50-80 AL
	Cost	221.314	218.314	217.988
	Grondstof	Aandeel (%)	Aandeel (%)	Aandeel (%)
1028	WHEAT 59% Starch	28.074	28.212	24.166
1000	BARLEY	20.000	20.000	20.000
1030	YELLOW CORN	15.000	15.000	15.000
1171	MILUREX LESTREM - WHEAT GLUTE	12.000	12.000	12.000
1719	ARG. SOYBML. 49	5.366	4.182	4.213
1750	RAPESEEDMEAL.VD	5.000	5.000	5.000
1135	WHEAT BRAN (pellet) 8.5% CF	5.000	5.000	5.000
1774	SUNFLOW.MEAL 37	2.079	3.541	4.000
2120	SOYBEAN OIL	1.841	1.841	1.857
1461	BEETPULP FRANCE	1.511	1.537	1.500
2400	LIMESTONE	1.429	1.586	1.737
1510	MOLASSES, BEET	1.000	1.000	2.643
2410	MONOCALCIUMPHOS	0.572	---	---
2210	L-LYSINE HCL	0.462	0.456	0.453
2470	SALT	0.300	0.300	0.300
2220	L-THREONINE	0.177	0.159	0.159
2200	DL-METHIONINE	0.060	0.056	0.057
2390	VITAMINS	0.050	0.050	0.050
2391	TRACE ELEMENTS	0.050	0.050	0.050
2397	CHOLIN CHLORIDE 70% (CC)	0.016	0.016	0.016
2230	L-TRYPTOPHANE	0.014	0.009	0.010
2020	SOYBEAN HULLS	---	---	1.774
3024	Ronozyme WX 2000 CT Matrix	---	---	0.010
3216	Ronozyme HiPhos 2GT 0 - 1000 FYT	---	0.005	0.005

	Name	GF Pig 50-80 EX	GF Pig 50-80 HP	GF Pig 50-80 AL
	Cost	221.314	218.314	217.988
	Nutriënt	gehalte (%)	gehalte (%)	gehalte (%)
101	Moisture (%)	11.621	11.629	11.745
102	Crude protein	14.526	14.500	14.580
103	Crude fat	4.000	4.000	4.000
104	Starch Ew.	41.910	41.989	39.724
108	Crude ash	5.075	4.767	5.139
109	Calcium av. pigs (incl. phytase)	0.780	0.894	0.965
110	Crude fiber	4.667	4.887	5.500
120	Calcium	0.780	0.750	0.821
121	Phosphorus	0.553	0.441	0.437
122	P inositol	0.312	0.320	0.316
127	P digestible Pigs	0.236	0.253	0.249
128	Phosphorus, std dig, pigs, pellet	0.232	0.250	0.249
129	Phosphorus, std dig, pigs, mash	0.260	0.278	0.274
130	Sodium	0.155	0.156	0.171
142	Na+K-Cl (meq/100 g)	15.116	15.119	17.471
180	Linoleic acid (C18:2)	1.795	1.796	1.801
214	Fermentable Carbodhydrates (pigs)	12.000	12.000	12.762
215	Inert Carbohydrates (pigs)	9.186	9.499	9.794

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	Name	GF Pig 50-80 EX	GF Pig 50-80 HP	GF Pig 50-80 AL
	Cost	221.314	218.314	217.988
	Nutriënt	gehalte (%)	gehalte (%)	gehalte (%)
224	NSP digest. Pig (g/kg)	119.508	119.715	124.668
300	Lysine	0.940	0.921	0.925
301	AID Lysine Pig	0.796	0.796	0.796
303	SID Lysine Pig	0.830	0.830	0.830
313	SID Methionine Pig	0.257	0.257	0.257
333	SID Met+Cys Pig	0.517	0.526	0.521
343	SID Tryptophane Pig	0.158	0.158	0.158
353	SID Threonine Pig	0.556	0.556	0.556
470	NE pigs 2015 (MJ/kg)	9.799	9.799	9.826
471	Nett Energy Pig 2015 (kcal/kg)	2340.000	2340.000	2346.588
472	EW Pig 2015 (x2100 kcal NE)	1.114	1.114	1.117
479	NEv pigs 2004 (MJ/kg)	9.406	9.408	9.435
480	NEtt Energy Pig 2004 (kcal/kg)	2247.033	2247.633	2254.018
481	EW Pig 2004 (x2100 kcal NE)	1.070	1.070	1.073
587	6-Phytase - 4a18 (FYT/kg)	0	1000	1000
1006	Endo-1,4-betaxylanase EC 3.2.1.8 - 4a	0	0	200
9003	Ca/P dig. pigs	3.310	2.961	3.293
9051	AID MET/LYS Pig	0.311	0.311	0.311
9053	AID M+C/LYS Pig	0.615	0.626	0.619
9054	AID TRP/LYS Pig	0.183	0.183	0.183
9055	AID THR/LYS Pig	0.634	0.634	0.634
9060	AID VAL/LYS Pig	0.689	0.707	0.700
9071	SID MET/LYS Pig	0.310	0.310	0.310
9073	SID M+C/LYS Pig	0.623	0.634	0.628
9074	SID TRP/LYS Pig	0.190	0.190	0.190
9075	SID THR/LYS Pig	0.670	0.670	0.670
9077	SID LEU/LYS Pig	1.000	1.006	1.000
9078	SID ILE/LYS Pig	0.531	0.539	0.539
9079	SID HIS/LYS Pig	0.343	0.341	0.338
9080	SID VAL/LYS Pig	0.716	0.734	0.727

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Price list 104 LCA voeders

	Name	GF Pig80-100 EX	GF Pig80-100 HP	GF Pig80-100 AL
	Cost	213.863	211.207	210.826
	Grondstof	Aandeel (%)	Aandeel (%)	Aandeel (%)
1028	WHEAT 59% Starch	28.474	28.611	24.732
1000	BARLEY	20.000	20.000	20.000
1030	YELLOW CORN	15.000	15.000	15.000
1171	MILUREX LESTREM - WHEAT GLUTE	12.000	12.000	10.500
1135	WHEAT BRAN (pellet) 8.5% CF	5.500	5.500	7.000
1750	RAPESEEDMEAL.VD	5.000	5.000	5.000
1774	SUNFLOW.MEAL 37	4.675	5.000	5.000
1461	BEETPULP FRANCE	2.000	2.000	2.000
1719	ARG. SOYBML. 49	1.871	1.710	1.775
1510	MOLASSES, BEET	1.456	1.273	2.673
2120	SOYBEAN OIL	1.334	1.331	1.327
2400	LIMESTONE	1.150	1.555	1.552
2410	MONOCALCIUMPHOS	0.475	---	---
2210	L-LYSINE HCL	0.438	0.416	0.414
2470	SALT	0.300	0.300	0.300
2220	L-THREONINE	0.157	0.137	0.140
2200	DL-METHIONINE	0.051	0.049	0.052
2390	VITAMINS	0.050	0.050	0.050
2391	TRACE ELEMENTS	0.050	0.050	0.050
2397	CHOLIN CHLORIDE 70% (CC)	0.016	0.016	0.016
2230	L-TRYPTOPHANE	0.005	0.000	0.003
2020	SOYBEAN HULLS	---	---	2.406
3024	Ronozyme WX 2000 CT Matrix	---	---	0.010
3211	Ronozyme HiPhos 2GT 0 - 500 FYT	---	0.002	0.002

	Name	GF Pig80-100 EX	GF Pig80-100 HP	GF Pig80-100 AL
	Cost	213.863	211.207	210.826
	Nutriënt	gehalte (%)	gehalte (%)	gehalte (%)
101	Moisture (%)	11.733	11.708	11.851
102	Crude protein	14.000	14.000	14.000
103	Crude fat	3.500	3.500	3.500
104	Starch Ew.	42.162	42.250	40.024
108	Crude ash	4.763	4.750	4.963
109	Calcium av. pigs (incl. phytase)	0.660	0.866	0.879
110	Crude fiber	5.134	5.188	6.000
120	Calcium	0.660	0.741	0.754
121	Phosphorus	0.547	0.448	0.444
122	P inositol	0.324	0.327	0.322
127	P digestible Pigs	0.215	0.231	0.226
128	Phosphorus, std dig, pigs, pellet	0.212	0.227	0.225
129	Phosphorus, std dig, pigs, mash	0.240	0.256	0.251
130	Sodium	0.159	0.159	0.169
142	Na+K-Cl (meq/100 g)	15.000	15.000	17.206
180	Linoleic acid (C18:2)	1.544	1.544	1.548
214	Fermentable Carbodhydrates (pigs)	12.091	12.101	13.099
215	Inert Carbohydrates (pigs)	9.874	9.947	10.384

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	Name	GF Pig80-100 EX	GF Pig80-100 HP	GF Pig80-100 AL
	Cost	213.863	211.207	210.826
	Nutriënt	gehalte (%)	gehalte (%)	gehalte (%)
224	NSP digest. Pig (g/kg)	120.627	120.856	127.154
300	Lysine	0.860	0.842	0.848
301	AID Lysine Pig	0.716	0.716	0.716
303	SID Lysine Pig	0.750	0.750	0.750
313	SID Methionine Pig	0.248	0.248	0.248
333	SID Met+Cys Pig	0.503	0.511	0.503
343	SID Tryptophane Pig	0.143	0.143	0.143
353	SID Threonine Pig	0.510	0.510	0.510
470	NE pigs 2015 (MJ/kg)	9.631	9.631	9.645
471	Nett Energy Pig 2015 (kcal/kg)	2300.000	2300.000	2303.265
472	EW Pig 2015 (x2100 kcal NE)	1.094	1.094	1.096
479	NEv pigs 2004 (MJ/kg)	9.243	9.243	9.244
480	NEtt Energy Pig 2004 (kcal/kg)	2208.068	2208.093	2208.491
481	EW Pig 2004 (x2100 kcal NE)	1.051	1.051	1.052
587	6-Phytase - 4a18 (FYT/kg)	0	500	500
1006	Endo-1,4-betaxylanase EC 3.2.1.8 - 4a	0	0	200
9003	Ca/P dig. pigs	3.068	3.209	3.334
9051	AID MET/LYS Pig	0.332	0.332	0.332
9053	AID M+C/LYS Pig	0.663	0.674	0.664
9054	AID TRP/LYS Pig	0.182	0.182	0.182
9055	AID THR/LYS Pig	0.640	0.640	0.640
9060	AID VAL/LYS Pig	0.727	0.749	0.733
9071	SID MET/LYS Pig	0.330	0.330	0.330
9073	SID M+C/LYS Pig	0.670	0.681	0.671
9074	SID TRP/LYS Pig	0.190	0.190	0.190
9075	SID THR/LYS Pig	0.680	0.680	0.680
9077	SID LEU/LYS Pig	1.029	1.049	1.037
9078	SID ILE/LYS Pig	0.543	0.558	0.553
9079	SID HIS/LYS Pig	0.358	0.360	0.355
9080	SID VAL/LYS Pig	0.756	0.777	0.761

16/23

Feed formulas

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Dairy concentrate

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23-07-2020 16:06

21592 Dairy feed 110 DVE

Artikel :		**Systeem :**	ALGEMEEN
Real batch size	1000.00000000 kg	**Optimalisatie :**	23/07/2020 16:05
Matrix	1 DNP VVT 327	**Prijs optimaal :**	224.03090894 / 1000kg
met prijslijst :	104 LCA voeders	**prijs afgerond :**	224.03090894 / 1000kg
met prijslijst :	104 LCA voeders		

Nr.	Raw material description	Aandeel	kg	min	max
1241	MAIZEGLFD.ROQUE	17.500	175.000	7.500	17.500
1750	RAPESEEDMEAL.VD	15.000	150.000	10.000	15.000
1030	YELLOW CORN	15.000	150.000	15.000	17.500
1719	ARG. SOYBML. 49	13.655	136.553	-	-
1774	SUNFLOW.MEAL 37	7.851	78.506	-	15.000
2020	SOYBEAN HULLS	5.000	50.000	2.000	5.000
1510	MOLASSES, BEET	5.000	50.000	5.000	5.000
1028	WHEAT 59% Starch	5.000	50.000	5.000	40.000
1000	BARLEY	5.000	50.000	5.000	20.000
1461	BEETPULP FRANCE	4.608	46.079	4.000	9.000
1171	MILUREX LESTREM - WHEAT GLUTENFEE	3.059	30.594	-	15.000
2400	LIMESTONE	1.643	16.430	-	-
2120	SOYBEAN OIL	0.919	9.190	-	1.500
2470	SALT	0.532	5.316	0.500	-
2459	MAGNESIUMOXYDE (50% Mg)	0.133	1.332	-	-
2391	TRACE ELEMENTS	0.050	0.500	0.050	-
2390	VITAMINS	0.050	0.500	0.050	-
	Total	**100.000**	**1000.000**		

Nr.	Nutrient description	aandeel	min	max
101	Moisture (%)	12.007	-	13.500
102	Crude protein	21.500	21.500	28.000
103	Crude fat	3.100	3.100	5.000
104	Starch Ew.	22.256	-	-
105	Sugars	6.583	-	-
107	Sugars + Starch	28.817	-	-
108	Crude ash	7.373	-	-
110	Crude fiber	8.576	-	11.000
116	NSP	30.752	-	-
117	Starch Am.	18.734	-	-
118	Crude fat (acid hydrolysis)	3.842	-	-
120	Calcium	0.950	0.950	1.500
121	Phosphorus	0.607	0.400	-
122	P inositol	0.409	-	-
130	Sodium	0.300	0.300	-
131	Potassium	1.322	-	-
132	Chlorine	0.430	-	-
133	Magnesium	0.350	0.350	-
136	Zwavel %	0.235	-	-
181	C18:3 Linoleic acid (n-3)	0.123	-	-
187	PUFA	1.413	-	-
188	n-6 PUFA	1.289	-	-
189	n-3 PUFA	0.123	-	-
200	ADF	11.363	-	-
201	NDF	22.529	-	-
202	ADL	2.312	-	-
250	Dig. CProt. Rum. (g/kg)	175.822	-	-
280	Undeg.Starch Rum	5.364	-	-
281	Undegr. Prot.Rum	7.214	-	-
285	DOM Ruminant (g/kg)	677.661	-	-
286	FOM Ruminant (g/kg)	520.000	520.000	-

18/23
1

Afdruk Prijslijst - LINPRO (dagprijzen franco geleverd)

Code		104
Name	LCA	
Description	LCA	
Date from		
Date to		
Preselections	<<	0
All systems		1
Systems	<<	0
Add specification's		0
Base price list		
Relative correction on base		
Absolute correction		
Corrections only for internal		0
Matrix to be used for price		1
	DNP VVT	

June 2020

Raw	Raw material description	Price	On dry
1000	BARLEY	172.000	0
1005	BARLEY, FLAKED	217.000	0
1014	OAT, EXTRUSION	306.000	0
1027	WHEAT 59ST PEL	204.000	0
1028	WHEAT 59% Starch	204.000	0
1029	WHEAT 59 ST ENZ	204.000	0
1030	YELLOW CORN	194.000	0
1035	MAIS, FLAKED	239.000	0
1121	WHEAT BRAN (meal) 10% CF	174.000	0
1135	WHEAT BRAN (pellet) 8.5% CF	174.000	0
1142	WHEAT BRAN (6% CF)	177.000	0
1152	WHEAT MIDDLINGS 6% CF	177.000	0
1171	MILUREX LESTREM - WHEAT	185.000	0
1175	Tarweglutenmeel	1230.000	0
1222	MAIZE FDML.C.NL	9999.000	0
1227	MAIZE FDML.FSPR	9999.000	0
1241	MAIZEGLFD.ROQUE	188.000	0
1260	MAIZEGERM.EXT.V	207.000	0
1291	PROTICORN ABF DDGS	237.000	0
1320	MALT SPROUTS 21	180.000	0
1400	PEAS (EC)	249.000	0
1461	BEETPULP FRANCE	189.000	0
1505	MOLASSES, CANE, ED&F	230.000	0
1510	MOLASSES, BEET	160.000	0
1521	CITROCOL	100.000	0
1603	DANEX SOYB.FFT	404.000	0
1605	FORTA	419.000	0
1610	SOYPREME (Danis)	434.000	0
1617	BOSOY | EXTRUDED SOYBEANS	398.000	0
1630	LINSEED	9999.000	0
1710	SOYBML 44 ARG.	316.000	0
1713	SOYBEANMEAL BRAZIL 46 CP	335.000	0
1717	BRAZIL SOYBML50	352.000	0
1719	ARG. SOYBML. 49	340.000	0

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Raw	Raw material description	Price	On dry
1725	SOYBML 46 NGMO	435.000	0
1734	PROXYSOY	399.000	0
1750	RAPESEEDMEAL.VD	238.000	0
1757	PROXYRAP	308.000	0
1762	Rapeseed expeller, Oliefabriek	9999.000	0
1773	SUNFLOW.MEAL 35	9999.000	0
1774	SUNFLOW.MEAL 37	248.000	0
1775	SUNFL.ML.EXT.28%	210.000	0
1781	SUNFLOWER EXPELLER 33/10	250.000	0
1801	LINSEED.EXP.BEL	364.000	0
1850	PALMKERNEL EXPLELLER CF<22%	174.000	0
1949	ALFALFA 14% CP	215.000	0
2011	OAT HULLS, 20-30% CF	142.000	0
2020	SOYBEAN HULLS	173.000	0
2100	ANIMAL FAT (3-5 FFA)	665.000	0
2103	LARD (PIG FAT)	720.000	0
2110	SALMON OIL (Norwegian)	1320.000	0
2120	SOYBEAN OIL	635.000	0
2127	LINSEED OIL	930.000	0
2130	RAPESEED OIL	740.000	0
2134	PALM OIL	580.000	0
2135	COCONUT OIL	850.000	0
2140	MEGALAC	1000.000	0
2142	DHA gold	11000.000	0
2146	DHA GOLD 85 (UH43834)	550.000	0
2200	DL-METHIONINE	2300.000	0
2206	MetaSmart dry	5500.000	0
2210	L-LYSINE HCL	1350.000	0
2220	L-THREONINE	1350.000	0
2230	L-TRYPTOPHANE	9000.000	0
2240	L-ISOLEUCINE	13000.000	0
2241	L-LEUCINE	15000.000	0
2242	L-VALINE	5000.000	0
2243	L-HISTIDINE	20000.000	0
2244	L-Arginine	6150.000	0
2250	CITRIC ACID	1400.000	0
2277	VEVOVITALL	1450.000	0
2290	UREUM	500.000	0
2311	BISCUITS TROTEC	236.000	0
2379	RONOZYME PRO-ACT MX BENELUX	15000.000	0
2380	0-INGREDIENT	500.000	0
2384	CAR.YELLOW 10%	62000.000	0
2390	VITAMINS	5000.000	0
2391	TRACE ELEMENTS	1500.000	0
2394	CHOLINE CL 75%	1000.000	0
2397	CHOLIN CHLORIDE 70% (CC)	1200.000	0
2400	LIMESTONE	38.000	0
2401	LIMESTONE GRANU	130.000	0
2410	MONOCALCIUMPHOS	475.000	0
2420	DICALCIUMPHOSPHATE 18 (Min.)	460.000	0
2459	MAGNESIUMOXYDE (50% Mg)	340.000	0
2460	MAGNESIUMOXYDE (54% Mg)	400.000	0
2461	MG SULPHATE 19	535.000	0
2470	SALT	85.000	0
2475	NA-BICARBONATE	390.000	0
2613	Bigromin Cazo 15 WX HiPhos -	713.000	0
2623	ST*DIL CYLACTIN	4701.000	0
2624	Porstimin Cazo15 WX Hiphos -	579.000	0

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8.3 Consolidated table for the impacts

Table 46 Consolidated table for the impacts

Pig	Impact Category	Unit	No phytase	Baseline	Xylanase	Benzoic acid 5	Benzoic acid 10			All solutions
	Climate change excl. LUC	kg CO_2 eq	2.88 10^{0}	2.85 10^{0}	2.82 10^{0}	2.83 10^{0}	2.88 10^{0}			2.85 10^{0}
	Climate change	kg CO_2 eq	4.16 10^{0}	4.08 10^{0}	4.07 10^{0}	4.03 10^{0}	4.08 10^{0}			4.07 10^{0}
	Eutrophication freshwater	kg P eq	8.14 10^{-8}	7.81 10^{-8}	7.55 10^{-8}	7.77 10^{-8}	7.92 10^{-8}			7.66 10^{-8}
	Eutrophication marine	kg N eq	1.30 10^{-1}	1.28 10^{-1}	1.24 10^{-1}	1.26 10^{-1}	1.27 10^{-1}			1.23 10^{-1}
	Respiratory inorganics	disease inc.	5.66 10^{-3}	5.54 10^{-3}	5.58 10^{-3}	5.48 10^{-3}	5.54 10^{-3}			5.58 10^{-3}
	Eutrophication terrestrial	mol N eq	5.08 10^{-7}	5.03 10^{-7}	5.03 10^{-7}	4.65 10^{-7}	4.44 10^{-7}			4.43 10^{-7}
	Ozone depletion	kg CFC11 eq	4.55 10^{-6}	4.55 10^{-6}	4.53 10^{-6}	4.45 10^{-6}	4.45 10^{-6}			4.43 10^{-6}
	Ionising radiation, HH	kBq U-235 eq	1.12 10^{-7}	1.08 10^{-7}	1.08 10^{-7}	1.05 10^{-7}	1.06 10^{-7}			1.06 10^{-7}
	Photochemical ozone formation, HH	kg NMVOC eq	6.85 10^{-2}	6.78 10^{-2}	6.78 10^{-2}	6.24 10^{-2}	5.93 10^{-2}			5.92 10^{-2}
	Non-cancer human health effects	CTUh	4.09 10^{-4}	3.88 10^{-4}	3.94 10^{-4}	3.81 10^{-4}	3.83 10^{-4}			3.89 10^{-4}
	Cancer human health effects	CTUh	2.72 10^{-2}	2.72 10^{-2}	2.66 10^{-2}	2.65 10^{-2}	2.64 10^{-2}			2.58 10^{-2}
	Acidification terrestrial and freshwater	mol H+ eq	3.02 10^{-1}	3.00 10^{-1}	3.00 10^{-1}	2.76 10^{-1}	2.62 10^{-1}			2.62 10^{-1}
	Ecotoxicity freshwater	CTUe	1.98 10^{1}	1.97 10^{1}	2.00 10^{1}	1.93 10^{1}	1.93 10^{1}			1.95 10^{1}
	Land use	Pt	5.31 10^{2}	5.29 10^{2}	5.23 10^{2}	5.17 10^{2}	5.17 10^{2}			5.11 10^{2}
	Water scarcity	m^3 depriv.	2.04 10^{0}	1.79 10^{0}	1.83 10^{0}	1.75 10^{0}	1.76 10^{0}			1.81 10^{0}
	Resource use, energy carriers	MJ	2.20 10^{1}	2.16 10^{1}	2.13 10^{1}	2.18 10^{1}	2.24 10^{1}			2.21 10^{1}
	Resource use, mineral and metals	kg Sb eq	6.90 10^{-7}	3.57 10^{-7}	3.61 10^{-7}	3.55 10^{-7}	3.62 10^{-7}			3.65 10^{-7}
Dairy	***Impact Category***	***Unit***	***Baseline***	***Vit E***	***25OHD3***	***Amylase***	***Biotin***	***B Carotene***		***All solutions***
	Climate change (excl LUC)	kg CO_2 eq	1.22 10^{0}	1.21 10^{0}	1.19 10^{0}	1.18 10^{0}	1.20 10^{0}	1.20 10^{0}		1.11 10^{0}
	Climate change	kg CO_2 eq	1.41 10^{0}	1.41 10^{0}	1.39 10^{0}	1.37 10^{0}	1.40 10^{0}	1.40 10^{0}		1.29 10^{0}
	Eutrophication freshwater	kg P eq	3.64 10^{-9}	3.70 10^{-9}	3.62 10^{-9}	3.55 10^{-9}	3.60 10^{-9}	3.88 10^{-9}		3.76 10^{-9}
	Eutrophication marine	kg N eq	6.04 10^{-3}	6.07 10^{-3}	5.97 10^{-3}	5.89 10^{-3}	5.97 10^{-3}	6.14 10^{-3}		5.85 10^{-3}
	Respiratory inorganics	disease inc.	3.18 10^{-3}	3.17 10^{-3}	3.12 10^{-3}	3.08 10^{-3}	3.12 10^{-3}	3.16 10^{-3}		2.92 10^{-3}
	Eutrophication terrestrial	mol N eq	2.05 10^{-7}	2.03 10^{-7}	2.00 10^{-7}	1.98 10^{-7}	2.00 10^{-7}	2.00 10^{-7}		1.82 10^{-7}
	Ozone depletion	kg CFC11 eq	1.16 10^{-6}	1.15 10^{-6}	1.14 10^{-6}	1.12 10^{-6}	1.14 10^{-6}	1.15 10^{-6}		1.06 10^{-6}
	Ionising radiation, HH	kBq U-235 eq	1.95 10^{-8}	1.94 10^{-8}	1.91 10^{-8}	1.89 10^{-8}	1.91 10^{-8}	1.94 10^{-8}		1.79 10^{-8}
	Photochemical ozone formation, HH	kg NMVOC eq	2.74 10^{-2}	2.71 10^{-2}	2.67 10^{-2}	2.65 10^{-2}	2.68 10^{-2}	2.68 10^{-2}		2.43 10^{-2}

	Non-cancer human health effects	CTUh	$7.01\ 10^{-5}$	$6.94\ 10^{-5}$	$6.84\ 10^{-5}$	$6.79\ 10^{-5}$	$6.87\ 10^{-5}$	$6.88\ 10^{-5}$		$6.31\ 10^{-5}$
	Cancer human health effects	CTUh	$9.61\ 10^{-3}$	$9.51\ 10^{-3}$	$9.38\ 10^{-3}$	$9.30\ 10^{-3}$	$9.40\ 10^{-3}$	$9.42\ 10^{-3}$		$8.57\ 10^{-3}$
	Acidification terrestrial and freshwater	mol H+ eq	$1.22\ 10^{-1}$	$1.20\ 10^{-1}$	$1.19\ 10^{-1}$	$1.18\ 10^{-1}$	$1.19\ 10^{-1}$	$1.19\ 10^{-1}$		$1.08\ 10^{-1}$
	Ecotoxicity freshwater	CTUe	$3.35\ 10^{0}$	$3.35\ 10^{0}$	$3.30\ 10^{0}$	$3.24\ 10^{0}$	$3.29\ 10^{0}$	$3.36\ 10^{0}$		$3.12\ 10^{0}$
	Land use	Pt	$1.04\ 10^{2}$	$1.04\ 10^{2}$	$1.02\ 10^{2}$	$1.01\ 10^{2}$	$1.02\ 10^{2}$	$1.04\ 10^{2}$		$9.56\ 10^{2}$
	Water scarcity	m^3 depriv.	$2.56\ 10^{-1}$	$2.57\ 10^{-1}$	$2.53\ 10^{-1}$	$2.48\ 10^{-1}$	$2.52\ 10^{-1}$	$2.63\ 10^{-1}$		$2.47\ 10^{-1}$
	Resource use, energy carriers	MJ	$3.58\ 10^{0}$	$3.57\ 10^{0}$	$3.52\ 10^{0}$	$3.46\ 10^{0}$	$3.51\ 10^{0}$	$3.58\ 10^{0}$		$3.34\ 10^{0}$
	Resource use, mineral and metals	kg Sb eq	$9.83\ 10^{-8}$	$9.94\ 10^{-8}$	$9.76\ 10^{-8}$	$9.54\ 10^{-8}$	$1.20\ 10^{-7}$	$9.93\ 10^{-8}$		$1.18\ 10^{-7}$
Broiler	***Impact Category***	***Unit***	***No phytase***	***Baseline***	***Protease***	***Xylanase***	***All enzymes***	***All enzymes + 25(OH)D3***	***All enzymes + Eubiotics***	***All solutions***
	Climate change (excl LUC)	kg CO_2 eq	$1.61\ 10^{0}$	$1.57\ 10^{0}$	$1.56\ 10^{0}$	$1.56\ 10^{0}$	$1.55\ 10^{0}$	$1.55\ 10^{0}$	$1.52\ 10^{0}$	$1.51\ 10^{0}$
	Climate change	kg CO_2 eq	$4.21\ 10^{0}$	$4.00\ 10^{0}$	$3.91\ 10^{0}$	$3.85\ 10^{0}$	$3.78\ 10^{0}$	$3.77\ 10^{0}$	$3.67\ 10^{0}$	$3.65\ 10^{0}$
	Eutrophication freshwater	kg P eq	$5.34\ 10^{-8}$	$5.00\ 10^{-8}$	$4.99\ 10^{-8}$	$5.00\ 10^{-8}$	$5.01\ 10^{-8}$	$5.00\ 10^{-8}$	$4.89\ 10^{-8}$	$4.87\ 10^{-8}$
	Eutrophication marine	kg N eq	$7.47\ 10^{-2}$	$7.18\ 10^{-2}$	$7.16\ 10^{-2}$	$7.19\ 10^{-2}$	$7.20\ 10^{-2}$	$7.18\ 10^{-2}$	$7.00\ 10^{-2}$	$6.98\ 10^{-2}$
	Respiratory inorganics	disease inc.	$6.53\ 10^{-3}$	$6.27\ 10^{-3}$	$6.17\ 10^{-3}$	$6.18\ 10^{-3}$	$6.06\ 10^{-3}$	$6.05\ 10^{-3}$	$5.70\ 10^{-3}$	$5.70\ 10^{-3}$
	Eutrophication terrestrial	mol N eq	$3.94\ 10^{-7}$	$3.82\ 10^{-7}$	$3.76\ 10^{-7}$	$3.82\ 10^{-7}$	$3.76\ 10^{-7}$	$3.75\ 10^{-7}$	$3.63\ 10^{-7}$	$3.61\ 10^{-7}$
	Ozone depletion	kg CFC11 eq	$5.32\ 10^{-6}$	$5.27\ 10^{-6}$	$5.25\ 10^{-6}$	$5.23\ 10^{-6}$	$5.21\ 10^{-6}$	$5.20\ 10^{-6}$	$5.16\ 10^{-6}$	$5.14\ 10^{-6}$
	Ionising radiation, HH	kBq U-235 eq	$1.38\ 10^{-7}$	$1.32\ 10^{-7}$	$1.32\ 10^{-7}$	$1.31\ 10^{-7}$	$1.31\ 10^{-7}$	$1.31\ 10^{-7}$	$1.30\ 10^{-7}$	$1.30\ 10^{-7}$
	Photochemical ozone formation, HH	kg NMVOC eq	$4.51\ 10^{-2}$	$4.33\ 10^{-2}$	$4.24\ 10^{-2}$	$4.34\ 10^{-2}$	$4.25\ 10^{-2}$	$4.23\ 10^{-2}$	$4.05\ 10^{-2}$	$4.03\ 10^{-2}$
	Non-cancer human health effects	CTUh	$6.23\ 10^{-4}$	$5.83\ 10^{-4}$	$5.75\ 10^{-4}$	$5.67\ 10^{-4}$	$5.61\ 10^{-4}$	$5.59\ 10^{-4}$	$5.47\ 10^{-4}$	$5.45\ 10^{-4}$
	Cancer human health effects	CTUh	$1.90\ 10^{-2}$	$1.91\ 10^{-2}$	$1.92\ 10^{-2}$	$1.90\ 10^{-2}$	$1.90\ 10^{-2}$	$1.90\ 10^{-2}$	$1.86\ 10^{-2}$	$1.85\ 10^{-2}$
	Acidification terrestrial and freshwater	mol H+ eq	$1.97\ 10^{-1}$	$1.91\ 10^{-1}$	$1.87\ 10^{-1}$	$1.91\ 10^{-1}$	$1.87\ 10^{-1}$	$1.86\ 10^{-1}$	$1.78\ 10^{-1}$	$1.77\ 10^{-1}$
	Ecotoxicity freshwater	CTUe	$1.86\ 10^{1}$	$1.85\ 10^{1}$	$1.84\ 10^{1}$	$1.85\ 10^{1}$	$1.83\ 10^{1}$	$1.83\ 10^{1}$	$1.79\ 10^{1}$	$1.78\ 10^{1}$
	Land use	Pt	$4.68\ 10^{2}$	$4.57\ 10^{2}$	$4.52\ 10^{2}$	$4.48\ 10^{2}$	$4.45\ 10^{2}$	$4.44\ 10^{2}$	$4.37\ 10^{2}$	$4.32\ 10^{2}$
	Water scarcity	m^3 depriv.	$2.66\ 10^{0}$	$2.51\ 10^{0}$	$2.48\ 10^{0}$	$2.52\ 10^{0}$	$2.49\ 10^{0}$	$2.48\ 10^{0}$	$2.44\ 10^{0}$	$2.43\ 10^{0}$
	Resource use, energy carriers	MJ	$1.68\ 10^{1}$	$1.62\ 10^{1}$	$1.61\ 10^{1}$	$1.61\ 10^{1}$	$1.60\ 10^{1}$	$1.60\ 10^{1}$	$1.57\ 10^{1}$	$1.57\ 10^{1}$
	Resource use, mineral and metals	kg Sb eq	$1.16\ 10^{-6}$	$8.03\ 10^{-7}$	$8.00\ 10^{-7}$	$7.91\ 10^{-7}$	$7.90\ 10^{-7}$	$7.91\ 10^{-7}$	$7.77\ 10^{-7}$	$7.69\ 10^{-7}$

8.4 Footprint for the feed additives

The DSM LCA team developed the Life Cycle Inventories of DSM ingredients used in the APS-footprint tool, applying the approach described below. DSM cannot disclose process details because this could possibly harm its competitive advantage. One could argue that to be fully compliant with ISO standards, this would be required. However, it can also be easily be argued that the contribution is below a threshold for cut-off, meaning that the impact of production would not have to be included at all. The latter approach would be sufficient to show that the additives result in real improvements of footprint. Therefore, we chose to disclose all of the Life Cycle impacts to the reviewers and the focus environmental impacts to the general public, so LCA experts can assess the relative impacts for themselves, and additive production experts can verify that these impacts are realistic.

8.4.1 Standards and guidelines

The LCAs, for the feed additives are based on ISO standards 14040 and 14044. On top of this the WBCSD Chemical Sector Life Cycle Metrics Guidance was followed.

8.4.2 Scope and system boundaries

The scope of the LCAs was cradle to factory gate, unpacked products. All life cycle stages until this point were included. The creation of infrastructure and indirect activities, like administrative and sales processes were excluded. For only one product packaging was included because of the rather intensive form of packaging. Still, in this case the contribution of packaging to the carbon footprint of the product was only 0.2%. Most of DSM products are first shipped to distribution centres. This transport has not been included. It is less than 1% of the footprint of the ingredients. Key assumptions are related to the production processes and locations of raw materials used in the production.

8.4.3 Methodologies and approaches

Cut off was not applied. We included all known inputs to and emissions from the processes. The allocation procedures prescribed by the WBCSD Chemical Sector Life Cycle Metrics Guidance [37] were applied. These in turn follow ISO guidelines. No avoided emissions or offsets were included. The LCAs were set up with an attributional approach.

8.4.4 Data sources and quality

The LCAs were executed using primary data for all DSM processes. For all upstream processes secondary data, mostly Ecoinvent (v.3.5) were used. In some cases, augmented with literature data for processes not available in Ecoinvent. In the selection of upstream processes, we balanced acceptable geographical, technological and temporal representativeness, completeness and reliability with acceptable effort. This usually means accepting the most appropriate Ecoinvent model, because getting better information than what is used in Ecoinvent is practically infeasible. The uncertainty depends a lot on the level of backward integration in the production process. Uncertainty ranges between 7 and 25%. The key contributors to uncertainty are the consumption figures based on secondary data.

8.4.5 Sensitivity analyses

In the cases that were extensively reported a complete sensitivity analysis was executed, for methodological choices, key assumptions and uncertainties. In these cases, the sensitivities are acceptable for the purpose of calculating the footprint of animal products produced with use of the ingredients as additives, because they contribute maximally 0.3% to the footprint in all impact categories and for all products. For climate change the maximum contribution is only 0.1%.

8.4.6 Review

The LCAs were not externally reviewed. They were all internally reviewed. For some cases review reports are available, for others these still needs to be developed.

8.4.7 End of life CO_2 emissions

In agreement with the PEFCR guideline for Dairy, end of life CO_2 emissions from all fossil carbon embodied in the products were included, in order to avoid that these are ignored by users, and to prevent errors, because they do not have access to the necessary information.

The aggregated environmental impacts of the feed additives according to the EF method are summarized in the table below.

Table 47 Aggregated environmental impacts of the feed additives per kg of additive

*Impact category**	*Fac-tor*	*Unit*	*Biotin*	*Beta carotene*	*25(OH)D3*	*Phytase*	*Xylanase*	*Protease*	*Amylase*	*Vitamin E*	*Benzoic acid*	*Eubiotics*
Climate change (excl LUC)	1	kg CO_2 eq	111	19	104	1	1	4	2	7	5	5
Climate change	1	kg CO_2 eq	111	19	104	1	1	5	3	7	5	8
Respiratory inorganics	1E-08	disease inc.	1231	65	347	8	9	38	10	13	5	16
Eutrophication freshwater	1E-04	kg P eq	194	27	242	7	6	22	12	11	2	9
Eutrophication marine	1E-03	kg N eq	111	13	92	2	4	10	6	9	1	17

* Data for all impacts have been collected and implemented in all calculations. However, they are not herewith displayed to prevent harming any competitive advantage linked to disclosure of manufacturing process information while the report is meant for an extended circulation.

8.5 Supporting information for broilers

8.5.1 Performance tables

We used Ross broiler performance tables (AVIAGEN, 2019 [34]) for describing animal performance. These tables provide weight and feed intake of the average animal for each day of their lives. For more convenient use we created regression formulas for feed intake and feed conversion ratio based on these tables. We also created expressions for mortality as a function of age. This includes relatively high mortality on day 1 and on the day of slaughter and a linearly decreasing mortality between these days.

On this basis we created the tables included in the following sections. The regression formulas are included at the bottom of each table. We chose the number of one day chickens started with such that at the moment of intermediate slaughter in the baseline case, there were 60000 animals present. The number of animals died on day 32 includes those slaughtered. For the cases with eubiotics, because of the faster growth, the animals are slaughtered one day younger. As performance is the same for all scenarios including only enzymes as additives the baseline table applies to all of these scenarios.

8.5.1.1 Baseline

Table 48 Baseline broilers

Day	Weight	Feed intake	FCR	Weight gain	Cumulative feed intake	Mortality	Number of animals died	Number of animals alive	Feed used by animals died
	gr	gr	kg/kg	gr	gr	%			kg
0	43	13	0.829	16	0	0.000	0	61957	0
1	59	16	0.896	18	13	0.400	248	61709	0
2	77	20	0.953	21	29	0.115	71	61638	1
3	98	24	1.004	23	49	0.113	70	61569	2
4	121	27	1.049	26	73	0.112	69	61500	3
5	147	32	1.091	29	100	0.111	68	61432	5
6	176	36	1.129	32	132	0.109	67	61365	7
7	208	40	1.164	35	168	0.108	66	61299	9
8	243	45	1.196	38	208	0.106	65	61234	11
9	281	50	1.227	41	253	0.105	64	61169	13
10	321	55	1.205	46	303	0.103	63	61106	16
11	367	59	1.223	49	358	0.102	62	61044	19
12	416	64	1.242	52	418	0.100	61	60983	22
13	467	69	1.262	54	482	0.099	60	60923	25
14	522	74	1.283	57	550	0.097	59	60864	29
15	579	79	1.305	60	624	0.096	58	60805	32
16	640	84	1.329	63	703	0.094	57	60748	36
17	703	90	1.354	66	787	0.093	56	60692	40
18	769	95	1.379	69	877	0.091	55	60636	44
19	838	101	1.406	72	972	0.090	55	60582	48
20	910	107	1.434	75	1074	0.088	54	60528	52
21	985	113	1.463	77	1181	0.087	53	60475	57
22	1062	119	1.494	80	1294	0.085	52	60424	61
23	1142	125	1.524	82	1412	0.084	51	60373	66
24	1224	131	1.556	84	1537	0.083	50	60323	70
25	1308	137	1.589	86	1668	0.081	49	60274	75
26	1394	143	1.623	88	1805	0.080	48	60226	80
27	1482	149	1.657	90	1948	0.078	47	60179	85
28	1571	154	1.692	91	2096	0.077	46	60133	90
29	1663	160	1.727	93	2250	0.075	45	60088	95
30	1755	165	1.763	94	2410	0.074	44	60044	100
31	1849	171	1.800	95	2576	0.072	43	60000	105
32	1944	176	1.837	96	2747	28.071	16843	43158	43383
33	2040	181	1.874	96	2922	0.069	30	43128	82
34	2136	186	1.912	97	3103	0.068	29	43099	85
35	2233	190	1.950	97	3289	0.066	29	43070	89
36	2331	194	1.987	98	3479	0.065	28	43042	92
37	2428	198	2.026	98	3673	0.063	27	43015	95
38	2526	202	2.064	98	3871	0.062	27	42988	98
39	2624	206	2.102	98	4074	0.060	26	42962	101
40	2722	209	2.140	98	4279	0.059	25	42937	103
41	2820	106	2.178	0	4488	0.057	25	42912	106
42	2820	0	2.178	0	4594	0.600	257	42655	1156
							Animals slaughtered day 42:		195969
							Total feed used:		242653

Regression formulas					
	Weight< 300 gr		Weight>300 gr		
Feed intake (gr)	FI = 0.8858*W$^{0.7156}$		FI=22.838+0.10452*W-0.000013274*W^{2}		
Feed conversion ratio (kg/kg	FCR=0.212*LN(W)+0.032		FCR=1.0799+0.00038943*W		
Mortality (%):	day 0	day 1	day 32	day 41	day 42
	0.4	0.115	incl. 28 % slaughtered	0.057	0.6

8.5.1.2 Eubiotics

Table 49 Eubiotics broilers

Day	Weight	Feed intake	FCR	Weight gain	Cumulative feed intake	Mortality	Number of animals died	Number of animals alive	Feed used by animals died
	gr	gr	kg/kg	gr	gr	%			kg
0	43	13	0.804	16	0	0.000	0	61957	0
1	59	16	0.869	19	13	0.400	248	61709	0
2	78	20	0.925	21	29	0.115	71	61638	1
3	99	23	0.975	24	49	0.113	70	61569	2
4	123	27	1.019	27	72	0.112	69	61500	3
5	149	31	1.060	30	99	0.111	68	61432	5
6	179	36	1.097	33	131	0.109	67	61365	7
7	212	40	1.131	36	166	0.108	66	61299	9
8	247	45	1.163	39	206	0.106	65	61234	11
9	286	50	1.193	42	251	0.105	64	61169	13
10	328	55	1.170	47	301	0.103	63	61106	16
11	374	59	1.188	50	356	0.102	62	61044	19
12	424	64	1.207	53	415	0.100	61	60983	22
13	477	69	1.226	56	479	0.099	60	60923	25
14	533	74	1.248	59	548	0.097	59	60864	28
15	592	79	1.270	62	621	0.096	58	60805	32
16	654	84	1.293	65	700	0.094	57	60748	36
17	719	90	1.318	68	784	0.093	56	60692	39
18	787	95	1.343	71	874	0.091	55	60636	43
19	858	101	1.370	74	969	0.090	55	60582	48
20	932	107	1.398	77	1070	0.088	54	60528	52
21	1009	113	1.427	79	1177	0.087	53	60475	56
22	1088	119	1.457	82	1290	0.085	52	60424	61
23	1169	125	1.488	84	1409	0.084	51	60373	65
24	1253	131	1.519	86	1534	0.083	50	60323	70
25	1339	137	1.552	88	1665	0.081	49	60274	75
26	1428	143	1.585	90	1802	0.080	48	60226	80
27	1518	148	1.619	92	1944	0.078	47	60179	85
28	1609	154	1.654	93	2093	0.077	46	60133	90
29	1703	160	1.689	95	2247	0.075	45	60088	95
30	1797	165	1.725	96	2407	0.074	44	60044	99
31	1893	170	1.761	97	2572	28.072	16856	43188	40568
32	1990	175	1.797	98	2742	0.071	31	43157	79
33	2087	180	1.834	98	2918	0.069	30	43128	82
34	2186	185	1.871	99	3098	0.068	29	43098	85
35	2284	189	1.908	99	3283	0.066	29	43070	89
36	2384	193	1.946	99	3472	0.065	28	43042	92
37	2483	197	1.983	99	3666	0.063	27	43015	95
38	2582	201	2.021	99	3863	0.062	27	42988	98
39	2682	204	2.058	99	4064	0.060	26	42962	100
40	2781	104	2.096	0	4268	0.059	25	42937	103
41	2781	0	2.096	0	4372	0.600	258	42679	1100
							Animals slaughtered day 41:		186594
							Total feed used:		230270

Regression formulas					
	Weight< 300 gr		Weight>300 gr		
Feed intake (gr)	FI = $0.8858*W^{0.7156}*0.984$		FI=$(22.838+0.10452*W-0.000013274*W^2)*0.984$		
Feed conversion ratio (kg/kg	FCR=(0.212*LN(W)+0.032)*0.9		FCR=(1.0799+0.00038943*W)*0.969		
	day 0	day 1	day 31	day 40	day 42
Mortality (%):	0.4	0.115	incl. 28 % slaughtered	0.057	0.6

8.5.1.3 25(OH)D3

Table 50 25(OH)D3 broilers

Day	Weight	Feed intake	FCR	Weight gain	Cumulative feed intake	Mortality	Number of animals died	Number of animals alive	Feed used by animals died
	gr	gr	kg/kg	gr	gr	%			kg
0	43	13	0.829	16	0	0.000	0	61957	0
1	59	16	0.896	18	13	0.400	248	61709	0
2	77	20	0.953	21	29	0.105	65	61644	1
3	98	24	1.004	23	49	0.104	64	61580	2
4	121	27	1.049	26	73	0.103	63	61517	3
5	147	32	1.091	29	100	0.101	62	61455	5
6	176	36	1.129	32	132	0.100	61	61394	6
7	208	40	1.164	35	168	0.098	60	61333	8
8	243	45	1.196	38	208	0.097	60	61274	10
9	281	50	1.227	41	253	0.096	59	61215	12
10	321	55	1.205	46	303	0.094	58	61157	15
11	367	59	1.223	49	358	0.093	57	61100	17
12	416	64	1.242	52	418	0.092	56	61044	20
13	467	69	1.262	54	482	0.090	55	60989	23
14	522	74	1.283	57	550	0.089	54	60935	26
15	579	79	1.305	60	624	0.088	53	60881	29
16	640	84	1.329	63	703	0.086	53	60829	33
17	703	90	1.354	66	787	0.085	52	60777	36
18	769	95	1.379	69	877	0.084	51	60726	40
19	838	101	1.406	72	972	0.082	50	60676	44
20	910	107	1.434	75	1074	0.081	49	60627	48
21	985	113	1.463	77	1181	0.080	48	60579	52
22	1062	119	1.494	80	1294	0.078	47	60532	56
23	1142	125	1.524	82	1412	0.077	47	60485	60
24	1224	131	1.556	84	1537	0.076	46	60439	65
25	1308	137	1.589	86	1668	0.074	45	60395	69
26	1394	143	1.623	88	1805	0.073	44	60351	73
27	1482	149	1.657	90	1948	0.071	43	60307	78
28	1571	154	1.692	91	2096	0.070	42	60265	82
29	1663	160	1.727	93	2250	0.069	41	60224	87
30	1755	165	1.763	94	2410	0.067	41	60183	91
31	1849	171	1.800	95	2576	0.066	40	60143	96
32	1944	176	1.837	96	2747	28.065	16879	43264	43477
33	2040	181	1.874	96	2922	0.063	27	43237	75
34	2136	186	1.912	97	3103	0.062	27	43210	78
35	2233	190	1.950	97	3289	0.061	26	43184	81
36	2331	194	1.987	98	3479	0.059	26	43158	84
37	2428	198	2.026	98	3673	0.058	25	43133	87
38	2526	202	2.064	98	3871	0.057	24	43109	90
39	2624	206	2.102	98	4074	0.055	24	43085	92
40	2722	209	2.140	98	4279	0.054	23	43062	95
41	2820	106	2.178	0	4488	0.053	23	43039	97
42	2820	0	2.178	0	4594	0.373	160	42878	720
							Animals slaughtered day 42:		196997
							Total feed used:		243162

Regression formulas						
		Weight< 300 gr		Weight>300 gr		
Feed intake (gr)		FI = $0.8858*W^{0.7156}$		FI=$22.838+0.10452*W-0.000013274*W^2$		
Feed conversion ratio (kg/kg		FCR=0.212*LN(W)+0.032		FCR=1.0799+0.00038943*W		
Mortality (%):		day 0	day 1	day 32	day 41	day 42
		0.4	0.105	incl. 28 % slaughtered	0.053	0.373

8.5.1.4 Eubiotics + 25(OH)D3

Table 51 Eubiotics + 25(OH)D3 broilers

Day	*Weight*	*Feed intake*	*FCR*	*Weight gain*	*Cumulative feed intake*	*Mortality*	*Number of animals died*	*Number of animals alive*	*Feed used by animals died*
	gr	gr	kg/kg	gr	gr	%			kg
0	43	13	0.804	16	0	0.000	0	61957	0
1	59	16	0.869	19	13	0.400	248	61709	0
2	78	20	0.925	21	29	0.105	65	61644	1
3	99	23	0.975	24	49	0.104	64	61580	2
4	123	27	1.019	27	72	0.103	63	61517	3
5	149	31	1.060	30	99	0.101	62	61455	4
6	179	36	1.097	33	131	0.100	61	61394	6
7	212	40	1.131	36	166	0.098	60	61333	8
8	247	45	1.163	39	206	0.097	60	61274	10
9	286	50	1.193	42	251	0.096	59	61215	12
10	328	55	1.170	47	301	0.094	58	61157	15
11	374	59	1.188	50	356	0.093	57	61100	17
12	424	64	1.207	53	415	0.092	56	61044	20
13	477	69	1.226	56	479	0.090	55	60989	23
14	533	74	1.248	59	548	0.089	54	60935	26
15	592	79	1.270	62	621	0.088	53	60881	29
16	654	84	1.293	65	700	0.086	53	60829	33
17	719	90	1.318	68	784	0.085	52	60777	36
18	787	95	1.343	71	874	0.084	51	60726	40
19	858	101	1.370	74	969	0.082	50	60676	44
20	932	107	1.398	77	1070	0.081	49	60627	48
21	1009	113	1.427	79	1177	0.080	48	60579	52
22	1088	119	1.457	82	1290	0.078	47	60532	56
23	1169	125	1.488	84	1409	0.077	47	60485	60
24	1253	131	1.519	86	1534	0.076	46	60439	64
25	1339	137	1.552	88	1665	0.074	45	60395	69
26	1428	143	1.585	90	1802	0.073	44	60351	73
27	1518	148	1.619	92	1944	0.071	43	60307	78
28	1609	154	1.654	93	2093	0.070	42	60265	82
29	1703	160	1.689	95	2247	0.069	41	60224	87
30	1797	165	1.725	96	2407	0.067	41	60183	91
31	1893	170	1.761	97	2572	28.066	16891	43292	40653
32	1990	175	1.797	98	2742	0.065	28	43264	72
33	2087	180	1.834	98	2918	0.063	27	43237	75
34	2186	185	1.871	99	3098	0.062	27	43210	78
35	2284	189	1.908	99	3283	0.061	26	43183	81
36	2384	193	1.946	99	3472	0.059	26	43158	84
37	2483	197	1.983	99	3666	0.058	25	43133	87
38	2582	201	2.021	99	3863	0.057	24	43108	90
39	2682	204	2.058	99	4064	0.055	24	43085	92
40	2781	104	2.096	0	4268	0.054	23	43061	94
41	2781	0	2.096	0	4372	0.373	160	42901	685
							Animals slaughtered day 41:		**187564**
							Total feed used:		**230744**

Regression formulas					
	Weight< 300 gr		**Weight>300 gr**		
Feed intake (gr)	FI = $0.8858*W^{0.7156}*0.984$		FI=$(22.838+0.10452*W-0.000013274*W^2)*0.984$		
Feed conversion ratio (kg/kg	FCR=(0.212*LN(W)+0.032)*0.9		FCR=(1.0799+0.00038943*W)*0.969		
	day 0	**day 1**	**day 31**	**day 40**	**day 41**
Mortality (%):	0.4	0.105	incl. 28 % slaughtered	0.054	0.373

8.5.2 Footprint contribution of ingredients broilers

Table 52 Footprint contribution of ingredients broilers

Impact Category	Unit	No phytase	Protease	Xylanase	All enzymes	All enzymes + 25(OH)D3	All enzymes + Eubiotics	All solutions
Climate change (excl LUC)	kg CO_2 eq	1.86E-04	1.36E-03	1.67E-05	1.56E-03	2.36E-03	9.16E-04	4.83E-03
Climate change	kg CO_2 eq	1.87E-04	1.55E-03	1.88E-05	1.76E-03	3.87E-03	9.16E-04	6.54E-03
Ozone depletion	kg CFC11 eq	8.37E-12	7.72E-11	8.87E-13	8.64E-11	1.39E-10	1.06E-10	3.31E-10
Ionising radiation, HH	kBq U-235 eq	9.32E-06	9.34E-05	9.29E-07	1.04E-04	8.26E-05	4.11E-05	2.27E-04
Photochemical ozone formation, HH	kg NMVOC eq	2.38E-07	3.66E-06	2.79E-08	3.93E-06	5.72E-06	1.70E-06	1.13E-05
Respiratory inorganics	disease inc.	1.34E-11	1.21E-10	1.16E-12	1.36E-10	7.58E-11	3.05E-11	2.42E-10
Non-cancer human health effects	CTUh	3.62E-11	1.96E-10	3.41E-12	2.36E-10	3.71E-10	3.88E-11	6.46E-10
Cancer human health effects	CTUh	1.87E-12	2.25E-11	1.77E-13	2.46E-11	2.82E-11	2.24E-12	5.50E-11
Acidification terrestrial and freshwater	mol H+ eq	1.17E-06	1.05E-05	9.96E-08	1.18E-05	8.22E-06	3.30E-06	2.33E-05
Eutrophication freshwater	kg P eq	1.04E-07	6.97E-07	7.99E-09	8.10E-07	3.95E-07	2.13E-07	1.42E-06
Eutrophication marine	kg N eq	3.30E-07	3.24E-06	4.77E-08	3.62E-06	7.83E-06	8.11E-07	1.23E-05
Eutrophication terrestrial	mol N eq	2.27E-06	3.06E-05	2.53E-07	3.31E-05	2.59E-05	5.41E-06	6.44E-05
Ecotoxicity freshwater	CTUe	1.10E-04	2.91E-03	1.44E-05	3.03E-03	1.03E-02	6.20E-04	1.40E-02
Land use	Pt	8.55E-03	8.20E-02	9.04E-04	9.15E-02	4.56E+00	2.52E-02	4.68E+00
Water scarcity	m^3 depriv.	5.66E-05	2.19E-03	8.15E-06	2.25E-03	7.67E-04	3.49E-04	3.37E-03
Resource use, energy carriers	MJ	2.03E-03	1.44E-02	1.72E-04	1.66E-02	3.03E-02	1.25E-02	5.94E-02
Resource use, mineral and metals	kg Sb eq	4.34E-10	1.90E-09	2.35E-11	2.36E-09	9.01E-09	3.16E-09	1.45E-08

8.5.3 The effect of improved product quality

For the Broilers case we were dealing with an increase of breast meat yield. To evaluate what the effect on product footprint is we analytically derive it for a generic case and then with the data for the Broiler system calculate what it is in this specific case.

Consider a system with an environmental impact I and multiple outputs with total value V, of which product 1 has production m_1 and price p_1.

With economic allocation the footprint of f_1 is $m_1p_1/V*I/m_1 = p1*I/V$. If there is a different process with the same products in different amounts, we have $f'_1 = p_1*I'/V'$.

Now $f'_1 / f_1 = V*I/V'/I'$.

In our case we are dealing with a process that has the same impact, so $f'_1 / f_1 = V/V'$. So the ratio of the footprints is the inverse of the ratios of the total values created. Note that this is irrespective of the masses produced, or the relative value of product 1 versus other products, so it is valid for all of the products.

In our case the amount of breast meat is increased by 4%, without increasing the total live weight. We assume that the relative decrease of weight of the other products is equal. Using the example of the LEAP guideline for poultry (LEAP, 2016) we have the following info. We set the total value at 100. The value of the breast meat is 41% of that, so 41. And the fraction of the weight is 37%. An increase in breast meat of 4% means the 38.48% of the meat is breast, representing a value of 42.64. The remainder is now 61.52% with a value of 61.52/63*59 = 57.61, increasing the total value to 100.25. This means that the value ratio is 1.0025, which can be simulated by an increase of output of 1.0025.

The source data: Table 9 of the LEAP Guideline (LEAP, 2016).

	Average mass of component (g)	Component % of total mass	Component as % of total economic value
Live Weight	2500	100	
Meat / Edible Products:			
Dark meat/leg quarter /back half	825	33	35%
Breasts/Boneless Skinless/bone-in	925	37	41%
Wings	150	6	13%
Inedible offal			
Inedible organs / viscera / fat/ giblets	160	6.4	6%
Head, Feet	190	7.6	3%
Blood, Feather	250	10	2%

8.6 Guideline indications on manure handling and system boundaries

Table 53 Guideline indications on manure handling and system boundaries

Guideline	*Allocation*	*System boundaries*
LEAP Large ruminants	**Manure off-farm** First the determination of whether the manure is classified as a coproduct, residual or waste is made on the basis of revenue generation for the operation. - Co-product (manure is valuable output): use biophysical reasoning. - Residual (manure has essentially no value): the system is cut-off at the boundary. - Waste (manure is landfilled, incinerated without energy recovery, or sent to a treatment facility): subsequent emissions assigned to the main co-products. No preferred method suggested. **Manure on-farm** Manure produced should be classified as on-farm used or off-farm exported. Manure amount kept on farm should be used as inventory for on-farm cultivations. LEAP feed needs to be followed.	The recommended system boundaries include all breeding and production/finishing animals on farms, and end with dressed carcass or milk products ready for transport to customers or storage.

LEAP Pig	Same as large ruminants, but with the following suggestion: "*This guidance recommends the consideration of manure as a residual material, provided it is used subsequently as a source of fertiliser or biomass energy*"	The recommended system boundaries start with feed production and extend through either the farm or processing gate.
LEAP Poultry	Same as Large ruminants	The recommended system boundaries start with the great grandparent generation, and end with dressed carcass or eggs ready for transport to customers or storage
LEAP Nutrient	Manure represents a valuable source of nutrients that can have multiple uses (applied, energy recovery, sold). Therefore, manure shall be considered as a co-product, with some exceptions (landfilling, "dumping", application excess and incineration without recovery)[32]. Method 1: bio-physical allocation using the heat energy, Method 2: Economic allocation based on the fertilizer value. In most cases, method 1 (biophysical) will be preferable due to its robustness and simplicity. However, it is recommended that when sufficient data is available, method 2 (economic) is evaluated.	These guidelines cover the system boundary from the cradle-to-primary processing gate.
LEAP Additives	No clear guidance: Nutrient cycling is an important element of the environmental impact of animal production. In more intensive systems, when the production of manure exceeds its capacity to serve as fertilizer, the reduction of the phosphorus and nitrogen excretion by the animals may represent an effective means to reduce the risk of leaching and eutrophication. In addition, improved feed conversion efficiency is a way to reduce nutrient concentration in the manure.	The system boundaries of this guideline are a combination of the boundaries of the different existing guidelines (feed production, livestock-related guidelines) and make the link to the production of feed additives and their uses along the feed chain and on the farm. From picture: cradle to gate.
Dairy PEFCR	• **Manure as residual product** Manure is exported from the farm as product with no economic value. No allocation: burden allocated to other products produced at farm, including pre-treatment of manure. • **Manure as co-product** Manure is exported from the farm as product with economic value. Economic allocation of the upstream burden shall be used for manure by using the relative economic value of manure compared to milk and live animals at the farm gate, provided proof is given that it is sold and used for fertiliser replacement at optimal rates for crops (i.e. if excess is applied it is treated as a Residual). Biophysical allocation based on IDF rules shall be applied to allocate the remaining emissions between milk and live animals. Environmental burden form manure treatment is fully allocated to manure as coproduct. • **Manure as waste** Manure is not used to produce products but treated as waste. Apply end-of-life formula and allocate environmental burden to other products produced on the farm, including treatment of manure.	Cradle to grave

[32] Based on LEIP, A., LEDGARD, S., UWIZEYE, A., PALHARES, J.C.P., ALLER, M.F., AMON, B., BINDER, M., CORDOVIL, C.M.D.S., DE CAMILLIS, C., DONG, H., FUSI, A., HELIN, J., HÖRTENHUBER, S., HRISTOV, A.N., KOELSCH, R., LIU, C., MASSO, C., NKONGOLO, N.V., PATRA, A.K., REDDING, M.R., RUFINO, M.C., SAKRABANI, R., THOMA, G., VERTÈS, F. and WANG, Y., 2019. The value of manure - Manure as co-product in life cycle assessment. Journal of environmental management, 241, pp. 293-304.

PEFCR guidance 6.3	Allocation within the farm module for cattle chapter quote: "Manure exported to another farm shall be considered as: • Residual (default option): when manure does not have an economic value at the farm gate, it is regarded as residual without allocation of an upstream burden. The emissions related to manure management up to farm gate are allocated to the other outputs of the farm where manure is produced. • Co-product: when exported manure has economic value at farm gate, an economic allocation of the upstream burden shall be used for manure by using the relative economic value of manure compared to milk and live animals at the farm gate. Biophysical allocation based on IDF rules shall nevertheless be applied to allocate the remaining emissions between milk and live animals. · Manure as waste: when manure is treated as waste (e.g. landfilled), the CFF shall be applied."	PEFCR system boundary should be described in the specific PEFCR
Red Meat PCR	For manure that leaves the animal farm the system boundaries are extended to include manure use at arable farming and avoided N and P fertilizer production and application: • Determine the type of fertilizer that would have normally been used by the farmer in a situation without manure. Default is CAN for nitrogen and (TSP) triple superphosphate for phosphate. • Determine the replacement rate; to define the level of replacement the differences in efficiency of manure as a nutrient source and artificial fertilizer needs to be accounted for. If no data is collected the default replacement rate is 50% for nitrogen and phosphate based on the tested N and P content in the manure. · Include a 100% of the transport, potential manure treatment and in-field manure application · Use the 50% default position for the replacement rate for the production, transport and application of fertilizer when calculating the replacement rate.	Cradle to retail

8.7 Comments from the reviewers

Critical Review
of

The applicability of LCA guidelines to model the effects of feed additives on the environmental footprint of animal production

according to
ISO 14040 & ISO 14044
and ISO/TS 14071

for

Blonk Consultants and DSM Nutritional Products

February 2021

Commissioned by: Blonk Consultants
Reviewers: Dr. Nathan Pelletier, University of British Columbia, Canada; Dr. Greg Thoma, University of Arkansas, USA, Dr. Theun Vellinga and Dr. Pim Mostert, Wageningen University and Research, the Netherlands
Primary References:

- ISO 14040 (2006): Environmental Management - Life Cycle Assessment - Principles and Framework
- ISO 14044 (2006): Environmental Management - Life Cycle Assessment – Requirements and Guidelines
- ISO/TS 14071 (2014): Environmental management -Life cycle assessment – Critical review processes and reviewer competencies: Additional requirements and guidelines to ISO 14044:2006

Secondary References:

- LEAP (2016): Environmental performance of large ruminant supply chains. Guidelines for assessment
- LEAP (2018): Environmental performance of pig supply chains. Guidelines for assessment

- LEAP (2016): Greenhouse gas emissions and fossil energy use from poultry supply chains: Guidelines for assessment
- EC (2018): The PEFCR for feed for food producing animals
- EC (2018): The PEFCR for dairy products
- Technical Secretariat for the Red Meat Pilot (2019) The PCR for Red meat

8.7.1 General Introduction and Context

Blonk Consultants collaborated with DSM Nutritional Products (DSM) (the Project Team) to conduct an LCA study comparing the environmental performance of livestock production (dairy, swine and broilers) with and without the use of feed additives. The Project Team aimed to complete the study in accordance with the ISO 14040 and 14044 standards, which are the methodological reference standards for life cycle assessment. They further endeavoured to utilize the relevant guidelines developed by the United Nations Livestock Environment Assessment and Performance (LEAP) Partnership, as well as the European Commission's Product Environmental Footprint Category Rules.

The LEAP Partnership is a multi-stakeholder initiative that is committed to improving the environmental performance of livestock supply chains, whilst ensuring its economic and social viability. LEAP develops guidance documents for understanding the environmental performance of livestock supply chains that build upon the ISO standards for LCA. LEAP has developed a series of guidance documents specific to different livestock species or for assessment of specific interactions between the livestock sector and the environment. A core aspect of the work programme for LEAP from 2019-2021 is to "road test" the guidance documents that have been developed to date in order to collect feedback for further improvement of the guidance that they provide. The European Commission has similarly supported development of product and sector category rules in furtherance of the EC Product and Organization Environmental Footprint methods, with road testing of the product category rules on-going.

The ISO standards include specific requirements for studies that are conducted in conformance with the standards, including a subset that are applicable in the case of studies that are intended to support comparative assertions as to the relative environmental performance of products that provide equivalent functions. Among these requirements is that the study be subjected to critical review by a review panel. Specifically, ISO 14044 section 5.1 states: "In order to decrease the likelihood of misunderstandings or negative effects on external interested parties, a panel of interested parties shall conduct critical reviews of LCA studies where the results are intended to be used to support a comparative assertion intended to be disclosed to the public." Such reviews are beneficial with respect to increasing the credibility of the study for the Commissioner as well as for consumers of the study results. The Project Team hence appointed a review panel to assess the compliance of the study with the ISO 14040 and 14044 standards.

Typically, a critical review involves:

1.) Identification of the review panel, which includes a panel chair and panel members. Panel members should be selected such that the panel together includes both strong LCA expertise as well as specific technical expertise of the product systems considered in the study.
2.) Submission of the study documents for review
3.) Responding to comments and recommendations from the review panel
4.) Documentation of the critical review process, including preparation of a final review report.

The review panel is required to review the study for compliance with the methodological requirements specified in the ISO 14044 standard and, more generally to ensure that:

- the methods used to carry out the LCA are scientifically and technically valid,
- the data used are appropriate and reasonable in relation to the goal of the study,
- the interpretations reflect the limitations identified and the goal of the study, and
- the study report is transparent and consistent.

Specific details regarding review processes and review competencies additional to the requirements and guidelines provided in ISO 14044 are specified in ISO/TS 14071

8.7.2 The Review Panel

The panel members selected for the critical review of this study were Dr. Nathan Pelletier (panel chair), Dr. Greg Thoma, Dr. Theun Vellinga, and Dr. Pim Mostert. Dr. Pelletier is an Assistant Professor and NSERC/EFC Industrial Research Chair in Sustainability at the University of British Columbia, Canada. He has considerable methodological expertise in LCA and its application to assessment of crop and livestock production systems. He has previously conducted and published LCA studies of conventional and alternative beef, pork and broiler production systems in the United States, egg production systems in the US and Canada, and a broad array of crop production and processing systems globally. Dr. Thoma is currently lead investigator for a number of life cycle initiatives in the food and agriculture sector including studies on fluid milk, cheese, milk delivery systems, and is project director for a recently completed 5-year, $5M USDA multi-university project focused on greenhouse gas mitigation for US swine production. Dr. Thoma also consults on other LCA work at the University of Arkansas focusing on rice, cotton, corn, and sweet corn. He was the scientific lead for the LEAP Partnership on the Environmental Benchmarking of Livestock Supply Chains technical advisory group for poultry which produced guidance in the application of LCA for assessment of sustainable poultry and egg production. Dr. Vellinga works at Wageningen University and Research (WUR), at Wageningen Livestock Research. As senior researcher, Dr. Vellinga has 30 years of experience in agricultural research, ranging from grassland management, grazing, environmental impacts, modelling farming systems, life cycle assessments, feed chain analysis and manure management. He is experienced in cooperation with policy workers, farmers and industry and is skilled in developing solutions to apply developed knowledge in practical tools for stakeholders. Dr. Pim Mostert is a researcher at WUR, Wageningen Livestock Research. He is working on modelling livestock systems, developing LCA methods, and conducting LCA studies about feed production and livestock systems. He has published several LCA studies about dairy production and greenhouse gas emissions.

8.7.3 The Critical Review Process

The panel for critical review of this study for conformance with the ISO standards was first convened on September 28th, 2020. The initial meeting between the panellists and the Project Team introduced panel members and addressed the intended scope and substance of the review (LCA of 14 feed additives used in the production of dairy, swine or broilers) as well as the review timeline. The Project Team provided the panellists with the following six documents, along with login credentials to access the APS-footprint tool (an on-line tool that operationalizes the study methods in a format that enables provision of user-defined data to generate LCA results for livestock production and test scenarios):

- APS-footprint tool General Methodology
- APS-footprint Methodology for Dairy Systems
- APS-footprint Methodology for Pig Systems
- APS-footprint Methodology for Broiler and Laying Hens
- LEAP LCA ISO Report
- Appendix 1. LCA of the potential contribution of micronutrition in sustainable livestock. Case studies based on multiple ingredients supplementation in broiler, fattening pig and dairy cow feed: Substantiation for the nutritional effects.

During the meeting, it was agreed to primarily utilize ISO 14044 as the reference method for the review, whilst bearing in mind that specific methodological choices made by the Project Team would also refer to PEF or LEAP guidelines. It was recognized that these should be generally expected to be ISO 14044 compliant, but that this may introduce some inconsistencies between the livestock group/feed additive studies. The reviewers would hence take this into account in interpreting the specific studies and their methodological consistency/compliance.

Each panel member was charged with reviewing:

(1) the general LCA methodology report
(2) the studies addressing the feed additives for their assigned livestock group (Pelletier - porcine; Thoma – broiler; Vellinga and Mostert - dairy)

(3) the APS-footprint method documents (general and livestock group-specific)
(4) the relevant sections of the Appendix describing the results of the literature review for performance gains attributable to the feed additives

It was agreed to use a common Excel-based template for evaluating the studies against the specific requirements of ISO 14044, but that review team members would also provide additional comments directly in the reports themselves. Two rounds of review were initially foreseen. Following each round, the panel chair would compile the documents, and generate a composite report of all comments submitted using the Excel template prior to returning them to the Project Team. The Project Team would respond directly to each comment in the Excel document as well as to the comments provided in the reports and report appendices, and modify the reports and appendices accordingly. These documents would then provide the basis for the subsequent round of review. All substantive comments provided by the panel members and the replies to the comments provided by the Project Team were to be documented in the Excel template and included as an appendix to the final review report.

In addition, the Project Team agreed to organize a series of webinars to demonstrate the implementation of the studies in the APS-footprint tool, specifically:

- Implementation of LEAP case studies in the APS-footprint tool
- Correctness of the calculations external to the APS-footprint tool (excel)
- Correct implementation of the methodology rules in the APS-footprint tool

On this basis, each reviewer was asked to assess the correctness of the implementation for their livestock group, with the information to be included in the final review report.

The original ambition was to submit the final review report by November 6. In order to accommodate the foreseen two-stage review process, the following timeline was identified, but with the caveat that it may be revisited if the first stage of the review pointed towards the need for fundamental changes to the study or to the scope/substance of the review.

Review 1 (10 days) Comments submitted directly to the Project Team by October 9th (reviewers to convene to discuss review at this time)
Reply 1 (10 days) Project Team review and reply to Review 1 by October 19th
Review 2 (5 days) Review team to consider replies and accommodations, and provide second review comments by October 24, along with review of APS-footprint tool implementation.
Reply 2 (5 days) Project Team to review second round of comments and reply to Review 2 by October 29
Review Report (5 days) Pelletier to compile final review report and send to review team for consideration by November 3.
Submission Pelletier to receive comments from review team by November 5 and submit final report to the Project Team on November 6.

Review Round I

Following the first round of review, the major concerns identified by the review panel were as follows:

(1) greater reporting detail and justification of methodological choices/assumptions and data were required in order to satisfy ISO 14044 requirements
(2) provision of all data (including references) and calculation methods were required in order to enable reproducing the analyses
(3) improved documentation/justification of choices and assumptions for the animal models were required
(4) presentation and application of a clear and systematic method for assessment of the suitability of the PEF/LEAP guidance documents (i.e. the road testing) were required
(5) presentation and application of a clear and systematic method to support the conclusions in the Appendix 1 document (substantiation for the nutritional effects) were required

(6) it should be clearly communicated that the report is not intended to and should not be used for the purpose of comparative assertions regarding the potential environmental benefits of specific feed additives relative to reference scenarios

Based on the outcomes of the first round of review, the Project Team (in consultation with DSM) further refined and clarified the goal of the study as follows:

"The main purpose of the study is to explore from a methodological standpoint, the applicability of those authoritative sector LCA guidelines (FAO LEAP and/or EC PEF) to the nutritional interventions resorting to feed additives. To this end, a diverse set of nutritional interventions (n=14 in total) based on the implementation of enzymes, vitamins, carotenoids, eubiotics, has been documented with an extensive bibliography (along the FAO LEAP Guidelines principles for feed additives) and further translated into effects observable at farm level. Three terrestrial target species are studied: broiler chickens, dairy cows, and fattening pigs, while the reference systems are designed from Dutch and Belgium references. The methodological exploration is reviewed by external experts along ISO requirements for LCA. "

On this basis, the Project Team further proposed to slightly revise the review assignment accordingly in order to emphasize the road testing of the LEAP and PEF guidelines as opposed to the analytical results themselves. Specifically, the Project Team requested that the reviewers evaluate "the ISO compliance of the road testing LCAs, involving our choices for and implementation of LCA methods, our results and our recommendations on the applicability of the sector LCA guidelines (FAO LEAP and/or EC PEF) to given nutritional interventions resorting to feed additives" in order to determine:

1. are they fit for purpose (substantiating the conclusions on methodology)?
2. are the quantitative results (substantiated with APS-footprint) and qualitative conclusions and methodological observations adequate?
3. are there other suggestions and observations that could be added to the recommendations regarding methodology improvement?

The following timeline for Review Round II was identified:

December 19: Review Round 2 comments submitted to Pelletier;
December 21: Pelletier submits compiled comments to the Project Team;
January 1: Project Team return revised documents to reviewers for final check;
January 10: Reviewers submit final check to Pelletier;
January 14: Pelletier submits compiled final comments and review report to the Project Team;

Review Round II

The panel members agreed that the study and associated reports were significantly improved from the first round, but flagged a number of outstanding comments/concerns that should be addressed in order to better align the study with ISO 14044 requirements as well as to meet the revised objectives. On this basis, the Project Team decided to undertake a final revision and to provide the revised documents and replies to the reviewer comments for a final check (essentially, a Review Round III) prior to concluding the study and the review process. The panelists agree to submit their final review comments to the panel chair by February 10th, with the aim of the final review report being complete by February 14th.

Review Round III

The review concluded on February 10, 2021 after the three rounds when the panel members each signaled that the majority of their concerns had been addressed and that the study reporting had achieved ISO compliance in most respects. The critical review report was then prepared and submitted to the Project Team on February 16, 2021 along with the appendix.

8.7.4 Concluding Statement

The study conducted the Project Team is generally of high quality and conforming in most respects with ISO 14044. The methods are scientifically and technically valid, and the data used are appropriate and reasonable in relation to the goal of the study. Moreover, the interpretations of the study results, to a large degree, reflect both the limitations identified as well as the goal of the study. The Project Team has been successful with respect to the goal of "road testing" the LEAP and EC PEFCR guidance documents, and making recommendations regarding potential ways to improve the guidance documents in subsequent iterations.

With respect to implementation of the methods in the online APS Footprint Tool, all panel members noted that they were unable to verify the actual code that was employed. Also, on the process of developing the baseline broiler systems, not all formulas were provided in the supporting material to compare against the documentation. However, the panel members observed that contribution analyses of the results generated by the tool were largely consistent with the expected magnitude and distribution of environmental impacts, which suggests that the implementation is, indeed, correct.

The three rounds of review and revision that constituted the critical review process served to improve the study in important respects, in particular relating to modifying the original goals of the study to emphasize the LEAP/PEF methods road testing aspect in place of advancing conclusions regarding the potential environmental benefits or impacts of feed additives. The panel members signalled, in conclusion of the third round, that the majority of their comments had been satisfactorily addressed, with the following exceptions:

- Despite that the main purpose of the study is to road test the methods rather than to support comparative assertions, the Conclusions and Summary section nonetheless draws conclusions regarding the environmental benefits of feed additives. Such conclusions might be construed as "comparative assertions," which the current study should not advance without first satisfying the additional requirements provided by ISO 14044 (for example, with respect to reporting quantitative uncertainty assessments)
- The discussion of allocation in the LEAP Road Testing document (4.3.3.2.5) appears to suggest that the benefit of an intervention would be higher with a different allocation strategy, whereas different strategies should only apportion the same level of benefit to the co-products in different ways

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Review Panel Chair Signature

_February 25, 2021________

Date

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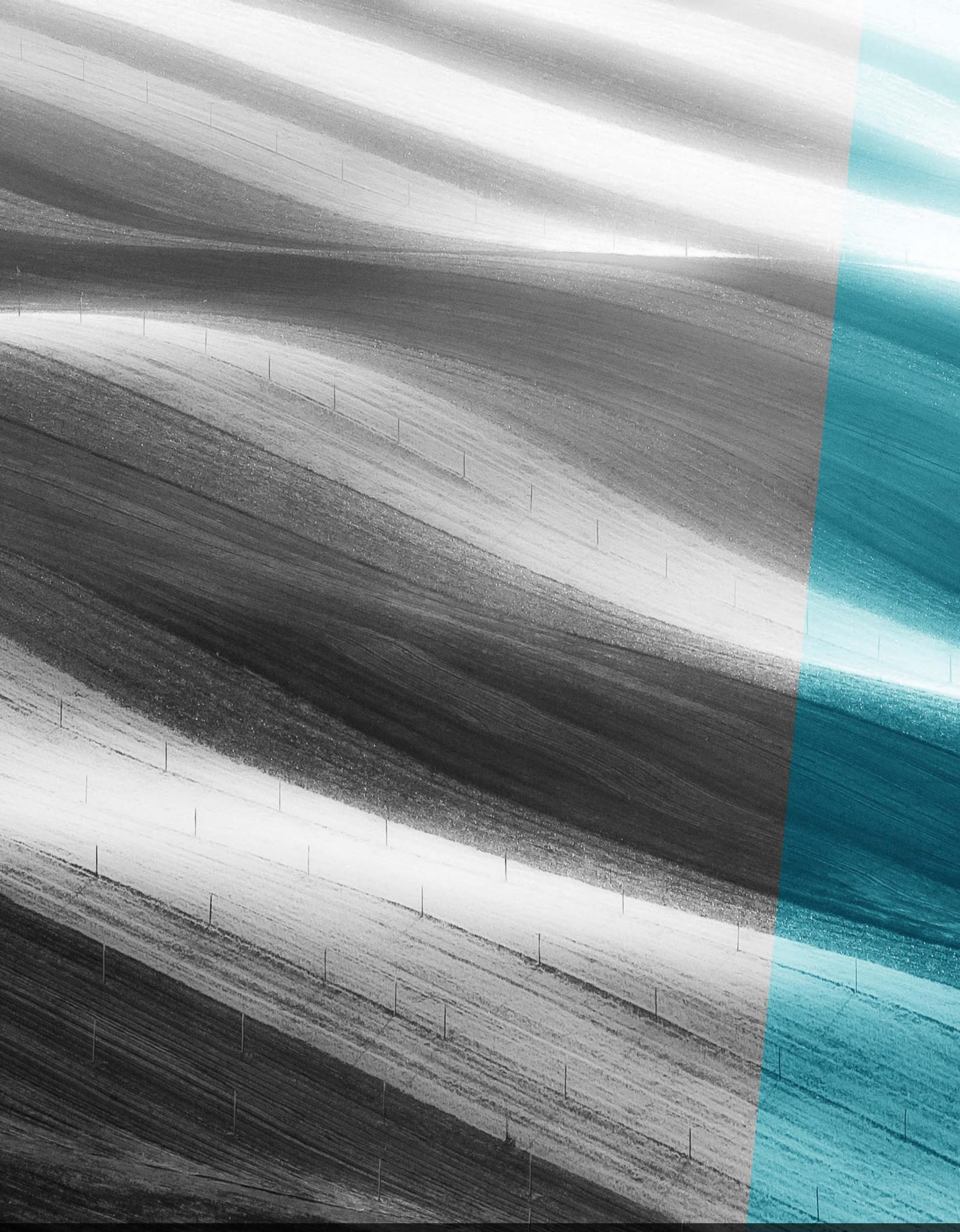

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