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# A path to sustainable and competitive Norwegian protein production for aquaculture and livestock feed

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# Abstract

The share of Norwegian ingredients in compound feeds for livestock and aquaculture has been falling since 2005. Increasing domestic protein production is one of the main ways to reverse this decline. If 100% of imported proteins in livestock feed are substituted with Norwegian produced proteins, the Norwegian share is expected to increase from about 75% to 81%-83%. For aquafeed, if 100% of imported proteins from non-grain sources are substituted with Norwegian produced proteins, the Norwegian share in aquafeed is expected to increase from about 5.5% (2016 data) to 31.6%.

Feed protein demand is estimated to increase from 987 000 metric tons (MT) in 2018 to 1 776 000 MT in 2050. 1 442 000 MT of proteins will be needed for aquafeed production and 334 000 for livestock feed production. These numbers assume a production goal of between 3-4 million MT of salmonid production by 2050.

14 promising protein production methods are evaluated, of which 8 are considered potentially viable based on criteria such as price competitiveness, sustainability and how technologically demanding production is. In total, the 8 viable methods are expected to contribute roughly 486 000 MT of proteins in 2050, in a moderate scenario. The 8 methods are mesopelagic fishing (150 000 MT), better/more roughage (120 000 MT), tunicate production (88 000 MT), increased grazing (45 000 MT), alkalized grains (30 000 MT), insect protein production (25 000 MT), meat and bone meal production (18 000 MT) and more protein- and oilseed production (10 000 MT).

It is concluded that reaching full self-sufficiency of proteins by 2050 is only possible for ruminant feed, but not for other livestock feed or aquafeed, even in a best-case scenario. It may still be worthwhile to invest in domestic protein production to mitigate food security risks.

The most important tool to support the growth of a domestic protein production industry is to increase R&D-funding. This is because the most promising production technologies are still in early stages of development, where progression is bottlenecked by a lack of knowledge rather than for example infrastructure or financial viability.

# Acknowledgements

Foremost, I would like to express gratitude to my advisor, Sigurd Rysstad, for continuous advice and encouragement. Besides my advisor, I would also like to thank Eystein Ystad (NIBIO/NMBU), Egil Prestløkken (NMBU), Arild Angelsen (NMBU), Sigurd Lars Aspesletten (Landbruksdirektoratet) and Andreas Myklebust Moksnes (Landbruksdirektoratet) for answering endless emails about agricultural policy, animal sciences, feed import and a wide range of related topics.

Furthermore, I would like to thank Anders Rognlien (Yara Norge) and Pål Øystein Stormorken (Yara International) for first suggesting me to investigate the case for roughage in Norway and advising me on that research. This is what eventually lead me down the path of examining the Norwegian feed protein market.

I would also like to extend my sincerest gratitude towards all the scientists, researchers, and professionals I have been in touch with while collecting data. The names are too many to list, but thank you to those of you in NMBU, SINTEF, Felleskjøpet Fôrutvikling, Felleskjøpet Rogaland Agder, Denofa, Pronofa, NIBIO, Havforskningsinstituttet, Skretting, Animalia, SSB, Regnskogfondet, Landbruksdirektoratet, Landbruksdepartementet, Fiskeridirektoratet, Hafrannsóknastofnun, NORSUS, Akvagroup, inFuture and the Japanese Agricultural, Forestry and Fisheries research council.

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# Contents

## Research problems

The share of domestically sourced proteins in feed for livestock in Norway (hereafter "the Norwegian share") has been declining since 2005. One important driver of this decline has been the relatively unimpeded availability of competitively priced protein imports from countries in South America and the Baltics, such as rapeseed meal and soybean products. In response, the Norwegian Agrarian Association (Norsk Bondelag) have called for policy changes to reverse this decline, based on concerns related to sustainability, food security and financial uncertainty for farmers. They want for the Norwegian share in feed to increase from 75% to at least 85% by 2025 and suggest that increasing domestic protein production is the best way to do so *(Internal work group within Norwegian Agrarian Association, 2020)*. This request has been taken seriously, not only within the Norwegian department of Agriculture and Norwegian Agriculture Agency (Landbruksdirektoratet), but also among big players in the Norwegian agricultural industry.

Meanwhile, the Norwegian aquaculture industry is growing at a rapid pace and there are wishes to increase production of farmed fish to as much as 5 million tons annually by 2050 (*Dagens Næringsliv, 2019)*. SINTEF point to increased Norwegian protein production as a criterion for a successful upscaling of aquaculture production, as proteins for feed is a key input factor in the aquaculture industry (*Gjøsund et al., 2020*).

In short, both the livestock and aquaculture industry are voicing demands for increased Norwegian protein production for feed. Academia and government also largely seem to be supportive. Landmark reports such as Grovfôr2020 and technological developments in alternative protein production suggest that there are legitimate ways to increase Norwegian protein production. But despite all this know-how, supposed financial incentives and good will, the Norwegian share has continued to fall. In this thesis, various novel and mature production methods for proteins will be examined, and an attempt will be made to understand why the Norwegian share has continued falling despite overwhelming interest in domestic protein production. An effort will also be made to understand if governmental market intervention can aid the growth of a sustainable domestic protein industry.

Specifically, the main question that will be asked is how to incentivize domestic Norwegian production of proteins for livestock and aquaculture feed that is competitively priced, sustainable and of sufficient quality. To answer this research question, some further research questions will also be posed:

1. Can Norway become self-sufficient with proteins for livestock- **and** aquafeed by 2050?
    i. Can Norway become self-sufficient with proteins for **livestock feed** by 2050?
    ii. Can Norway become self-sufficient with proteins for **aquafeed** by 2050?
2. Do aquafeed producers and livestock feed producers compete for the same protein goods?
3. Are there protein production methods available in Norway that can compete with soybean or rapeseed imports in terms of global carbon footprint per kg protein produced?

# Background and theory

## Why protein?

The main nutrients in compound feeds, ordered by weight, are carbohydrates, proteins, fats, minerals, and vitamins. Most fats, minerals, and vitamins are imported, but the total quantities used of each nutrient is small. Moving production to Norway may be costly due to a lack of economies of scale and would have less of an impact on the Norwegian share in the feed given the lower quantities used. There are also not the same environmental concerns with vitamin and mineral production as are associated with protein imports, such as land use change from rainforest deforestation and international transportation of millions of metric tons (MT) of goods. This leaves carbohydrates and proteins as the two main targets for increasing the Norwegian share of compound feed.

Carbohydrates in feed come mainly from grains, in combination with some additives like molasses, beet pulp and corn gluten. Molasses, beet pulp and corn gluten cannot be produced in Norway, so to increase the Norwegian share of carbohydrates in feed, policies should be enacted that increase Norwegian grain production. This could for example take the form of a subsidy to grain farmers.

Besides increasing grain production, the main way to increase the Norwegian share is to produce more proteins in Norway. How to best do so is a complex question, and answering it relies on intimate knowledge of various protein production methods, the impacts of international trade and an understanding of the Norwegian feed protein market. Answering the question of how to best increase the Norwegian share by increasing protein production, and to examine if it is at all possible within constraints of price competitiveness and sustainability, will be the focus of this study.

## Why 2050?

Increasing Norwegian protein production will take time, as it requires significant investments into R&D and infrastructure. Early exploratory studies on some of the protein production methods that will be mentioned in this report are just now underway, in 2022. For other protein production methods, like mesopelagic fishery, projects have been ongoing since the early 1980's, and researchers in those fields still do not expect to see significant breakthroughs for some years yet. If this report was going to analyze if proteins could contribute significantly to increasing the Norwegian share in livestock feed to 85% by 2025, as is the goal of the Norwegian Agrarian Association, the answer would likely be no. Instead, a longer time horizon was chosen. 2050 was convenient for two reasons. First, the EU aims to be climate-neutral by 2050 (*2050 Long-Term Strategy*, n.d.), which ties in with the focus on sustainability in this report. Second, the previous Norwegian minister of fishery set very clear production goals for the aquafeed industry by 2050, and therefore some number of published reports on the topic already reference 2050 in sections on long term strategy.

# Status of Norwegian share in feed

## Norwegian share in livestock feed

Table 1 shows the Norwegian share in feed in a "typical" year. It has been reproduced from reports by Animalia and the Norwegian Agrarian Association (in parentheses) (Roka et al., 2020), (Norwegian Agrarian Association, 2021) The Norwegian share listed is the share of ingredients by weight that are sourced from Norwegian production.

*Table 1: Norwegian share in feed for livestock. Source: Animalia, Norwegian Agrarian Association (in parentheses).*

| | ***Share of compound feed in feed (%)*** | ***Share of roughage in feed (%)*** | ***Norwegian share in compound feed (%)*** | ***Norwegian share in compound + roughage (%)*** |
|---|---|---|---|---|
| Dairy cows | 45 (43) | 55 (57) | 60 (45) | 82 (76) |
| Suckler cow (ammeku) | 7 (8) | 93 (92) | 63 (70) | 97 (98) |
| Beef cattle | 39 (27) | 61 (73) | 63 (70) | 86 (92) |
| Sheep/lamb | 12 (9) | 88 (91) | 63 (70) | 96 (97) |
| Pigs | 100 (90) | 0 (10) | 71 (75) | 71 (78) |
| Broilers (slaktekylling) | 100 (100) | 0 (0) | 40 (55) | 40 (55) |
| Layers (verpehøne) | 100 (100) | 0 (0) | 54 (55) | 54 (55) |

An assumption is made that in a typical year, 100% of the roughage is produced domestically. Note that broilers and layers are grouped together in the table by the Norwegian Agrarian Association. The numbers differ slightly between the two reports due to different methodology.

Norwegian dairy and beef production is primarily intensive, with goals of high yields. Therefore, a relatively high share of compound feed is used. Production of suckler cows on the other hand is extensive. Output is low, but feed costs are also low as suckler cows mainly graze or eat roughage. Similarly, sheep and lamb mainly graze, although sows are fed some compound feed in the period leading up to birth. Sheep are also sometimes fed compound feed during winter. Pigs and poultry are fed almost solely on compound feed, and thus have the lowest Norwegian shares.

*Table 2: Norwegian share given that all proteins are produced domestically. Source: Own calculations, based on data from Animalia, and the Norwegian Agrarian Association.*

| | ***Data from Animalia*** | ***Data from Norwegian Agrarian Association*** |
|---|---|---|
| Dairy cows | 88 | 82 |
| Suckler cow (ammeku) | 98 | 99 |
| Beef cattle | 90 | 95 |
| Sheep/lamb | 97 | 99 |
| Pigs | 85 | 90 |
| Broilers (slaktekylling) | 56 | 71 |
| Layers (verpehøne) | 68 | 69 |
| Weighted average | 81 | 83 |

Table 2 shows what the Norwegian share in livestock feed would be today if all imported proteins would be substituted with Norwegian produced proteins. As can be seen, it is almost possible to reach the goal of a Norwegian share of 85% by changing the source of proteins only.

To find the results in Table 2, the following assumptions and calculations were made: Annual Norwegian grain production in a typical year is about 1.2 million MT, with a protein share of 10.5% by dry weight, or 105 000 MT. Approximately 40% of produced grains go to livestock feed, meaning that Norwegian grains cover roughly 105 000*0.4 = 42 000 MT of the livestock feed protein demand. These approximations were provided by an expert in livestock nutrition from NMBU.

Total Norwegian protein demand for use in livestock feed in 2018 was 312 000 MT (see Table 14). So 42/312 = 13.5% of proteins are produced domestically already. We assume that there is no domestic protein production outside of grains for use in compound feed for livestock. To reach 0% imported proteins, the remaining 86.5% of proteins would were to be produced in Norway.

The protein content in feed for each animal is calculated on Table 9. We use these numbers together with information from Table 1 to find how much the Norwegian share would increase in each compound feed type if 86.5% of the proteins were to be produced in Norway. To do this we use the following formula for each animal type (dairy cow, suckler cow, sheep/lamb etc.) to find the Norwegian share in compound feed and roughage for those animal types:

$$Norwegian\ share\ in\ compound\ feed\ and\ roughage\ given\ 100\%\ domestic\ protein\ production = Share\ of\ roughage\ in\ feed + \big((Norwegian\ share\ in\ compound\ feed + (0.865 * Protein\ content\ in\ feed) * Share\ of\ compound\ feed\ in\ feed)\big)$$

This gives the results shown in Table 2, except the weighted average. As the feed consumption between different animal types is very different, taking a simple average would give the wrong impression of the overall Norwegian share. We give each feed type a weight by dividing the tonnage of compound feed that goes to each animal type by the total feed demand (see Table 13). We then multiply the Norwegian share in compound feed and roughage for each animal type with its corresponding weight and sum the results. This gives an overall Norwegian share in compound feed of 81% if using the data from Animalia, and 83% if using the data from the Norwegian Agrarian Association, given that the Norwegian share of protein is 100%.

## Norwegian share in aquafeed

The Norwegian share in aquafeed in 2016 was calculated to be 5.5%. To find this number the following calculations and assumptions were made:

First off, no Norwegian grain is used in livestock feed production (NOFIMA, 2014). Furthermore, 0.4% of ingredients in aquafeed come from novel protein sources, but none of these are produced in Norway. (Aas et al., 2019).

Marine proteins and marine oils constituted 24.9% of aquafeed ingredients in 2016, of which 21.9% came from Norwegian fish meal and fish oil. This number was found by first multiplying aquafeed turnover (1 708 000 MT in 2016) by the share of marine ingredients (24.9%) to find that marine ingredient demand was approximately 425 000 MT in 2016. Then, this number was compared to imports of marine oils and proteins in 2016 (332 000 MT), meaning that approximately $425\ 000 - 332\ 000 = 93\ 000\ MT$ of marine oils and proteins were produced in Norway, or 21.9%. The Norwegian share is then 21.9%*24.9% = 5.5%, as no other ingredients in aquafeed were produced in Norway.

High quality fish meal contains between 60-72% crude protein by weight (Cho & Kim, 2011). It is not known how the 93 000 MT of Norwegian produced marine ingredients are divided into production of fish meal and fish oil. For the sake of the calculation, it is assumed that 70% of the production was fish meal and 30% fish oil. If that is the case, Norwegian produced ingredients in aquafeed contributed roughly $\left(\frac{0.60+0.72}{2}\right) * 0.70 * 93\ 000 \approx 43\ 000\ MT$ of proteins to aquafeed in 2016. The protein content in Norwegian aquafeed in 2016 was 35.6% on average (Aas et al., 2019), meaning that protein demand in 2016 was $1\ 708\ 000 * 0.356 = 608\ 000\ MT$, so Norwegian produced proteins contributed roughly $\frac{43\ 000}{608\ 000} = 10.5\%$ of **protein demand (**not overall Norwegian share) in aquafeed, if the 70/30 split between fishmeal and oil is correct.

The percentage of carbohydrate ingredients in aquafeed is 12.6% as of 2020 (Aas et al., 2022). These ingredients are likely to contain about 10% protein, so 1.26% of compound feed proteins come from carbohydrates, or 1 708 000*1.26% = 21 500 MT.

Then, if the remaining $608\ 000 - 43\ 000 - 21\ 500 = 543\ 500\ MT$ of non-grain proteins in aquafeed were to be produced in Norway, the Norwegian share in aquafeed would increase from 5.5% to around 31.8%. “Non-grain protein” is specified because it is expected that grains for use in aquafeed will continue to be imported.

## The Norwegian feed protein market

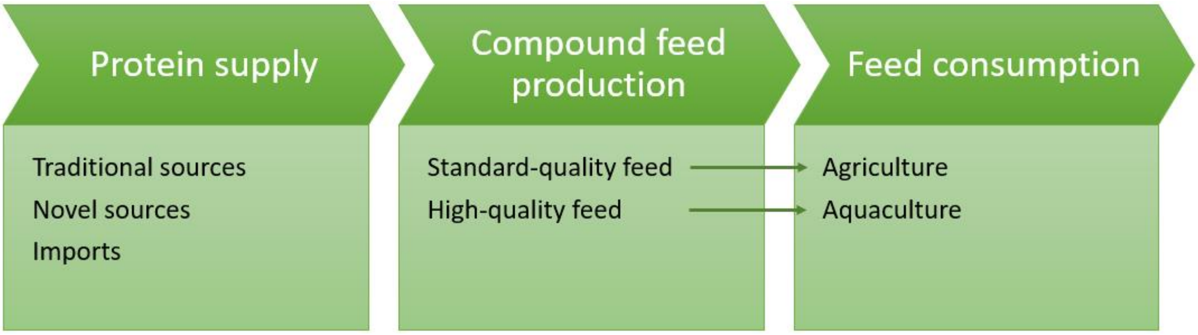

*Figure 1: Norwegian feed protein market. Examples of traditional sources are grains and roughage. Examples of novel sources is insect proteins and fish meal from mesopelagic fish.*

The Norwegian feed protein market can be modelled as a value chain with three major steps. First is protein supply. Proteins are supplied from traditional sources, novel sources, and imports. The traditional sources are fishmeal from byproducts from the fishing industry, domestic grain production and domestic roughage production. Novel sources are for example insect proteins and fish meal from mesopelagic fish. Imports are mainly soy ingredients (soy meal, soy protein concentrate), rapeseed ingredients (rapeseed meal, rapeseed oil) and carbohydrate ingredients (grains, beet pulp, molasses). Carbohydrate ingredients are included, as these also contain proteins. In 2020, only 0.4 % of the ingredients in aquafeed came from novel sources (Aas et al., 2022), but this share is expected to rise. The corresponding number for livestock feed is not known but is also likely close to 0.

In step 2, the supplied proteins are bought by fish feed mills that produce high-quality feed, and livestock feed mills that produce standard-quality feed. High-quality feed is made from ingredients like high-quality fish meal, soy protein concentrates and food-grade grains. Standard quality feed on the other hand is made from standard-quality fish meal, soy meal and feed-grade grains.

In step 3, the high-quality feed is sold and used in the aquaculture industry, while the standard-quality feed is used in the agriculture industry.

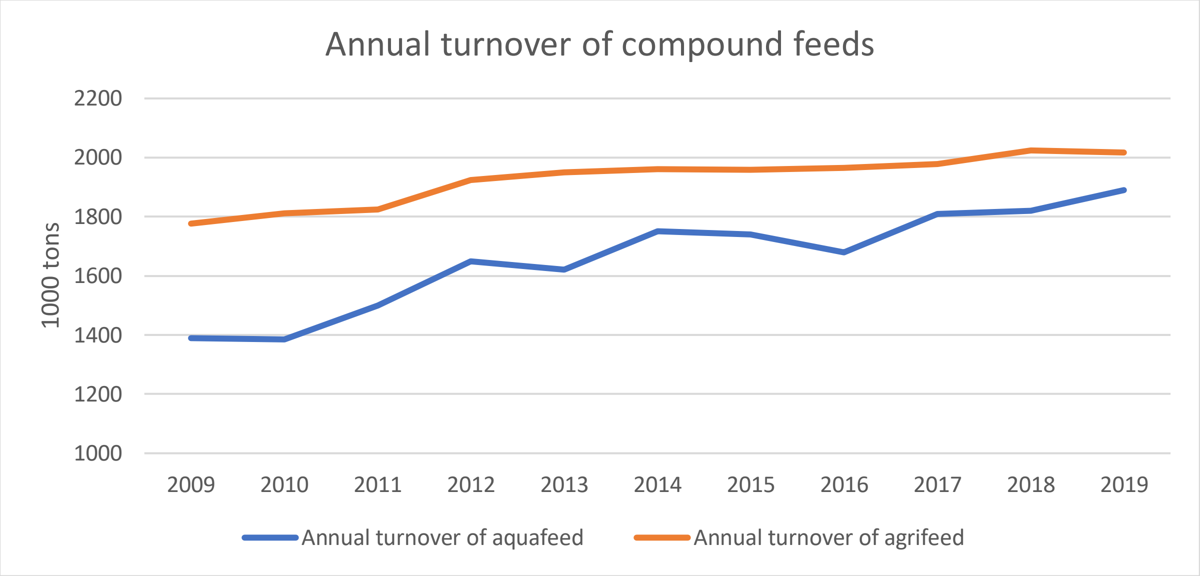

*Figure 2: Annual turnover of compound feed in Norway since 2009. Source: Kraftfôrsatistikken, Sjømat Norge.*

Figure 2 shows annual turnover for aquafeed and livestock feed since 2009. The turnover for livestock feed has grown at a low and stable rate, while turnover for aquafeed has seen a substantial increase. Data for 2021 is not yet available, but the consumption of aquafeed will likely have overtaken consumption of livestock feed by the time of writing.

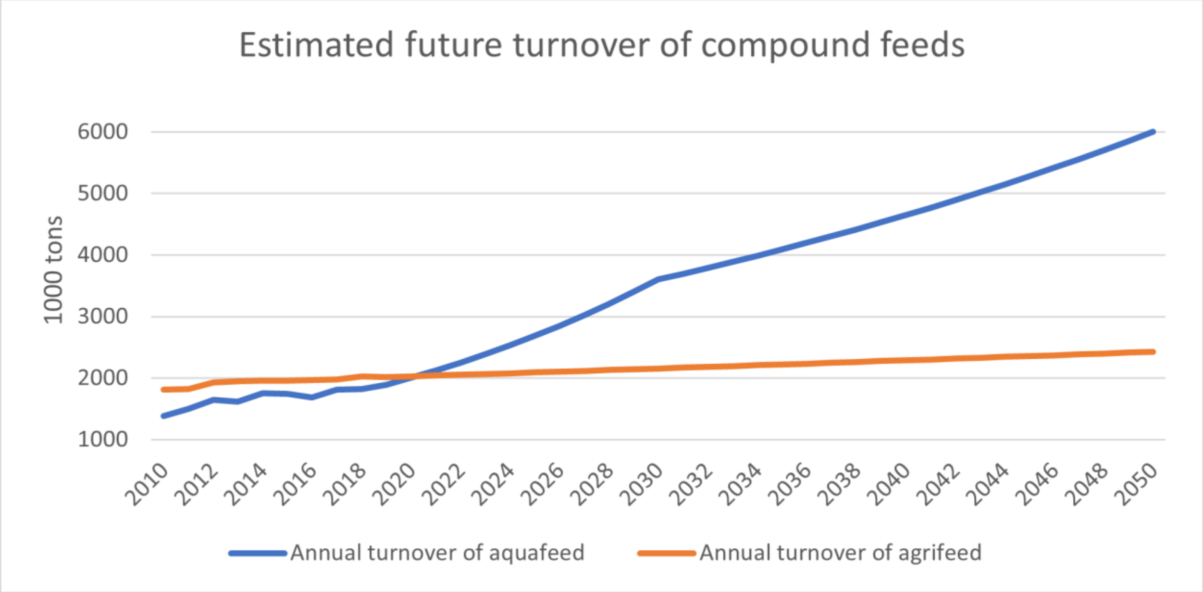

*Figure 3: Future estimates for compound feed turnover. Source: See paragraph below.*

A 2010 report by the registrar and classification company DNV, in cooperation with the Norwegian Academy of Technology Sciences, has projected the production of Norwegian salmonids to reach 5 million tons by 2050, requiring 6 million MT of aquafeed (*Verdiskaping-Basert-Pa-Produktive-Hav-i-2050.Pdf*, n.d.). This is based on a feed conversion ratio of 1.2, where 1.2 kg of aquafeed is assumed to produce 1kg of salmonid meat.

Figure 3 shows a possible trajectory for turnover of compound feeds. The trend for compound feed is based on actual numbers until 2020, and then it is assumed that livestock feed demand will grow uniformly to 2 130 000 MT by 2050 (see table 15 for justification). The trend for aquafeed is based on actual numbers until 2020, then on DNV estimates of compound feed demand by 2030 and 2050. It is assumed that demand will grow uniformly from 2020 to 2030 to reach the estimate set by DNV, and then uniformly from 2030 to 2050 but at a slower rate.

In 2017, a new quota system called the “Traffic Light system” was introduced that limits expansion of offshore aquaculture in areas with too much salmon lice. This traffic light system is a tool that is used to when and where concessions can be given for increased aquaculture production, Efforts have been made to overturn these production restrictions in courts, but the suits have been stricken down (NTB, n.d.).

In private communication with DNV, the authors of the report indicate that growth is likely going to be lower than the projected amount. A report by PwC from 2019 polled industry leaders and experts about their thoughts on the growth prospects of the aquaculture industry (*PwC, 2019*). A “clear majority” found the goal of 5 million tons production capacity by 2050 to be unrealistic. In private communication, Yngve Torgersen, director general of the department for aquaculture in the Norwegian Ministry of Trade, Industry and Fishery, writes that the goal of 5 million MT by 2050 “was set by the previous government, and therefore does not bind the current government”.

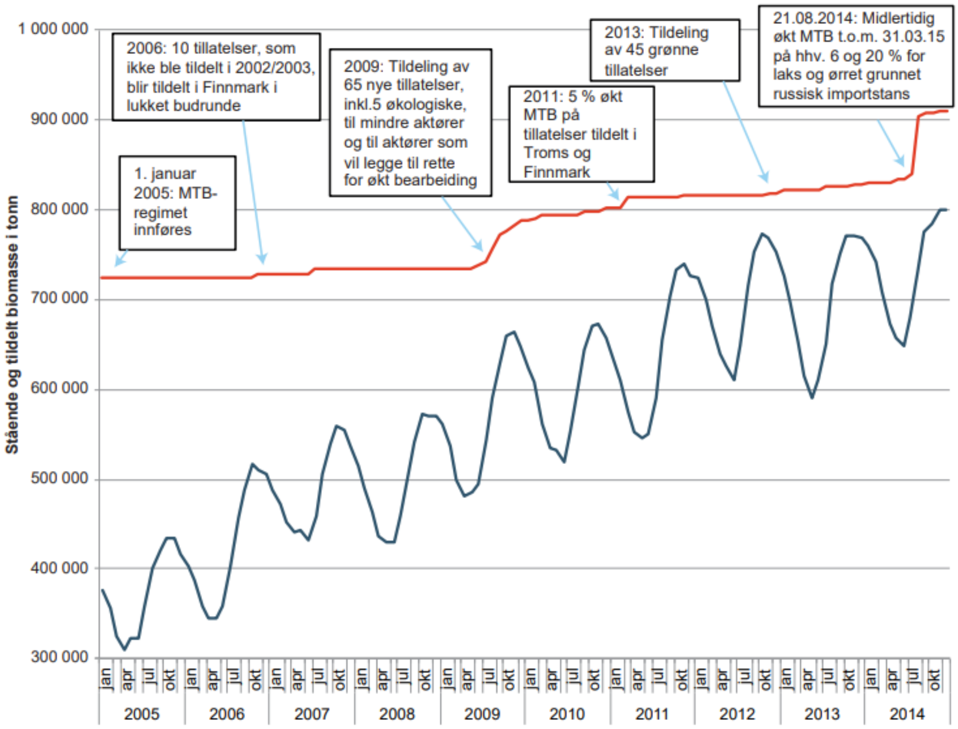

*Figure 4: Development in aquaculture production (black) and concession limits (red). (Source: Fiskeridirektoratet, NFD)*

Figure 4 shows the growth in aquaculture production compared to the concession limit for production from 2005 to 2014. If growth is going to increase to 5 million MT by 2050, concessions must continue to be granted at a very high pace. Given the current challenges with salmon lice, local pollution from offshore facilities, escaped salmon and difficulties in securing enough EPA/DHA[1] for aquafeed, 5 million MT is an unrealistic number.

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[1] EPA (eicosapentaenoic acid ) and DHA (docosahexaenoic acid) are omega-3 polyunsaturated fatty acids that are essential for fish health and growth.

Unfortunately, no other projections have been made for the growth of the Norwegian aquaculture industry towards 2050. In this report, two scenarios will be examined. A low-growth scenario where production is 3 million tons by 2050, and a moderate-growth scenario where production is 4 million tons by 2050. The current feed conversion ratio of 1.2 from the DNV report will be used, as well as an estimate of a 2050 future feed conversion ratio of 1.1. In the two scenarios, between 3.3 and 4.8 million tons of aquafeed will therefore be required to meet production goals.

## Trends in imports

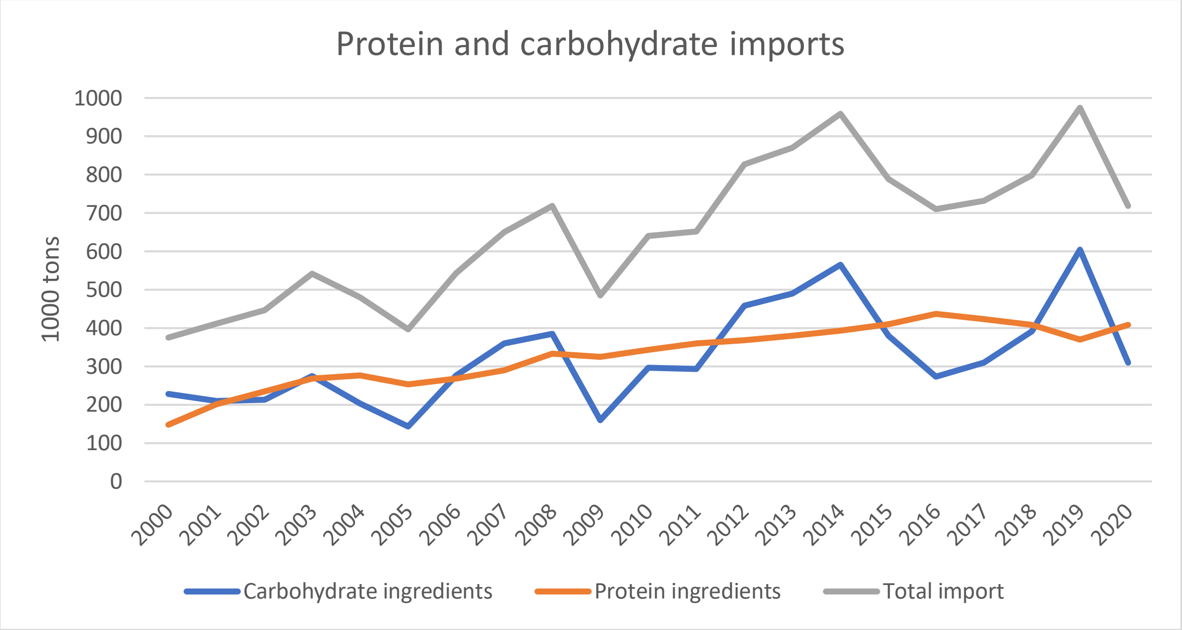


*Figure 5: Total feed protein and carbohydrate imports to Norway since year 2000.Source: SSB.*

As Figure 5 shows, carbohydrate and protein imports have trended upwards since 2000. Combined imports have increased from 375 000 MT in 2000 to 718 000 MT in 2020. The total carbohydrate import is far more volatile than protein imports, however. According to experts in Felleskjøpet Fôrutvikling this is because the feed mills that produce feed for livestock are required to use domestically produced carbohydrates (grains) before they can use import carbohydrates. In years with high production of feed grade grains, imports of carbohydrates will fall in the following year, regardless of global market price. In years with low production, imports of carbohydrates will rise the following year. This should lead to a natural volatility in carbohydrate imports.

In a normal year, about 25% of the grains are used in the period after harvest until the end of the year. The remaining 75% of the harvest is stored and used in production the year after harvest, according to information received by private communication from a domain expert in Felleskjøpet Fôrutvikling. A simple regression can be set up with total carbohydrate import in year+1 as the dependent variable and total domestic grain production as the independent variable. If we run this regression, we find a significant negative correlation between domestic production and imports in the following year. For each ton of increased grain production, there is a decrease of 0.64 tons of grain imports the following year on average, with a t-stat of -6.15. We reject the null hypothesis that there is no correlation and find that increased Norwegian grain production does lead to lower grain imports in the following year. For proteins, there is no such requirement of using Norwegian product before imports because there is barely any domestic protein production at all. We therefore see stable levels of imports over time, correlated with rising demand for compound feed.

## Compound feed production in Norway

The major livestock animals in Norway are cattle (dairy cows, suckler cows, beef cattle), pigs, poultry (broiler chickens, layer chickens), and sheep/lamb. Meanwhile, salmonids (Atlantic salmon, rainbow trout and sea trout) make up around 97.5% of Norwegian farmed fish production. Combined, these species account for nearly all feed demand in Norway. In the following section, some major dietary requirements of proteins for these species will be detailed, as well as information about Norwegian compound feed production

### Production of livestock feed

In 2016, 1 964 000 metric tons (MT) of compound feed for livestock were produced and sold in Norway (Kraftfôrstatistikk, n.d.). 1 800 000 of these tons were produced by four mills: Felleskjøpet Agri (750 000 MT), Felleskjøpet Rogaland Agder (375 000 MT), Fiskå Mølle (350 000 MT) and Norgesfôr (325 000 MT) (Norgesfôr, Fiskå og Felleskjøpet, 2018). Felleskjøpet Agri and Felleskjøpet Rogaland Agder are independent cooperatives that operate in different geographical areas, but that cooperate closely. Small mills and individual farmers produced the remaining 164 000 MT. In 2020, total production had increased slightly to about 2 002 000 MT of compound feed (Landbruksdirektoratet, 2021). On average, compound feed turnover has grown by 0.6% a year since 1996.

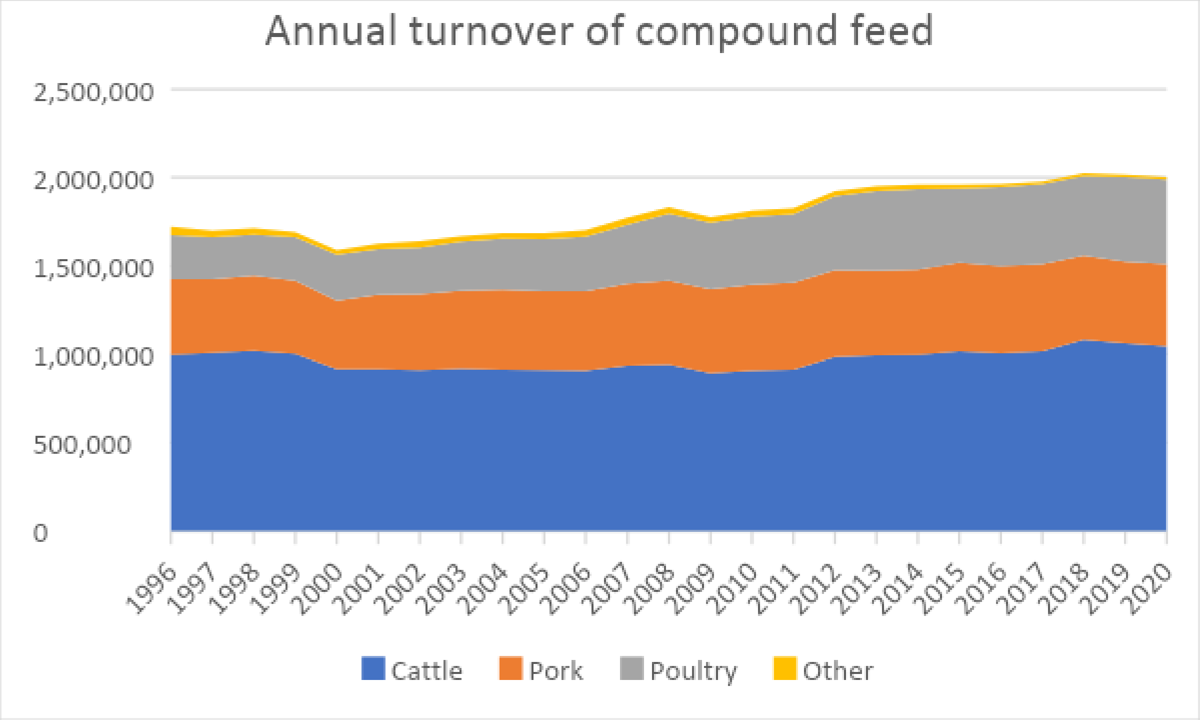


*Figure 6: Annual turnover of compound livestock feed in Norway for the period 1996-2020 (Kraftfôrstatistikk, n.d.).*

Compound feed differs in exact composition based on what animal it targets, production requirements, as well as ingredient cost and availability. The main carbohydrate ingredient used in compound feed for livestock is feed-grade grains, while the main protein ingredients is imported soybean meal and rapeseed meal. Note that the mills are only allowed to use substitute carbohydrate sources once all Norwegian feed-grade grain has been used. As rapeseed meal is both carbohydrate and protein rich, the mills have tended to substitute rapeseed meal for the more protein-dense soy in years where there is high Norwegian grain production, and vice versa in years with low Norwegian grain production. However, the relative price of soybean meal to rapeseed meal is still a more important factor in determining the ratio of protein imports. Corn is imported as a carbohydrate source in years with especially low Norwegian grain production. Fats, minerals, vitamins, and amino acids are added in small quantities. Most of these ingredients are imported, apart from some limited Norwegian production of peas and field beans. Molasses, beet pulp and corn gluten are also imported in small quantities and added to the feed concentrates. Table 3 lists the fat and protein-content of the most common ingredients used in compound feed.

*Table 3: Protein and fat content in main feed ingredients (Adler, Løes, 2014).*

| ***Ingredient*** | ***Protein-content in dry matter*** | ***Fat-content in dry matter*** |
|---|---:|---:|
| Grain (Barley) | 12% | 2% |
| Grain (Oats) | 13% | 5% |
| Grain (Wheat) | 14% | 2% |
| Grain (Corn) | 9% | 4% |
| Soybean | 39% | 19% |
| Soybean meal | 49% | 2% |
| Rapeseed | 22% | 45% |
| Rapeseed meal | 37% | 2% |
| Peas | 24% | 1% |
| Beet pulp | 10% | 1% |

Rapeseed and soybeans are too high in fat-content, so these are usually pressed into soybean meal and rapeseed meal before being shipped to Norway. As can be seen, there is some protein in grains (9-14%) but mostly carbohydrates. Soybean meal and rapeseed meal are clearly the most protein dense products, at 49% and 37% respectively, and help ensure intensive dairy- and meat production. Note that in the aquaculture industry, even higher protein density is required so soy protein concentrates with approximately 70% protein content are used in place of soybean meal.

To give an idea of the major ingredients in feed, Table 4 shows the content of three different compound feeds for dairy cows produced by Felleskjøpet in 2014 and 2016, by weight. The ingredients in other livestock feed is similar, see Appendix A for a full list (in Norwegian).

*Table 4: Content of three different compound feeds for dairy cows produced by Felleskjøpet in 2014 and 2016 (Felleskjøpet, 2016).*

| ***Ingredient*** | ***Favør 80*** | | ***Elite 80*** | | ***Energi Premium 80*** |
|---:|---:|---:|---:|---:|---:|
| | 2014 | 2016 | 2014 | 2016 | 2016 |
| Norwegian grains (incl. oilseeds) | 68 | 69 | 54 | 56 | 46 |
| Imported corn | 0 | 0 | 0 | 0 | 8 |
| Imported soy | 11 | 11 | 12 | 12 | 14 |
| Imported rapeseed meal | 9 | 8 | 9 | 11 | 13 |
| Other imported raw materials (molasses, beet pulp, corn gluten) | 8 | 8 | 19 | 16 | 13 |
| Imported fats | 1 | 0 | 2 | 1 | |
| Minerals, vitamins and other | 3 | 4 | 4 | 4 | 4 |
| SUM | 100 | 100 | 100 | 100 | 100 |

ENERGI PREMIUM 80 is used for dairy cows where target annual production per animal is above 8500kg milk, ELITE 80 is for production of 7000-8500kg milk and FAVØR 80 is for low to medium-intensity production with production less than 7500kg milk. The feeds targeting higher production quantities tend to substitute carbohydrates for a higher percentage of proteins and fats, as can be seen from the higher soy, rapeseed and fat contents in Energi Premium 80. Note that for dairy cows, feed composition varies only slightly from year to year.

## Production of aquafeed

The total turnover of aquafeed was 1 894 000 MT in 2019 (*Fiskeridirektoratet, 2020)* representing more than 50% of total production costs of farmed fish in Norway (*Zahirovic, 2012*). Feed is the most important target for improving efficiency and sustainability in the aquaculture industry.

The average protein content in aquafeed is 35.6% (Aas et al., 2019). This very high protein content necessitates use of high-value, protein dense ingredients, such as soymeal concentrates and rapeseed meal. Almost all proteins used in aquafeed are imported (NOFIMA, 2014). Together with fish meal, these ingredients provide the high protein content required for intensive fish farming.

Salmonids also need sources of EPA/DHA in their diet. These are omega-3 polyunsaturated fatty acids, usually found in fish and some algae. In 2015, the average EPA/DHA content in fish feed in Norway was 2.4% (Aas et al., 2019). However, Lutfi et al. find significant increase in salmon health, growth rates and meat quality in fish that are fed up to 3.5% EPA/DHA over fish that are fed less EPA/DHA (Lutfi et al., 2022). In a scenario where 4.8 million tons of aquafeed is needed, the demand for EPA/DHA will be between 115 000 - 168 000 tons, depending on production targets.

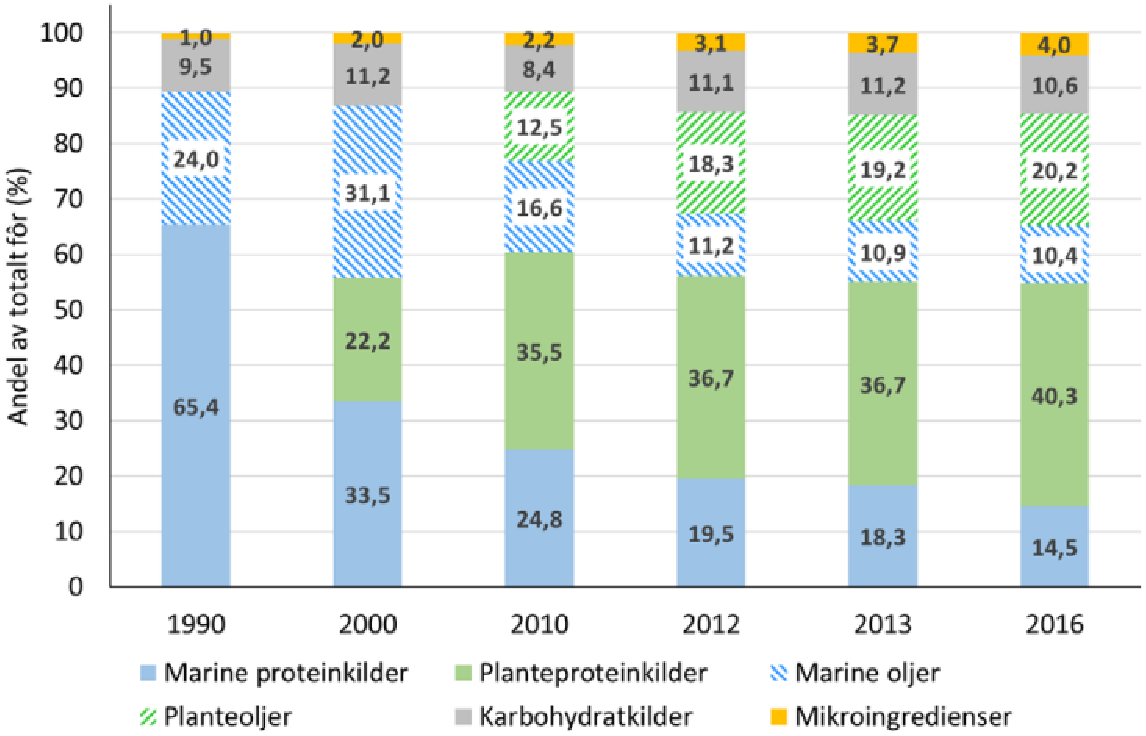


*Figure 7: Composition of salmon feed 1990-2016. Reproduced from (Aas, 2019)*

Over the last 30 years, marine protein sources and marine oils in aquafeed have increasingly been substituted with plant proteins and plant oils. In 2016, aquafeed contained 24,9% marine ingredients, down from 89,4% in 1990. With current technology, only ingredients from marine sources can supply a substantial amount of EPA/DHA (see chapter on protein supply in 2050). Further substitution is therefore unlikely to happen, as EPA/DHA-content in feed has become a limiting factor.

Aquafeed must also have high water stability. While choice of ingredients and binding agents matter most for water stability, manufacturers also pay attention to granularization levels and the temperature at which production occurs at (Fish Feed Machinery, 2018). This makes the process of producing aquafeed moderately more complex than livestock feed.

No Norwegian company has produced feed for both fish and livestock in the last 30 years. Production of aquafeed is done either by dedicated mills such as Skretting, or by aquaculture companies as a part of their value chain, such as Mowi (formerly Marine Harvest). This is unlike some other countries, for example Japan, where most aquafeed is produced in mills that also produce livestock feed. According to an expert on Norwegian feed production in Felleskjøpet Fôrutvikling, one major reason is that Norwegian aquaculture companies demand aquafeed of higher quality than what is used in for example Asian countries where they produce mostly Asian Carp. This can be explained by the fact that salmon is marketed as a higher quality fish, with a sale price of about twice that of Asian Carp, and customers have more stringent demands for meat quality. To meet the market demands for quality, better quality feed is used for fish farms in Norway than in Asian countries, and therefore Norwegian aquafeed mills use both higher quality ingredients and different machines than what is required for lower quality feed. In Norway, aquafeed is produced using an extruder instead of a pellet press for example. Extruder technology makes it easier to increase the water stability of the feed and lets manufacturers target a certain pellet buoyancy. Water stability is important, because if pellets dissolve too quickly in water the nutritional content will diminish. Having a correct pellet buoyancy is vital as salmonids prefer eating slowly sinking feed rather than floating feed or bottom feed. For livestock feed a pellet press is more commonly used, as the machine is cheaper and extruder technology is not needed.

The feed ingredients used for fish and livestock also differ significantly in quality, even if they are based on the same raw material. Some examples are listed in the table below.

*Table 5: Examples of ingredient quality in aquafeed and livestock feed.*

| ***Aquafeed*** | ***Livestock feed*** |
|---|---|
| High quality fish meal | Regular quality fish meal |
| Food-grade grains | Feed-grade grains |
| Soy protein concentrate (70% protein) | Soy meal (49% protein) |

The common denominator is that the fish feed ingredients are of higher quality and higher cost, as technical requirements and nutritional requirements are higher for farmed fish than for livestock.

## Theoretical perspectives

The compound feed market has two segments, aquafeed and livestock feed. The aquafeed segment consists of aquafeed mills on the supply side and the aquaculture industry on the demand side. Aquafeed is a largely uniform product, with only minor differences in nutrient composition and technical qualities from supplier to supplier. The livestock segment consists of livestock feed mills on the supply side and the livestock industry on the demand side. Livestock feed varies greatly in relative composition of ingredients based on the species it targets, but the ingredients are similar across species, typically grains, rapeseed, soy, fats, vitamins, and minerals. The process for creating livestock feed is uniform no matter the species, and thus livestock feed targeting different species can be manufactured in the same factory at low additional costs.

The level of supply at each price point on the supply curve is driven by the factors of production. The main factors are labor and capital. The production process for creating animal feed is relatively simple, and the share of labor costs is low. Capital is the umbrella term capturing costs of all the physical assets such as machinery, tools, buildings, and feed ingredients. Capital represents the majority of costs related to feed production. In this analysis, machinery, tools, and buildings are treated as purely fixed costs. An assumption is made that maintenance costs are low enough to have a negligible impact in a scenario-based analysis. Furthermore, we assume that the price of non-protein feed ingredients is directly tied to inflation, such that purchasing power parity of agents in the market remains constant over time. This simplifies the analysis, which aims to understand what impact increased Norwegian protein production will have on the feed market specifically, not how changes in other nutrient availability impacts the market.

Note that suppliers can import proteins from the global feed protein market, as a price taker. There is a tariff on imports, varying by protein source, usually set around 5-12%. This implies that protein from domestic producers only will impact the market if the product is competitively priced when accounting for import tariffs. This is unless regulation is put in place that requires feed mills to use domestically produced proteins before they are allowed to import, as is done for grains. It should be noted that it is possible that a product that is certified to only contain Norwegian produced proteins may be more attractive on the Norwegian market, and as such Norwegian produced proteins could remain competitive at a slightly higher price than imported proteins.

The level of demand at each price point is mainly a factor of the price farmers and fish farmers can get for meat and fish in their respective markets. This is essentially an income effect. If the price of meat and fish rises, the willingness to pay for feed will increase proportionally, by a cross-price elasticity factor. The cross-price elasticity measures the responsiveness in the quantity demanded of one good when the price for another good changes. Note that the market for meat in Norway is heavily regulated and subsidized, which will impact the cross-price elasticity. The fish market is also regulated on the supply side by a concession-based system. A “Traffic Light System” indicates if concessions can be given for increased production in a specific area (green), if expansion should be halted (yellow), or if production must decrease (red). The number of salmon lice is what determines the color.

Fish, poultry, and pigs are fed solely on compound feed, so there is no substitution effect for these segments of the market. If the price of livestock and/or aquafeed rises, the marginal cost of production of fish, poultry and pork rises and with no available substitutes of feed, production will fall. So, an increase in protein prices will lead to a proportional and direct decrease in production. There is some friction in the short run as farmers have limited ability to change production within one production cycle, but as feed ingredients are bought mainly on futures contracts or at prices determined by cooperatives at regular intervals, it is unlikely that this friction has significant impact on the market as prices of compound feed do not change on a daily or even weekly basis. Note that since proteins are imported from the global market, it is global market conditions that determine protein price changes, not domestic factors.

Dairy cows, beef cows and sheep graze and eat roughage, and so rely on these feed sources for only part of their protein intake. For these animals a substitution effect will be observed. If compound feed prices increase, farmers can substitute compound feed for roughage in the long run. In this market however, there is significant friction in the short run. Farmers cannot choose to increase roughage production in the middle of the season, as one must use more fertilizer early in the season to improve yields, for example. Thus, the substitution effect from shifting to roughage will happen the following season, at the earliest, unless farmers purchase roughage from external sources. Some farmers also lack the knowledge or resources to improve the quality and yield of their roughage production and will be less able to shift their production in response to changes in the compound feed market. Another option available for farmers with beef cows is to let the beef cows graze either in a fenced pasture or on rangeland, instead of keeping them in a barn and feeding large amounts of compound feed, which is the more common and intensive production method. Cows that graze (suckler cows) usually have a calf each season that consumes all the milk the mother producers. The calves are either sent for slaughter or sent to graze to become a suckler cow. After multiple seasons, the suckler cow is slaughtered for meat. Oxen that graze are castrated (castrates) and allowed to graze until slaughter. This is an extensive production method with low yields and large numbers of animals, but low input costs that make up for the lower yield.

On the supply side, producers have some choice in where they source their proteins and already show high responsiveness to price changes of particular protein goods. Soy products, for example, have become more expensive than rapeseed products per gram of protein in recent years, and as expected, rapeseed has overtaken soy as the chief protein import to Norway. Generally, this effect is not as large as one would think however, as there also is high covariance in price of different protein goods. When soy products increase in price, rapeseed products also tend to increase in price, for example. There are also not that many different protein goods available on the market, and producers are to some degree bound by specific properties of those protein goods. For example, fish meal and fish oil is used in aquafeed despite exorbitant prices, as they contain necessary omega-3 fatty acids. Note that producers have limited possibility of varying the relative nutrient composition in the feeds, by for example decreasing protein content, as the animals need certain levels of nutrients to meet production requirements set by customers.

# Method

## Data collection

Data collection was primarily done by literature review. In several cases, estimates from literature had to be contextualized by information from domain experts. This is because much of the technology discussed in the report is new, and studies on potential production is still ongoing. The goal of the data collection process was threefold:

1. Make an estimate of feed protein demand in 2050.
2. Find which protein sources are potentially viable candidates for increasing the Norwegian share by 2050. Viability was determined by factors such as price competitiveness, sustainability, comparative advantage in production, technological requirements, nutritional fit, and scale of production.
3. Make an estimate of protein supply from each viable source in 2050.

With these numbers, it is possible to estimate supply and demand scenarios for the feed protein market in 2050. These scenarios may then be used to examine what policies might be effective for increasing the Norwegian share in animal feed.

## Unit definitions

### Units used for protein production

In reports on protein production, three units for magnitude of proteins tend to be used. The first, often used when talking about imports of protein, talks about proteins as tonnage of "protein raw material" (proteinråvare). A "protein raw material" is defined as any raw material containing 20% or more proteins by dry weight. This is a poor measure when considering total protein demand, as different protein raw materials have different protein content, which makes comparison difficult. In addition, non-protein raw materials such as grains also contain protein, but around 11% rather than >20%, which adds a layer of confusion.

A second measure used is protein content by weight. This is the measure used throughout this report, as key data on feed content which used in almost all calculations is given in protein content by weight. In cases where sources use any other unit, those units have been converted to protein content by weight.

A third measure used is protein content by **dry** weight. This is a measurement of how much protein by weight a product contains when all moisture is removed. This is a fine measurement, but since vital data was given in "wet" weight, that unit was chosen instead.

### Units used for weight

The unit used for weight throughout this report is metric tons (MT). 1 MT equals 1000 kg.

### Measuring sustainability

To compare how sustainable various production methods are, the main measure used has been emissions of CO2-equivalents. The impact of production on natural ecosystems is also discussed where appropriate. A more encompassing discussion of sustainability, considering factors such as impact of production on developing countries, gender equality, responsible consumption, sustainable communities and more, has not been possible due to time constraints.

## Estimating supply and demand

Prognoses for demand for feed proteins for livestock feed and aquafeed were made.

To estimate forecasted supply, feed ingredient matrixes were constructed. These matrixes look at what the possible protein sources are, and how big a share of total demand it is realistic that each source can meet based on established literature. An example is given below:

*Table 6: Example of feed ingredient matrix.*

| ***All feed*** | ***Moderate case*** | ***Best case*** | ***Worst case*** |
|---:|---|---|---|
| *Protein demand* | | | |
| *Current production* | | | |
| New protein source 1 | | | |
| New protein source 2 | | | |
| New protein source 3 | | | |
| **SUM production** | | | |
| Remaining imports | | | |

Finding reliable estimates for future supply and demand of feed proteins has been challenging. Long term forecasts are inherently unreliable, and a large share of potential production in 2050 comes from novel protein sources. For many of these novel protein sources, there is no established body of literature that speaks to their efficacy. Many studies are currently under way, but not yet published. Knowledge about varying protein production methods is therefore in large part informal and fragmented.

Furthermore, many actors in the industry have conflicts of interest when reporting estimates for future production. In several cases, such as with for example mesopelagic fishery, improved roughage production and alkalized grains, the estimates for future production from different industry actors vary by as much as a factor of 5-10. In general, there is a clear trend in that industry actors who have a financial interest in a technology report the highest estimates.

Due to a lack of literature for many production methods, the estimates used in this study are contextualized by information received through private communication from domain experts. Because of conflicts of interest, it has been vital to collect information from as many domain experts as possible, in an effort to triangulate data and reduce bias. Furthermore, great care has been taken to critically evaluate all sources of information. Most of the information presented in this study is from published literature, but a large share has also been taken from comments and information provided by over 50 researchers in various fields. When selecting what people to contact, an effort has been made to reach out to researchers with differing opinions, so that no single perspective is overrepresented.

Despite the significant efforts to reduce bias and to collect reliable estimates, parts of this study remain difficult to replicate due to the nature of the exploratory data collection process. To combat this issue, a significant effort is made to clearly state what assumptions have been made for the various estimates used, and to show any calculation involved in finding each data point. Furthermore, it should be emphasized that this is an exploratory study which purpose is to map out different scenarios for the feed protein market in 2050, but not to make very precise predictions about isolated data points.

Once these models have been constructed, it may be possible to determine what the optimal combination of protein production sources are, given certain factors like cost, feed quality, nutritional fit, and sustainability. Then, a review will be done of possible policy tools that can be used within a WTO framework, and a suggestion can be made for what policy regulations to enforce, or not to enforce, to ensure sustainable and competitive Norwegian protein production for aquaculture and livestock feed.

## A note on the use of theoretical models

Economic papers often rely heavily on the use of theoretical models such as: AS-AD models for modelling aggregated supply and demand; the Heckscher-Ohlin model, Ricardian model, or specific factors model for modelling international trade; or Cobb-Douglas production functions for deriving production functions and analyzing input factors, for example. Using such models has been considered in this paper. Some of them have not been relevant, for example the international trade models, as Norway is a price taker on the global protein market. Others have felt too general. The estimates for 2050 are already highly uncertain due to the long time perspective, so using generalized models to comment on uncertain scenarios felt too far removed from reality to be worth spending much time on.

Similarly, the use of econometric models has been avoided for the most part, as there is little reason to believe that past trends in the Norwegian protein market will determine the future trajectory of the Norwegian protein market, outside of what is covered in the chapter on supply and demand estimates.

# Protein supply and demand estimates for 2050

This chapter is split in two main parts. In the first part, prognoses for protein supply for 2050 are made. These prognoses for supply are based on a review of current and novel protein production methods. In the second part, prognoses for protein demand in 2050 are made, both for the livestock industry and the aquaculture industry. The numbers for demand are based on estimates of growth in the number of animals and expected changes in feed efficiency.

These prognoses are bound to be highly uncertain. Some of the major sources of uncertainty are unexpected changes in trade policy (WTO, EEA, Norwegian government), unexpected technological development, changes in global feed prices or feed input prices, changes in population, and potential changes in consumer trends. In general, it is advised to take any single prediction made in the following chapter with a grain of salt. Instead, the goal of the analysis is to get a general sense of what the production possibilities and demand may be in the future and explore these various possibilities in loosely defined scenarios.

## Protein Supply in 2050

In this sub-chapter, the potential for Norwegian production of proteins in 2050 is explored. A set of requirements for a protein source to be viable is defined. Various protein production methods are then compared to these requirements, based on literature review and expert opinion.

### Requirements for viability

For a protein source to be viable for use in Norwegian feed production, several requirements must be met. Most importantly, production must be price competitive with imported protein goods. The tariff on protein imports for feed is in the range of 5-12% (*Tolltariffen*, n.d.) and pressure from WTO suggests that tariffs will fall, rather than rise, in the future. Proteins for aquafeed must be price competitive with soy protein concentrate, and proteins from livestock feed must be price competitive with soymeal and rapeseed meal.

Secondly, the product must not have other use cases where prices will be higher. Pelagic fish, for example, is a rich source of proteins and EPA/DHA with low production costs. However, pelagic fish fetches a much higher price when sold for human consumption, so aquafeed producers cannot compete.

The climate footprint from production must also be lower or like the climate footprint of imported proteins. Due to changes in customer preferences, aquaculture companies are increasingly looking to make production of farmed fish more sustainable (*PwC, 2021*). The use of soy in fish farming is frequently a topic in national media (Hykkerud, 2020) (Kringstad, 2021) A less sustainable protein source would likely not be considered attractive by farmers and aquaculture companies unless it is far cheaper than its alternatives.

Production must also be possible in Norway, and the technological barriers to enable production should not be insurmountable.

Preferably, production should have a comparative advantage. If it is more efficient to produce a protein source outside of Norway than in Norway, production will eventually move abroad, as expected tariffs in 2050 will likely be even lower than they are today, due to pressure from the WTO. Furthermore, production should be of stable quality. The consumer market for meat and fish is sensitive to quality problems, and “food scares” could cause considerable harm to producers that use feed of varying quality (Brunsø et al., 2002).  Production should preferably also not “crowd out” production of other feed sources.

Feed sources also must contain the right concentration of proteins to be used in either aquaculture or livestock feed and should have an appetizing taste. If not, animal growth is likely to be stunted. Furthermore, the presence of heavy metals and other toxic materials must be below regulated thresholds, and there must be proof that protein uptake from the feed source is efficient in the target animal groups. For fish feed, it is also important that the protein source aids in producing feed pellets that do not disintegrate in water and that have the correct buoyancy. If the protein source also contains EPA/DHA, this is a bonus for use in fish feed, as there is a shortage of EPA/DHA.

Various protein production methods have been evaluated to see to which degree they meet the above criteria, and how many MT of protein each source is likely to contribute by 2050.

## Sources of current protein production

### *Norwegian protein production*

Current protein production is 42 000 MT from Norwegian produced grains (see page 8-9 for calculation), 43 000 MT from Norwegian produced fish meal (see page 9 for calculation) and some unknown amount from roughage and grazing.

### *Import proteins*

The vast majority of import proteins are from soybean products and rapeseed products (Landbruksdirektoratet, 2021). The price of production of these products is between 12 and 18 NOK per kg/protein as of 2020 (Gjøsund et al., 2020). In context of most other protein production methods that will be discussed, that is very cheap.

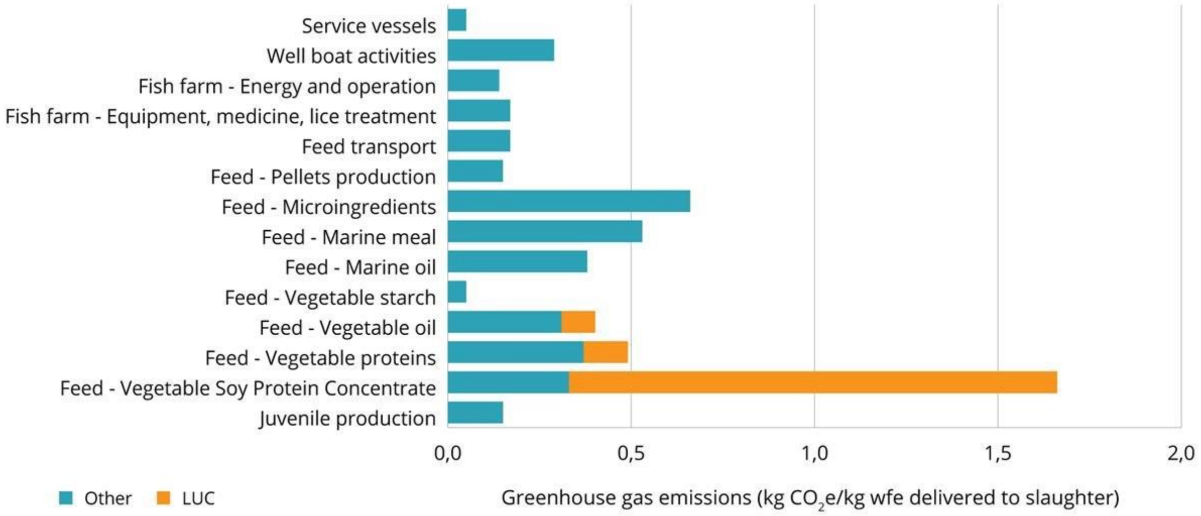


*Figure 8: Carbon footprint of soybean production and import to Fredrikstad (Winther et al., 2017.).*

The above graph shows greenhouse gas-emissions (GHG-emissions) related to the different parts of the aquaculture production value chain. «LUC” is emissions related to land-use change.  For soy production, the main type of land-use change is deforestation and soil erosion (Malins, 2020). However, the tool used for determining LUC-related emissions in the analysis above does not incorporate impact of buying “no deforestation”-certified soy such as

ProTerra, which makes up 100% of Norwegian soy purchases. In private communication, the developers of the LUC-estimator tool write that:

> "In the LUC methodology, we account for LUC over a period of 20 years. If the certificate guarantees that no land has been converted for 20 years, then you could set the LUC emissions to zero. The tool does not consider any indirect market effects. In case the certificate stretches a shorter period of time, one should actually still use the result from the LUC tool for the greenhouse gas calculation"

In a carbon footprint analysis done by the sustainability consulting company EnCiclo for AMAGGI, the supplier of ProTerra-certified soil to Norway, it is found that emissions due to LUC for AMAGGI is 0.0308kg CO2 per kg soy delivered to Fredrikstad (EnCiclo, 2020). This number is non-zero due to because some of the land used by AMAGGI is ProTerra-certified for a period of less than 20 years. Therefore, if an assumption is made that purchasing ProTerra certified soy has no indirect market effect, the emissions from LUC should be almost 0.

This assumption is probably not correct, however. When certified soy is purchased by Norwegian companies, total soy demand will increase. To compensate for this increased demand, soy produces will have to grow on a larger area, and the only way they can achieve this is by deforestation as there is no more non-rainforest area to expand into. It may then not matter that much if Norway purchases the soy from non-rainforest areas, because it will indirectly lead to deforestation regardless. In practice, the indirect market effects are probably not as large as the direct market effects, so purchasing of ProTerra certified soil will lead to some LUC but probably not as much as if purchasing non-certified soy.

There are no technological barriers to soybean and rapeseed production. Soybean concentrates and rapeseed meals are a good nutritional fit for use in feed.

| ***Criteria*** | ***Comment*** |
|---:|---|
| Price competitive | Price per kg of protein between 12 and 18 NOK as of 2020. |
| Competing use cases | Also sold for human consumption and for bioethanol production. However, supply is big enough to cover the demand for these competing use cases, and more. |
| Sustainable | Soybean and rapeseed production is by itself relatively sustainable, with emissions of <6kg CO2 per kg of protein (Gjøsund et al., 2020). However, LUC from soybean production may contribute to CO2-emission and destruction of natural ecosystems (Winther et al., 2017). Emissions from shipping from for example Brazil to Norway are overstated, only representing about 4% of total emissions. |
| Comparative advantage | Not applicable as these goods are imported. |
| Technological barriers | Few/none. Efficiency can still be improved, but this is not required for profitability. |

| | |
|---|---|
| Nutritional fit | Can be pressed into concentrates or meals that work well in aquafeed and livestock feed. Use of rapeseed in cattle feed improves nutrient uptake. |
| EPA/DHA | Does not contain EPA/DHA. |
| Potential tonnage | Virtually unlimited |

## Potential sources of increased protein production

### *Harvest of mesopelagic fish*

Mesopelagic fish are fish that live on depths between 200-1000 meters. These tend to be small and bony and not fit for human consumption. The fish are high in protein and EPA/DHA however, and thus represent a potentially high-quality source of proteins for aquaculture fish feed. Total global biomass of mesopelagic fish is estimated at somewhere between 1 and 10 billion tons (Irigoien et al., 2014). The estimate of 1 billion tons comes from a 1980 report, while the estimate of 10 billion tons comes from a 2014 report done with a reviewed methodology and newer equipment. The newer estimate is more likely to be correct, but there is significant uncertainty in the estimates still. A conservative estimate, based on the 1980-estimate of 1 billion tons global mesopelagic fish biomass, shows that 14.7- 18.5 million tons would be found in the Northeast Atlantic (Pauly et al., 2021). This number may be several times higher, given the new estimates of total biomass. In comparison, Norwegian fishers fished about 2.5 million tons of wild pelagic fish in 2019 (*SSB Fiskeri, 2019*), and thus mesopelagic fish could potentially represent a large source of both protein and EPA/DHA.

SINTEF estimates show that in an optimistic scenario, up to 150 000 tons of protein and 12 000 tons of EPA/DHA can be harvested from the mesopelagic fish stock annually by 2050, by Norwegian fisheries(*Bærekraftig Fôr Til Norsk Laks 2020.Pdf*, n.d.). Later in the same report it is suggested that as much as 10 million tons of mesopelagic fish may theoretically be fished annually by 2050, but no source is given for this new estimate, and such a number is not supported in the literature. The number of 150 000 tons of proteins is more realistic. Preliminary results from ongoing projects dealing with mesopelagic resources (EU MEESO, EU SUMMER, SFI Harvest) suggest that mesopelagic fishing may not necessarily be profitable in the short to medium term even if harvesting quotas would be awarded. The reason for this is mainly linked to considerable additional costs that might arise with needed vessel modifications or investment into new vessels to conduct an efficient mesopelagic fishery. These modifications include storing capacity, conservation and processing methods, as well as changed fishing gear.

Early attempts at fishing mesopelagic fish have been made, but fisheries have met significant hurdles. Despite the large total biomass, the concentration of mesopelagic fish is around 1 gram of fish per cubic meter of ocean (Lamhauge et al., 2008). This extreme dispersion rate makes efficient harvest difficult, and climate gas emissions from trawling are high. In addition, there has been difficulties in processing the fish before decomposition sets in, in part because the mesopelagic fish “explodes” when brought to the surface due to big pressure differences (Olsen et al., 2020).

Little research on how exploitation of mesopelagic fish stock impacts marine ecosystems has been done, and if fishing becomes profitable there is an expectation that stringent quotas will be enforced in a “better safe than sorry”-approach. If these obstacles are overcome, mesopelagic fishing could potentially represent a protein source where Norwegian industry will have comparative advantage over other nations both in terms of natural resources and technological competence. This best-case scenario is optimistic however, and we may not see any profitable mesopelagic fishing even by 2050.

A potential tonnage of 150 000 MT is selected in the moderate case, relying on estimates made by SINTEF. The potential tonnage in a best-case scenario is unknown. SINTEF operates with a theoretical maximum of 1.5 million MT proteins from mesopelagic fish, but this number is unreasonably high for reasons discussed above. To harvest “only” 300 000 MT of proteins 2 million MT of mesopelagic fish must be harvested (Gjøsund et al., 2020). As mentioned earlier, Norwegian catch of pelagic fish is about 2.5 million MT today, so the mesopelagic fishing fleet would have to rival the size of the entire current Norwegian fishing fleet for a harvest of 300 000 MT to be possible, to put the number in perspective. A best-case of 300 000 MT of proteins from mesopelagic fish will still be used, but this is a very high estimate. It is set for the sake of exploring potential future scenarios.

| ***Criteria*** | ***Comment*** |
|---|---|
| Price competitive | Likely, given sufficient technological progress, as fish meal and fish oil are valuable commodities. |
| Competing use cases | Protein production is likely the best use case for mesopelagic fish, as it contains EPA/DHA and is not attractive for human consumption. |
| Sustainable | May cause damage to ecosystems. High fuel usage from trawling. |
| Comparative advantage | Abundant access due to long coastline. Technological and labor expertise from domestic fishing industry. |
| Technological barriers | Requires considerable technological progress. Challenges may be impossible to solve within profitability constraints. |
| Nutritional fit | High protein and fish oil content, biologically available. Some worries about levels of cadmium and other heavy metals (Olsen et al., 2020) |
| EPA/DHA | Contains 12 000 – 24 000 MT EPA/DHA. |
| Potential tonnage | 150 000 – 300 000 MT |

### *Harvest of pelagic fish*

Pelagic fish is an excellent source of both protein and EPA/DHA and can be harvested at reasonable prices. Fishing capacity is already maximized however, and most of the fish is sold for human consumption. Increasingly large amounts of pelagic fish are also being sold directly for human consumption, so protein for the feed market from this source may potentially decrease in the coming years.

| ***Criteria*** | ***Comment*** |
|---|---|
| Other use cases | Pelagic fish is used as human food. |

### *Better roughage production*

While roughage is only consumed by ruminants, it still represents a major share of all consumed livestock feed proteins. Roughage is already produced on most Norwegian cattle farms, as it grows well in less fertile areas where food-grade grains cannot be produced and allows farmers to cut feed costs. Recent projects such as Grovfôr2020 show that roughage production methods can be improved, with expected protein yield increases of up to 20% given the right conditions (source: Private communication. Results from Grovfôr2020 have not been published). Widescale adoption of more efficient production methods could lead to an estimated increase of 350 000 tons of proteins in roughage according to numbers from Yara Norway, which would offset protein demand in compound feed by a similar amount. This number is likely too high.

An expert on roughage production in NIBIO suggests two main ways to increase protein production from roughage. The first is to increase roughage yields. NIBIO-estimates show that it may be possible to increase average dry weight yield of roughage from 700 kg/daa to 840 kg/daa. These numbers are slightly lower than what Yara achieve in their experiments, but experimental plots tend to have higher yields than what farmers achieve in practice. With a protein content of 13% by dry weight, this would lead to an increase in protein yields from 91 kg/daa to 109 kg/daa. This represents an increase in protein yield by 18kg/daa. With 5 million daa of roughage producing area, this would lead to an increase in protein production of 90 000 MT. This is a highly ambitious, but not impossible goal.

The second way is to increase the concentration of proteins by dry weight. This can be achieved in three main ways. The first is to increase the number of harvests each season, which will result in more leaf growth and less straw growth. This would lead to an increase in protein content from 13% to 17%, meaning that protein yield increases to 119 kg/daa, from 91 kg/daa. This results in an increase in protein production of 140 000 MT. Roughage yields by weight decrease if you harvest more times per season however, so realistically this number should be smaller. The second possibility is to increase the amount of clover in meadows. Clovers fixate up to 10k nitrogen/daa into soil, which is used by other plants, and therefore increase protein yields (*Verdien av -kløver i eng | Buskap*, n.d.). The amount of protein contributed by planting clover is not known. The third way is to increase the amount of fertilizer used. This will increase protein content, but there is diminishing returns to fertilizing. Results from experiments done by NLR have shown that by increasing fertilization from 27 to 36 kg N/daa only results in 4 kg N/daa uptake in grass (*Fornuftig å gjødsle sterkare for å auke proteininnhaldet?*, n.d.). This would lead to an increase in protein yields from about 13% to 15%, increasing the protein yield from 91 kg/daa to 105 kg/daa. This would increase total protein yields by about 70 000 MT. However, the contribution of clover nitrogen fixation falls rapidly with increased fertilization.

The total increase in proteins if all the strategies are executed would then be around 90 000 + 140 000 + 70 000 = 300 000 MT of additional protein production, if they are added up. This is not realistic, as following one strategy generally will have a negative impact on results of other strategies. In practice, any of the mentioned strategies seem to increase total protein yields by about 70 000 – 90 000 MT, but once you have realized this initial potential there are diminishing returns on adopting further measures.

There is also another concern. Despite the promising numbers, Norwegian farmers have been slow to adopt the supposedly more efficient production methods. It is possible that the costs of changing production methods, both in inputs and time, have been understated. Increasing the number of harvests each season is time consuming and increases diesel usage significantly, while increased fertilizing represents a high cost as well. In years where fuel and fertilizer prices are high, it is unlikely that producing better quality roughage is worthwhile. Farmers are also pressed for time, and it may be that by spending more time producing better roughage, the farmers must forgo some other benefit. If this is the case, it is possible that the opportunity cost of roughage production is higher than expected.

For the moderate case, it will be assumed that farmers will combine some of the methods to increase protein yields, resulting in an increase in protein production of 120 000 MT. This is a rough guess. In the best-case scenario, it is assumed that some combination of the following hold true: Diminishing returns from combining strategies for increasing yields are lower than expected, fuel and fertilizer prices fall to a more reasonable level, roughage production sees increased subsidization, or fully automated harvesting is developed such that opportunity cost due to time pressure is reduced. A rough guess assumes that this would results in an increase in protein production of about 180 000 MT.

| ***Criteria*** | ***Comment*** |
|---:|---|
| Price competitive | Varies with cost of fertilizer and fuel. In years with relatively low fertilizer and fuel prices, roughage production can be very cheap. |
| Competing use cases | Production area could be used for grazing, but grazing also contributes to feed protein production. |
| Sustainable | Roughage is produced and used locally, and GHG-emissions from production is relatively low. |
| Comparative advantage | Due to low profit margin, most roughage is produced where it is used, reducing international competition. |
| Technological barriers | If full potential is to be reached, some technological progress is necessary. |
| Nutritional fit | Can only be used for livestock feed, and protein content of roughage must be high to achieve good yield. Has widespread demand regardless. |
| EPA/DHA | Does not contain EPA/DHA. |
| Potential tonnage | 120 000 - 180 000 MT |

### *Increased grazing*

The Norwegian Agriculture Agency have investigated the potential for increased grazing for cattle as a measure to increase the Norwegian share in feed. The main ways to increase grazing is to extend the grazing season and send more animals to graze. Extending the grazing season is mainly possible for cows, as sheep/lamb already graze most of the season. Grazing decreases the demand for compound feeds, and is an important tool to sustain cultural landscapes, which is one of the major policy goals in Norwegian agricultural policy. It is however difficult to produce high quantities of meat and milk of high quality if the grazing season is extended, or if more animals graze. The lower costs due to less feeding do not offset loss in income from less intensive production (The Norwegian Agriculture Agency, 2021), given current input costs. The Norwegian Agriculture Agency does therefore not recommend incentivizing increased grazing as a measure to increase the Norwegian share in feed (The Norwegian Agriculture Agency, 2021).

Studies find that the environmental impact of producing milk does not differ significantly if compound feed is substituted with increased grazing (Steinshamn et al., 2021). The Agricultural Agency write that one major reason for relatively low emissions from grazing is because production of methane is lower when grazing compared to when fed compound feed. However, if the grazing season is extended, it is not given that feed uptake from grazing remains stable, so yields may decrease if the grazing season is extended. Furthermore, emissions are expected to rise as the season goes on. This is because grass become more fiber rich as they grow. When cows eat more fiber, the methane emissions increases.

In Table 1 we find that the share of compound feed in suckler cows is 7%-8%, while the share in dairy cows is 43%-45%, and in beef cattle is 27%-39%. Therefore, by sending cows on pasture, it is possible to cut the share of compound feed from about 27%-45% to 7%-8%. If we send all cows on pasture, this would reduce compound feed usage for ruminants by roughly 74%-82% in total, if grazing areas are unlimited. Protein demand from dairy cows and beef cattle is estimated to be 116 000 MT in 2050 (see table 15), so increased grazing could then replace 86 000 – 95 000 MT of import proteins. This is a very rough calculation. In a moderate case, it is assumed that about half of this potential can be taken out by 2050, or about 45 000 MT.

| ***Criteria*** | ***Comment*** |
|---:|---|
| Price competitive | Grazing is very cheap, but yields decrease, so more animals must be reared. Likely price competitive if protein import prices increase. |
| Other use cases | Grazing area could be used for roughage production, but roughage also contributes to feed protein production. |
| Sustainable | Emissions from grazing are approximately equal to emissions from compound feed production. Keeps land clear. However, if grazing season is extended, emissions may rise. |
| Comparative advantage | Norway is abundant in grasslands and pastures that are not suitable for intensive plant production. |
| Technological barriers | None. |
| Nutritional fit | Natural feeding pattern for ruminants. |
| EPA/DHA | Does not contain EPA/DHA. |
| Potential tonnage | 45 000 MT – 90 000 MT |

### *Increased cultivation of protein- and oilseeds*

Cultivation of protein- and oilseeds like rapeseed, peas and field beans yields cheap proteins (24 NOK per 1kg of proteins), with low emissions (Gjøsund et al, 2020.). However, Norway has strong comparative disadvantage compared to more temperate zones. There is also relatively little farmland that can sustain protein- and oilseed growth. Furthermore, there is a political preference to grow food for human consumption in those areas that could sustain protein growth. With these constraints in mind, there is potential to quadruple the tonnage of proteins from protein- and oilseeds by 2050 to about 30 000 tons, which would not make a large dent in protein import requirements. Seed improvements may allow for slightly better yields, but even then, upscaling production to high enough levels for this method to make a big impact is likely not possible in Norway (Abrahamsen et al., 2019).

An alternative to make growing of protein- and oilseeds more attractive is to allow for gene modification (GMO) of plants such as rapeseed to make these plants yield EPA/DHA. Early trials show that uptake of EPA/DHA from gene modified rapeseed to be equally efficient as uptake from fatty fish in humans (West et al., 2021). The total production would likely still be small however, and planting of GMO crops is not legal in the EU currently, and unpopular among consumers. In a Norwegian 2020 study, only 26% of respondents say that they believe the use of GMO crops is ethical (Bugge, 2020, p. 24). Furthermore, EPA/DHA-yielding rapeseed would likely be sold for human consumption before being offered to the aquaculture industry, due to high demand.

A potential tonnage of 10 000 MT is assumed in a moderate case, relying on estimates made by the report by Abrahamsen et al. A potential tonnage of 30 000 MT is assumed in a best case, relying on estimates made by SINTEF (Gjøsund et al., 2020). This best case assumes that seed improvements and climate change has made it easier to grow protein- and oilseeds in Norway.

| ***Criteria*** | ***Comment*** |
|---:|---|
| Price competitive | Relatively cheap production. |
| Competing use cases | Margins are higher on use for human consumption. |
| Sustainable | Plant production is relatively sustainable. |
| Comparative advantage | Production is only efficient in southern parts of Norway, replaces other valuable crops. |
| Technological barriers | Seed improvements (sortsutvikling) is required for full potential. |
| Nutritional fit | High protein content if pressed into protein meal. Proteins are biologically available. |
| EPA/DHA | Contains only trace amounts of EPA/DHA. |
| Potential tonnage | 10 000 – 30 000 MT. |

### *Production of insect proteins*

Insect production is being attempted on a small scale in several European countries. In Norway, Pronofa is building an insect production factory and aim to start production by 2024. According to Pronofa, they may be able to supply as much as 25 000 tons of insect-based protein from 50 000 tons of insect biomass by 2025. Defatted insect meal may reach protein contents of up to 82%, depending on treatment (Makkar et al., 2014), making high protein insect meals suitable even for aquafeed. Costs of production are still uncertain, but a report by the World Wildlife Foundation (WWF-UK) estimates that “cost of production of insect meal could fall between the current market prices of soymeal and fishmeal, with costs falling over time with economies of scale» (Gupta et al., 2021W). If the technology matures, production of insects may be a viable source of proteins in the future. Production is bound by access to feedstock substrates, however. According to the WWF report, dairy by-products, brewer’s grains, vegetable by-products and bakery by-products are the most accessible sources of insect substrates in the UK today. Meanwhile, surplus from retail, bakery with animal by-products and food surplus from manufacturing are listed as “achievable” sources, should government regulation become less constrained. In total, the estimate of available feedstock substrate for insects in the UK is projected to be 3.46 million tons by 2050, in an optimistic but not unrealistic scenario. From this, 241 000 tons of insect meal can be produced annually, with a total protein content of 135 000 – 197 000 tons.

The availability of food waste and food industry by-products is likely to be much smaller in Norway than in the UK given the lower population and GDP. In 2020, the GDP of UK was approximately 7.5 times higher than the GDP of Norway. If the access to insect substrates is similar in the two countries, we could then assume a protein production capacity of about $\frac{\frac{135+197}{2}}{7.5}$ = 22 000 MT. This method of making an estimate is unreliable, as there are structural differences in the Norwegian and UK economy. Pronofa estimate that their first factory alone will be able to produce 25 000 MT, so the real number is likely higher.

The Norwegian aquaculture industry is disproportionally large compared to our population however, and produces very high quantities of fish sludge, which is currently unexploited as a resource. Fish sludge is waste from aquaculture production, mainly uneaten feed and faeces. Around 200 000 MT of fish sludge by dry weight is discarded from aquaculture production today (Drønen, 2022), which could grow to more than 400 000 MT as aquaculture production is set to double. In UK estimates, approximately 3.4 million MT of substrate produce 135 000 - 197 000 MT of proteins, giving a substrate to protein ratio of between 25:1 and 17.3:1. Fish sludge is nutrient dense (Aas, 2021), so an assumption is made that the ratio by using sludge would be on the lower end of the range. Then, from 400 000 MT of fish sludge, roughly 20 000 MT of insect proteins could be produced. Currently, the use of fish sludge is not approved as an insect substrate, but research is being done by Ragn-Sells (source: Private communication) into possibility of changing this regulation.

This would suggest that Norwegian insect protein production capacity may be at a minimum of 45 000 MT by 2050. There is not enough information on availability of insect substrates available to make an accurate prediction. In private communication, Pronofa has indicated that they are interested in supplying proteins to the pet-food market, as well as aquafeed and livestock feed market. Generally, pet feed manufacturers outcompete aquafeed manufacturers for proteins, who outcompete livestock producers. Insect meal has a high enough protein content to be demanded by the aquafeed industry. Therefore, insect proteins are unlikely to contribute much, if anything, to securing Norwegian production of proteins for livestock, but may play a part in securing proteins for aquafeed. A guess is made that 20 000 MT of proteins from insect production is sold to the pet feed industry, and the rest to the aquafeed industry in a moderate case. In a best-case scenario, a potential tonnage of 40 000 MT directly to the aquafeed industry is assumed, to account for inaccuracies in the estimation method. This estimate relies on restrictions on use of fish slurry being lifted.

| ***Criteria*** | ***Comment*** |
|---|---|
| Price competitive | "Cost of production of insect meal could fall between the current market prices of soymeal and fishmeal, with costs falling over time with economies of scale" (WWF-UK). May be price competitive for pet feed and aquafeed, but not for livestock feed. |
| Competing use cases | Margins are higher for use in pet feed industry. Production may be higher than pet feed demand. |
| Sustainable | Production is associated with medium levels of CO2 emissions. Uses waste by-products from other industries. |
| Comparative advantage | Access to domestic waste, potential access to high amounts of fish slurry |
| Technological barriers | Requires some technological progress for prices to be competitive. |
| Nutritional fit | Proteins are biologically available to fish and livestock. |
| EPA/DHA | Contains marginal amounts of EPA/DHA. |
| Potential tonnage | 25 000 – 40 000 MT |

### *Alkalized grains*

Alkalization of grains is done by adding urea and some material containing the enzyme urease to grains. The enzyme splits the urea into ammonia (NH3) and CO2-molecules. Ammonia is basic and will increase the pH of the grains and increases the availability of non-protein nitrogen (NPN) in feed for cows. In the rumen of the cow there are microbes that can produce proteins that the cow needs if fed with amino acids and energy (typically carbohydrates). The claim is that by increasing the NPN and pH in cows feed, the production of proteins within the cow's rumen can be increased, and so offset the need for proteins in the feed. Imported proteins may then be replaced by Norwegian grains, and thus increase the Norwegian share. However, there is little conclusive research on the efficacy of alkalized grains yet. Leidulf Nordang in Felleskjøpet Fôrutvikling, a leading voice in the industry, suggests that alkalization will not in fact offset a need to have proteins in the feed (Bondebladet, 2021). Urease occurs naturally in the cow's rumen, and in most modern cow feed urea is already added directly to the feed. Nordang suggest that conversion of proteins in the gut is already maximized, and bottlenecked not by NPN-availability or pH, but by access to proteins that can be broken down into amino acids, which are necessary components for building new proteins in the rumen.

Despite these concerns, initial studies done on yield from cows fed with alkalized grains show either no difference in yield or increases in yield in cows fed on alkalized grain diets. In no cases has feeding of alkalized grains shown decreases in yield. Exactly why feeding with alkalized grains leads to increases in yield is uncertain, and it may be because of some other effect than protein synthesis entirely.

The main producer of alkalized grains in Norway, Strand Unikorn, claims that "AlkaGrains" can offset imports of 170 000 tons of proteins. In private communication, a scientist who works actively with studies on alkalized grains expresses doubts about the number of offsetting 170 000 tons of protein imports but says that it is still possible that some level of protein imports can be offset. “If we are able to offset 30 000 – 40 000 metric tons of proteins annually, I would be satisfied”, says this scientist, but adds that he does not believe there is enough information available to make any surefire claims about potential impact of alkalized grains yet.

Another challenge with alkalized grains is that production is relatively expensive. Strand Unikorn claim that the price of barley must be 0.18-0.24 kroner lower for alkalized grain to be price competitive with soybeans (Landbruksdirektoratet, 2021).

A potential tonnage of 30 000 MT is assumed in a moderate case, relying on the domain expert “guestimate”. A tonnage of 170 000 MT is assumed in a best case, relying on estimates from Stand Unikorn.

| ***Criteria*** | ***Comment*** |
|---:|---|
| Price competitive | Could be price competitive if either barley becomes cheaper or import prices increase. |
| Competing use cases | No competing use cases. |
| Sustainable | Uncertain. Studies examining emissions from this process are underway. |
| Comparative advantage | Grain mills already must use Norwegian grains in their production, by law. Increasing nutritional value of that grain has only upside. |
| Technological barriers | Experts are uncertain if alkalization of grains can increase protein content in feed at all. |
| Nutritional fit | Alkalized grains have shown to increase yields from dairy/beef production. |
| EPA/DHA | Does not contain EPA/DHA. |
| Potential tonnage | 30 000 – 170 000 MT. |

### *Processing of meat and bone meal (MBM)*

The use of meat and bone meal (MBM) for poultry and pork feed has recently been greenlit again in the European Union, after a long-standing ban due to worries about MBM spreading bovine spongiform encephalopathy (mad cow disease). It will likely become legal again in Norway as well. However, MBM may still not be used in ruminant feed. In the EU, if MBM is to be used, there are strict requirements for separating production lines of different feeds. This includes frequent quality testing to ensure that there is no cross-contamination of MBM into ruminant feed. In a 2020 article, Keili Hagen, advisor in Felleskjøpet AR, claims that up to 15 000 MT of protein from MBM may be produced in Norway, given current level of slaughter production. This number excludes MBM from ruminants (*“Animalsk protein som alternativ til soyamjøl,” 2020*). In a separate report, a team of researchers find that as much as 50 000 MT of MBM could be produced in Norway in 2021 given that there were no restrictions in place for use of MBM, with an average protein content of 55%. This means a production of 27 500 MT of proteins a year (*Kjøttets Tilstand 2021*, 2021). The total production of animals for slaughter is expected to rise only slightly towards 2050 (see Table 11 and Table 15), so the access to slaughter by-products in 2050 will only be slightly higher.

To compensate for this slight increase in access to slaughter by-products, the number 27 500 is adjusted up to 30 000 MT.

18 000 – 30 0000 MT is a relatively minor amount, and it seems unlikely that livestock feed mills will be interested in incorporating MBM into their production. This is because all livestock feed is produced in the same mills and separating production lines would require significant infrastructure investments. MBM may be used in aquafeed, however. This has two advantages. First is that aquafeed is produced in separate mills than livestock feed, so no separation of production lines is needed. Secondly, it should not be a problem to feed MBM from ruminants to fish, so aquafeed producers can also use proteins from ruminant MBM. Given that MBM was price competitive in livestock feed in the 1990s, and prices of soy were much lower then, it is likely that MBM to aquafeed would be price competitive today.

In the scenarios, a tonnage of 18 000 MT will be used for the moderate case, which assumes that the restriction of MBM from ruminant feed is upheld. In a best-case scenario, a tonnage of 30 000 MT is assumed.

| ***Criteria*** | ***Comment*** |
|---:|---|
| Price competitive | Likely, as it was competitive in the 1990s. Have been unable to verify. |
| Other use cases | No other use cases. |
| Sustainable | Reuse of waste product. |
| Comparative advantage | Low margins on use of waste-product makes it unlikely that importing MBM is worthwhile. |
| Technological barriers | Few. |
| Nutritional fit | Low tonnage and high risk of contamination makes MBM unsuitable for livestock feed. It is however a good fit for aquafeed. |
| EPA/DHA | Does not contain EPA/DHA. |
| Potential tonnage | 18 000 – 30 000 MT |

### *Increased filleting of fish in Norway*

As of 2017, 860 000 tons, or 87.7% of farmed salmon was exported whole (*PwC, 2019*). Due to high labor costs, filleting has not historically been profitable to do in Norway, and thus filleting is done in countries with lower labor costs. With automated filleting factories, the comparative disadvantage from high labor costs become less important, and it may become profitable to fillet in Norway. This means that much more of the rest raw materials from salmon production stays in the country, and can be used for human consumption, pharmaceutical products, and pet feed, for example. Products in these categories fetch higher prices than aquafeed, so aquafeed producers are crowded out by other industries that can afford using more expensive inputs. A report from PwC estimates that the reuse of rest raw materials could be worth between 6 and 8 billion Norwegian kroner. However, the same report indicates that the cost of enhancing rest raw materials will be too costly for use in aquafeed or livestock feed, even with mature technology (*PwC, 2019*).

| ***Criteria*** | ***Comment*** |
|---|---|
| Price competitive | Fish cuttings are too expensive to use in aquafeed or livestock feed production. |

### *Harvest of tangle (Laminaria hyperborea) and/or brown algae (Ascophyllum nodosum)*

Tangle is the most common kelp by biomass in Norwegian waters. Brown algae is another very widespread kelp. The harvest and production process is similar for both kelps. Harvest is relatively costly (60-120 NOK per kg of proteins) and associated with high CO2-emissions ( Gjøsund et al., 2020). The harvest of kelps is strictly regulated, and widespread production is unlikely to be possible.

| ***Criteria*** | ***Comment*** |
|---|---|
| Price competitive | Harvest of tangle and brown algae is expensive |
| Sustainable | Harvest of tangle and brown algae is associated with high CO2-emissions. Harvest is also restricted due to the importance of tangle and algae in natural ecosystems. |

### *Harvest of zooplankton (Calanus finmarchicus and/or krill)*

Zooplankton are found in enormous amounts in Norwegian oceans. Current harvest methods are extremely expensive however, costing at least 600 NOK per kg of proteins. (Gjøsund et al., 2020) A quantum leap in efficiency of harvesting must be made for zooplankton to be remotely viable as a protein source for animal feed.

| ***Criteria*** | ***Comment*** |
|---|---|
| Price competitive | Harvesting of zooplankton is extremely expensive. |

### *Harvest of conifer by-products and leaves*

Conifers such as pines, spruces and yews grow throughout Norway. Every year, 10 million $m^3$ of conifers are harvested and used to produce lumber and paper (Gjøsund et al., 2020, p. 49). Waste by-products from logging, such as leaves, branches and treetops contain cellulose, hemicellulose and lignins. Cellulose and hemicellulose can be hydrolyzed into sugars, which in turn can be fed to microorganisms that produce bioethanol, proteins, and EPA/DHA. In this way, logging by-products can be used to produce proteins. These processes were discovered in the 1950s and are well understood and have been tested out for use in commercial production not only abroad, but also in Norway. According to a SINTEF report, producers have struggled to drive protein production costs low enough to compete with soy and rapeseed production. While it is possible to improve efficiency, a “problem” is that bioethanol and especially EPA/DHA are more valuable than proteins, so even if efficiency improves, production will likely be centered around EPA/DHA-production rather than protein production. CO2-emissions from the fermentation and hydrolyzation processes are also quite high, estimated at >12 kg CO2 per kg proteins. For these reasons, harvest of conifer by-products and leaves for producing proteins is assumed to be unviable.

| ***Criteria*** | ***Comment*** |
|---:|---|
| Price competitive | Outcompeted by soy and rapeseed production. |
| Competing use cases | Producing EPA/DHA with conifer by-products is more valuable. Producing bioethanol may be more valuable. |
| Sustainable | Medium to high CO2-emissions. |
| Comparative advantage | Abundant conifer growth in Norwegian forests. |
| Technological barriers | Room for improving efficiency of production processes. |
| EPA/DHA | Can be used to produce EPA/DHA **or** protein, but not both simultaneously. |

### *Production of tunicates*

Tunicates are a species of marine invertebrates that grow on underwater structures such as ropes, floating docks, and rock outcroppings. The animal is rich in protein and EPA/DHA. SINTEF estimate that to produce 100 000 MT of proteins, tunicates must be grown over an area of about 25-33km$^2$. This would also produce 2000-6000 MT of EPA/DHA. To feed that amount of tunicates, plant planktons from an area of about 3000-10 000 km$^2$ have to be harvested (Gjøsund et al., 2020, p. 71). The Norwegian exclusive economic zone connected to the mainland is 875 000 km$^2$ (Wikipedia, 2022), to put his number in perspective. In other words, one could theoretically produce up to 8.75 million tons of proteins if every single square kilometer of Norwegian fishing waters were used either for tunicate production or plankton harvest. This is not even remotely realistic, but even if 1% of this area is exploited for production of tunicates, that would result in a protein production of 87 500 MT of proteins.

Outside of its nutritional fit, tunicate meal works well as an ingredient in aquafeed. A 2022 study estimates that up to 50% of fish meal in aquafeed can be replaced by tunicate meal without impacting the technical properties of feed pellets, such as water stability and buoyancy (Samuelsen et al., 2022).

Tunicates also has potential to be used to produce bioethanol (Hrůzová et al., 2021).

Research on tunicates is still in its infancy. It is not clear if production is price competitive or sustainable. Impacts of intensive tunicate production on natural ecosystems must be examined, as well as CO2-emissions from plant plankton harvest and harvest of tunicates for processing into tunicate meal. Making a credible estimate of production in 2050 is not possible at the current time. A guess of 87 500 MT of proteins from tunicates in a moderate case (using 1% of marine areas) and 262 500 MT (using 3% of marine areas) in a best case is assumed.

| ***Criteria*** | ***Comment*** |
|---|---|
| Price competitive | Unknown |
| Competing use cases | Can be used to produce bioethanol. |
| Sustainable | Unknown |
| Comparative advantage | Access to vast Norwegian marine exclusive economic zone for tunicate production and plant plankton harvest. |
| Technological barriers | Efficiency improvements in tunicate production must be made, and sustainability impacts must be analysed. |
| Nutritional fit | Contains high amounts of proteins and EPA/DHA, and does not compromise physical feed quality. |
| EPA/DHA | Contains 2-6% EPA/DHA. |
| Potential tonnage | 87 500 – 262 500 MT. |

### *Cultivation of microalgae*

Cultivation of microalgae is expensive per kg of protein (20-300 NOK per kg of proteins) and associated with extremely high emissions (175-450 kg of CO2 per kg of protein) (Gjøsund et al., 2020). Production has comparative disadvantage in Norway, as microalgae is best cultivated in very large, open dams in warm climates. The emissions render this protein production method unviable.

| ***Criteria*** | ***Comment*** |
|---|---|
| Price competitive | Cultivation of microalgae is extremely expensive. |
| Sustainable | Cultivation of microalgae is associated with extremely high emissions. |
| Comparative advantage | There is disadvantage to production because of cold climate. |

### *Cultivation of macroalgae*

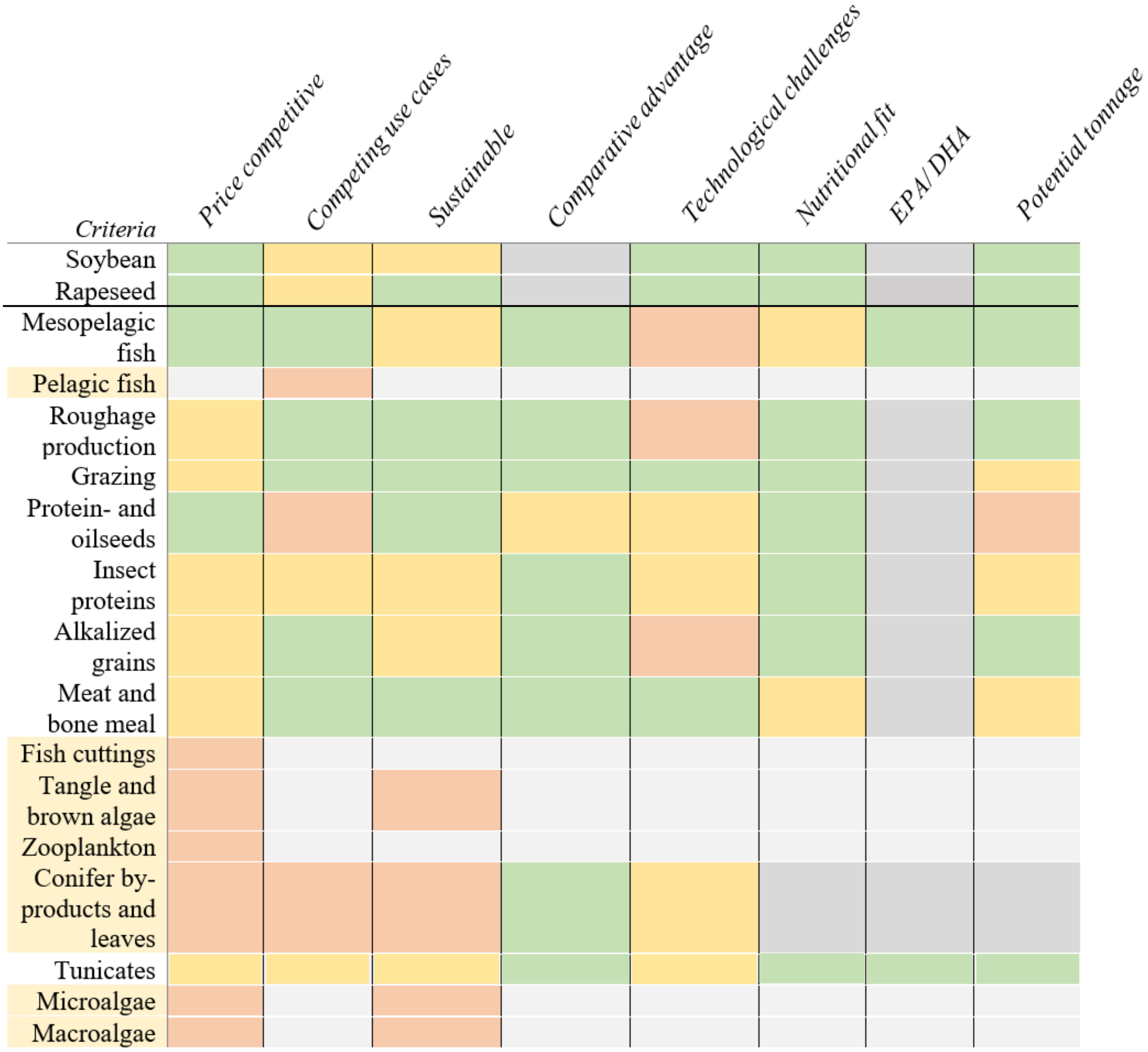
Cultivation of macroalgae is extremely expensive (6500 NOK per kg of proteins) and associated with high emissions (36-84 kg of CO2 per kg of protein) (Gjøsund et al., 2020). Due to the exorbitant costs, cultivation of macroalgae is clearly unviable.

| ***Criteria*** | ***Comment*** |
|---|---|
| Price competitive | Cultivation of macroalgae is extremely expensive. |
| Sustainable | Cultivation of macroalgae is associated with high emissions. |

## Supply summary

A survey of various protein production methods has been made. Production methods were judged on criteria like price competitiveness, sustainability, technological barriers and more. The judgement was based on literature review and expert opinion. The results are summarized in table 19. For some methods it was immediately obvious that production would be unviable. In these cases, a full analysis of all criteria was not done to save time (shown in light grey in the table). An example is production of macroalgae, where production cost is estimated to be 325 times more expensive than roughage, per kg of produced proteins. Soybeans and rapeseed are included as a baseline.

*Table 7: Multi-criteria analysis of protein production methods. Legend: Green/Yellow/Red: Meets criteria/Partially meets criteria/Does not meet criteria. Dark grey: Not applicable. Light grey: Not evaluated.*



| *Criteria* | *Price competitive* | *Competing use cases* | *Sustainable* | *Comparative advantage* | *Technological challenges* | *Nutritional fit* | *EPA/DHA* | *Potential tonnage* |
|---|---|---|---|---|---|---|---|---|
| Soybean | 🟩 | 🟨 | 🟨 | ⬛ | 🟩 | 🟩 | ⬛ | 🟩 |
| Rapeseed | 🟩 | 🟨 | 🟩 | ⬛ | 🟩 | 🟩 | ⬛ | 🟩 |
| Mesopelagic fish | 🟩 | 🟩 | 🟨 | 🟩 | 🟥 | 🟨 | 🟩 | 🟩 |
| Pelagic fish | ⬜ | 🟥 | ⬜ | ⬜ | ⬜ | ⬜ | ⬜ | ⬜ |
| Roughage production | 🟨 | 🟩 | 🟩 | 🟩 | 🟥 | 🟩 | ⬛ | 🟩 |
| Grazing | 🟨 | 🟩 | 🟩 | 🟩 | 🟩 | 🟩 | ⬛ | 🟨 |
| Protein- and oilseeds | 🟩 | 🟥 | 🟩 | 🟨 | 🟨 | 🟩 | ⬛ | 🟥 |
| Insect proteins | 🟨 | 🟨 | 🟨 | 🟩 | 🟨 | 🟩 | ⬛ | 🟨 |
| Alkalized grains | 🟨 | 🟩 | 🟨 | 🟩 | 🟥 | 🟩 | ⬛ | 🟩 |
| Meat and bone meal | 🟨 | 🟩 | 🟩 | 🟩 | 🟩 | 🟨 | ⬛ | 🟨 |
| Fish cuttings | 🟥 | ⬜ | ⬜ | ⬜ | ⬜ | ⬜ | ⬜ | ⬜ |
| Tangle and brown algae | 🟥 | ⬜ | 🟥 | ⬜ | ⬜ | ⬜ | ⬜ | ⬜ |
| Zooplankton | 🟥 | ⬜ | ⬜ | ⬜ | ⬜ | ⬜ | ⬜ | ⬜ |
| Conifer by-products and leaves | 🟥 | 🟥 | 🟥 | 🟩 | 🟨 | ⬛ | ⬛ | ⬛ |
| Tunicates | 🟨 | 🟨 | 🟨 | 🟩 | 🟨 | 🟩 | 🟩 | 🟩 |
| Microalgae | 🟥 | ⬜ | 🟥 | ⬜ | ⬜ | ⬜ | ⬜ | ⬜ |
| Macroalgae | 🟥 | ⬜ | 🟥 | ⬜ | ⬜ | ⬜ | ⬜ | ⬜ |

Of the 14 protein production methods, 7 were considered unviable (marked in yellow), while 8 were considered potentially viable.

Table 8 summarizes the estimated tonnage from the potentially viable sources. The cases will be defined in the chapter on scenarios.

*Table 8: Increase in domestic protein production, 2022-2050.*

| ***All feed*** | ***Moderate case*** | ***Best case*** | ***Worst case*** |
|---:|---:|---:|---:|
| Better roughage | 120 | 180 | 50 |
| Grazing | 45 | 90 | 20 |
| Alkalized grains | 30 | 170 | 0 |
| Protein- and oilseeds | 10 | 30 | 10 |
| Meat and bone meal | 18 | 30 | 0 |
| Insect protein | 25 | 40 | 25 |
| Mesopelagic fish | 150 | 300 | 0 |
| Tunicates | 88 | 263 | 0 |
| **SUM** | **486** | **1103** | **105** |

## Protein demand in 2050

In this sub-chapter, prognoses for domestic demand of feed proteins in 2050 will be made. First, the demand for proteins for livestock feed will be estimated, then the demand for proteins for aquafeed, before the two are combined. A calculation is also done that shows what the Norwegian share would be today if all imported proteins would be replaced by Norwegian produced proteins.

### Feed protein demand for livestock feed

The demand for proteins from livestock feed in 2050 was found by comparing estimates of growth in number of livestock with the protein content in livestock feed.

For protein content in livestock feed, the most sold Felleskjøpet brand feed for each animal type, according to Felleskjøpet advisors, was used as a reference. In some cases, I had access to the two most common feed types. In these cases, the protein content used was an average of the two. The content declaration of each feed in Table 10 can be found in Appendix A.

It should be noted that there is slight variation in protein content by feed type, and generally the more expensive and less sold feed types have slightly more proteins than the most sold feed. Only using the most sold feed types therefore introduces a bias that understates total protein demand marginally. It was not possible to find exact sales numbers for every single feed for each animal, so using the most sold or two most sold feeds was the best approximation possible.

The protein content by animal category is listed in the table below. Note that this is protein by feed weight, not by dry weight (kg/TS). According to a feed product manager in Felleskjøpet, the dry weight in most of Felleskjøpet's feed is ~88% of feed weight.

*Table 9: Protein content in most sold feeds for livestock, by feed weight. Source: Felleskjøpet*

| ***Animal*** | ***Feed name*** | ***Protein content*** |
|---:|:---|---:|
| Dairy cow* | Formel Elite 80 / Formel Favør 80 | 14,5 % |
| Suckler cow* | Ammeku konsentrat | 18,6 % |
| Beef cow* | Formel Biff 4+ / Formel Biff 6+ | 12,1 % |
| Sheep/lamb | Formel Sau / Formel Lam | 16,3 % |
| Goat and reindeer** | None, see note | 16,2 % |
| Broiler | Kromat Kylling 2 Låg | 19,0 % |
| Layer | Fryd Vekst | 16,5 % |
| Pig | Format Vekst 120 | 16,4 % |
| Other animals** | None, see note | 16,2 % |

For cows (*), the protein percentage in feeds listed by Felleskjøpet is protein percentage after the additive urea has been converted to protein by microbes in the rumen. The percentage of proteins from urea is listed in the ingredient declaration, so it is possible to calculate the protein content form non-urea-sources. The numbers in Table 9 list proteins from non-urea sources only, to give a clearer estimate of protein demand.

For goat and reindeer, and other animals (**), the protein content in feed was unknown. A weighted average of the other feeds was used. The total feed demand for these groups is low, so this assumption is unlikely to have a big impact on further calculations.

For growth in number of livestock by 2050, numbers from a NIBIO note "Framskrivninger for jordbrukssektoren til Perspektivmeldingen 2020"(Hoem, Gjerald, 2020) were used. The note is not available online but can be supplied upon request. The relevant table is reproduced on the following page.

*Table 10: Number of livestock by 2018, 2020, 2025, 2030, 2040, 2050. Source: SSBs utslippsregnskap, trend from NIBIO (2019)*

| Animal | 2018 | 2020 | 2025 | 2030 | 2040 | 2050 |
|---|---:|---:|---:|---:|---:|---:|
| Dairy cow | 211523 | 209922 | 192534 | 188262 | 184373 | 179459 |
| Suckler cow | 92304 | 99998 | 113945 | 127891 | 134624 | 138471 |
| Heifer for breeding | 114152 | 116246 | 111620 | 113459 | 111269 | 110034 |
| Heifer for slaughter | 30193 | 30713 | 32285 | 34618 | 35639 | 36066 |
| Ox for slaughter | 181684 | 172755 | 170933 | 176395 | 178017 | 177450 |
| Sow | 44903 | 44085 | 44521 | 43531 | 41139 | 38268 |
| Boar | 1344 | 1344 | 1344 | 1344 | 1344 | 1344 |
| Piglet | 248835 | 246503 | 254489 | 254199 | 250258 | 241970 |
| Slaughter pig | 1642094 | 1628490 | 1685579 | 1687788 | 1669105 | 1620324 |
| Adolescent pig for breeding | 38939 | 38564 | 39792 | 39734 | 39114 | 37839 |
| Layer hen | 4308640 | 4466478 | 4872916 | 5293855 | 5859914 | 6375284 |
| Layer chicken | 2143725 | 2222256 | 2424475 | 2633910 | 2915548 | 3171965 |
| Broiler chicken | 62738774 | 64728038 | 68391249 | 72002764 | 81154516 | 89320425 |
| Turkey for slaughter | 825264 | 945588 | 962311 | 978666 | 1001567 | 1010801 |
| Duck and goose for slaughter | 274298 | 308471 | 314356 | 320136 | 328519 | 332447 |
| Turkey/Duck/Goose for breeding | 12336 | 13914 | 14324 | 14734 | 15419 | 15904 |
| Horse | 72472 | 72128 | 71420 | 71420 | 71420 | 71420 |
| Dairy goat | 34583 | 34725 | 34987 | 35338 | 35863 | 36040 |
| Other goats | 23413 | 23509 | 23686 | 23924 | 24280 | 24400 |
| Sheep over 1 year | 669711 | 659658 | 638176 | 621214 | 594271 | 575772 |
| Sheep under 1 year | 696357 | 684223 | 657873 | 636429 | 601251 | 575196 |
| Ferret | 136993 | 97852 | 0 | 0 | 0 | 0 |
| Fox | 27554 | 19681 | 0 | 0 | 0 | 0 |
| Deer | 7970 | 7970 | 7970 | 7970 | 7970 | 7970 |
| Reindeer | 213012 | 213012 | 213012 | 213012 | 213012 | 213012 |

The relevant livestock were grouped to be matched with the categories for feed type listed in Table 10. The groups match data received by Animalia that will be used later. Numbers for heifer for breeding, heifer for slaughter, and ox for slaughter were aggregated and represented as “Beef cow”. Sows, boars, piglets, slaughter pigs and adolescent pigs for breeding were aggregated and grouped as “Pig”. Layer hen and layer chickens were grouped as “Layer”. Dairy goats, other goats and reindeer were grouped as “Goat and Reindeer”. Sheep over 1 year and sheep under 1 year were grouped as “Sheep/lamb”. Turkey, duck and goose for slaughter and breeding, as well as horse, were grouped as “Other animals”. Fox and Ferrets were excluded as these are no longer legal to breed for commercial purposes. Deer were excluded as they do not eat compound feed. If the relative ratio of animals within a grouping (for example ratio of layer chickens to layer hens) stays similar throughout the time periods, such groupings should not lead to biases in feed demand estimates. This is not exactly the case, so this way of grouping animals leads to some bias in the calculation.

The growth rate from 2018 to 2050 for the aggregated animal groups was found, as shown in Table 11.

*Table 11: Growth in livestock. Other animals include turkey, duck, geese, and horses.*

| ***Animal*** | ***Animals in 2050 (1000s)*** | ***Growth in number of animals 2018-2050*** |
|---:|---:|---:|
| Dairy cow | 179 | -15% |
| Suckler cow | 138 | 50% |
| Beef cow | 324 | 1% |
| Sheep/lamb | 1151 | -16% |
| Goat and reindeer | 60 | 4% |
| Broiler | 89320 | 42% |
| Layer | 9547 | 48% |
| Pig | 1940 | -2% |
| Other animals* | 1644 | 21% |

A weakness in this part of the data collection is that estimates in growth of animals rely on numbers from NIBIO only. It would be preferable to triangulate the estimates using other data sources, as they are very uncertain. Unfortunately, there are no other available prognoses for growth by animal type available that go farther than 2025, so triangulation was not possible.

Next, the total feed demand per animal was calculated. The Norwegian Agriculture Agency publishes numbers for total demand for compound feed by year, and by animal grouping.

*Table 12: Total compound feed demand 2018. Source: Kraftfôrstatistikken, Landbruksdirektoratet.*

| ***Animal*** | ***Compound feed demand metric tons (MT)*** |
|---:|---:|
| Ruminants | 1 081 977 |
| Poultry | 448 387 |
| Pigs | 476 534 |
| Other feed | 17 324 |
| SUM | 2 024 221 |

Researchers from Animalia have calculated the share for ruminants and poultry in more finely masked categories. This data was supplied through private communication. By using this information, it was possible to calculate the compound feed demand for various ruminants and poultry.

*Table 13: Share of compound feed demand by sub-grouping. Source: Animalia/Own calculations.*

| ***Ruminants*** | ***Share of compound feed demand*** | ***Compound feed demand (MT)*** |
|---|---|---|
| Dairy cow | 57,9% | 626 465 |
| Suckler cow | 2,4% | 25 967 |
| Beef cow | 29,4% | 318 101 |
| Sheep/lamb | 9,4% | 101 706 |
| Goat and reindeer | 0,9% | 9738 |
| SUM Ruminants | 100,0% | 1 081 977 |
| ***Poultry*** | ***Share of compound feed demand*** | ***Compound feed demand (MT)*** |
| Broiler | 47,3% | 212 087 |
| Layer | 52,7% | 236 300 |
| SUM Poultry | 100,0% | 448 387 |

Finally, by combining the feed demand per animal group, projected growth in number of animals, and the protein content in the feed for each animal, an estimate for total protein demand from livestock feed by 2050 was made.

*Table 14: Compound feed demand and protein demand in 2018 and 2050. Source: Own calculations.*

| ***Animal*** | ***Growth in number of animals 2018-2050*** | ***Compound feed demand, 2018 (1000 MT)*** | ***Compound feed demand, 2050 (1000 MT)*** | ***Proteins in compound feed, 2018 (1000 MT)*** | ***Proteins in compound feed, 2050 (1000 MT)*** |
|---|---|---|---|---|---|
| Dairy cow | -15% | 626 | 532 | 91 | 77 |
| Suckler cow | 50% | 26 | 39 | 5 | 7 |
| Beef cow | 1% | 318 | 322 | 38 | 39 |
| Sheep/lamb | -16% | 102 | 86 | 17 | 14 |
| Goat and reindeer | 1% | 10 | 10 | 2 | 2 |
| Pig | -2% | 477 | 468 | 78 | 77 |
| Broiler | 42% | 212 | 302 | 40 | 57 |
| Layer | 48% | 236 | 350 | 39 | 58 |
| Other animals | 21% | 19 | 23 | 3 | 3 |
| SUM | - | 2026 | 2130 | 312 | 334 |

## Feed protein demand for aquafeed

The next step was to find the feed protein demand for the aquaculture industry. This process was much simpler, as the average protein content in Norwegian aquafeed is known. In 2016, the average protein content of aquafeed was 35.6% (Aas et al., 2019). This is based on information supplied by the four big Norwegian aquafeed producers: BioMar, Cargill, Mowi and Skretting. It is unlikely that this percentage will change dramatically over time. This is for two reasons: There has already been decades of research into salmon nutrition, so the protein content is likely already optimized, and salmon is traded on contract with strict standards on for example meat quality, so producers cannot freely change feed composition in responses to changes in input prices. With an annual turnover of 1 894 000 MT of aquafeed, the protein demand from the aquaculture industry in 2019 was 0.356*1 894 000 = 674 000 MT. The domestic production was about 43 000 MT from fish meal.

*Table 15: Aquafeed demand (left) and protein demand for use in aquafeed (right), in 2050.*

| | | Feed to production ratio | |
|---|---|---|---|
| | | 1.1 | 1.2 |
| Salmonid production 2050 (million MT) | 3 | 3.3 | 3.6 |
| | 4 | 4.4 | 4.8 |

| | | Feed to production ratio | |
|---|---|---|---|
| | | 1.1 | 1.2 |
| Salmonid production 2050 (million MT) | 3 | 1.175 | 1.282 |
| | 4 | 1.566 | 1.709 |

In 2050, the estimated production of salmonids is 3 million MT (low growth) or 4 million MT (high growth). Todays feed to production ratio is 1.2, but the 2010 report by DNVS assumes that this may fall to 1.1 with further optimizations in feed efficiency. Given these numbers, compound feed demand in 2050 will be between 3.3-4.8 million MT, and protein demand will therefore be between 1.175-1.709 million MT. For the sake of simplicity, the 50th percentile of this range is used in further discussion, which is 1.442 million MT.

## Demand summary

*Table 16: Feed protein demand in 2018 and 2050.*

| ***Feed protein demand (1000 MT)*** | *2018* | *2050* |
|---|---|---|
| Livestock feed | 312 | 334 |
| Aquafeed | 674 | 1442 |
| Total demand | 986 | 1776 |

In 2018, the total feed protein demand in Norway was 986 000 MT. 312 000 MT was used for livestock feed, of which about 42 000 MT was sourced from Norwegian grains, with a remaining import demand of approximately 270 000 MT. For aquafeed, the domestic production was about 43 000 MT from fish meal, with a remaining import demand of approximately 631 000 MT. As found through data collection, the demand for proteins for livestock feed will increase only slightly to about 350 000 MT by 2050. The demand for protein in aquafeed is estimated to increase dramatically, on the other hand, to 1442 million MT by 2050. The estimate of total protein needed by 2050 is 1776 million MT, of which 18% will be demanded by livestock feed producers and 82% by aquafeed producers.

## Scenarios

In this chapter, several scenarios for supply and demand in 2050 will be constructed and discussed.

In the three following tables, three scenarios for increased Norwegian protein production between 2022 and 2050 will be listed. These scenarios reflect a moderate case, a best case, and a worst case. The moderate case shows cautiously optimistic numbers selected by triangulating data from multiple sources and assumes some technological progress and some relevant policy change by 2050. This is the most reliable scenario. The best-case scenario is more optimistic, using estimates from the higher end of the spectrum, and is reliant on significant technological progress and policy change that may not be possible to achieve. The worst case reflects a scenario where labor and capital allocation has adjusted to internalize recently acquired industry knowledge, but where little technological progress and limited policy changes are made. An assumption is made that other protein production methods not listed below are infeasible. More information that defends this assumption can be found in the overview of potential protein production methods.

In this scenario it is assumed that price of import proteins rises approximately with inflation. A discussion on what would change if price of import proteins changes drastically follows.

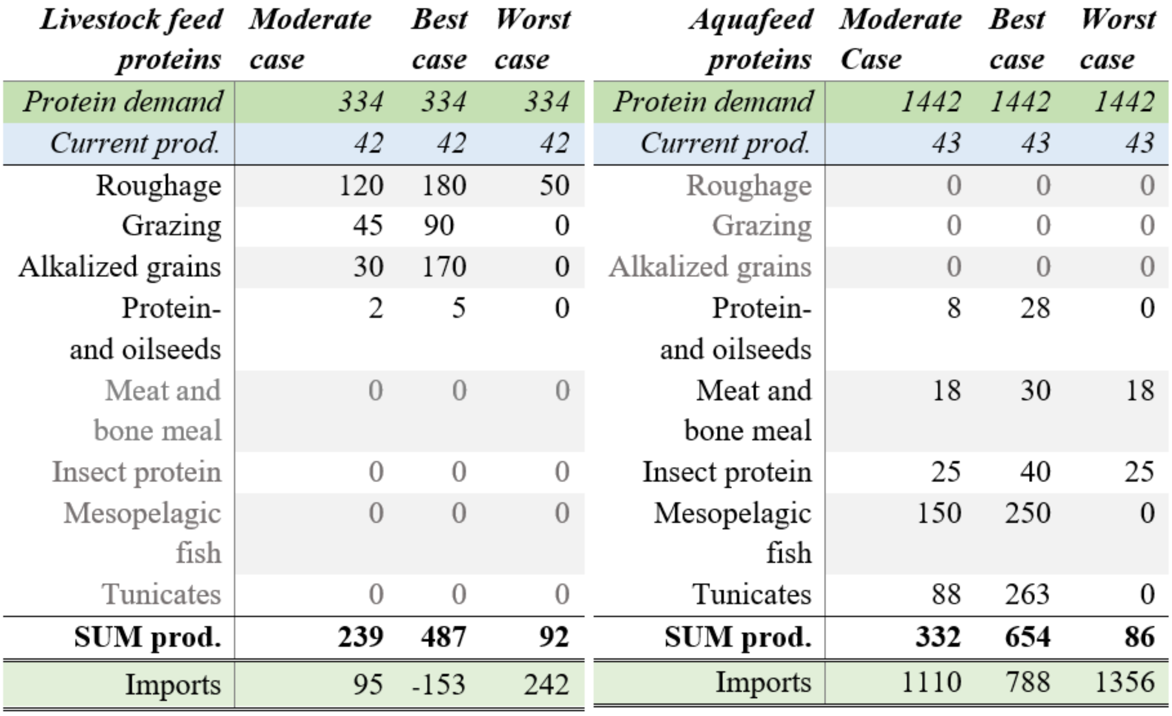
*Table 17: Increase in domestic protein production, 2022-2050.*

| ***All feed*** | ***Moderate case*** | ***Best case*** | ***Worst case*** |
|---:|---:|---:|---:|
| *Protein demand* | *1776* | *1776* | *1776* |
| *Current production* | *85* | *85* | *85* |
| Better roughage | 120 | 180 | 50 |
| Grazing | 45 | 90 | 0 |
| Alkalized grains | 30 | 170 | 0 |
| Protein- and oilseeds | 10 | 30 | 10 |
| Meat and bone meal | 18 | 30 | 0 |
| Insect protein | 25 | 40 | 25 |
| Mesopelagic fish | 150 | 300 | 0 |
| Tunicates | 88 | 263 | 0 |
| **SUM production** | **571** | **1188** | **170** |
| Remaining imports | 1205 | 588 | 1606 |

Table 17 shows the three scenarios for feed proteins going to both aquafeed and livestock feed. Sources for the numbers can be found in the data collection chapter. The domestic protein production increases by respectively approx. 486 000 MT, 1 103 000 MT and 85 000 MT in the moderate, best, and worst case. In all cases, the majority of total demanded proteins are still imported. This is in large part because of the high protein demands from high projected growth in the aquaculture industry.

Some protein sources cannot be used in both feed types however, either due to cost restrictions or ingredient composition. Technical requirements for protein sources used in aquafeed are more stringent than for those used in livestock feed, for example. Aquafeed must be easy to extrude, must not dissolve easily in water and must have the correct buoyancy, for example. The higher overall protein content in aquafeed also requires the use of more protein dense ingredients, which leaves out some options for aquafeed. Furthermore, two of the most promising protein production methods, namely better roughage, and alkalized grains, can only be digested by ruminants, so there is also no competition from aquafeed producers for these methods. Meat and bone meal will likely not be viable for use in livestock feed due to expensive infrastructure needed to prevent spread of BCE, which is not a concern in aquafeed, so livestock producers will not compete with aquafeed producers for MBM. These findings are reflected in table 18.

*Table 18: Supply and demand of proteins for livestock feed (left) and aquafeed (right) in 2050. Units: 1000 MT.*



| ***Livestock feed proteins*** | ***Moderate case*** | ***Best case*** | ***Worst case*** |
|---|---|---|---|
| *Protein demand* | *334* | *334* | *334* |
| *Current prod.* | *42* | *42* | *42* |
| Roughage | 120 | 180 | 50 |
| Grazing | 45 | 90 | 0 |
| Alkalized grains | 30 | 170 | 0 |
| Protein- and oilseeds | 2 | 5 | 0 |
| Meat and bone meal | 0 | 0 | 0 |
| Insect protein | 0 | 0 | 0 |
| Mesopelagic fish | 0 | 0 | 0 |
| Tunicates | 0 | 0 | 0 |
| **SUM prod.** | **239** | **487** | **92** |
| Imports | 95 | -153 | 242 |

| ***Aquafeed proteins*** | ***Moderate Case*** | ***Best case*** | ***Worst case*** |
|---|---|---|---|
| *Protein demand* | *1442* | *1442* | *1442* |
| *Current prod.* | *43* | *43* | *43* |
| Roughage | 0 | 0 | 0 |
| Grazing | 0 | 0 | 0 |
| Alkalized grains | 0 | 0 | 0 |
| Protein- and oilseeds | 8 | 28 | 0 |
| Meat and bone meal | 18 | 30 | 18 |
| Insect protein | 25 | 40 | 25 |
| Mesopelagic fish | 150 | 250 | 0 |
| Tunicates | 88 | 263 | 0 |
| **SUM prod.** | **332** | **654** | **86** |
| Imports | 1110 | 788 | 1356 |

For livestock feed, more than half the estimated protein demand may be met even in the moderate case. Insect proteins and mesopelagic fish will both be too expensive to utilize in livestock feed, leaving better roughage as the key resource to meet demand for Norwegian produced proteins. This reflects findings in other reports and projects such as “Bruk av fôrressurser” (*Norwegian Agriculture Agency, 2020*), “Grovfor2020”(*Grovfôrøkonomi på fem minutter | Buskap*, 2020.), and internal documents from the Norwegian Agrarian Association. Note that this assumes that fertilizer and fuel prices remain relatively constant in terms of purchasing power parity from 2018 prices. In years with especially high fuel and fertilizer prices, such as in 2021 and 2022, the protein production from roughage will likely be significantly reduced, as these input costs represent most costs of better roughage production.

Pigs and poultry consume only compound feed however, and cannot utilize proteins from roughage, grazing or alkalized grains. This is especially problematic given that demand for poultry is estimated to see the highest increase towards 2050 of any livestock animal. 192 000 MT out of 334 000 MT of the protein demand for livestock in 2050 comes from pork and poultry production (see table 13). In the best case, only 5000 MT of the 192 000 MT required for pig and poultry feed are produced domestically.

The greatest source of variation between the cases is what role alkalized grains will play in a future Norwegian protein industry. Estimates from expert sources range between 0 to 170 000 tons protein production by 2050. As of May 2022, it is unclear whether it is more likely that the final number will end up in the lower or higher end of this range. Several studies are underway to measure the impact and efficacy of grain alkalization, and more conclusive estimates are expected within the next few years.

In the best case, more proteins may be produced than are demanded for use in livestock feed. A requirement for the best case to occur is that farmers succeed in increasing the concentration of proteins in roughage. If that happens, farmers will likely substitute some compound feed for roughage, until the market reaches an equilibrium with 0 imports, and marginally lower compound feed usage.

Increased production of meat and bone meal and protein- and oilseeds is unlikely to impact the livestock market much. Protein- and oilseeds of higher quality will first be sold for human consumption, then as an ingredient in aquafeed, before it becomes available for use in livestock feed. For meat and bone meal, production is likely to be relatively pricey, so most of the product will go to aquafeed. Additionally, meat and bone meal may not be used in ruminant feed, and because of risk of contamination to other livestock feed, livestock feed mills will likely opt out of using the little meat and bone meal they can access entirely.

In the worst case, some farmers will adopt to better roughage production methods, but not on a large scale due to for example prohibitive input costs or time squeeze. Furthermore, research on alkalized grains will yield poor results. In this case, almost all protein demand for livestock feed will have to be met by imports and roughage, much like the current situation.

For aquafeed, the majority of protein demand will continue to be covered by imports in all scenarios. Even in the best case, Norwegian production of proteins will not even be close to covering the extremely high demand of proteins from the aquaculture industry. Better roughage and alkalized grains are not options for aquafeed, as these proteins cannot be digested by fish. There have been some early experiments on separating grass proteins from ensilage for use in fish feed, but the technology is still in its infancy and the grass proteins have an unappetizing taste that fish do not like. Increased proteins from alkalized grains cannot be utilized by fish, as protein synthesis from alkalized grains happens in the rumen of cattle specifically.

In the moderate case, mesopelagic fish will be the biggest contributor to Norwegian production of proteins for aquafeed, followed by insect protein production and meat and bone meal production. This is in accordance to findings made in “Bærekraftig fôr til norsk laks, although the best case scenario has been adjusted down significantly compared to the best case in SINTEFs report, due to a much lower projected mesopelagic fish harvest. Mesopelagic fish serves double duty as a source of EPA/DHA as well, which there already is a shortage of on the global market. Unfortunately, there are significant hurdles to overcome in terms of cost efficiency, ecosystem preservation and climate gas emissions with mesopelagic fishery, which makes estimates imprecise. It is possible that one or more of the challenges will remain unsolved, leading to no fishing of mesopelagic fish by 2050 in the worst case.

Production of insect proteins is limited by availability of insect substrate. In the moderate case, insect producers will be able to utilize a wide range of substrates from various domestic industries, but widescale use of fish slurry from farmed fish will not be cost efficient or maybe still not legal, as is the case today. In the best case, challenges related to use fish slurry will be solved, and availability of insect substrates in Norway will be outsized compared to GDP, leading to large insect protein production in Norway. In either case, it is expected that insect proteins will remain an expensive protein source, and barely competitive with imported proteins. In the worst case, it is assumed that the factory that is currently being built with Pronofa will be maintained, and will use the cheapest and most easily available substrates for production, but no new investments in infrastructure for insect proteins will be made.

In the moderate case, it is assumed that either costs of producing meat and bone meal will go down, or there will be a policy shift to enforce increased use of cuttings from the meat processing industry. This is not unrealistic, as such a policy would represent a meaningful contribution to a more circular economy, which is a widely accepted political goal. The bottleneck in production is availability of meat cuttings, which will likely remain stable as Norwegian meat production is projected to remain stable. Trimmings from the aquaculture industry will not be used for MBM due to prohibitive cost, even with significant infrastructure investment (PwC, 2019).

As can be seen, an increase in the Norwegian share of livestock feed towards 2050 is not only possible, but likely. For aquafeed, the Norwegian share can also be increased somewhat, as almost 100% of proteins today are imported, but the Norwegian production in the moderate case only amounts to a fraction of total protein demand.

## What if the price of import proteins rises or falls dramatically?

Productivity in soybean and rapeseed farming has increased significantly and total farmed area has also increase. It is expected that this trend will continue (Kristanti et al., 2018) (Wesz Jr, 2016)  If global demand stops increasing, this could result in a dramatic decrease in prices of imported proteins. In this unlikely scenario, Norwegian protein production would almost certainly fall to 0 or close to 0, as the production methods described in this report already are barely price competitive with imported proteins, if at all. The total compound feed demand would likely also increase, and therefore also total protein demand, to compensate for the price change. This can happen by incentivizing beef and milk production, by reducing the production of suckler cows and castrates in favor of beef cows and dairy cows.

If global protein demand increases much faster than global protein supply, or there is an external supply shock, prices of import proteins may rise dramatically. A supply shock could happen due to drought or other extreme weather, widespread crop disease or rapid increases in prices of inputs like fertilizer or fuel. With high import protein prices, protein production methods that have been considered too expensive may become price competitive, and existent production may be increased, if possible.

However, most protein production methods mentioned in the report are limited in scale, for example by technological constraints, access to inputs, issues in feeding or environmental constraints. Roughage production for example, is area intensive. If production increases drastically, farmers must drive much farther to harvest and package roughage that is far away from the farm, increasing both carbon footprint and time usage. In addition, areas that are used for grain production today would have to be replaced with roughage, which might not be worthwhile.

Alkalization of grains is limited by how much protein cows can synthesize in the rumen and cannot exceed the best case of 170 000 tons of protein, according to calculations done by Strand Unikorn (Landbruksdirektoratet, 2020, p. 84).

While production of protein- and oilseed may be increased somewhat if protein prices are high, the demand for both food grade grains and protein- and oilseed for human consumption also will increase in such a scenario. An increase in import protein prices could even exert downwards pressure on supply of protein- and oilseed for animal feed.

Meat and bone meal and insect proteins are both already limited by availability of slaughter by-products and insect substrates, and production cannot be increased further than what is detailed in the moderate and best-case scenario. Because of these restraints, it is unlikely that an increase of price of import proteins will play a big role in increasing the production of proteins from insects or MBM.

There is one significant exception, however. If the price of import proteins increases dramatically, it is possible to shift to extensive livestock production. This would mean feeding less compound feed to livestock and increasing reliance on grazing. This would decrease yields per animal, so to compensate, more animals would have to be reared and larger areas converted to grazing land. Such a shift would lead to a lower demand for feed proteins.

# Policy

In this chapter, some possible ways to influence the domestic market for proteins are explored.

## How to impact the protein feed value chain with policy

As Norway is a member of the WTO, there are restrictions on what policy tools the Norwegian government can use to influence the market for feed proteins. The keystone of the WTO agreement is GATT article XI, which outlines the prohibition on quantitative trade restrictions. Outside specific cases, member countries are not allowed to set "explicit limits, or quotas, on the physical amounts of particular commodities by volume or by value" (Veggeland et al., 2003). The intent of article XI is to prevent usage of other trade policy measures than tariffs, in a bid to simplify trade policy for importers and exporters. This aligns with the main goal of WTO, which in general has been to facilitate simple and predictable trade regulations and to erode protectionist measures. Protectionist measures such as tariff-increases on protein imports could lessen the competition from international trade, but protectionism is largely off the table due to WTO regulations and pressure.

To impact the protein feed value chain, government policies must then target either protein supply, feed production, or feed consumption. Production of compound feed is already highly efficient, with producers exploiting economies of scale. The feed mills are required to use Norwegian produced grains before import grains for production of livestock feed, but there are otherwise no significant restrictions on production, and the market is open to entry. Feed producers are already cooperating with protein suppliers of novel proteins, and seem willing to use any protein source as long as it is competitive, based on the criteria mentioned in the chapter on supply. On the feed consumption side of the market, the goal is to reach some level of aggregate production targeted by the cooperatives as efficiently as possible. Farmers are already pressed financially, and do not have much option besides purchasing the cheapest compound feed available. There is some willingness to purchase feeds with higher Norwegian shares but forcing this politically will likely not be feasible as only the farmers with high profit margins will be able to comply.

In aquaculture feed production, companies must compete on the global market, and forcing these producers to use more expensive domestically sourced proteins in their feed is also bound to cause deadweight losses in an industry that is already pressed. According to an expert on compound feed production in Felleskjøpet, profit margins for aquafeed producers were so low in the 1990s that several aquafeed producers had to shut down. One should be careful about pressing aquafeed producers too hard, even if the aquaculture industry at large has high margins.

The best option then is to stimulate the protein supply from traditional and novel sources so these sources can better compete with imports.

## Policy suggestions

One of the early goals in this thesis was to give a comprehensive overview of relevant policy suggestions that may incentivize competitive and sustainable Norwegian protein production. After several months of research, it has become clear that attempting to suggest policy changes is a risky proposition. The politics behind the Norwegian agricultural system are extremely complex, and policy changes tend to have far-reaching consequences outside the intended direct effect. Regardless, there is some low-hanging fruit to point to.

The most obvious policy suggestion, granted that there is a widespread wish to increase the Norwegian share, should be to continue funding R&D into protein production technology. Efficiency in soybean and rapeseed production is sure to increase further, and most protein production methods mentioned in this report are already struggling to compete with soybeans and rapeseed, if they compete at all. If there is a wish to shore up a high percentage of aquafeed proteins with domestically produced proteins it is imperative to support highly experimental and uncertain technologies with high potential tonnage, such as mesopelagic fishing and tunicate production. This is because Norwegian protein production will not be even remotely large enough to cover the needs of the aquaculture industry without significant breakthroughs in these technologies with a high potential tonnage. Industry actors may also not have the same incentives to support R&D into these very uncertain technologies, which makes earmarking funding more important.

There are also some policy roadblocks that may hinder further protein production unnecessarily. Norwegian politicians should be quick to follow EU deregulation of meat- and bone meal, as the EU policy changes are well researched. In general, the danger of BCE from MBM is only a risk in cases where animals are at risk of eating meat from their own species and is otherwise overblown. The use of fish sludge in insect substrate production would also represent a major contribution to a circular economy if it were to be allowed and would increase the potential tonnage from insect proteins significantly. However, research into effects of using fish sludge in feeds must be investigated thoroughly before such regulation is suggested. If fish sludge use is approved and then later found to be harmful to human health, it could cause significant long-term harm to acceptance of using insect proteins in feed.

A more thorough investigation into impacts of potential EPA/DHA-shortages on aquafeed production should be made, and efforts should be made to secure EPA/DHA access, preferably in a way that also increases protein production. After having spoken to a wide range of industry actors, the prevailing pattern of thought seems to be that there are many possible ways to produce EPA/DHA, and that access to these vital fatty acids will be unproblematic even with a rapidly growing aquaculture industry. This is not necessarily true. Only mesopelagic fish, conifer by-products and tunicates represent large potential sources of EPA/DHA, and of these mesopelagic fish and tunicates are highly experimental technologies with uncertain trajectories for future production. A shortage in EPA/DHA is a real risk that may inhibit growth in the aquaculture industry. Fortunately, the high value of EPA/DHA also creates opportunities. Novel protein production methods that happen to also produce EPA/DHA become far more competitive, so there may be ways to turn this risk into a benefit.

It may also be valuable for the Department for Agricultural policy and the Department of Aquaculture, Seafood and Markets to clearly communicate a plan for a scenario where protein imports dry up og import prices increase dramatically. Feed access in such a situation would be heavily limited for livestock farmers, and not available at all for aquaculture producers, which would represent a massive external shock to inputs. Aquaculture producers and farmers will react according to their economic interest in such a situation, but the transition to a new level of production will likely be smoother if agents know how the government intends to react in response to such an input shock.

Further research should be done to consider the impact of more policy changes pertaining to topics such as:

- Increased support for growing proteins in less fertile areas
- Incentives to improve roughage quality
- Incentives to increase grazing, especially in years with high input costs for compound feed production.
- Incentives to use sustainable ingredients in compound feed
- Incentives to use Norwegian produced proteins before import proteins.
- Effect of further substituting beef cattle production with combined dairy/beef production.

## Conclusion

The share of Norwegian ingredients in compound feeds for livestock and aquaculture has been falling since 2005. In recent years, there has been widespread calls from industry actors and NGOs in the agricultural sector to reverse this trend. Aquafeed producers also wish to use more Norwegian ingredients in their feed, in a bid to keep up with customer demands. Increasing Norwegian protein production has been seen as one of the most promising ways to achieve a higher Norwegian share in animal feed. In this report, it is estimated that if all proteins in livestock feed were to be replaced by Norwegian produced proteins today, the Norwegian share would increase from about 75% to 81-83%. For aquafeed, the Norwegian share would increase to roughly 31.8% if all non-grain proteins are produced domestically.

Meanwhile, the aquaculture industry is expected to more than double its output by 2050. With a feed conversion ratio of 1.1-1.2, the protein demand is estimated to increase from 987 000 MT to 1 776 000 MT. Livestock feed demand is estimated to increase marginally. This means that if the Norwegian share is going to increase overall, Norwegian protein production must increase dramatically.

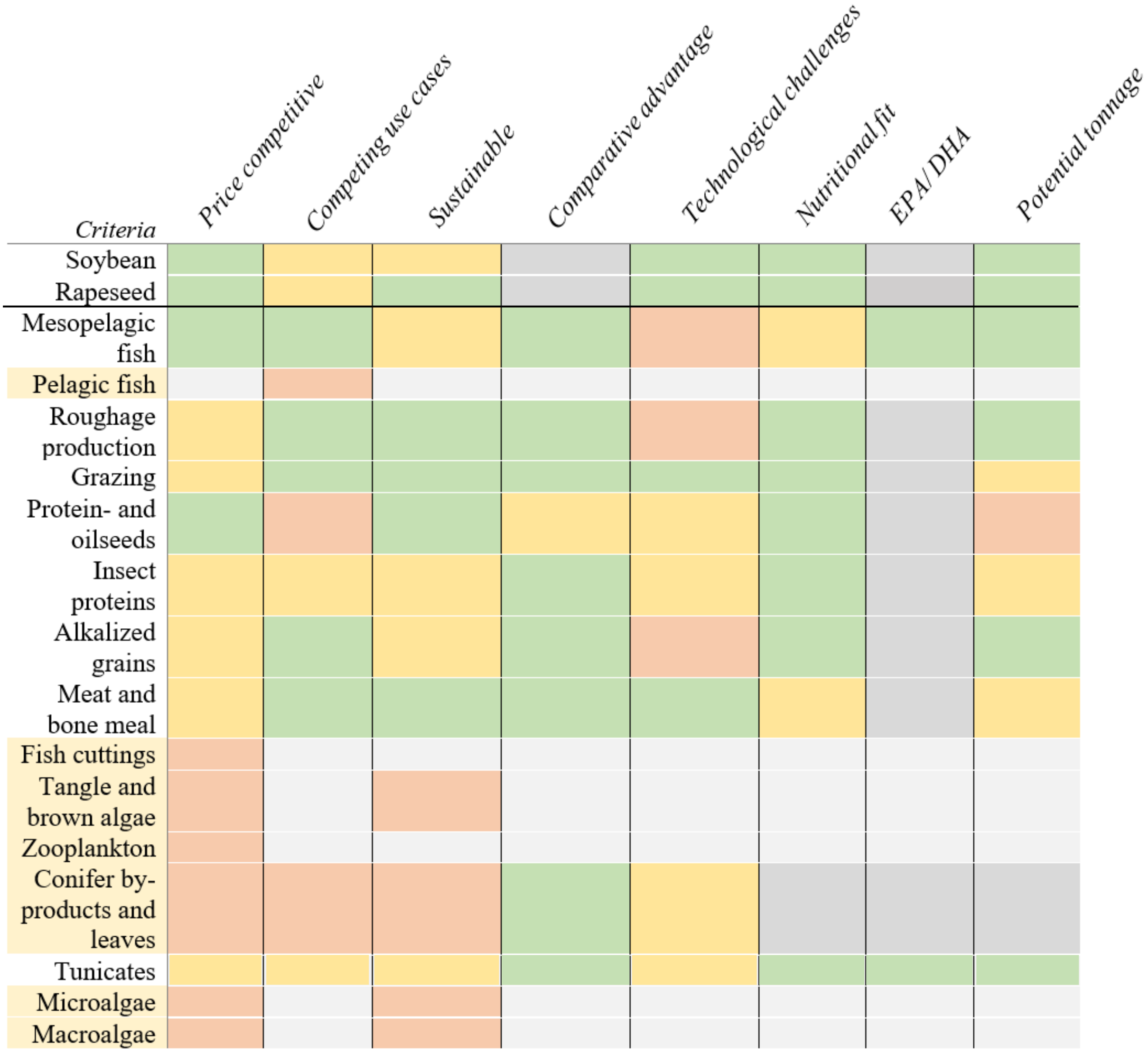
*Table 18: Feed protein demand in 2018 and 2050.*

| ***Feed protein demand (1000 MT)*** | *2018* | *2050* |
|---:|---:|---:|
| Livestock feed | 312 | 334 |
| Aquafeed | 674 | 1442 |
| Total demand | 987 | 1776 |

Current Norwegian protein production is small. In a “typical year” it is estimated that protein from grains supply about 42 000 metric tons (MT) of proteins, while proteins from fishmeal contribute 43 000 MT of proteins. The remaining proteins are imported. If the overall Norwegian share is to increase, the growth in protein production must outstrip the growth in the aquaculture industry.

A survey of various protein production methods was made. Production methods were judged on criteria like price competitiveness, sustainability, technological barriers and more. The judgement was based on literature review and expert opinion. The results are summarized in table 19. For some methods it was immediately obvious that production would be unviable. In these cases, a full analysis of all criteria was not done to save time (shown in light grey in the table). An example is production of macroalgae, where production cost is estimated to be 325 times more expensive than roughage, per kg of produced proteins. Soybeans and rapeseed are included as a baseline.

*Table 19: Multi-criteria analysis of protein production methods. Legend: Green/Yellow/Red: Meets criteria/Partially meets criteria/Does not meet criteria. Dark grey: Not applicable. Light grey: Not evaluated.*



| *Criteria* | *Price competitive* | *Competing use cases* | *Sustainable* | *Comparative advantage* | *Technological challenges* | *Nutritional fit* | *EPA/DHA* | *Potential tonnage* |
|---|---|---|---|---|---|---|---|---|
| Soybean | 🟩 | 🟨 | 🟨 | ▨ | 🟩 | 🟩 | ▨ | 🟩 |
| Rapeseed | 🟩 | 🟨 | 🟩 | ▨ | 🟩 | 🟩 | ▨ | 🟩 |
| Mesopelagic fish | 🟩 | 🟩 | 🟨 | 🟩 | 🟥 | 🟨 | 🟩 | 🟩 |
| Pelagic fish | ⬜ | 🟥 | ⬜ | ⬜ | ⬜ | ⬜ | ⬜ | ⬜ |
| Roughage production | 🟨 | 🟩 | 🟩 | 🟩 | 🟥 | 🟩 | ▨ | 🟩 |
| Grazing | 🟨 | 🟩 | 🟩 | 🟩 | 🟩 | 🟩 | ▨ | 🟨 |
| Protein- and oilseeds | 🟩 | 🟥 | 🟩 | 🟨 | 🟨 | 🟩 | ▨ | 🟥 |
| Insect proteins | 🟨 | 🟨 | 🟨 | 🟩 | 🟨 | 🟩 | ▨ | 🟨 |
| Alkalized grains | 🟨 | 🟩 | 🟨 | 🟩 | 🟥 | 🟩 | ▨ | 🟩 |
| Meat and bone meal | 🟨 | 🟩 | 🟩 | 🟩 | 🟩 | 🟨 | ▨ | 🟨 |
| Fish cuttings | 🟥 | ⬜ | ⬜ | ⬜ | ⬜ | ⬜ | ⬜ | ⬜ |
| Tangle and brown algae | 🟥 | ⬜ | 🟥 | ⬜ | ⬜ | ⬜ | ⬜ | ⬜ |
| Zooplankton | 🟥 | ⬜ | ⬜ | ⬜ | ⬜ | ⬜ | ⬜ | ⬜ |
| Conifer by-products and leaves | 🟥 | 🟥 | 🟥 | 🟩 | 🟨 | ▨ | ▨ | ▨ |
| Tunicates | 🟨 | 🟨 | 🟨 | 🟩 | 🟨 | 🟩 | 🟩 | 🟩 |
| Microalgae | 🟥 | ⬜ | 🟥 | ⬜ | ⬜ | ⬜ | ⬜ | ⬜ |
| Macroalgae | 🟥 | ⬜ | 🟥 | ⬜ | ⬜ | ⬜ | ⬜ | ⬜ |

Of the 14 protein production methods, 7 were considered unviable (marked in yellow), while 8 were considered potentially viable. It was concluded that overall protein production from the potentially viable production methods will contribute between 123 000 and 930 000 MT of domestically produced proteins for feed by 2050. Given a demand of 1 776 000 MT of feed proteins in 2050, remaining demand for imported proteins will be between 765 000 and 1 673 000 MT. In a moderate case, which is the case with the most solid support in the literature, it is assumed that Norwegian protein production may reach around 450 000 MT in 2050. This will necessitate import of 1 326 000 MT of proteins to cover expected feed protein demand.

It must be emphasized that these numbers are *extremely* uncertain. The findings should be used as a tool to explore potential decision spaces and to anchor expectations, not as precise estimates for actual production.

*Table 20: Increase in domestic protein production, 2022-2050. Units: 1000 MT.*

| ***All feed*** | ***Moderate case*** | ***Best case*** | ***Worst case*** |
|---:|---:|---:|---:|
| *Protein demand* | *1776* | *1776* | *1776* |
| *Current production* | *85* | *85* | *85* |
| Better roughage | 120 | 180 | 50 |
| Grazing | 45 | 90 | 0 |
| Alkalized grains | 30 | 170 | 0 |
| Protein- and oilseeds | 10 | 30 | 10 |
| Meat and bone meal | 18 | 30 | 0 |
| Insect protein | 25 | 40 | 25 |
| Mesopelagic fish | 150 | 300 | 0 |
| Tunicates | 88 | 263 | 0 |
| **SUM production** | **571** | **1188** | **170** |
| Remaining imports | 1205 | 588 | 1606 |

Research question 1 asks if Norway can become self-sufficient with proteins for livestock- **and** aquafeed by 2050. As can be seen in Table 20, the answer is no. Even in the best case, it will not be possible to meet the full demand for feed proteins, mainly due to explosive growth in the aquaculture industry.

Research question 1.i asks if Norway can become self-sufficient with proteins for **aquafeed** by 2050. The answer is no.

Research question 1.ii asks if Norway can become self-sufficient with proteins for **livestock feed** by 2050. To answer this question, it is easier to first answer research question 2.

Research question 2 asks if aquafeed producers and livestock feed producers compete for the same protein goods. The answer is that there is only competition for some protein resources. Aquafeed is a premium product that fetches a higher price than livestock feed, so for protein sources that can be used in both feeds, aquafeed producers will outcompete livestock feed producers.

Technical requirements for protein sources used in aquafeed are more stringent than for those used in livestock feed, however. Aquafeed must be easy to extrude, must not dissolve easily in water and must have the correct buoyancy, for example. The higher overall protein content in aquafeed also requires the use of more protein dense ingredients, which leaves out some options for aquafeed. Furthermore, two of the most promising protein production methods, namely better roughage, and alkalized grains, can only be digested by ruminants, so there is also no competition from aquafeed producers for these methods. Meat and bone meal will likely not be viable for use in livestock feed due to expensive infrastructure needed to prevent spread of BCE, which is not a concern in aquafeed, so livestock producers will not compete with aquafeed producers for MBM. These findings are reflected in table 23.

*Table 21: Supply and demand of proteins for livestock feed (left) and aquafeed (right) in 2050. Units: 1000 MT.*

| ***Livestock feed proteins*** | ***Moderate case*** | ***Best case*** | ***Worst case*** |
|---:|---:|---:|---:|
| *Protein demand* | *334* | *334* | *334* |
| *Current prod.* | *42* | *42* | *42* |
| Roughage | 120 | 180 | 50 |
| Grazing | 45 | 90 | 0 |
| Alkalized grains | 30 | 170 | 0 |
| Protein- and oilseeds | 2 | 5 | 0 |
| Meat and bone meal | 0 | 0 | 0 |
| Insect protein | 0 | 0 | 0 |
| Mesopelagic fish | 0 | 0 | 0 |
| Tunicates | 0 | 0 | 0 |
| **SUM prod.** | **239** | **487** | **92** |
| Imports | 95 | -153 | 242 |

| ***Aquafeed proteins*** | ***Moderate Case*** | ***Best case*** | ***Worst case*** |
|---:|---:|---:|---:|
| *Protein demand* | *1442* | *1442* | *1442* |
| *Current prod.* | *43* | *43* | *43* |
| Roughage | 0 | 0 | 0 |
| Grazing | 0 | 0 | 0 |
| Alkalized grains | 0 | 0 | 0 |
| Protein- and oilseeds | 8 | 28 | 0 |
| Meat and bone meal | 18 | 30 | 18 |
| Insect protein | 25 | 40 | 25 |
| Mesopelagic fish | 150 | 250 | 0 |
| Tunicates | 88 | 263 | 0 |
| **SUM prod.** | **332** | **654** | **86** |
| Imports | 1110 | 788 | 1356 |

The answer to research question 2 is that there is only direct competition for proteins produced by some methods. These are protein- and oilseeds, insect proteins, mesopelagic fish, and tunicates. For the other production methods there is little or no competition between the two market segments. Knowing this is helpful for concluding if it will be possible to reach 100% self-sufficiency for the livestock feed market.

Initially, by looking at table 21, it does look like it is possible to become fully self-sufficient for livestock feed, at least in a best-case scenario. This is because more proteins are produced than demanded. However, there is a problem. Pigs and poultry consume only compound feed, and cannot utilize proteins from roughage, grazing or alkalized grains. This is especially problematic given that demand for poultry is estimated to see the highest increase towards 2050 of any livestock animal. 192 000 MT out of 334 000 MT of the protein demand for livestock in 2050 comes from pork and poultry production (see table 13). In the best case, only 5000 MT of the 192 000 MT required for pig and poultry feed are produced domestically.

We will likely be able to produce enough proteins to be self-sufficient for ruminant feed, but not for non-ruminant livestock feed. The answer to research question 1.ii is therefore also no. This assumes that all proteins from mesopelagic fish, insect proteins and tunicates will be of high enough quality to use in fish feed. In practice, some percentage of the product will likely be of too low quality to use in aquafeed production, and may therefore be sold for use in livestock feed. This can lead to both a higher Norwegian share in feed, and higher profit margins for producers of novel proteins. Further research should be made to investigate the impact of such an arrangement.

Research question 3 asks if there are protein production methods available in Norway that can compete with soybean or rapeseed imports in terms of global carbon footprint per kg protein produced. Roughage production, grazing, and protein- and oilseed production is likely to contribute to lower emissions than soybean imports, and similar or lower emissions than or rapeseed imports. Insect proteins, tunicate production, alkalized grains and mesopelagic fishing may potentially be sustainable given technological advances, but there is not enough data available yet to conclude.

If the Norwegian share is to increase substantially, every production method mentioned in the paragraph above must be exploited fully. This strategy may lead to higher CO2-equivalent emissions than producing proteins only from the most sustainable sources, and then importing the rest. Further research should be made to estimate the impact of a feed strategy where a high Norwegian share is the goal.

## Why increase the Norwegian share?

With effort, it will be possible to increase the Norwegian share of proteins in feed. However, Norway will continue being reliant on protein imports in the foreseeable future. This may not be so bad.  Soy protein meal for example, is traded on standardized contract on reputable mercantile exchanges, and Brazilian producers must adhere to stringent quality controls. Furthermore, Winther et al. find that «Transport of feed ingredients from the market to Norway is for instance less than 4% of the feed carbon footprint at the point where it is delivered to the fish farmer. (Winther et al 2020).” The carbon footprint of soy production has also likely been overestimated, as impacts of buying certified soy has not fully been investigated. For rapeseed meal, the CO2-emissions are even lower.

A reduction in soy protein concentrate and rapeseed meal use could be an efficient way to reduce total emissions from compound feeds, but this necessitates a less CO2-intensive alternative.

The Norwegian Agrarian association also argue that ensuring a fully domestic feed value chain will decrease geopolitical risks. In the case of crises in the global protein market or problems with importing product because of blockades or natural disaster, feed mills will not be able to produce enough concentrate feed to fully supply the aquaculture and agriculture industries. In such a scenario, a share of the livestock herd must be slaughtered, and aquaculture production must be decreased. While this sounds dramatic, Norway still has access to vast quantities of food resources, mostly through catching of wild fish. While an attempt to produce proteins when it is viable should be made to reduce food security risks, it is important to keep in mind that protein imports are not as bad as they are made out to be.

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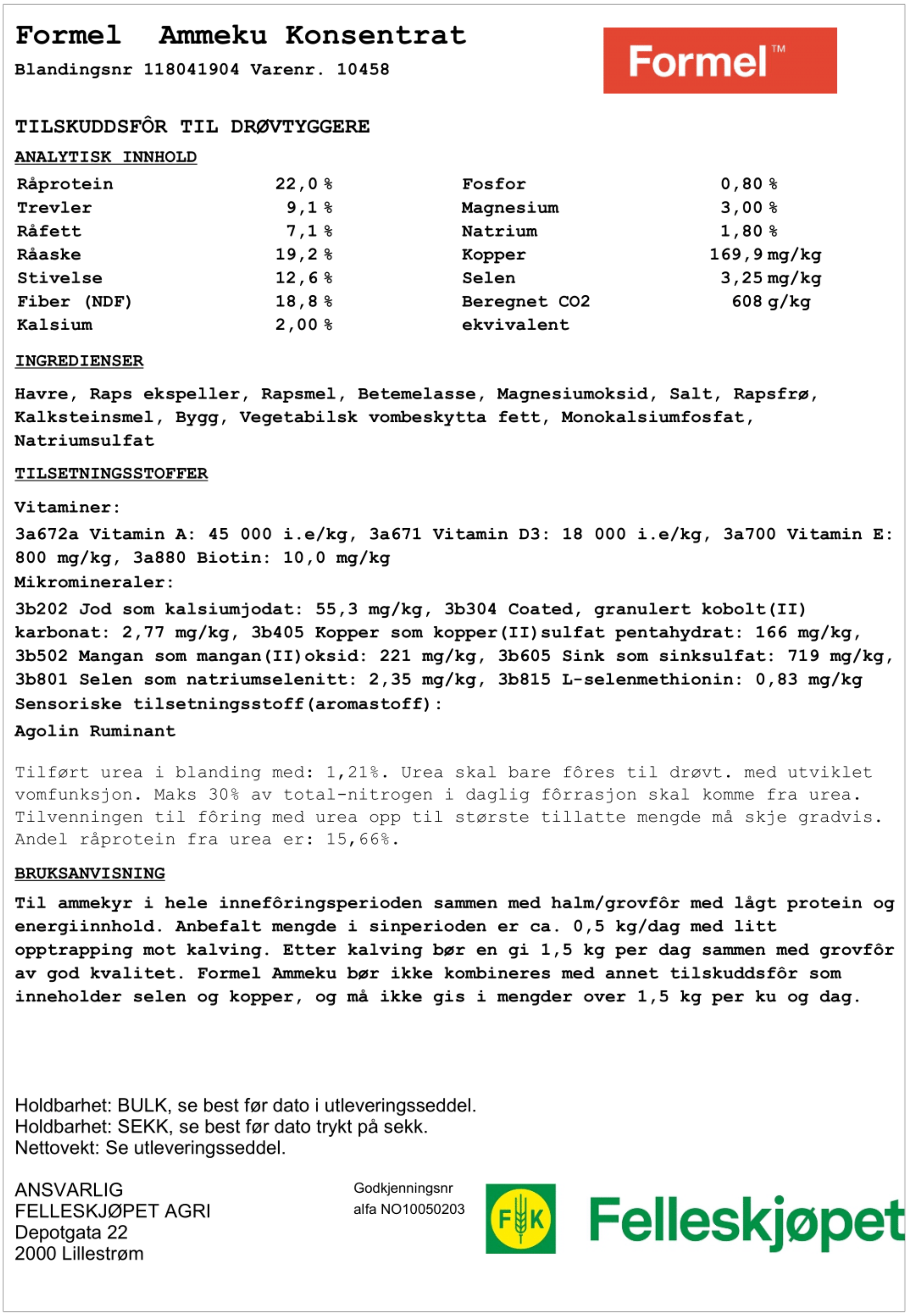
# Appendix A: Content declaration for Felleskjøpet livestock feed



**Formel Ammeku Konsentrat**

**Blandingsnr 118041904 Varenr. 10458**

**TILSKUDDSFÔR TIL DRØVTYGGERE**

**ANALYTISK INNHOLD**

| | | | |
|---|---|---|---|
| Råprotein | 22,0 % | Fosfor | 0,80 % |
| Trevler | 9,1 % | Magnesium | 3,00 % |
| Råfett | 7,1 % | Natrium | 1,80 % |
| Råaske | 19,2 % | Kopper | 169,9 mg/kg |
| Stivelse | 12,6 % | Selen | 3,25 mg/kg |
| Fiber (NDF) | 18,8 % | Beregnet CO2 ekvivalent | 608 g/kg |
| Kalsium | 2,00 % | | |

**INGREDIENSER**

Havre, Raps ekspeller, Rapsmel, Betemelasse, Magnesiumoksid, Salt, Rapsfrø, Kalksteinsmel, Bygg, Vegetabilsk vombeskytta fett, Monokalsiumfosfat, Natriumsulfat

**TILSETNINGSSTOFFER**

Vitaminer:

3a672a Vitamin A: 45 000 i.e/kg, 3a671 Vitamin D3: 18 000 i.e/kg, 3a700 Vitamin E: 800 mg/kg, 3a880 Biotin: 10,0 mg/kg

Mikromineraler:

3b202 Jod som kalsiumjodat: 55,3 mg/kg, 3b304 Coated, granulert kobolt(II) karbonat: 2,77 mg/kg, 3b405 Kopper som kopper(II)sulfat pentahydrat: 166 mg/kg, 3b502 Mangan som mangan(II)oksid: 221 mg/kg, 3b605 Sink som sinksulfat: 719 mg/kg, 3b801 Selen som natriumselenitt: 2,35 mg/kg, 3b815 L-selenmethionin: 0,83 mg/kg

Sensoriske tilsetningsstoff(aromastoff):

Agolin Ruminant

Tilført urea i blanding med: 1,21%. Urea skal bare fôres til drøvt. med utviklet vomfunksjon. Maks 30% av total-nitrogen i daglig fôrrasjon skal komme fra urea. Tilvenningen til fôring med urea opp til største tillatte mengde må skje gradvis. Andel råprotein fra urea er: 15,66%.

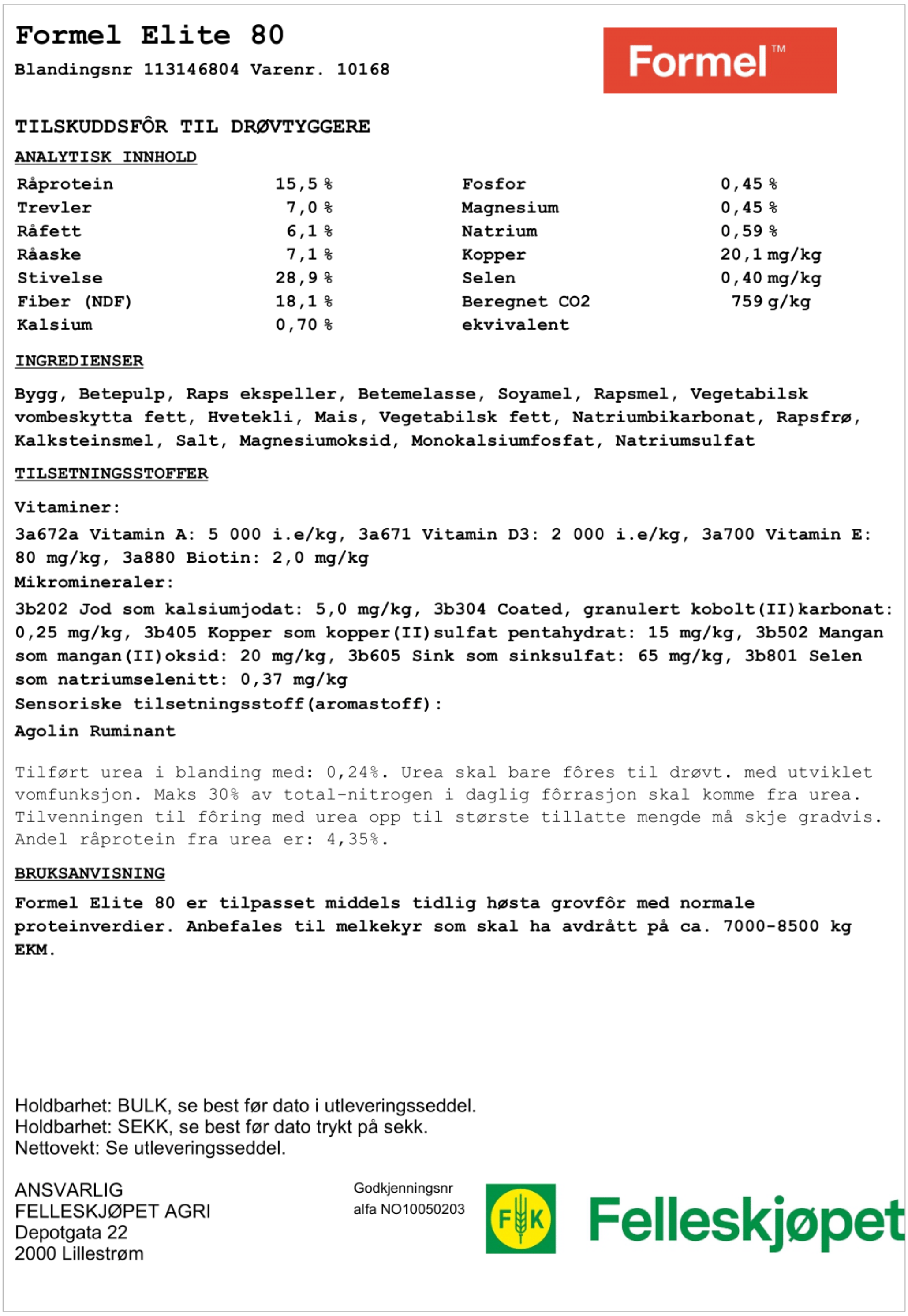
**BRUKSANVISNING**

Til ammekyr i hele innefôringsperioden sammen med halm/grovfôr med lågt protein og energiinnhold. Anbefalt mengde i sinperioden er ca. 0,5 kg/dag med litt opptrapping mot kalving. Etter kalving bør en gi 1,5 kg per dag sammen med grovfôr av god kvalitet. Formel Ammeku bør ikke kombineres med annet tilskuddsfôr som inneholder selen og kopper, og må ikke gis i mengder over 1,5 kg per ku og dag.

Holdbarhet: BULK, se best før dato i utleveringsseddel.
Holdbarhet: SEKK, se best før dato trykt på sekk.
Nettovekt: Se utleveringsseddel.

ANSVARLIG
FELLESKJØPET AGRI
Depotgata 22
2000 Lillestrøm

Godkjenningsnr
alfa NO10050203



# Formel Elite 80

Blandingsnr 113146804 Varenr. 10168

## TILSKUDDSFÔR TIL DRØVTYGGERE

**ANALYTISK INNHOLD**

| | | | |
|---|---|---|---|
| Råprotein | 15,5 % | Fosfor | 0,45 % |
| Trevler | 7,0 % | Magnesium | 0,45 % |
| Råfett | 6,1 % | Natrium | 0,59 % |
| Råaske | 7,1 % | Kopper | 20,1 mg/kg |
| Stivelse | 28,9 % | Selen | 0,40 mg/kg |
| Fiber (NDF) | 18,1 % | Beregnet CO2 ekvivalent | 759 g/kg |
| Kalsium | 0,70 % | | |

**INGREDIENSER**

Bygg, Betepulp, Raps ekspeller, Betemelasse, Soyamel, Rapsmel, Vegetabilsk vombeskytta fett, Hvetekli, Mais, Vegetabilsk fett, Natriumbikarbonat, Rapsfrø, Kalksteinsmel, Salt, Magnesiumoksid, Monokalsiumfosfat, Natriumsulfat

**TILSETNINGSSTOFFER**

Vitaminer:

3a672a Vitamin A: 5 000 i.e/kg, 3a671 Vitamin D3: 2 000 i.e/kg, 3a700 Vitamin E: 80 mg/kg, 3a880 Biotin: 2,0 mg/kg

Mikromineraler:

3b202 Jod som kalsiumjodat: 5,0 mg/kg, 3b304 Coated, granulert kobolt(II)karbonat: 0,25 mg/kg, 3b405 Kopper som kopper(II)sulfat pentahydrat: 15 mg/kg, 3b502 Mangan som mangan(II)oksid: 20 mg/kg, 3b605 Sink som sinksulfat: 65 mg/kg, 3b801 Selen som natriumselenitt: 0,37 mg/kg

Sensoriske tilsetningsstoff(aromastoff):

Agolin Ruminant

Tilført urea i blanding med: 0,24%. Urea skal bare fôres til drøvt. med utviklet vomfunksjon. Maks 30% av total-nitrogen i daglig fôrrasjon skal komme fra urea. Tilvenningen til fôring med urea opp til største tillatte mengde må skje gradvis. Andel råprotein fra urea er: 4,35%.

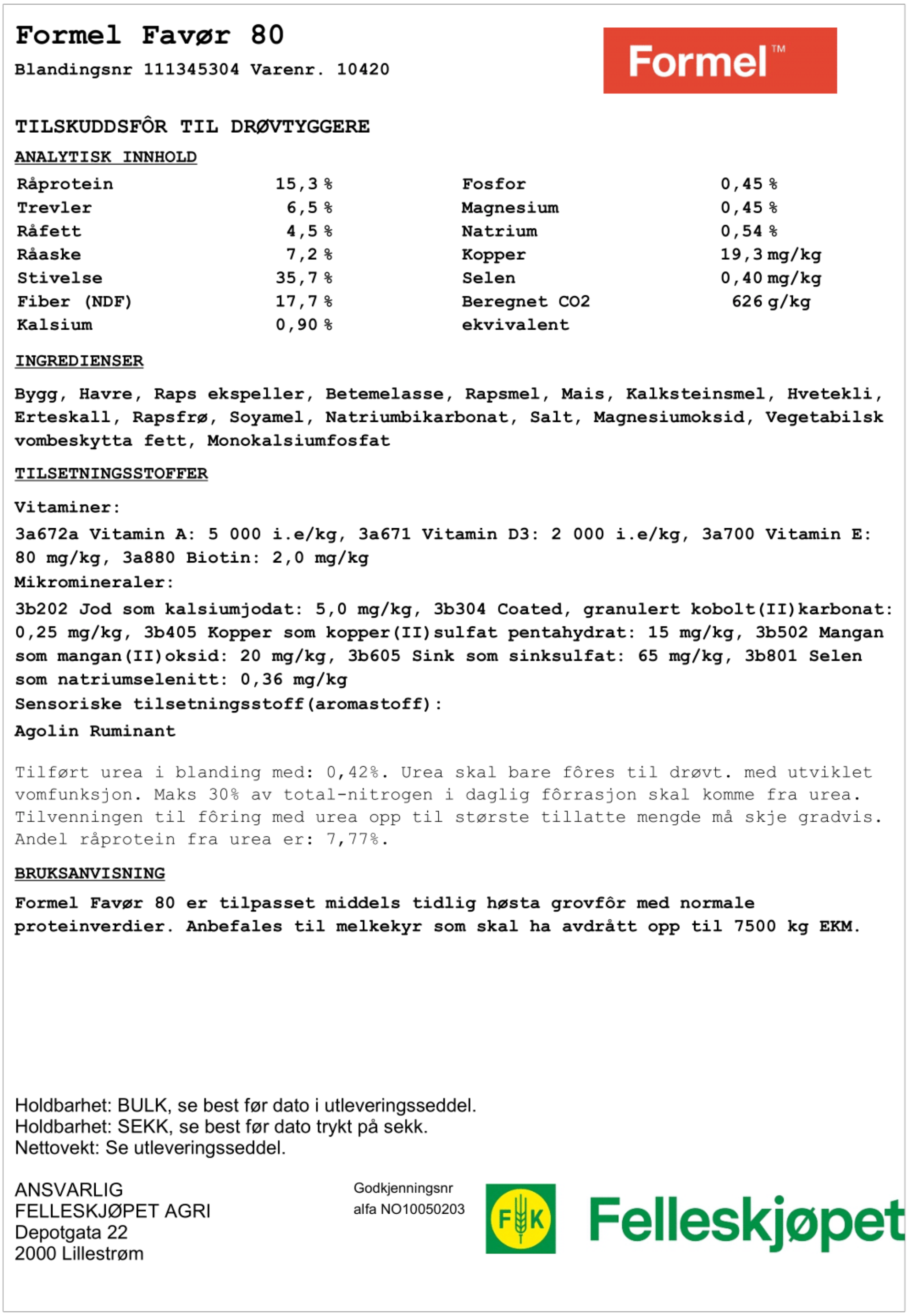
**BRUKSANVISNING**

Formel Elite 80 er tilpasset middels tidlig høsta grovfôr med normale proteinverdier. Anbefales til melkekyr som skal ha avdrått på ca. 7000-8500 kg EKM.

Holdbarhet: BULK, se best før dato i utleveringsseddel.
Holdbarhet: SEKK, se best før dato trykt på sekk.
Nettovekt: Se utleveringsseddel.

ANSVARLIG
FELLESKJØPET AGRI
Depotgata 22
2000 Lillestrøm

Godkjenningsnr
alfa NO10050203



# Formel Favør 80

Blandingsnr 111345304 Varenr. 10420

Formel™

## TILSKUDDSFÔR TIL DRØVTYGGERE

**ANALYTISK INNHOLD**

| | | | |
|---|---|---|---|
| Råprotein | 15,3 % | Fosfor | 0,45 % |
| Trevler | 6,5 % | Magnesium | 0,45 % |
| Råfett | 4,5 % | Natrium | 0,54 % |
| Råaske | 7,2 % | Kopper | 19,3 mg/kg |
| Stivelse | 35,7 % | Selen | 0,40 mg/kg |
| Fiber (NDF) | 17,7 % | Beregnet CO2 ekvivalent | 626 g/kg |
| Kalsium | 0,90 % | | |

**INGREDIENSER**

Bygg, Havre, Raps ekspeller, Betemelasse, Rapsmel, Mais, Kalksteinsmel, Hvetekli, Erteskall, Rapsfrø, Soyamel, Natriumbikarbonat, Salt, Magnesiumoksid, Vegetabilsk vombeskytta fett, Monokalsiumfosfat

**TILSETNINGSSTOFFER**

**Vitaminer:**

3a672a Vitamin A: 5 000 i.e/kg, 3a671 Vitamin D3: 2 000 i.e/kg, 3a700 Vitamin E: 80 mg/kg, 3a880 Biotin: 2,0 mg/kg

**Mikromineraler:**

3b202 Jod som kalsiumjodat: 5,0 mg/kg, 3b304 Coated, granulert kobolt(II)karbonat: 0,25 mg/kg, 3b405 Kopper som kopper(II)sulfat pentahydrat: 15 mg/kg, 3b502 Mangan som mangan(II)oksid: 20 mg/kg, 3b605 Sink som sinksulfat: 65 mg/kg, 3b801 Selen som natriumselenitt: 0,36 mg/kg

**Sensoriske tilsetningsstoff(aromastoff):**

Agolin Ruminant

Tilført urea i blanding med: 0,42%. Urea skal bare fôres til drøvt. med utviklet vomfunksjon. Maks 30% av total-nitrogen i daglig fôrrasjon skal komme fra urea. Tilvenningen til fôring med urea opp til største tillatte mengde må skje gradvis. Andel råprotein fra urea er: 7,77%.

**BRUKSANVISNING**

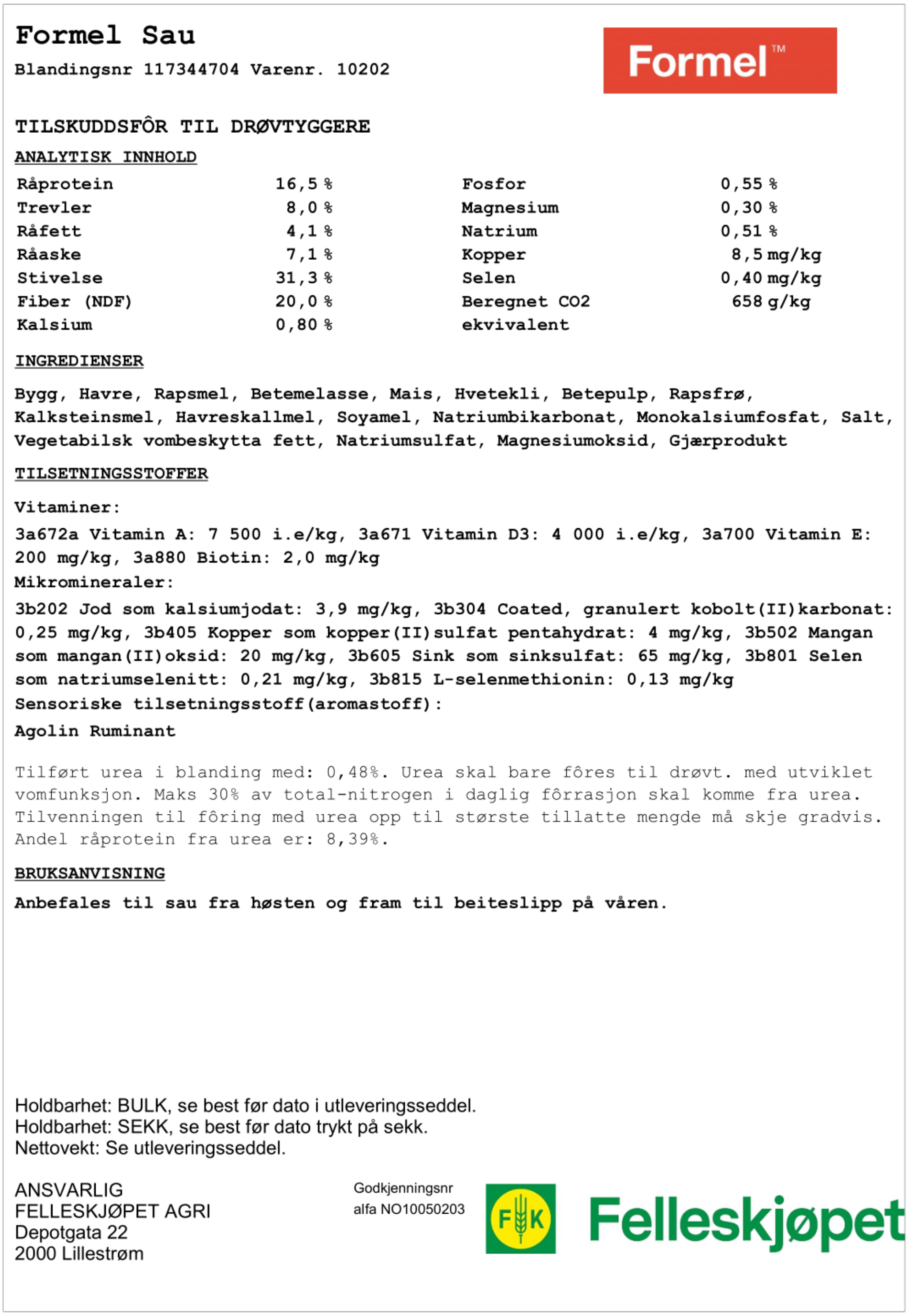
Formel Favør 80 er tilpasset middels tidlig høsta grovfôr med normale proteinverdier. Anbefales til melkekyr som skal ha avdrått opp til 7500 kg EKM.

Holdbarhet: BULK, se best før dato i utleveringsseddel.
Holdbarhet: SEKK, se best før dato trykt på sekk.
Nettovekt: Se utleveringsseddel.

ANSVARLIG
FELLESKJØPET AGRI
Depotgata 22
2000 Lillestrøm

Godkjenningsnr
alfa NO10050203

Felleskjøpet



## Formel Sau

Blandingsnr 117344704 Varenr. 10202

Formel™

### TILSKUDDSFÔR TIL DRØVTYGGERE

**ANALYTISK INNHOLD**

| | | | |
|---|---|---|---|
| Råprotein | 16,5 % | Fosfor | 0,55 % |
| Trevler | 8,0 % | Magnesium | 0,30 % |
| Råfett | 4,1 % | Natrium | 0,51 % |
| Råaske | 7,1 % | Kopper | 8,5 mg/kg |
| Stivelse | 31,3 % | Selen | 0,40 mg/kg |
| Fiber (NDF) | 20,0 % | Beregnet CO2 ekvivalent | 658 g/kg |
| Kalsium | 0,80 % | | |

**INGREDIENSER**

Bygg, Havre, Rapsmel, Betemelasse, Mais, Hvetekli, Betepulp, Rapsfrø, Kalksteinsmel, Havreskallmel, Soyamel, Natriumbikarbonat, Monokalsiumfosfat, Salt, Vegetabilsk vombeskytta fett, Natriumsulfat, Magnesiumoksid, Gjærprodukt

**TILSETNINGSSTOFFER**

Vitaminer:

3a672a Vitamin A: 7 500 i.e/kg, 3a671 Vitamin D3: 4 000 i.e/kg, 3a700 Vitamin E: 200 mg/kg, 3a880 Biotin: 2,0 mg/kg

Mikromineraler:

3b202 Jod som kalsiumjodat: 3,9 mg/kg, 3b304 Coated, granulert kobolt(II)karbonat: 0,25 mg/kg, 3b405 Kopper som kopper(II)sulfat pentahydrat: 4 mg/kg, 3b502 Mangan som mangan(II)oksid: 20 mg/kg, 3b605 Sink som sinksulfat: 65 mg/kg, 3b801 Selen som natriumselenitt: 0,21 mg/kg, 3b815 L-selenmethionin: 0,13 mg/kg

Sensoriske tilsetningsstoff(aromastoff):

Agolin Ruminant

Tilført urea i blanding med: 0,48%. Urea skal bare fôres til drøvt. med utviklet vomfunksjon. Maks 30% av total-nitrogen i daglig fôrrasjon skal komme fra urea. Tilvenningen til fôring med urea opp til største tillatte mengde må skje gradvis. Andel råprotein fra urea er: 8,39%.

**BRUKSANVISNING**

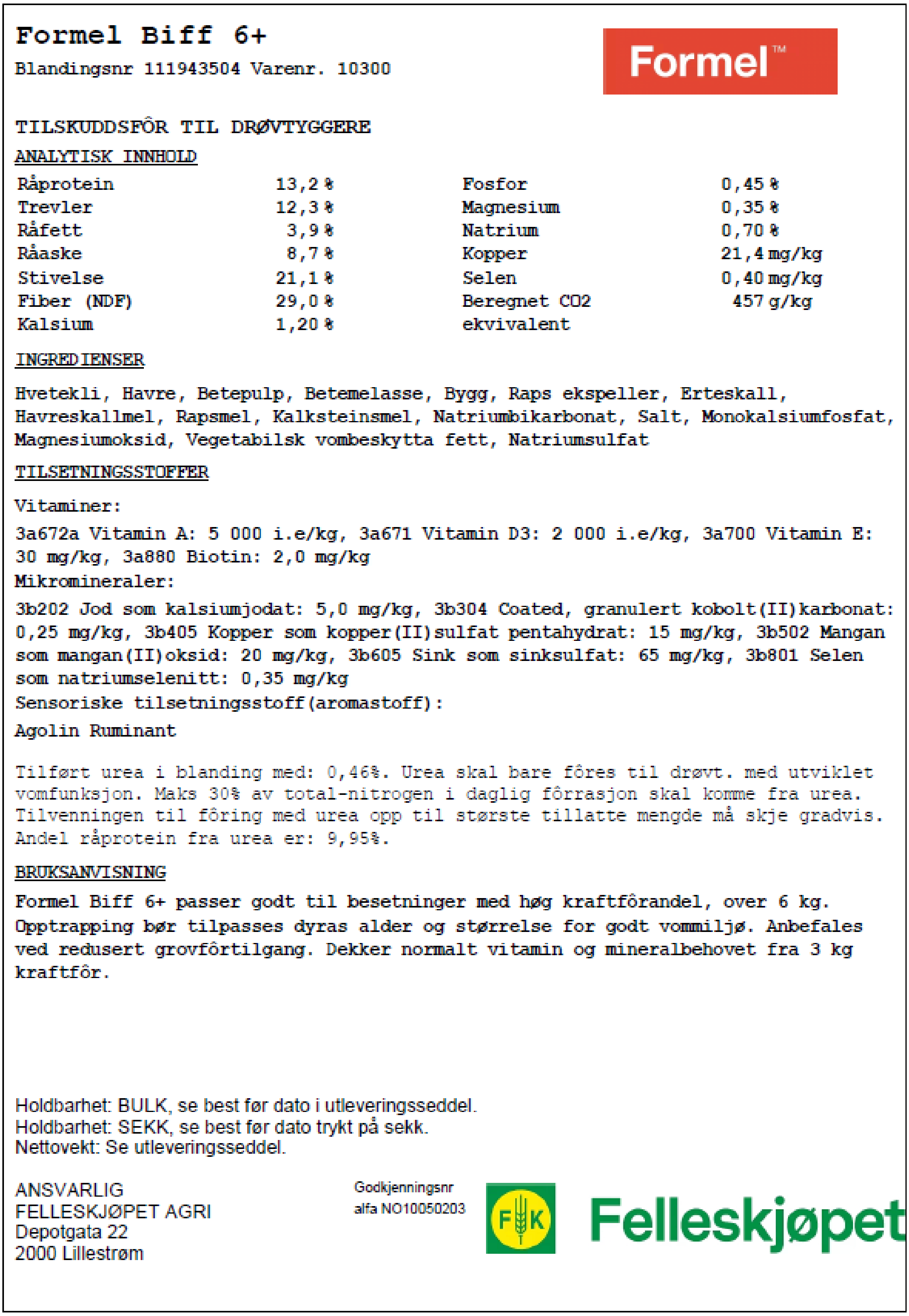
Anbefales til sau fra høsten og fram til beiteslipp på våren.

Holdbarhet: BULK, se best før dato i utleveringsseddel.
Holdbarhet: SEKK, se best før dato trykt på sekk.
Nettovekt: Se utleveringsseddel.

ANSVARLIG
FELLESKJØPET AGRI
Depotgata 22
2000 Lillestrøm

Godkjenningsnr
alfa NO10050203

FK Felleskjøpet



## Formel Biff 6+

Blandingsnr 111943504 Varenr. 10300

Formel™

TILSKUDDSFÔR TIL DRØVTYGGERE

ANALYTISK INNHOLD

| | | | |
|---|---|---|---|
| Råprotein | 13,2 % | Fosfor | 0,45 % |
| Trevler | 12,3 % | Magnesium | 0,35 % |
| Råfett | 3,9 % | Natrium | 0,70 % |
| Råaske | 8,7 % | Kopper | 21,4 mg/kg |
| Stivelse | 21,1 % | Selen | 0,40 mg/kg |
| Fiber (NDF) | 29,0 % | Beregnet CO2 ekvivalent | 457 g/kg |
| Kalsium | 1,20 % | | |

INGREDIENSER

Hvetekli, Havre, Betepulp, Betemelasse, Bygg, Raps ekspeller, Erteskall, Havreskallmel, Rapsmel, Kalksteinsmel, Natriumbikarbonat, Salt, Monokalsiumfosfat, Magnesiumoksid, Vegetabilsk vombeskytta fett, Natriumsulfat

TILSETNINGSSTOFFER

Vitaminer:

3a672a Vitamin A: 5 000 i.e/kg, 3a671 Vitamin D3: 2 000 i.e/kg, 3a700 Vitamin E: 30 mg/kg, 3a880 Biotin: 2,0 mg/kg

Mikromineraler:

3b202 Jod som kalsiumjodat: 5,0 mg/kg, 3b304 Coated, granulert kobolt(II)karbonat: 0,25 mg/kg, 3b405 Kopper som kopper(II)sulfat pentahydrat: 15 mg/kg, 3b502 Mangan som mangan(II)oksid: 20 mg/kg, 3b605 Sink som sinksulfat: 65 mg/kg, 3b801 Selen som natriumselenitt: 0,35 mg/kg

Sensoriske tilsetningsstoff(aromastoff):

Agolin Ruminant

Tilført urea i blanding med: 0,46%. Urea skal bare fôres til drøvt. med utviklet vomfunksjon. Maks 30% av total-nitrogen i daglig fôrrasjon skal komme fra urea. Tilvenningen til fôring med urea opp til største tillatte mengde må skje gradvis. Andel råprotein fra urea er: 9,95%.

BRUKSANVISNING

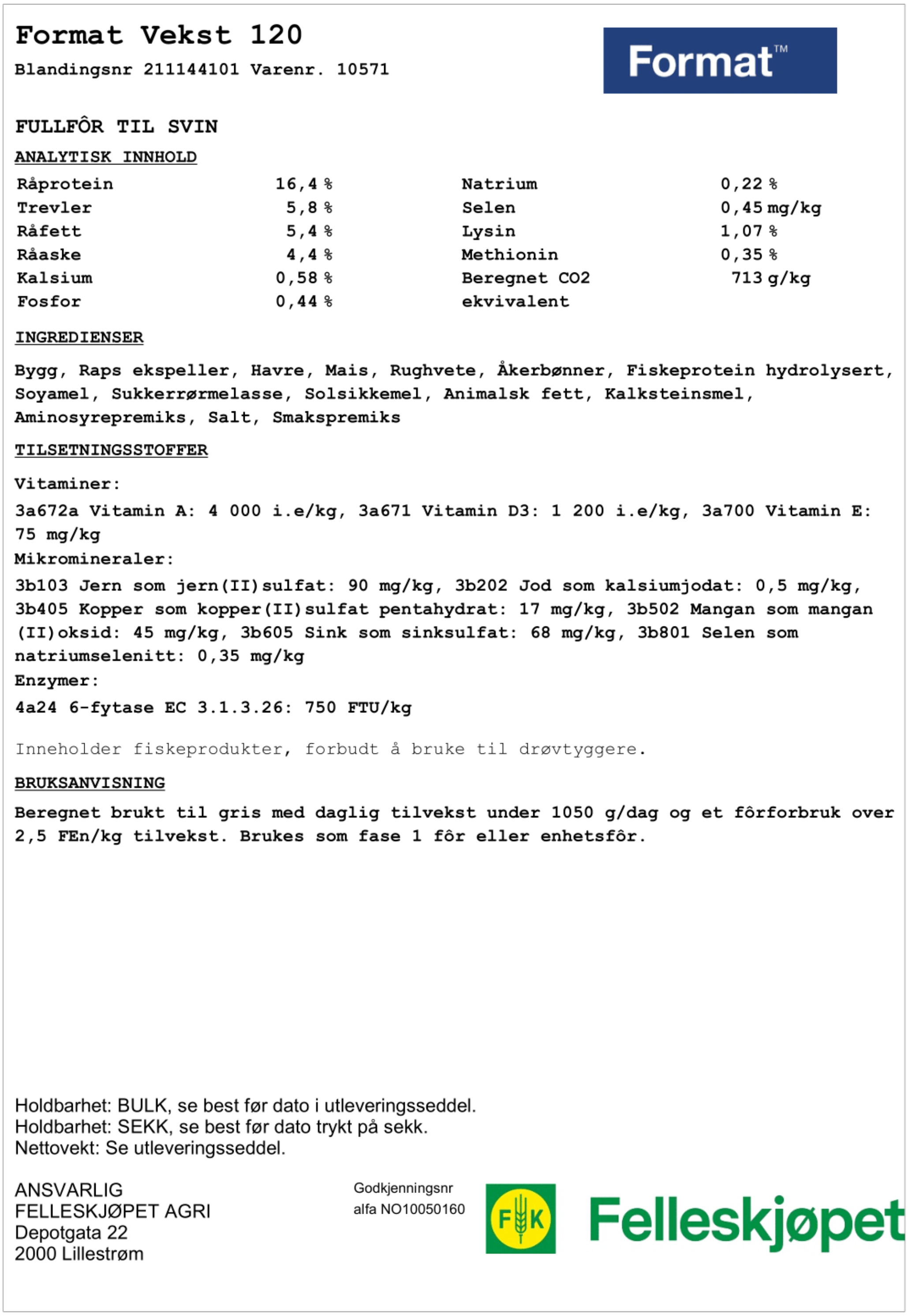
Formel Biff 6+ passer godt til besetninger med høg kraftfôrandel, over 6 kg. Opptrapping bør tilpasses dyras alder og størrelse for godt vommiljø. Anbefales ved redusert grovfôrtilgang. Dekker normalt vitamin og mineralbehovet fra 3 kg kraftfôr.

Holdbarhet: BULK, se best før dato i utleveringsseddel.
Holdbarhet: SEKK, se best før dato trykt på sekk.
Nettovekt: Se utleveringsseddel.

ANSVARLIG
FELLESKJØPET AGRI
Depotgata 22
2000 Lillestrøm

Godkjenningsnr
alfa NO10050203

FK Felleskjøpet



## Format Vekst 120

**Blandingsnr 211144101 Varenr. 10571**

### FULLFÔR TIL SVIN

**ANALYTISK INNHOLD**

| | | | |
|---|---|---|---|
| Råprotein | 16,4 % | Natrium | 0,22 % |
| Trevler | 5,8 % | Selen | 0,45 mg/kg |
| Råfett | 5,4 % | Lysin | 1,07 % |
| Råaske | 4,4 % | Methionin | 0,35 % |
| Kalsium | 0,58 % | Beregnet CO2 ekvivalent | 713 g/kg |
| Fosfor | 0,44 % | | |

**INGREDIENSER**

**Bygg, Raps ekspeller, Havre, Mais, Rughvete, Åkerbønner, Fiskeprotein hydrolysert, Soyamel, Sukkerrørmelasse, Solsikkemel, Animalsk fett, Kalksteinsmel, Aminosyrepremiks, Salt, Smakspremiks**

**TILSETNINGSSTOFFER**

**Vitaminer:**

**3a672a Vitamin A: 4 000 i.e/kg, 3a671 Vitamin D3: 1 200 i.e/kg, 3a700 Vitamin E: 75 mg/kg**

**Mikromineraler:**

**3b103 Jern som jern(II)sulfat: 90 mg/kg, 3b202 Jod som kalsiumjodat: 0,5 mg/kg, 3b405 Kopper som kopper(II)sulfat pentahydrat: 17 mg/kg, 3b502 Mangan som mangan (II)oksid: 45 mg/kg, 3b605 Sink som sinksulfat: 68 mg/kg, 3b801 Selen som natriumselenitt: 0,35 mg/kg**

**Enzymer:**

**4a24 6-fytase EC 3.1.3.26: 750 FTU/kg**

Inneholder fiskeprodukter, forbudt å bruke til drøvtyggere.

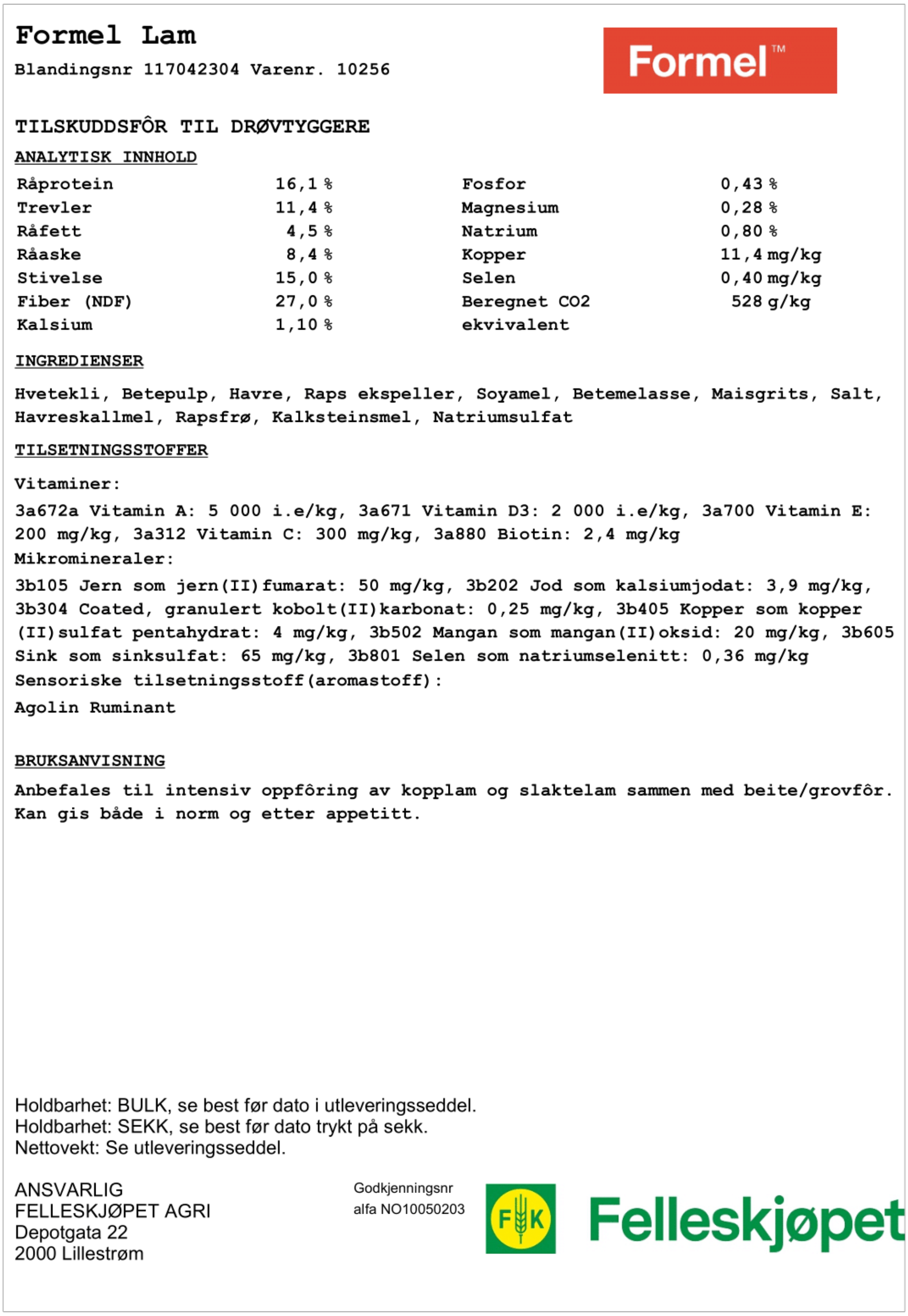
**BRUKSANVISNING**

**Beregnet brukt til gris med daglig tilvekst under 1050 g/dag og et fôrforbruk over 2,5 FEn/kg tilvekst. Brukes som fase 1 fôr eller enhetsfôr.**

Holdbarhet: BULK, se best før dato i utleveringsseddel.
Holdbarhet: SEKK, se best før dato trykt på sekk.
Nettovekt: Se utleveringsseddel.

ANSVARLIG
FELLESKJØPET AGRI
Depotgata 22
2000 Lillestrøm

Godkjenningsnr
alfa NO10050160



# Formel Lam

Blandingsnr 117042304 Varenr. 10256

## TILSKUDDSFÔR TIL DRØVTYGGERE

### ANALYTISK INNHOLD

| | | | |
|---|---|---|---|
| Råprotein | 16,1 % | Fosfor | 0,43 % |
| Trevler | 11,4 % | Magnesium | 0,28 % |
| Råfett | 4,5 % | Natrium | 0,80 % |
| Råaske | 8,4 % | Kopper | 11,4 mg/kg |
| Stivelse | 15,0 % | Selen | 0,40 mg/kg |
| Fiber (NDF) | 27,0 % | Beregnet CO2 ekvivalent | 528 g/kg |
| Kalsium | 1,10 % | | |

### INGREDIENSER

Hvetekli, Betepulp, Havre, Raps ekspeller, Soyamel, Betemelasse, Maisgrits, Salt, Havreskallmel, Rapsfrø, Kalksteinsmel, Natriumsulfat

### TILSETNINGSSTOFFER

Vitaminer:

3a672a Vitamin A: 5 000 i.e/kg, 3a671 Vitamin D3: 2 000 i.e/kg, 3a700 Vitamin E: 200 mg/kg, 3a312 Vitamin C: 300 mg/kg, 3a880 Biotin: 2,4 mg/kg

Mikromineraler:

3b105 Jern som jern(II)fumarat: 50 mg/kg, 3b202 Jod som kalsiumjodat: 3,9 mg/kg, 3b304 Coated, granulert kobolt(II)karbonat: 0,25 mg/kg, 3b405 Kopper som kopper (II)sulfat pentahydrat: 4 mg/kg, 3b502 Mangan som mangan(II)oksid: 20 mg/kg, 3b605 Sink som sinksulfat: 65 mg/kg, 3b801 Selen som natriumselenitt: 0,36 mg/kg

Sensoriske tilsetningsstoff(aromastoff):

Agolin Ruminant

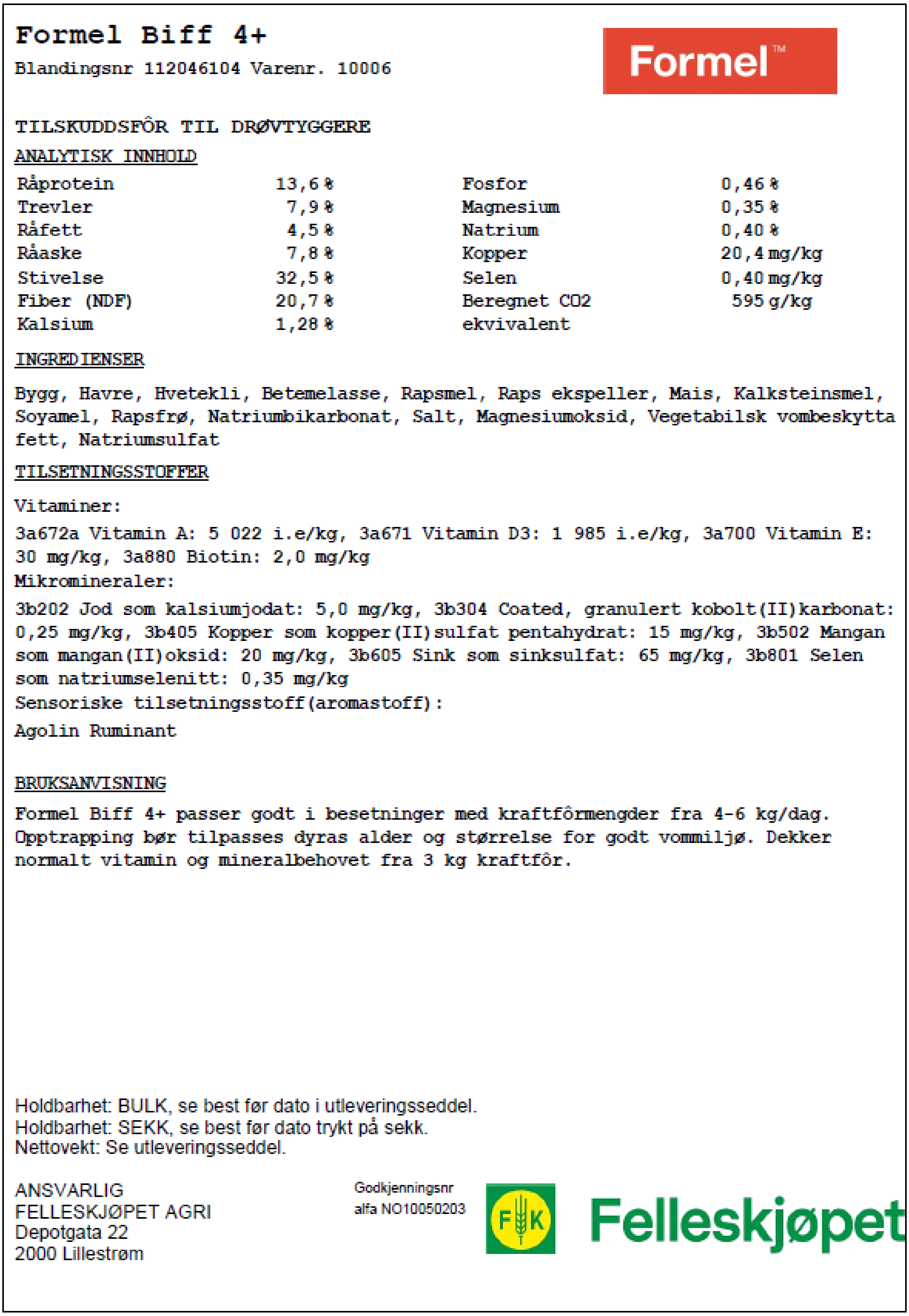
### BRUKSANVISNING

Anbefales til intensiv oppfôring av kopplam og slaktelam sammen med beite/grovfôr. Kan gis både i norm og etter appetitt.

Holdbarhet: BULK, se best før dato i utleveringsseddel.
Holdbarhet: SEKK, se best før dato trykt på sekk.
Nettovekt: Se utleveringsseddel.

ANSVARLIG
FELLESKJØPET AGRI
Depotgata 22
2000 Lillestrøm

Godkjenningsnr
alfa NO10050203



# Formel Biff 4+

Blandingsnr 112046104 Varenr. 10006

Formel™

TILSKUDDSFÔR TIL DRØVTYGGERE

ANALYTISK INNHOLD

| | | | |
|---|---|---|---|
| Råprotein | 13,6 % | Fosfor | 0,46 % |
| Trevler | 7,9 % | Magnesium | 0,35 % |
| Råfett | 4,5 % | Natrium | 0,40 % |
| Råaske | 7,8 % | Kopper | 20,4 mg/kg |
| Stivelse | 32,5 % | Selen | 0,40 mg/kg |
| Fiber (NDF) | 20,7 % | Beregnet CO2 ekvivalent | 595 g/kg |
| Kalsium | 1,28 % | | |

INGREDIENSER

Bygg, Havre, Hvetekli, Betemelasse, Rapsmel, Raps ekspeller, Mais, Kalksteinsmel, Soyamel, Rapsfrø, Natriumbikarbonat, Salt, Magnesiumoksid, Vegetabilsk vombeskytta fett, Natriumsulfat

TILSETNINGSSTOFFER

Vitaminer:

3a672a Vitamin A: 5 022 i.e/kg, 3a671 Vitamin D3: 1 985 i.e/kg, 3a700 Vitamin E: 30 mg/kg, 3a880 Biotin: 2,0 mg/kg

Mikromineraler:

3b202 Jod som kalsiumjodat: 5,0 mg/kg, 3b304 Coated, granulert kobolt(II)karbonat: 0,25 mg/kg, 3b405 Kopper som kopper(II)sulfat pentahydrat: 15 mg/kg, 3b502 Mangan som mangan(II)oksid: 20 mg/kg, 3b605 Sink som sinksulfat: 65 mg/kg, 3b801 Selen som natriumselenitt: 0,35 mg/kg

Sensoriske tilsetningsstoff(aromastoff):

Agolin Ruminant

BRUKSANVISNING

Formel Biff 4+ passer godt i besetninger med kraftfôrmengder fra 4-6 kg/dag. Opptrapping bør tilpasses dyras alder og størrelse for godt vommiljø. Dekker normalt vitamin og mineralbehovet fra 3 kg kraftfôr.

Holdbarhet: BULK, se best før dato i utleveringsseddel.
Holdbarhet: SEKK, se best før dato trykt på sekk.
Nettovekt: Se utleveringsseddel.

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FK

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