PROJECT X

FEED-X

Climate-KIC

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# Category De-Risking

Summary

PUBLICALLY AVAILABLE

# Innovation to Transform the Feed Industry

# Acknowledgements

The following report is a summary of 7 studies that have brought together the opinions and assessment of industry and academic leads. We would like to express our gratitude to all those that have made contributions to the FEED-X project so far, but especially to the seven research teams that have conducted the assessments, the many peer reviewers that have provided key comments on these reports as well as the four organisations that have supported the work so far;

- WWF
- Skretting
- EIT Climate KIC
- IKEA

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The reports that fed into this report were extensively reviewed and this integrated analysis was reviewed by:
Dr Piers Hart, WWF, Cristina Torres, WWF CL, Dr Jenna Boywer, Skretting Global, Christoph Mathiesen IKEA SE, Frédéric Févé, Family Office Investment and Daniel Peon IADB.

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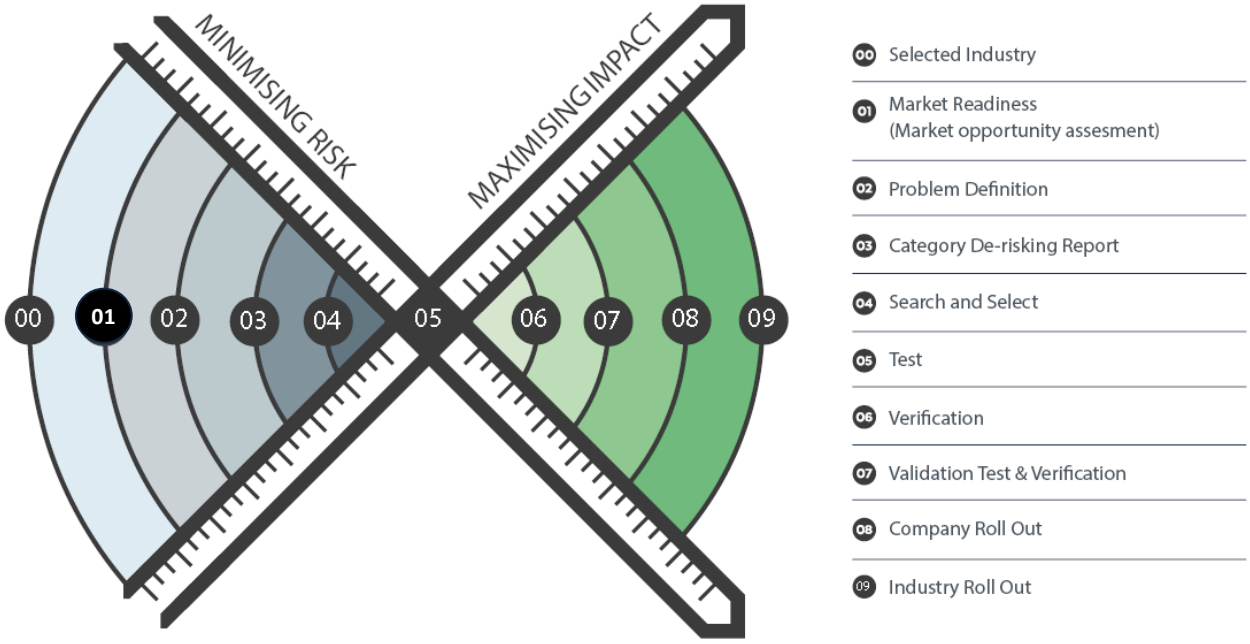
# Contents

## The Organisation

Project X was incubated in WWF in 2015 to enable value chain transformation by increasing the speed and scale at which entire industries transition in their sustainability agendas. Since February 2018 Project X has been established as a B Corp [1] that still works closely with WWF.

Our mission is to transform the sustainability performance of ten industry value chains most responsible for biodiversity decline and climate change impacts, in ten years. We work on the premise that no single organisation or sector can tackle industry-wide change on their own. Project X has taken a leadership position to bring together the relevant corporates, financiers, investors, insurers, innovators, NGOs and scientists (and, in the near future, governments and regulatory bodies) to collaborate and transparently generate and adopt replicable and scalable solutions, fast.

We provide a solution, which is scientifically researched, reviewed and tested, and which offers systemic impact, thus embedding long-term sustainability in it. We do this through a proven market-pull approach with a number of core activities, detailed here:




Minimising Risk (stages 0-4) – We first secure advanced commitment from a lead corporate (major player in the industry) to procure sustainable solutions at scale. We then invest heavily in independent analysis experts to unpick the value chain and examine diverse risks to the adoption of various sustainable solutions. A short-list of solution types suitable for pilot testing is identified and those providers are invited to pitch their solutions to a selection panel. This is all undertaken transparently to ensure industry-wide buy-in and consensus on the most appropriate and sustainable solutions.

Maximising Impact (stages 5-9) – We short-list the highest performing solutions, which are tested at scale by the lead corporate, with ensuing results demonstrated and independently verified. The lead corporate is given first mover advantage on the evidenced solutions, following which we collate expressions of interest from other interested corporations. Advance market commitment from corporations accelerates the price performance of the sustainable solutions, compared with business-as-usual technologies, to further encourage industry-wide adoption.

1 B Corp pending Status obtained January 2019. B Corp Certification to be awarded May 2019.

Knowledge Exchange – Cross-cutting the whole programme is a module of Knowledge Exchange, which engages the wider value chain early in the process. This enables Project X to understand the problem from various perspectives along the value chain, uncover sustainability risks and opportunities, promote results, coordinate testing of the solutions at different sections of the value chain and share learnings, thus accelerating wider adoption and shift 10% of the industry. We aim to roll out industry adoption as soon as the lead adopter is up and running, so that companies representing 10% of an industry (i.e. with enough significant purchasing power to pull the market through sustainable procurement) can adopt solutions previously determined, tested and demonstrated by the lead corporate adopter.

This report summarises the results of researchers exploring risk from 6 different perspectives. The results were explored by external reviewers from the finance community asking; "has risk been dealt with sufficiently to enable adoption of the category" or enable the shift from the current category of raw material or technology to a novel category, one that has a higher sustainability performance than business as usual. Their conclusion was positive; the sustainability index presented here was considered very rigorous and comprehensive.

## The FEED-X Need and Opportunity

The problem: Feeding the world's growing population under conditions of climate change may be the biggest challenge humanity has ever faced. A significant, and often overlooked, issue in the food system is the scale and inefficiency of feed production for livestock, where animals are fed more protein than the protein they gain through growth. This has a huge cost to the planet and climate change: 1bn tonnes of feed is produced globally, accounting for over 40% of total plant protein grown (e.g. soybean) and 16% of global fish capture. While aquaculture companies have reduced their dependence on fishmeal since the 90s (65% to 16%), fishmeal has been replaced by soybean protein, which is a big driver of deforestation (17 to 46 million hectares between 1990-2010 in South America[2]).

The need: The next 11 years leading up to 2030 is the most critical time humanity has ever faced. To reduce the ecological footprint of the feed industry we need a systemic shift: from feed pellets containing fish, soy protein and fish oil as the source of Omega 3, to sustainable sources including algae and insects as alternative protein sources. Work is being done to innovate and adopt new approaches, technologies and solutions, but change is not happening quick enough to address the climate change and biodiversity crises we are facing in a timely manner. There are a number of barriers to the fast and scaled adoption of the most appropriate (sustainable, efficient, effective) solutions. The Project X model addresses each of the barriers, enabling change at the pace the planet needs it.

The opportunity: Nutreco-Skretting[3] ("Skretting"), representing 35% of the salmon industry and 10% of the shrimp industry feed production (£4.5bn procurement power), expressed an economic and reputational need to source alternative Omega 3 solutions. Project X has already obtained and contracted advanced market commitment from Skretting to identify and transparently test, at scale, alternative sustainable feed solutions for the aquaculture industry – FEED-X. Skretting also committed to supporting FEED X to shift 10% of the feed industry (representing 107 tonnes) through to sustainable purchasing, focusing primarily on alternative sustainable protein and oils. However, to get this broader industry adoption, we need to engage other players along the value chain in addition to

[2] WWF, 2014

[3] Nutreco-Skretting represents 35% of the salmon feed industry segment and 10% of the shrimp feed industry segment and has a £4.5b procurement power.

the lead corporate adopter, Skretting. This will be through the process of knowledge exchange, supported by key foundations and knowledge partners.

Why it is timely: Fish consumption provides 3 billion people with 15% of their average intake of protein. Europe constituted 35% of the seafood market in 2007, but only 10% of world population – highlighting the potential in other regions to increase per capita consumption. Based on expected income growth, there will be a seafood deficit of around 79 million tonnes by 2030. Aquaculture could be an alternative to satisfy the increased demand for fish proteins[4]. However, aquaculture needs to be (a) healthy/good for human consumption (b) sustainable, so as not to further deplete the planet's ecosystem.

Our approach

Our approach is based on minimising the risk of purchasing at a system's level to scale of adoption of sustainable alternatives in the value chain. This includes minimising the risk for the buyers, the investors, the financiers, the innovators, the NGOs, the donors. To do this we look at the value chain as a whole and independently assess key intervention points and impact areas for biodiversity and climate that could be addressed through procurement. We work with the best researchers in their fields, at a global level, to independently assess the potential alternatives that could be procured by the lead corporates in the industry, helping them to move from unsustainable dollar procured to sustainable dollars procured. We undertake an objective and transparent peer review of critical risks that could negatively impact the adoption of the potential alternatives, at scale. Main areas of risk consider among other, economic, environmental, social, ethical, nutritional, value chain adaptability, legal / policy. We also look at the insurability potential of the new alternatives to reduce the risk of scaling at the appropriate price points.

- We reduce the risk of trading, accelerating the demonstration (real life environment) of independently assessed sustainable alternatives. We reduce the risk of trading by providing independent, objective and transparent analysis of the performance of the sustainable alternatives – 7 perspectives (economic, environmental, social, ethical, nutritional, value chain adaptability, legal / policy)
- We reduce the risk of trading by identifying the best innovations able to address the key challenges of our planet and the needs of the corporate, within the approved categories.
- We reduce the risk of trading by mobilising the first commercial exchange of value between buyers and suppliers of sustainable alternatives – starting with low complexity / low impact test, moving to a large scale procurement for successful and externally validated innovations
- We reduce the risk of trading by mobilising the funds for both innovators and buyers as well as the commercialisation, ensuring early market commitment to procure.
- We reduce the risk of trading by providing investors and financiers with a low risk pipeline of innovations with guaranteed access to market
- We reduce the risk of trading by adding credible and novel insurance models into the programme

An independent, objective and transparent assessment of the sustainable alternatives will enable the buyer to shift and confidently procure large volumes. We have a robust 9-stage model. Our core model has been tried and tested at RBS and Cummins, providing us with innumerable insights and knowledge, critical to an effective execution.

The Project X de-risking methodology is a crucial enabler for the broader scaling up and industry adoption, since it focuses on de-risking (minimising the risks) the adoption of innovations at scale, at a

[4] Source: PriceWaterhouseCoopers Market readiness report (2018)

system's level. It secures early commitment to sustainable purchasing from the value chain and then continues until the scale-up (10% of industry) is successful. Since it is based on market demand, once risk is decreased and benefits proven, wider adoption should happen.

## The Category De-risking stage

Category De-risking is a fundamental step in every Project X programme to help define what are the most sustainable, scalable and investible solutions before entering into the search and selection phase for SMEs that can fit the brief for the industry. This stage is both a research and engagement tool in that it that works with corporations, financiers and academics to research, analyse and drive consensus on a clear set of recommendations for the best solutions to solve industry challenges, on a category or thematic level which were defined in stage 2, the problem definition and value chain assessment stage.

This stage seeks to allow adoption to take place

- FEED Buyers in Skretting-Nutreco
- Feed buyers in 10% of industry

This stage enables key communities to meet their risk assessments

- Finance/investor community finance the innovations selected
- Insurance community insure the innovations selected
- Retailers purchase more sustainable fish and shrimps

Each research theme seeks to understand risks posed by scaling up innovations with the greatest potential to deliver sustainability gains in the feed value chain by looking at risk across six themes: environmental, nutritional, ethical, social acceptability, economic, and political. The results allow Project X to identify a short list of innovations, evaluate and scale the best in class SMEs

### Definitions

CATEGORY: is a lack or a needs outcome statement that describes the intervention into the system opening the door for innovation.

CATEGORY DE-RISKING: Is the assessment of risks posed by scaling-up innovations, which have the greatest potential to deliver sustainability gains in the value chain across 6 themes or lenses.

Categories to be de-risked by all 6 lenses were the following:

### I FEED INGREDIENT CATEGORIES:

Applicable to Salmon and Shrimp feed; while also avoiding negative impacts associated with less sustainable ingredients (e.g. GHG emissions and BD loss), and promote positive environmental outcomes.

a) Nutritional solutions creating net positive environmental effects using secure by-products from the food industry, including but not limited to: food co-products, CO2 and energy.
b) Nutritional solutions creating the health effects equal to or greater than fatty acids (e.g. DHA-EPA)
c) Nutritional solutions using inputs that create environmentally restorative effects

### II FEED PRODUCTION CATEGORIES:

Applicable to Salmon and Shrimp feed: Feed use efficiency through innovations that directly avoid negative environmental impacts i.e. GHG emissions and BD loss associated with feed production processes in factories.

d) Technology solutions creating net positive effects using renewable energy, packaging waste, energy waste, sustainable transport.

## III FEED PERFORMANCE CATEGORIES:

Applicable to Salmon and Shrimp feed; while also improving feed use efficiency through solutions that indirectly avoid negative impacts associated with salmon and shrimp production systems (e.g. GHG emissions and BD loss), and promote positive environmental outcomes.

e) Technology solutions increasing the health, survival and growth performance of the fish/shrimp
f) Integrated information systems solutions increasing feed waste efficiencies
g) Innovations moving the whole farm production foot print off land

These 7 innovation categories formed a common analytical framework whereby risk could be assessed systematically from 6 perspectives or lenses. The wildcard option was left as an open innovation category to capture the unknown-unknown innovations.

The risk lenses, or themes involved, are:

- Political/legal: Assessment compliance to national and international laws (EU, USA perspective) enabling or restricting feed alternatives, assessing their affect on the uptake of innovation, or the compliance of technological advances that could affect feed.
- Social acceptability: The awareness and acceptance of the global consumer and the buyers and the retailers that represent those views.
- Environmental: Assessed the environmental risk assessment and impact (Life Cycle assessment) of alternative feeds through a thorough assessment of selected feed-ingredient alternatives
- Nutritional: Assessed the nutritional risk assessment and impact of alternative feeds through a thorough assessment of selected feed-ingredients from a shrimp and fish perspective
- Economic: To assess the commercial viability of the selected options as compared with BAU and conduct sensitivity analysis (price, volumes, time, functionality/operations).
- Ethical: An overview on animal welfare associated with solutions through process or as an impact of scaling

The results of these 6 assessments were then integrated into a single matrix and scored according to the level of risk using the same category framework. The table shows the deliverables for each of the following lenses. The following section then provides a summary of the results from each of the six-lens assessments and a summary of the integrated findings.

| Overall Stage 3 : Category De-Risking |
| --- |
| AIM: to adequately assess selected alternative feed-ingredient challenger solutions (for salmon and shrimp) against selected existing feed-ingredients currently in use and assess technologies that may reduce feed requirements |

| Deliverables across the 6 lenses (and possible other hidden lens) | | | | | |
|---|---|---|---|---|---|
| Nutritional assessment | Environmental assessment | Legal Compliance (policy) | Ethical Risk | Social Acceptability | Economic Assessment |
| Key outcomes: Understand the nutritional risk assessment and impact of alternative feeds through a thorough assessment of selected feed-ingredients from human and fish perspective | Key outcomes: Understand the environmental risk assessment and impact (Life Cycle assessment) of alternative feeds through a thorough assessment of selected feed-ingredient alternatives | Key outcomes: Identification (screening) of national and international trade regulations affecting feed alternatives Identification of national and international enabling or restrictive policies that may affect feed alternatives, assessing their affect on the key countries/regions (EU, USA) | Key outcomes: Increased understanding of incumbent (fish meal, fish oil, vegetable meal, and vegetable oils) and challenger feed-ingredients from 3 important ethical lenses: 1. Animal welfare considerations: i.e. impact of new feeds on animals etc. 2. Social well being: effects on livelihoods - trade-offs associated with replacing one feed-ingredient industry with another Human rights: human rights (i.e. labour, slavery corruption) | Key outcomes: Understanding of current consumer perceptions and willingness to engage with issues relating to the food chain in salmon farming and shrimp farming Increased understanding of consumer and societal acceptance of potential new ideas for more sustainable salmon food (and shrimp) Assess whether people are willing to pay more for certified products and/or sustainability premiums | Key outcomes: Understand the economic value generated by developing sustainable salmon feed-ingredients, from the perspectives of the value chain stakeholders An increased understanding of how speeding up the introduction of sustainable ingredients to market creates economic value |
| Integrated Matrices of results<br>Integrates risk across the six lenses and provides an overall combined risk assessment | | | | | |
| Best 3 categories that provided the lowest overall risk rating across the 6 lenses<br>Best performing priority solutions are identified<br>Risk criteria are identified<br>Process of evaluating novel ingredients, raw materials and new technologies is identified | | | | | |
| Engagement with the following communities to get feedback on their perception of risk | | | | | |
| Finance community | Insurance community | Retailer consortium | | | |
| Finalised CDR report | | | | | |
| The combined assessment identifies the categories of solutions most easily adopted due to the risks being adequately assessed for investors to invest, insurers to insure and retail purchasers to purchase | | | | | |

The following section provides the summary of results from each of the 6 lenses.

# Six Lens Assessments

## 1. Environmental Assessment

The environmental lens assesses the potential novel feed ingredients for salmon and shrimp diets and technologies across 7 categories of innovation. These system categories were defined in stages 1 and 2, and resulted in a framework of system categories, categories and priority solution to be de-risked in stage 3. The aim of the environmental de-risking is to give insights on potential risks in the fish feed value chain by highlighting environmental hotspots of novel feed ingredients, according to the principles of Life Cycle Assessment framework. Literature review and experts' judgement are also used to support the analysis.

In this study, 62 priority solutions within 3 categories (or 7 sub-categories) in system category I, Feed ingredients were analysed using 4 different environmental impact criteria: land use, greenhouse gas emissions, water use and energy use. Each priority option was compared to a specific benchmark of an equivalent "conventional" ingredient and assigned a risk classification. System category II, Feed Production and III, Feed Performance were evaluated separately using life cycle criteria and expert judgement.
The following risk levels were defined

- High Risk – C: The criterion is considered relevant and the option will likely perform worst than the established benchmark.
- Moderate Risk – B: The criterion can be significant depending on the context and the option will likely perform very similar to the established benchmark.
- Low Risk – A: The criterion is not considered a relevant issue and the option will likely perform better than the established benchmark.
- Unknown Risk - 0: The environmental impact is unknown and/or sufficient information to assign a score is lacking.

Assuming that availability was not a limiting factor, results indicated food industry by-products have potentially low environmental risk, as novel ingredients, to sustainably substitute conventional ingredients such as soybean meal. Land animal proteins (i.e. slaughterhouse by-products) were also considered a good candidate as protein rich novel ingredients as they were found to have a better environmental profile compared to conventional ingredients, due to being a low (economic) value by-products of the meat industry. Although microbial protein production and insects farming as fish feed ingredients were promising, there were still significant gaps in research to achieve commercial scale. These technologies can be environmentally competitive when microbes and insects grow on waste streams and waste substrates. If that is not the case, the environmental performance is compromised, and it is very likely that food-grade applications for these ingredients have a priority from a market standpoint. Algal oil was the only source of omega fatty acids that could potentially substitute fish oil, should its production be economically viable.

For microbial protein, insect farming and algae farming, the production system configuration is very important and therefore primary input data from innovators is a prerequisite to better understand the systems' performance. Technological advances with regards to increased fish health, survival and growth performance are essential to the viability and environmental sustainability of aquaculture. Aquaculture's environmental performance may increase with the inclusion of renewable energy sources, smart monitoring systems and nutrient cycling.

The greatest challenge was the lack of information and specific system configuration especially on the very new ingredients that is required for LCA assessment. It was also noted by the study that biodiversity related risks were not considered by the LCA assessment methodology, only as a proxy through landuse, which also under evaluated marine environmental impacts.

The study was limited to the production of ingredients ("cradle to gate" scope). In later stages of assessment, its recommended that a fair and complete appreciation of the environmental impact of novel feed ingredients would require the scope to include the full compound feed and animal production system.

A report and supplementary excel file were the main deliverables of the environmental lens for the FEED-X stage 3, category de-risking.

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## 2. Nutritional Assessment

As input for Feed-X stage 3 category de-risking report, the Nutritional lens research focuses on nutritionally assessing the suitability of salmon and shrimp' potential novel feed ingredients/resources (e.g. unconventional feedstuffs of plants or animal origin). The selection of relevant categories to assess was identified by Project X in a previous step to this study and resulted in a listing of system categories, sub-categories and priority examples to be de-risked in stage 3 (Project X, 2018).

Here, eighty-four priority solutions were analysed regarding five fundamental criteria for their suitability as an ingredient/resource in aquafeeds, especially shrimp and salmon: protein concentration, ash concentration, crude fibre concentration, anti-nutritional factors (ANFs) and toxicity. The level of suitability is given for each species and colour coded as: green (suitable), yellow (maybe suitable) and red (not suitable), respectively.

The criteria were combined in the following way:

- Crude protein: percentage where the threshold of 40% was chosen as suitable but if it were lower and it could be processed, it was deemed may be suitable. This was applicable if there was high protein and it had anti-nutritional factors
- It was considered not suitable if crude protein levels were lower than 40% (preference for Salmon is greater than 60%) and there were other criterion that made it unsuitable.
    - Ash content less than or equal to 20% with low crude protein
    - Fibre content less than or equal to 10% with low crude protein
    - Anti-nutritional factors and low protein
    - Toxicity if combined with other anti-nutritional factors and low protein

The results for salmon indicated 32 suitable solutions, 27 maybe suitable solutions and 25, not suitable solutions. For shrimp, 32 solutions were suitable, while 34 were maybe suitable and 18 were not suitable. The designation of "maybe" means that promising solutions might need processing (e.g. extraction) and/or R&D are necessary for its suitability. The evaluation of suitability of each feed nutrient priority solution was based on pre-defined criterion and information withdrawn from literature/databases.

Several key topics were identified for further R&D investment by the salmon and shrimp aquafeed industry and its suppliers:

(i) Processing and the development of efficient/proper nutrient extraction, fractionation and/or concentration methods for specific selected feed ingredients/resources;
(ii) Inactivation and/or extraction methods related to ANFs;
(iii) (solid-state) Fermentation;
(iv) Production of protein hydrolysates;
(v) Further development of the ingredients/resources of non-marine omega-3 fatty acids sources;
(vi) Digestibility of specific feed ingredients; and
(vii) Constraints of specific feed ingredients e.g. maximum inclusion levels related to nutrition or processing e.g. pelletability.

There was a close research collaboration with Blonk Consultants, responsible for FEED-X' Environmental lens.

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## 3. Legal Compliance

The legal report reviewed the legal conditions imposed on alternative, potentially more sustainable feed ingredients, processes, techniques and methods in aquaculture fisheries of salmon and shrimp, taking the EU and the U.S. as an example. Unfortunately, there are as many legal regimes as there are states and blocs of states. Thus, the sheer amount of legislation is staggering. Hence there was a need to limit the legal assessment to two key states and to specific items. With regard to the feed ingredients, the assessment is focused on food and feed safety. For processes, techniques and methods, other legal fields come into play, in particular maritime law.

Assessment criteria:

- Red - Legal compliance is unattainable under the current legal framework. Under the current legal framework it is not possible to get the ingredient/process approved and released on the market.
- Dark Orange - Legal compliance is not attainable in the short term. Neither this ingredient/process, nor a similar ingredient/process, is yet approved.
- Light Orange- Legal compliance is attainable. A similar ingredient/process is approved but the ingredient/process itself is not.
- Green Compliant - this ingredient/process is already legally approved and can enter the market.
- Gray Unknown or insufficient data available - either further research is needed or no legal materials are available.

The assumption was that if a novel ingredient is approved in both US and EU, it will also approved in both America and Asia too.

- Example in terms of Insects, they are permitted in the EU but there are a lot of conditions. In the US, insects are not approved in a federal level, so there is a lot of confusion in a state level.

- Similarly with sludge and manure – these are the red; compliance unattainable in the EU, but completely approved for the US and any potential for cannibalism evokes a red for EU, but green for US.
- NGOs have promoted sustainability, but these are still not legal requirements, but voluntary i.e. ASC and IFFO, RS – labelling is required to provide the assurance.

The key findings were as follows:

- First, that the legal approach for salmon and shrimp is the same. Therefore, it is expected that the legal assessment can also be useful for other aquaculture species.

- Second, it is striking that so many alternatives are already approved and on the market, and therefore easy to introduce in aquaculture both in the EU and the US. Overall, the results show that regulation will frequently not constitute an obstacle to the introduction of alternatives. One should not become overly optimistic though. Where approval is needed, it can be complex and time-consuming. In general, the more novel an ingredient is (e.g. a production that is not commonly used, using special strains of bacteria, yeast, algae and so on), the more complex and time-consuming the legal approval procedure becomes.

- Third, while EU and US legislation are perceived to be very different, the outcomes are frequently the same. Important differences between the EU and the US arise with regard to the use of manure and sludge to feed animals and potential cannibalism. While the EU bans these practices, the US does not.

- Fourth, at the international level, NGOs have added sustainability requirements. However, meeting these requirements is voluntary, and is only visible through labelling.

It was further recommended that:

- Grey category ingredients (insufficient data) should still be considered as potential alternative ingredients that can be further developed and subjected to approval.
- R&D resources and efforts should avoid ingredients in the red category, as legislation around these items is unlikely to change in the foreseeable future.

## 4. Ethical Risk

A practical framework in which to measure the impact of this transition on salmon and shrimp welfare was established. A welfare outcome measure (WOM) framework was identified as the most objective way to directly assess animal welfare. WOMs are recorded directly from the animals within a system that can objectively tell us about how the animals have experienced that system. Ethical scopes of the salmon and shrimp supply chains were carried out to identify where the key welfare risks lay. Following this, WOM risk assessment frameworks for salmon and shrimp were described. The WOMs in these frameworks can be used to measure welfare in feed trial or commercial settings and provide a holistic view of animal welfare. WOMs for salmon and shrimp were split into the following four categories: livability, disease, injuries and mobility and behavior.

Measures that were considered as specifically important risk factors for diet change were highlighted. In salmon these measures were; fin condition, vertebral deformities, eye condition and snout deformities. In shrimp, specific risk factors for diet change were considered to be; red coloration, dark gills/pleopoda, lacerations, wounds and broken antenna. However, it is recommended that the full list of WOMs is collected to provide a holistic picture of welfare. For example, mortality should never be considered without taking into account medicinal treatments in order to ensure that animals are being treated when required and diseases are not being masked by excessive medicine use. It is also recommended that environmental data on important factors such as water quality, temperature and salinity are also collected alongside WOMs to avoid attributing any differences in welfare to feed that relate to other factors.

In commercial settings, WOM data should be collected from an entire lifecycle of standard production to establish a baseline level for each measure. Alternatively, in trial settings, groups fed standard and novel feeds can be grown alongside each other to provide truly comparable results. In trials settings, the environments of the tanks and care of the fish should be identical apart from the variable of interest (feed type). The treatment of the fish should be similar to what would be expected in a commercial environment as possible, so the results are commercially relevant.

The frameworks provided represents a good starting point for considering salmon and shrimp welfare; they do not represent a complete list of possible WOMs, nor a minimum requirement for measuring welfare. Although important for measuring welfare, behavioural measures are lacking from the framework due to difficulties in capturing and analysing this information. The frameworks also do not take into account the welfare of other animals in the salmon and shrimp supply chain. Switching to novel proteins may mean increasing insect farming and soybean production which may pose welfare risks as well as benefits. These influences on animal welfare should also be considered alongside the direct risks to salmon and shrimp. The WOM framework described in this report covering the categories of liveability, disease, injury, mobility and behaviour need to also be applied to insect welfare, if the expansion of insect farming and their utilisation as novel feed and food sources continues. However, measuring the effects of deforestation on non-target species is more difficult. As a general rule, any negative impacts on non-target species should be considered, tracked and minimised.

## Social wellbeing assessment tool

A social wellbeing assessment tool was also developed using a WOM approach. This was not presented as it was a tool to be applied to innovations/suppliers rather than an assessment, although as part of bench marking its use in the future fish meal/oil from Chile and Soy meal in Brazil were assess using its 9 criteria.

| | | |
|---|---|---|
| 1.Basic rights (recruitment, traceability, licences to operate) | 4. Earnings: minimum wage considerations | 7.Viability (gender equality/women leadership, economic dependence, family) |
| 2. Worker protection (i.e. collective action, right to strike, ability to gather evidence) | 5. Health and safety – under 5 mortality, accidents at work, family health provision | 8. Flexibility (debit, advancement, seasonality) |
| 3. Vulnerable populations (training, migrants) | 6. Education & training– children out of school, training to develop and improve | 9. Partnerships (government, 3rd part certifiers, NGOs, Church, Private sector) |

Assessment of Suppliers was boiled down to a statement about how well-known risks are and whether positive actions are being taken to address them. The user looks at each wellbeing category grouping (e.g. worker rights + worker protections + vulnerable populations) and focuses on the proportion of unknown risks (relative proportion of yellow), and proportion of scores for positive and negative conditions of actions (relative proportion of green/benefits and mitigating actions vs. red/risky conditions).

The tool and the scoring and synthesis methods used were not intended to quantify risk in any definitive way for decision making. The tool will not provide exact thresholds for determining severity of problems or what must be done about them. The assessment is qualitative and relational. It is intended to facilitate discussions by the Company about priorities and feasibility in changing supply chains to support social wellbeing as well as better ecological outcomes.

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## 5. Social Acceptability Assessment

This was an assessment of current consumer perceptions, social acceptability of potential new ideas/claims for more sustainable salmon and shrimp food working in the interface between consumers, retails, the industry, sources and etc. 3,000 consumers around the world were surveyed in 6 countries with the largest end use markets for salmon (US/UK/Brazil/ Germany/France/China). 8 experts/market influencers were interviewed to provide qualitative assessment of the claims associated with the categories and priority solutions.

Three criteria were used to assess the claims in the analysis:

1. Appeal – do you like this idea?
2. Relevance – how much does it matters for you
3. Purchase – how does it influence consumer willingness to pay?

CLAIM SCORE – combination of the 3 criteria where respondents passed a claim through all three criteria.

The results were coded red-amber-green with:

- results over 7 as green (6 claims)
- over 5 as amber (7 claims)
- under 5 as red (8 claims)

For the expert interviews, a red/amber/green ranking was allocated based on their views on whether this was a relevant and value-adding route to progress.

Results:

- In general category a) could be progressed 'behind the scenes' but they not an appealing story for consumers, unless it sounds natural and not too 'yukky'. There were 4 medium risk claims (amber), and 4 high risk claims (red). With experts being more open with 5 medium risk claims, 2 low risk claims and only 1 high risk claim. The following additional points were made about this category
    - Progress some areas behind the scenes, but manage communications carefully.
    - Look for more natural protein alternatives where possible, ideally with positive nutritional benefits to end consumer
    - Include some sustainable soy still acceptable to experts
    - Insects could be socially acceptable tomorrow, especially if it is explained that insects are a natural food for salmon and shrimp. However, to say that insects feed on waste is a detail too far for consumers
    - Treat 'waste' with care and avoid anything that sounds too scientific or unnatural
    - Animal waste to be avoided. Could pursue yeast or algae but not a public communications story

- In general categories b) and c) have natural and health benefits that makes them more socially acceptable, unless they are too technical. Experts are more open to technology. For consumers each one had a high, low and medium risk claim for consumers and then for experts there were 7 medium risk claims and 1 low risk claim: where 'Feed made from seaweed and rich in Omega 3' being the lowest risk for both consumers and experts.

- In general categories Categories e) and f) were more polarising among consumers who were in favour of human health benefits but concerned about manipulating fish health. Experts were more open in general. The following points were noted:
    - Two claims received <u>low risk</u> rating from both consumers and experts: "Balanced feed that avoids the need for antibiotics" and "Feed that is free from antibiotics".
    - Two claims were <u>favoured</u> "Feed which improves the health and strength of the fish" and "Feeding system that naturally self cleans the water, for healthier fish and environment"
    - The greatest contradiction between consumers and experts was with "Digital monitoring of fish health so they get exactly the nutrient balance they need" which was low risk for experts, but high risk for consumers.

- In general categories d) and g) were not progressed to the quantitative stage because when they were researched in the qualitative phase they were not felt by the public to address the sustainable feed issue directly.

As general points to be applied to any priority solution considered the following were worth noting:

- Consumers have a low knowledge and interest in the food chain of salmon and this is even lower in shrimp.
- However, there is evidence of a growing interest in the origin of food. For example, responsible sourcing was one of the higher scoring drivers of choice in the survey
- Consumers want their food to be safe, natural and healthy. This guided the scoring they gave to the various categories and claims

Marketing is the art of how you wrap up an idea so in general the following was recommended:

- If we have the endorsement of the retailers, farmers, industry – and we can market in a good way – consumers will follow and might accept well the alternative ingredients.
- Hormones, antibiotics – people are very scared with what is added to the food chain – human health

**Rules of success for the most appealing claims:**

- Sound like they are naturally part of the food chain- seaweed, insects (for some)
- Deliver a nutritional benefit to the end consumer
- Help the fish stay healthy
- Don't sound too 'yukky' i.e. would be something you could imagine eating
- Safe to eat- antibiotics is a big topic

**Claims with lower appeal:**

- Topics which sound too scientific and unnatural
- Technology - needs to be handled with care
- Anything too far from human consumption- e.g. industrial waste
- High 'yuk' factor- chicken feathers, insects to some extent

- Retail experts, on the other hand, were very open and engaged. They were particularly drawn to more technical solutions such as microalgae, as well as more natural solutions around seaweed or insects. They are under pressure to secure more supplies of good value healthy fish to their customers in a way that is sustainable, and are keen to share this pressure with farms and feed manufacturers. They need to tread a fine line between technology and nature.
- It was concluded that the social risk considerations need to start with the experts: the retailers, farmers and sector specialists. Consumers trust these groups to get it right for them, and will listen to them,. Some categories are riskier to communicate today, but they might be acceptable tomorrow, so the communication needs to be managed proactively and with transparency.

## 6. Economic Assessment – Harvard

Economic de-risking for FEED-X innovations in the economic analysis focused on Feed ingredient system categories. Feed production and feed delivery system innovations were not modeled due to lack of data on firm specific practices, however aspects or factors that might influence costs were noted. Having said that those priority solutions based on sugars and food waste were removed from analysis due to inconsistencies found in figures for production cost data. Other ingredients (e.g. cassava) were removed because of insufficient production cost data.

Category innovations that had sufficient evidence for conclusive financial modeling and only 4 of those were taken forward. Insects fed on food industry by-products or food waste, Microbial fermented waste proteins, non-marine oil sources of omega 3 and Seaweed fed insect proteins.
The key points made in the analysis were the following

- Fish oil resource constraints pose a severe challenge to economic viability and will create significant future profit losses. As fish oil is a scarce resource limited by environmental depletion, quotas, illegal and unreported harvesting, and climatic phenomenon, fish oil as a status-quo feed input is facing rapidly decreasing supply
- After 2030, when all supply available in 2015 will be depleted, the firms will collectively face a minimum profit loss of $53.6 million per year assuming stable inflation and volume of demand

As the Big Four consume increasing proportions of the feed industry, sustainable ingredients can provide a resource alternative during times of price peaks for status quo feed ingredients in the short-term.

Production costs can fall by 70% to 90% for every doubling of output quantity. In economic de-risking analysis, this was modeled using a inverse square root relationship.

- After factoring in economies of scale, major global feed partners are projected to save at least

1.65% on production cost until 2030, ranging from €0.1 Billion to €2.3 Billion for Skretting.
- Substantial levels of carbon dioxide emitted during fish oil and fishmeal processing and transport pose a challenge to viability of the status-quo.
- Fish Oil and Fishmeal produced 7 million tons CO2eq in emissions in 2011. This accounted for 15% of the global fishing industry emissions for that year. From 2020 and on, greenhouse gas emissions attributed to the use of fish oil and fishmeal will impose an increasing social cost. By 2050, external damages will amount to $483 million per year

Factors found that might affect the economic viability of some innovations
- Reducing the deaths and mitigating Early Mortality Syndrome (EMS) would save up to 40-50% of shrimp stocks, and cut losses of the industry by up to $2-5 billion.
- Disease control technologies could save the aquaculture industry up to $6 billion annually, as some diseases have the potential (category e))

Maximized Growth Rates
- Increasing feed inputs only increases production if feed is limited. In well managed systems, feed should be slightly limited as this will optimize the use of natural foods, reduce pollution loading and generally maintain near maximum growth rates. If the shrimp are hungry they are less likely to waste what food is offered and water quality is less likely to be harmed by excess nutrients in the system.
- The protein, carbohydrate and lipid contents in Labeo gonius increased significantly with addition of algal feed compared to that fishes fed with conventional feed during the experimental tenure. Among the three algal feed, all the parameters measured were fishes fed with mixed algal feed AF.

Economic model showed the following:
1. Price volatility – resource constraints are going to pose major challenge to price viability (fish oil slide).
2. The big 4 firms will face a profit loss of €53.6 million per year. Fishmeal is less of a constraint.
3. Status quo ingredients costs are very volatile; switching to alternative sustainable ingredients during times of price-peaks would provide a viable alternative for Status quo feed ingredients in the short time. As these ingredients become scarcer, their price volatility will increase; using these alternative ingredients will help mitigate the price volatility.

In general the team concluded the following about the economic viability of the categories of innovation that could be assessed:
- Insect and bacterial protein are the most viable alternatives for Big 4 global feed producers, while algae-based feeds show lower viability.
- Field crickets show the greatest decrease in value proposition for Big 4 feed producers in terms of economies of scale, suggesting that insect proteins may scale more poorly with increased output.
- Price volatility mitigation as well as the potential to reduce social costs of carbon as an externality, offer strong economic incentives for the adoption of sustainable innovations.
- Growth performance metrics were shown to be improved by using one of the FEED-X sustainable feed innovations (mixed algal feed) in experimental trials, generating additional economic incentive for transition

The greatest challenge for the team was working with low levels of data, there was insufficient data on categories 2 and 3 so they could not be assessed.

The following production cost estimates were used in for the financial models and therefore any potential solution being considered needs to be assessed in terms of where it falls comparatively with the baselines used. The models can be used with the new data to generate comparative curves to demonstrate economic viability.

| Cost estimates used in the financial models | Euros/tonnes |
|---|---|
| Category a) 2. Insects fed on waste | |
| Termites - Average Estimate | €238 |
| Black Soldier Fly Larvae | €209 |
| Field Crickets | €3.230 |
| Category a) 3. Microbial proteins through fermentation | |
| Bacteria (Profloc) Production Cost - Low Estimate | €1.000 |
| Bacteria (Profloc) Production Cost - Middle Estimate | €1.050 |
| Bacteria (Profloc) Production Cost - High Estimate | €1.100 |
| Microalgae Production Cost - Low Estimate | €4.950 |
| Category b) Plant based Omega 3 | |
| Algal Oil Production Cost - Low Estimate | €1.649 |
| Algal Oil Production Cost - Average Estimate | €3.123 |
| Algal Oil Production Cost - High Estimate | €7.120 |
| Benchmarked existing ingredients | |
| *Status Quo* Fishmeal Production Cost - Average Estimate | €1.760 |
| *Status Quo* Fish Oil Production Cost - Average Estimate | €1.320 |

HARVARD UNDERGRADUATE CBE

## Discussion of the results

The results of each lens or risk assessment where discussed with the 6 research teams and strategic project stakeholders and the following points were made:

Priority solutions assessed.

- Insects – surprising results, the challenge of scaling insects needs to be understood more – interest in a more detailed study (IKEA)
- Sludge from hatcheries – cost effective, but going to the lower trophic levels would be better.
- Economic viability of the categories changes with commitment, and de-risking
- Need a way to make "yukky" but best potential solutions sound more appealing to the consumer - Another role of NGOs like WWF is in presenting and positioning the solutions so that consumers value them as natural and not "yukky"

Process of searching for novel solutions/innovations

- Finding solutions that de-couple us from harvesting marine resources – that's why finding other sources of long chain Omega 3 fatty acids are so important.
- The process is open to other solutions/innovations in search and select so that there can be an expansion to those assessed in the CDR.

Creating the "Market Pull"

- We are providing the demonstration for legislators, but they need corporates on board first. It's important to bring them specific solutions – policies could also provide incentives to shift the market.
- Working with retailers to push through innovative solutions
- Good traceability is required is good in developed markets, so for salmon its good, Shrimp traceability is more challenging but WWF is working on it.
- Market-pull will help us accelerate and compress time – consumers need to be taken on a journey of knowing the problem and then the solution – if not today then tomorrow.

## INTEGRATED RESULTS

From the six lenses a series of criterion were determined that were used to assess the levels of risk relevant for each perspective. These were found to be the following:

Economic Lens

- Production cost/tonne
- Feed rate - Kg/ha/day
- Available volumes/price sensitivity
- Feed conversion ratio
- *Risk aspects considered*: Modelled Economic Viability results and a rational for expecting a lower feed conversion ratio.

Ethical Lens

- Animal wellbeing - behaviour
- Disease – incidence/persistence: condition, gut
- Body Damage – Injuries: fin, vertebrae, eye, snout, wounds
- Mortality
- *Risk aspects considered*; risk of wild caught species, replace-ability of the protein, digestibility of the protein, use of animals as protein source, slaughter/death of animal, benefits and risk associated with non target species and seaweed

Social wellbeing – 9 criterion were identified to assess specific suppliers

Environmental Lens

- Landuse/Biodiversity impact – hectares/unit produced
- Climate change/GHG emissions – CO2/unit produced
- Water use – Litres/unit produced
- Fossil fuel Energy use – KWh/unit produced
- *Risk aspects considered*: benchmarked against known value of proteins/ ingredients used by the feed industry

Social Acceptability Lens

- APPEAL: A broad emotional reading of how likeable the claim is
- RELEVANCE: A measure of how well the claim fits.
- PURCHASE: A measure of how likely the respondent would be to buy the product.
- OVERALL CLAIM SCORE RANKING
- Conditions of progression
- Consumer opinion/expert opinion

Legal (political) Lens

- Compliance with EU/US laws/regulations
  - Compliance is attainable – a similar ingredient/process is approved but the ingredient/process itself is not
  - Compliance is not attainable in the short term
  - Compliance is unattainable under the current legal framework
  - Unknown or insufficient data available

Nutrition Lens

- Crude Protein % - greater than 40% for shrimp and greater or equal to 60% for Salmon
  - Anti-nutritionals – type and affect (permanence)
  - Ash content – less than 20%
  - Toxicity – chemicals/minerals or organism
  - Fibre content less than 10%

- *Critical Risk aspect* if the solution was deemed unsuitable nutritionally for Salmon and Shrimp it was not suitable in any other risk aspect. The overall risk rating was assigned high or 0.

## Scoring Methodology

A simple scoring approach has been chosen after much consideration and applied systematically across all six lens results and each level of risk was given a corresponding value, with 4 denoting low risk and 0 denoting high risk with the recommendation of not to progress with the option. Data deficient or unknown risk were assigned the same value as higher risk with the recommendation to progress with significant conditions. Following numbering convention Medium risk was then assigned a value of 3 and, low risk the highest value of 4. See the key below.

None of the lenses were weighted – all lens overall scores were equally important, however a nutritional factor was applied to the Feed ingredient system categories.

Table 1: Key of risk ratings for integration

| **Project X KEY** | | | | |
|---|---|---|---|---|
| **Risk rating value given** | Level of risk for each criteria | Threshold value | total rating range | Rational applied |
| 4 | Low risk: Progress | 24 | ≥18≤24 | |
| 3 | Medium risk: Progress with conditions | 18 | ≥12<18 | at least 3 medium risk or better |
| 1 | Higher risk: Progress with significant conditions | 12 | ≥9<12 | at least 3 are higher risk,or 2 are high |
| 0 | High risk: Do not progress | 8,9 | <9 | (4 have value =1, and 2 have value =2) gives value 8 as threshold: nutritional is=0 |
| 1 | Higher risk - Data deficient | 12 | ≥9<12 | at least 3 are unknown risk |

Methodology for applying the risk ratings and total scores was the following

- Rules and criteria were applied per lens across the same framework of priority solutions: using lens aspects or rules for each of the priority solutions (i.e. ethical and economic)
- For the ethical lens where it considered it a risk to animal welfare if there was not sufficient protein digestibility for the animals; and for this aspect the ethical lens was given the same risk rating as the nutritional lens
- If the nutritional assessment designated the priority solution as high risk, with value = zero, then this factor resulted in the overall average score as zero or high risk because the priority solution was not suitable for either Salmon nor Shrimp
- EU compliance results for the Legal lens was used for the overall score value and risk rating so the priority solutions under US compliance would look slightly different.
- All lenses had their own overall risk rating scores for each priority solution calculated in the same way.
- Average value of the assigned values for each level of risk for each relevant risk criteria or aspect of risk considered by the lens.
- Each total rating score across the six lenses for each priority solution was calculated in the same way, where the sum of all the six lens overall values were added together then multiplied by the nutritional factor (of either zero or 1).
- The range of values that this overall value fell into, then determined its overall risk rating. There were rules applied however to manage risk conservatively if 50% of the overall score for each lens have the same risk rating, i.e. unknown risk then the overall risk was assigned as an unknown risk rather than a higher risk.

The latest version of the scoring system allows for a user to set their own weighting across the six different themes reflecting their own priorities; environment and ethical over social acceptability or legal for example. This allows for a different set of results to emerge than the ones described where no weighting was used.

Table 2 summarising the overall risk assessment per category

| Category a) Nutritional solutions creating net positive environmental effects using waste streams, including but not limited to: food waste, CO2 and energy. | | Category b) Nutritional solutions creating health effects equal to or greater than fatty acids (e.g. DHA-EPA). | | Category c) Nutritional solutions using inputs that create environmentally restorative effects (e.g. ecosystem rehabilitation); | | Category d) Technology solutions creating net positive effects using renewable energy, packaging waste, energy waste, sustainable transport | | Category e) Integrated technologies incorporating digital monitoring to increase the health, survival and growth performance of the fish/ shrimp, | | Category f) Integrated information systems solutions increasing feed waste efficiencies, | | Category g) Innovations moving the whole farm production foot print off land | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 72 | **Category Total priority solutions assessed** | 12 | **Category total priority solutions assessed** | 4 | **Category total priority solutions assessed** | 5 | **Category total priority solutions assessed** | 5 | **Category total priority solutions assessed** | 4 | **Category total priority solutions assessed** | 4 | **Category total priority solutions assessed** |
| 10% | Low risk: Progress | 42% | Low risk: Progress | 25% | Low risk: Progress | 0% | Low risk: Progress | 0% | Low risk: Progress | 0% | Low risk: Progress | 0% | Low risk: Progress |
| 54% | Medium risk: Progress with conditions | 42% | Medium risk: Progress with conditions | 75% | Medium risk: Progress with conditions | 20% | Medium risk: Progress with conditions | 100% | Medium risk: Progress with conditions | 75% | Medium risk: Progress with conditions | 25% | Medium risk: Progress with conditions |
| 3% | Higher risk: Progress with significant conditions | 17% | Higher risk: Progress with significant conditions | 0% | Higher risk: Progress with significant conditions | 20% | Higher risk: Progress with significant conditions | 0% | Higher risk: Progress with significant conditions | 25% | Higher risk: Progress with significant conditions | 0% | Higher risk: Progress with significant conditions |
| 7% | Unknown risk, Data deficient - requires more research to proceed | 0% | Unknown risk, Data deficient - requires more research to proceed | 0% | Unknown risk, Data deficient - requires more research to proceed | 40% | Unknown risk, Data deficient - requires more research to proceed | 0% | Unknown risk, Data deficient - requires more research to proceed | 0% | Unknown risk, Data deficient - requires more research to proceed | 75% | Unknown risk, Data deficient - requires more research to proceed |
| 26% | High risk: Do not progress | 0% | High risk: Do not progress | 0% | High risk: Do not progress | 20% | High risk: Do not progress | 0% | High risk: Do not progress | 0% | High risk: Do not progress | 0% | High risk: Do not progress |

The results per category are given in the appendices.

## FEED INGREDIENT Results

Category a) Nutritional solutions creating net positive environmental effects using waste streams, including but not limited to: food co-products, CO2 and energy.

- 72 priority solutions were assessed overall, 54% are medium risk, 10% are low risk and 7% had unknown risk and would need more research to proceed So this category offered a large number of options.
- 6 options were given** symbol to denote that they were more suitable for shrimp
- 26% or 19 of the priority solutions were given the highest overall risk rating, due to the nutritional risk, which was assigned as unsuitable nutritionally speaking for Salmon and Shrimp.

Protein/starches – from the integrated RAG rating (1a,1b, and 1c) – ones to proceed

- 6 priority solutions were low risk; Spent distillers grain, Whey Protein Concentrates, Citrus seed meal, Potato leaf protein concentrate and Corn gluten meal and pea protein concentrate – are recommended to progress without conditions. The later two are already used by the feed industry so the innovative aspect would have to be as sourced as food industry by-products or demonstrated in another way
- 25 priority solutions were medium risk, and can proceed with conditions
- Land animal proteins were very contentious from a social acceptability perspective and could be deemed in general terms higher risk and recommended to proceed with significant conditions, however once more specific solutions were considered 8 were considered medium risk and could proceed with conditions around how they are communicated and accepted socially.
- 4 priority solutions were only assessed by the nutritional Lens; rat, tadpole meal, frog waste meal and snail meal – only snail meal (or muscles) was found to be nutritionally interesting so it is recommended further assessment by other lenses. Therefore only proceed once more research is done on the specific innovations.

Insects fed on food industry by-products (group 2) ones to proceed

- Insects fed on unused food by-products are worth considering certainly in Europe, but with conditions on how they are communicated – emphasize less insect and more as an alternative to soy and greater clarity on their environmental impacts – the majority were amber, so proceed with conditions. Black soldier fly Larvae fed on food by products was green and can progress without conditions.

Protein from fermentation on processes using types of waste stream (3a, 3b, 3c and 4) ones to proceed

- Of the 11 options assessed,7 were medium risk and 4 were either higher or high (highest risk rating) risk (i.e .those relating to excrement by-products): Fermentation with Bacteria, micro algae, algae, Yeasts and fungi could proceed with conditions. Surprisingly Single celled protein was higher risk rating because it has unknown risks in three lenses; economic, environment and legal, its recommended therefore to proceed only once more research is done on the specific innovations.

Category b) Nutritional solutions creating the health effects equal to or greater than Omega 3 fatty acids (e.g. DHA-EPA),

- 13 priority solutions were assessed overall, most, 42% were medium risk and 42% were low risk, and 17% were higher risk.
- 5 had a total risk score value between 18 to 24
- 5 had a total risk score value between 12 but less than 18
- 2 had a total risk score value between 9 but less than 12

Category b) Nutritional solutions creating the health effects equal to or greater than Omega 3 fatty acids (e.g. DHA-EPA)

- Assessed adequately by all four lenses

Bacteria, seaweeds and other plants

4 options were rated as low risk, and can proceed however note that GHG emissions, water use and fossil fuel energy use were all identified as unknown risk; therefore this data would need to be provided by the innovators assessed.

- 6 options were rated as medium risk principally because although similar products have been approved, it was not necessarily the named species assessed by the nutritional team or the same approved fermentation process, so proceed if they can be related to an approved species or processes (this may require an influence EU regulations to approve more species). Note that all were assessed to have relatively high environmental impacts, except Yeasts. They were considered higher risk for environment due to their potential for GHG emissions and use of fossil fuel energy source which depends on the production process, so could be reduced.
- All options (excluding the GM options) were felt to be reasonably socially acceptable due to the health link as long as communications did not emphasize the science too much
- 2 of the options were rated higher risk, higher risk because they have been genetically modified but from a legal perspective there was not sufficient data to assess their risk, similarly there was not enough data to assess their economic viability, when combined with the higher environmental assessment. So these two options are recommended to proceed only if solutions can provide information on their legal compliance, economic viability and show they have low environmental impacts.

Category c) Nutritional solutions using inputs that create environmentally restorative effects (i.e. kelp forests harvested as a source that also support ecosystem rehabilitation).

- 4 priority solutions were assessed overall, 75% were medium risk and 25% were low risk
- All 4 seaweed options were interesting, with insects fed on seaweed being rated low risk and to proceed; all others were medium risk, nutritionally protein content is lower, and environmental risks in GHG emissions and fossil fuel energy use being high. Socially the option linked to kelp forests was higher risk for experts, similarly insects fed on seaweed were a concern for consumers, although overall this option was low risk and could proceed.

## FEED PRODUCTION Results

Category d) Technology solutions creating net positive effects using renewable energy, packaging waste, energy waste, sustainable transport.

- 5 priority solutions were assessed, the nutritional lens dropped out as its assessment was not relevant; the scoring reflected this.
- The social acceptability assessment rejected these claims early on because they were not perceived by the public to address the sustainability issue associated with FEED. This was not a reason not to proceed, but caution with communications as the public will not think favourably on solutions that address the feed production process. From an ethical perspective there is an indirect benefit where this category is seen to address climate change impacts that affect wildlife.
- Recycling or re-using packaging was assessed as having medium risk, and to progress with conditions on more information on the environmental risks and economic viability.
- Package free feed was rated higher risk so should only proceed with conditions; the legal ramifications relating to food safety issues with package free feed need to be understood.
- 3 priority solutions were categorized as unknown risk and 2 relate to extrusion technologies, these solutions can proceed however as long as more information is provided on the specific solutions. The other relates to the mapping of local food waste streams, which needs more research to understand what an innovation could entail in practice.

## FEED PERFORMANCE Results

Category e) Technology solutions increasing the health, survival and growth performance of the fish/shrimp.

- 5 priority solutions were assessed,

- Nutritional lens was not relevant and environment did not have enough information for an assessment.
- Social acceptability rated three of the options as good to progress (i.e. low risk) (2 were ways avoiding antibiotic use, third was associated with monitoring the water quality), however given these same options were assessed by the legal lens as possible with conditions, the overall rating was assigned as medium risk, to progress with conditions.

Category f) Integrated information systems solutions increasing feed waste efficiencies

- 4 priority solutions were assessed,
- Only two of the lenses were able to assess the category priority solutions and only generally. However the social acceptability lens rated one of the options as good to progress, naturally cleaning systems. However the legal and environmental lens did not have sufficient data so overall, these were rated medium risk.
- Solutions that emphasize business efficiencies was not socially acceptable and was therefore rated as higher risk overall, given other lenses assessed the risks as unknown.

Category g) Innovations moving the whole farm production foot print off land

- 4 priority solutions were assigned amber, medium risk – progress with conditions.
- Only two lenses were able to assess the priority solutions with sufficient information, if general. Social acceptability assessed all four priority options as good to proceed without conditions because they all emphasized naturalness and the marine environment (linked to seaweed). However the legal assessment was able to assess aquaponic systems as compliant in the US and compliant with conditions in the EU and was the only priority solution rated as medium risk and therefore could proceed with conditions on understanding the environmental risks and economic viability.
- 3 other priority solutions did not have enough information to be assessed in 3 of the 4 lens and were rated as unknown risk.

## Overall Conclusions

13 Low risk: Recommend proceeding without conditions
FEED INGREDIENTS
Category a:
Food industry waste

- Spent grains (alcohol processing)
- Whey protein concentrate
- Citrus seed meal
- Potato, leaf protein concentrate

Food industry By-products

- Corn industry - Corn gluten meal
- Pea protein concentrate

Insects fed on food waste steams

- Black soldier fly larvae

Category b: Omega 3 oil sources

- Bacteria
- Recombinant Escherichia coli and L. Lactis
- Methanotrophs
- Seaweeds
- Micro-algae

Category c: Restorative sources

- Protein from insects fed on seaweeds

57 Medium risk: Recommend proceeding with conditions – 6 that could be interesting for shrimp. 47 of these were in the Feed Ingredient system category; the vast majority in category a (39), and then in category b (5) and c (3). Feed Production only had one in category d). Feed performance had nine

medium risk priority solutions; five in category e), three in category f) and one in category g). See the tables in the annex for the exact distribution of these results across the categories.

10 priority solutions were designated as having an unknown risk level and in this case the recommendation would be to proceed with more research and analysis.

Six higher risk priority solutions were designated and it would be recommended to proceed with caution.

20 Highest risk priority solutions were designated, the recommendation in this case would be to stop, not to proceed unless the current context changes. These 20 were distributed across the categories in the following way, but only examples are given here as the following tables provide more detail.

FEED INGREDIENTS (19) Highest Risk
Category a: 19 in total but the following are some examples see the full list in Table 5.

- 3. Whey, whey concentrate and whey permeate (cheese)
- 4. Egg shell waste (dried shell)
- 5. Pomace (skin and seeds) (light wines)
- 6. Citrus zest, peel, membrane residue after juice extraction
- 7. Fibre, concentrated fruit juice,- Pineapple mill juice
- 9. Organic wastes, - Guava waste,
- 10. Sugar beet pulp - hydrated and dehydrated
- 13. Olive stones (vegetable oil)
- Sludge
- Manure and poultry litter
- Manure protein concentrate
- Process waters from the seafood industry contain valuable nutrients

FEED PRODUCTION Highest Risk

- Mapping of local food waste streams to be used in local farms - this is a complementary solution

Finally therefore If only three categories were to be put forward for fast track adoption, categories, a, b, and c would be proposed, but with refinement of excluding options that had been deemed highest risk. Any solution within these three categories of medium risk (amber) rating and or unknown risk (grey) rating would need to either meet conditionality or provide sufficient data whereby assessment could be made in the lens criterion required.

This is not to exclude any innovation from category d) to g) but the solution put forward would have to provide key data to ensure criterion across the 6 lenses could be met

The financial, insurance and retail communities were asked to assess whether risk has been considered sufficiently to enable the fast track adoption of any category or set of priority solutions within the best performing categories. They felt that the 6 lens approach was very comprehensive definition of sustainability, the scoring akin to a sustainability index, but asked that a weighting option be provided. The final version of the assessment tool has a weighting score system incorporated into it to enable users to define their own priorities within the sustainability index framework. This allows for a more flexible approach whilst ensuring it builds on the rigorous analysis presented. This is available upon request.

Table 3: Results of the priority solutions for categories a), b) and c)

| Category a) Nutritional solutions creating net positive environmental effects using waste streams, including but not limited to: food waste, CO2 and energy. 72 priority solutions assessed; | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1) Protein (processed or concentrated) or starch from locally available food waste stream (e.g. cassava) (15) | | 1a) By-products of food industry | | 1b) Wild cards (LAP) | | 2) Protein from Insects fed on Food waste and/or food industry coproducts | | 3a.Microbial - Sustainable CO2 source, Bio-gas, | | 3b.Food waste or food industry co-product (sugars), | | 3c.Waste product such as: Cellulose | | 4) Unknown Protein from using energy waste |
| 22 | TOTAL | 13 | TOTAL | 17 | TOTAL | 9 | TOTAL | 2 | TOTAL | 4 | TOTAL | 1 | TOTAL | 4 | TOTAL |
| 18% | LOW RISK | 15% | LOW RISK | 0% | LOW RISK | 11% | LOW RISK | 0% | LOW RISK | 0% | LOW RISK | 0% | LOW RISK | 0% | LOW RISK |
| 41% | MEDIUM RISK | 62% | MEDIUM RISK | 47% | MEDIUM RISK | 78% | MEDIUM RISK | 100% | MEDIUM RISK | 75% | MEDIUM RISK | 100% | MEDIUM RISK | 25% | MEDIUM RISK |
| 0% | HIGHER RISK | 0% | HIGHER RISK | 6% | HIGHER RISK | 0% | HIGHER RISK | 0% | HIGHER RISK | 25% | HIGHER RISK | 0% | HIGHER RISK | 0% | HIGHER RISK |
| 5% | UNKNOWN RISK | 0% | UNKNOWN RISK | 24% | UNKNOWN RISK | 0% | UNKNOWN RISK | 0% | UNKNOWN RISK | 0% | UNKNOWN RISK | 0% | UNKNOWN RISK | 0% | UNKNOWN RISK |
| 36% | DO NOT PROCEED | 23% | DO NOT PROCEED | 24% | DO NOT PROCEED | 11% | DO NOT PROCEED | 0% | DO NOT PROCEED | 0% | DO NOT PROCEED | 0% | DO NOT PROCEED | 75% | DO NOT PROCEED |

Categories b) and c)

| | 5) Non-marine (non-animal) oil sources of Omega-3 | | 6) Protein from seaweeds (process or concentrated), | | 7) Protein from insects fed on seaweeds |
|---|---|---|---|---|---|
| 12 | TOTAL | 3 | TOTAL | 1 | TOTAL |
| 42% | LOW RISK | 0% | LOW RISK | 100% | LOW RISK |
| 42% | MEDIUM RISK | 100% | MEDIUM RISK | 0% | MEDIUM RISK |
| 17% | HIGHER RISK | 0% | HIGHER RISK | 0% | HIGHER RISK |
| 0% | UNKNOWN RISK | 0% | UNKNOWN RISK | 0% | UNKNOWN RISK |
| 0% | DO NOT PROCEED | 0% | DO NOT PROCEED | 0% | DO NOT PROCEED |

Low risk solutions per category

**13 Low risk: Recommend proceeding without conditions**
FEED INGREDIENTS
Category a:
*1.Food industry waste*
- Spent grains (alcohol processing)
- Whey protein concentrate
- Citrus seed meal
- Potato, leaf protein concentrate

*1a, 1b, Food industry By products*
- Corn industry - Corn gluten meal
- Pea protein concentrate

*2. Insects fed on food waste steams*
- Black soldier fly

**13 Low risk: Recommend proceeding without conditions**
FEED INGREDIENTS
Category b: *Omega 3 oil sources*
- Bacteria
- Recombinant Escherichia coli and L. Lactis
- Methanotrophs
- Seaweeds
- Micro-algae

Category c: *Restorative sources*
- Protein from insects fed on seaweeds

Table 4 of results: Medium Risk priority solutions

| PX | 1) Protein (processed or concentrated) or starch from locally available food waste stream (e.g. cassava) (15) | PX | 1a) By-products of food industry | PX | 1b) Wild cards (LAP) | PX | 2) Protein from Insects fed on Food waste and/or food industry coproducts | PX | 3a.Microbial - Sustainable CO2 source, Bio-gas, | PX | 3b.Food waste or food industry co-product (sugars), | PX | 3c.Waste product such as: Cellulose | PX | 4) Unknown Protein from using energy waste |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2. Pomace (apples)** | | 1a) By-products of food industry | | Poultry offal meal, Poultry by-product meal, feet, heads, viscera | | Common Housefly - Housefly maggot meal | | Bacteria (Methanomonas) - (Methylophilus Methylotrophus | | Heterotrophic Algae | | Fungi that grows on cellulose | | Use waste heat for flocculation of proteins |
| | Grape seed oil meal | | • Sugar industry-betaine** | | Feather meal | | Mealworm (Tenebrio molitor) | | Microalgae (Spirulina Arthospira or Chlorella) | | Yeast | | | | |
| | 8. Peelings (potatoes) | | Grain industry - Rice protein concentrate | | Hatchery by-product meal | | House Cricket, Banded Cricket or Field Cricket | | | | Fungi | | | | |
| | 9. Organic wastes, mash from grain, fruit or potato (spirits)- Wheat bran, ** | | Corn industry - Corn gluten feed** | | Hog hair meal, hydrolysed | | Desert locust meal (S. gregaria) | | | | | | | | |
| | 9. Organic wastes, mash from grain, fruit or potato (spirits)- Potatoe starch, | | • Dairy industry - Yeast treated dairy waste | | Blood meal | | House cricket (Anabrus domestica) | | | | | | | | |
| | 11. Pomace (skin, pulp & seeds) (tomatões) | | • Bread and confect. Industry - Bakery waste** | | Viseral, - liver meal | | Mormon cricket (Anabrus simplex) | | | | | | | | |
| | 12. Crude & extracted press cake or spent meal (vegetable oils/ margarines)- Jatropha (Jatropha sp.) kernel meal, defatted, detoxified or non-toxic | | • Inuline industry - Fresh chicory root | | Cattle horn and hoof meal | | Pupae (silkworm pupae meal) | | | | | | | | |
| | Cottonseed meal (protein level high but ANF and EAA limit its inclusion, s | | • Consumer oil industry - Soya, Rapeseed, Jatropha<br>Palm oil | | Leather meal | | | | | | | | | | |
| | 14. Wheatfeed / wheat middlings (wheat milling products)** | | | | | | | | | | | | | | |

| PX | 5) Non-marine (non-animal) oil sources of Omega-3 | PX | 6) Protein from seaweeds (process or concentrated), | PX | *7) Protein from insects fed on seaweeds* | PX | 8) Use of solar and wave powder to produce/test feed and ingredients | PX | *9) Alternative technology,* | PX | 10) Integrated technologies incorporating digital monitoring to increase the health, survival and growth performance of the fish/ shrimp (i.e. including digital health control, A.I. biomass control) | PX | 11) Integrated information systems solutions increasing feed waste efficiencies- Systems (digital or otherwise) that use coproducts including sludge water from pens or ponds | PX | 12) Unknown Innovations - Innovations moving the whole farm production foot print off land |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Yeast Yarrowia Lipolytica | | Seaweed (Red macroalgae) e.g.Palmaria palmata | | | | Packaging waste recycling or reusing | | | | Biosensor (habitat level), to monitor growth, disease, stress, death, population | | For Shrimp: Biofloc system | | Aquaponics |
| | Phaeodactylum tricornutum, Nannochloropsis sp. and Desmodesmus sp. | | Seaweed (Brown macroalgae) e.g. Ascophyllum nodosum and Macrocystis pyrifera | | | | | | | | Vaccines and alternatives for antibiotics (i.e. natural practices, probiotics, etc) | | Development of algorithms for feeding and behaviour | | |
| | Marine diatom, Crypthecodinium, thraustochytrids, Thraustochytrium, Ulkenia and Schizochytrium sp. | | Green macroalgae e.g. Sea lettuce (Ulva spp.) | | | | | | | | Enzymes as alternatives for antibiotics | | Precision feeding | | |
| | GM diatom, P. Tricornutum | | | | | | | | | | Anti-quorum sensing bacteria (as the next generation of antibiotics) | | | | |
| | Schizochytrium (modified) | | | | | | | | | | Automatic systems to measure water quality/ quantity parameters | | | | |

Table 5 of results: High risk priority solutions

| PX | 1) Protein (processed or concentrated) or starch from locally available food waste stream (e.g. cassava) (15) | PX | 1a) By-products of food industry | PX | 1b) Wild cards (LAP) | PX | 2) Protein from Insects fed on Food waste and/or food industry coproducts | PX | 4) Unknown Protein from using energy waste | PX | 8) Use of solar and wave powder to produce/test feed and ingredients |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 3. Whey, whey concentrate and whey permeate (cheese) | | Dairy industry - Milk permeate | | Poultry bone meal | | WILDCARD Process waters from the seafood industry contain valuable nutrients | | Sludge | | Mapping of local food waste streams to be used in local farms |
| | 4. Egg shell waste (dried shell) | | • Sweets industry - Licorice roots | | Animal by-products as bone meal, calcinated | | | | Manure and poultry litter | | |
| | 5. Pomace (skin and seeds) (light wines) | | • Fruit and vegetables industry - Artichoke (Cynara cardunculus), aerial part, ensiled | | Animal by-products as bone meal, raw or steamed | | | | Manure protein concentrate | | |
| | 6. Citrus zest, peel, seed, membrane residue after juice extraction (Orange peels, silage, fresh & citrus pulp) | | | | Rumen content | | | | | | |
| | 7. Fibre, concentrated fruit juice, protein from potato starch, potato protein concentrate - Pineapple mill juice | | | | | | | | | | |
| | 9. Organic wastes, mash from grain, fruit or potato (spirits)- Guava waste, | | | | | | | | | | |
| | 10. Sugar beet pulp - hydrated and dehydrated | | | | | | | | | | |
| | 13. Olive stones (vegetable oil) | | | | | | | | | | |

# Appendix

## Research Teams

| Name of Researchers | Organisation | Expertise |
|---|---|---|
| Oistien Thorsen<br>Dr Amanda Deakin | Fai Farms | Animal welfare and social wellbeing assessment and tool |
| Dr Jeroen Kals<br>Dr Seyda Ozkan-Gulzari, Seyda"<br>Raquel de Paiva Seroa da Motta, MSc<br>Dr Theun Vellinga, | Wageningen University & Research (WUR) – Livestock Research Team (WRL) | Nutrition, Nutrition and Environment |
| Prof. Andrea Kessen &<br>Matij Kajić | Law School Utrecht University | Marine Law |
| Stefania Meconcelli<br>Katherine Maxwell<br>Marcello De Vites<br>Jamie Brogen | Edinburgh Centre for Carbon Innovation (ECCI) | Innovation analysis<br>Stakeholder anlaysis<br><br>Innovation & Business Strategy |
| Paulina Gual Rojas MSc<br>Elena Koukouna, MSc | Blonk Consultants | Environment, LCA |
| Lucy Richardson<br>James Smith<br>Jeane Beaton | Brand Legacy | |
| Katherine Qian<br>Tanisha Mugwimi<br>Charles Hua<br>Esther Iya<br>Lisa Wang<br>Clea Schumer | Harvard University, HUCBE | Economic analysis |
| Dr Karen Lawrence | Project X | CDR integrated report<br>CDR summary report<br>Decision Tree |

Peer reviewers

| Name | Organisation | Expertise | Lens reviewed |
|---|---|---|---|
| Piers Haart<br>Clarus Chu<br>Cristina Torres | WWF - UK<br>WWF - UK<br>WWF - Chile | Aquaculture, Salmon<br>Seafood sector<br>Aquaculture | All 6 lenses reviewed by internal Skretting experts<br>Integrated report |
| Jenna Bowyer<br>Trygve Lee | Skretting | Procurement<br>Sustainability | All 6 lenses reviewed by internal experts<br>Integrated report |
| Christoph Mathiesen | IKEA Sweden | Sustainability and environment, Marketing, FEED regulations | All 6 lenses reviewed by internal IKEA experts<br>Integrated report |
| Muriel Mambrini<br>Chris Vogliano<br>Riccardo Germano<br>John Kazzer | One Planet Network | Nutrition and environment<br>Environment<br>Policy<br>Environmental | Nutritional<br>Nutritional<br>Legal<br>Environ<br>mental |
| Beatrix Richards | Solidaridad | Supply chains, Environment, Policy | Environmental, Ethical, Legal |
| Trevor Ward | UTS, AU | Environment and Ethical | Ethical |
| Belissa Rossa | ADB Washington | Innovation, Finance | Economics<br>Integrated report |
| Frederic Feve | Family offices | Investment Finance | Economics<br>Integrated report |
| Marte Vassbotten | PwC Norway | Seafood, Salmon | Economics |
| Michael Tlusty | UMB, USA | Sustainable seafood and aquaculture | Social acceptability |
| Daniel Peon | IADB | Sustainability | Integrated report |