Assessment of environmental impact of FeedKind™ protein

The Carbon Trust's mission is to accelerate the move to a sustainable, low carbon economy. It is a world leading expert on carbon reduction and clean technology. As a not-for-dividend group, it advises governments and leading companies around the world, reinvesting profits into its low carbon mission.

Authors:

Tom Cumberlege
Senior Consultant
tom.cumberlege@carbontrust.com

Tom Blenkinsopp
Analyst
thomas.blenkinsopp@carbontrust.com

Jamie Clark
Analyst
jamie.clark@carbontrust.com

Table of contents

Acknowledgments 4

Introduction 5

1 Product Footprint 7

2 Product Footprint Results 8

3 Potential for Change 12

4 Comparative Research 14

5 Other considerations 20

6 Conclusion 22

References 23

Acknowledgments

The Carbon Trust wrote this report based on an impartial analysis of primary and secondary sources, including expert interviews.

The Carbon Trust would like to thank everyone that has contributed their time and expertise during the preparation and completion of this report. Special thanks goes to:

Martin Barrow, Carbon Trust; Mark Driscoll, Forum for the Future; Duncan Williamson, WWF; Jonathan Shepherd, Seafish

This report was sponsored by Calysta. For the avoidance of doubt, this report expresses independent views of the authors.

CALYSTA

Introduction

If current trends continue it is estimated that by 2050 the global population will exceed 9 billion people. Assuming a business as usual scenario with current consumption and wastage patterns, feeding this growing population will require a 70% increase in the amount of food produced by 2050 compared with 2006. [1, 2, 3]

One of the major challenges faced is to adequately feed this population, whilst also minimising or avoiding the major impacts of agriculture, such as greenhouse gas emissions, ecosystem degradation through land use change, and water competition [1, 4]. Agriculture already accounts for 13% of the world's greenhouse gas emissions. Coupled with a growing population, many parts of the developing world are also moving out of poverty, and hence consuming greater amounts of meat and dairy products which are products with the most significant environmental impacts.

Fish are seen as an important source of protein and are expected to play a major role in ensuring future food security [1, 3]. In addition fish has far lower environmental impacts especially when compared to the trend of increased livestock, which is increasingly viewed as unsustainable; as is the option of expanding current agricultural practices at the expense of grasslands, savannahs and virgin forests [4].

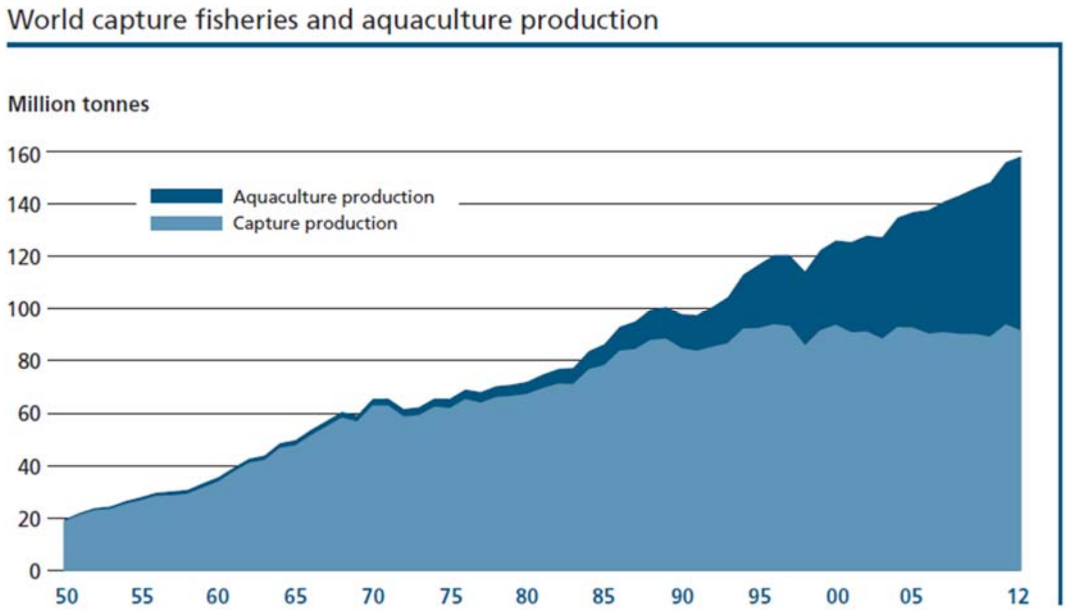
As the demand for land increases (not only for grazing and crop production but also biomass for fuels), land price and competition will increase, thereby threatening food security [4].

Water use has been growing at more than twice the rate of the population increase in the last century. By 2025, 1.8 billion people will be living in regions with absolute water scarcity, and two-thirds of the world population could be under stress conditions [5].

As a result of these factors, future agricultural production will be under mounting pressure, as it increasingly competes for these two already strained resources.

The number of wild-caught fish has plateaued in recent decades (Figure 1), and there are increased calls for changes in fishing practices to help protect stocks [1, 2, 6, 7]. As a result, Aquaculture has been identified as an important approach by which the food needs of the growing population can be met [1, 3, 7]. Indeed, the Earth Policy Institute has shown that farmed fish production has recently overtaken beef production [8]. Aquaculture already supplies over half of the seafood produced for human consumption [9]. In order to meet the future demand for farmed-fish, increasing volumes of high protein fish feed are required.

Figure 1 Sources of fish (Million t) [7]



It is essential that the growing demand for fish feed is met with high protein feeds with minimal environmental impacts. It is important that the full environmental impact (greenhouse gas emissions, water impact and land use requirements are taken into account) to minimise the burden associated with the production and processing of ingredients [1]. While not the focus on this paper, social impacts such use of child labour, human rights issues and living wage are also key issues for the aquaculture industry to address.

Fish oil and fishmeal are major components in many feeds [1, 10, 11, 12, 13]. Fish oil is obtained from the tissue of oily fish, and is high in long chain Omega-3 fatty acids. Fish do not naturally produce these polyunsaturated fatty acids, and in the wild they will accumulate them through consumption of smaller prey fish or algae. However, in aquaculture these fatty acids must be added to the feed. Fishmeal is a powdered product that is produced from approximately 65 percent whole 'forage' fish from reduction fisheries and 35% from the dried bones and offal by-products of fish processed for human consumption [7]. Fishmeal is used in fish feed and in feed for terrestrial livestock and provides a balanced composition of protein and minerals, and improves feed efficiency. Fish used to source fishmeal and fish oil typically are small pelagic species, such as Peruvian Anchovy.

Concerns have been raised regarding the sustainability of fish oil and fishmeal due to their being sourced in part from wild-caught fish [13] and availability as a result of increased competition with direct human consumption for the health supplements market as well as food [3, 13, 1].

FeedKind protein has been developed by Calysta to overcome these challenges, and provide a protein rich alternative to many of the current ingredients in fish feed.

In order to evaluate the environmental impacts of FeedKind protein, The Carbon Trust has carried out an analysis of the carbon, water and land use footprint of Calysta's product. The results of this analysis, as well as a comparison with current substitute ingredients are presented within this report.

1 Product Footprint

1.1 Methodology

The product footprint presented in this report has been calculated in accordance with the requirements of PAS 2050[1], using primary and secondary sources of data provided by Calysta and other internal and external expertise. The Carbon Trust used the latest emission factors from Footprint Expert version 4.0[2], as well as researching additional emission factors when required.

The product footprint evaluates the greenhouse gas, water and land use impact of one tonne of dried FeedKind protein from cradle to leaving the factory gate. The boundary of the footprint considers the individual ingredients, the energy requirements, inputs for the manufacturing phase, and waste outputs. The construction of the production facility and associated capital equipment is outside the boundary of the analysis. Similarly, the downstream fish farming and feed conversion ratios are outside the scope of this analysis. Individual inputs and ingredients have been calculated on a 'per tonne of product' basis, using mass balance data from Calysta.

The Carbon Trust have used a footprint model to calculate the product footprint, which also allows different scenarios to be modelled. The scenarios include the use of renewable electricity, biogas, and the potential use of carbon-capture and storage (CCS) technology within the production stage. By altering these scenarios, the product's environmental impacts can be assessed in a range of circumstances.

1.2 Introduction to FeedKind protein

The analysis carried out focuses on the production of one tonne of FeedKind protein. This product is supplied as dry powder or dried pellets, and is used as a single-cell protein ingredient in fish feed. Unlike other conventional fish feed ingredients, FeedKind protein is manufactured on land in a large production facility. It also has a significantly longer shelf life than typical fishmeal alternatives. Single cell proteins are already consumed daily by millions of people, and form the basis of popular brands such as Quorn, Marmite and Vegemite.

The product is formed during the fermentation of methanotrophic microorganisms (Methylococcus capsulatus (Bath)), with small amounts of scavenger microorganisms to assist in culture stability (Alca ligenes acidovorans, Bacillus brevis and Bacillus firmus), with methane, ammonia and mineral salts. Natural gas or other methane source is pumped through a specialized fermenter, and the microorganisms metabolise the gas as their sole source of energy, producing a high-protein biomass. Wet product is extracted from the fermenter and dried, before being pelletised and packaged for shipping. Typically the fermenter will run for seven weeks continuously, before requiring three days of cleaning. The cycle will then repeat.

It should be noted that FeedKind protein is not currently in commercial production. This product footprint is based on data from a decommissioned facility that had a production capacity of approximately 10,000 tonnes per annum. The location for the new facility is assumed to be Mobile, Alabama, USA for the purposes of this study. Commercial production is expected to begin in 2018, with an expected production rate of at least 20,000 tonnes per annum.

[1] PAS2050: Specification for the assessment of the life cycle greenhouse gas emissions of goods and services. This standard was introduced with the aim of providing a consistent internationally applicable method for quantifying product carbon footprints.

[2] Software developed by the Carbon Trust used to calculate and manage consistent carbon footprints for products and services.

2 Product Footprint Results

In the default scenario, Calysta will use both natural gas and electricity from the US National grid as the primary inputs to the fermentation process. The results of the product footprint analysis conclude that the final pelletized FeedKind protein product has the following product footprint:

- Carbon: 5,819 $kgCO_2e$/tonne of product
- Water: 18.982 m^3/tonne of product
- Land Use: 33.99 m^2/tonne of product

Each of these categories will now be evaluated further.

2.1 Footprint Results: Carbon

The carbon footprint for the production of FeedKind protein can be split into four primary sources, as shown in figure 2. Looking at each of these categories individually, it is shown that 'Waste' has the largest impact on the carbon footprint at 46%.

'Waste' includes all waste outputs from the production process. The largest contribution to this is carbon dioxide gas produced by respiration of the microorganisms being released to the atmosphere during the fermentation process, which accounts for 88% of the waste footprint. The microorganisms within the fermenter metabolize the methane within the natural gas. However, not all methane can be consumed, and a small volume of this gas is captured and combusted within the drying process. This makes up the remaining 12% of the 'Waste' footprint.

The next highest contributor to FeedKind protein's carbon footprint is 'Energy and Fugitives', which make up 35% of the overall carbon footprint.

Electricity is required to power the facility. Heat is used to convert water to steam and to dry the product, and electricity to power the on-site cryogenic facility to produce pure oxygen and nitrogen for the fermentation process. It is important to note that the geographical location of the site has a significant impact on the electricity emission factor used. This is due to the varying mix of energy generation technologies contributing to the respective national electricity grid. It is assumed the production facility is to be located in the United States, which has an average emission factor of 0.49845 $kgCO_2$/kwh. This is much higher than the average for the EU, which is 0.35047 $kgCO_2$/kwh.

In addition to being the primary energy source for the microorgansims, natural gas is also required for the operation of the dryer. Unlike the natural gas entering the fermenter, this gas is combusted directly. The natural gas accounts for 67% of the carbon impact from energy.

Figure 2: FeedKind protein Lifecycle Carbon Footprint (kgCO_2e/tonne product)

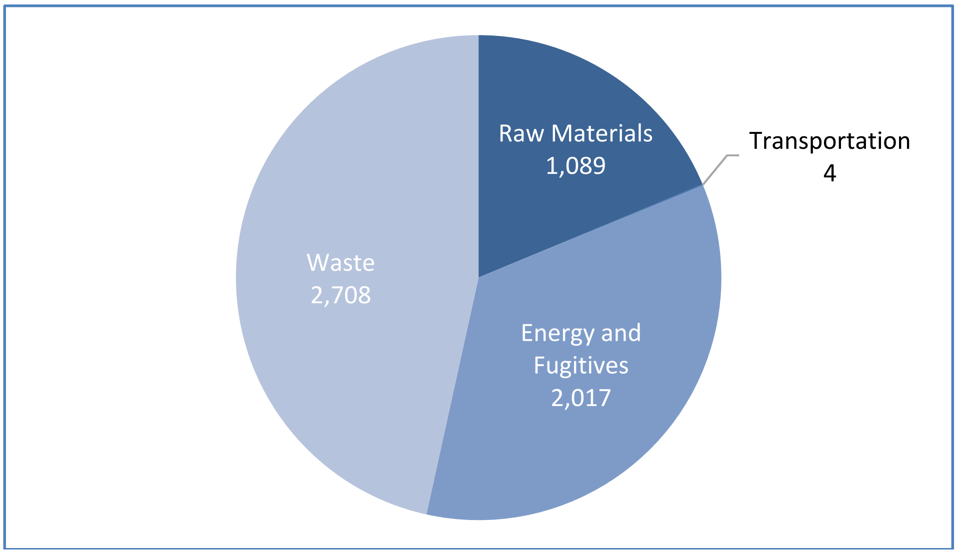


Figure 3: FeedKind protein Lifecycle Water Footprint (m^3/tonne of product)

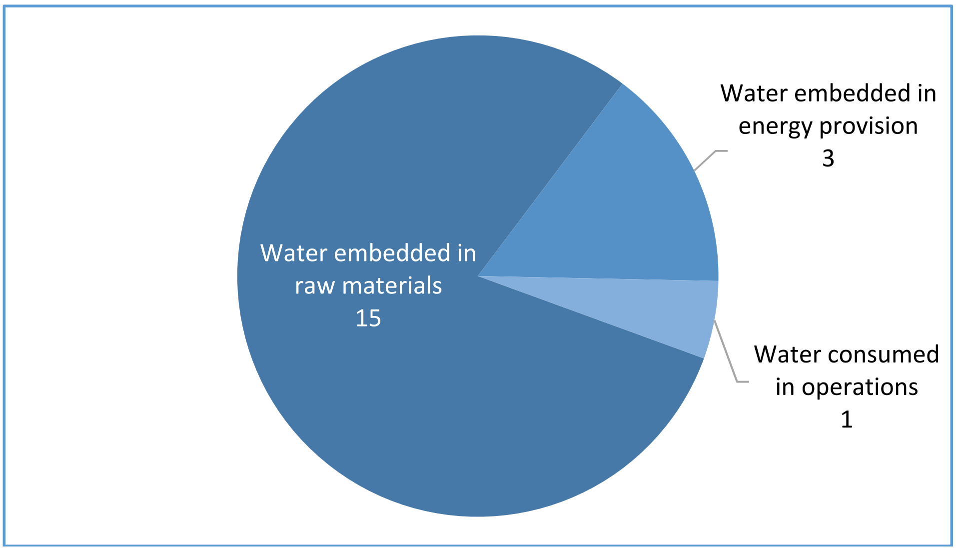
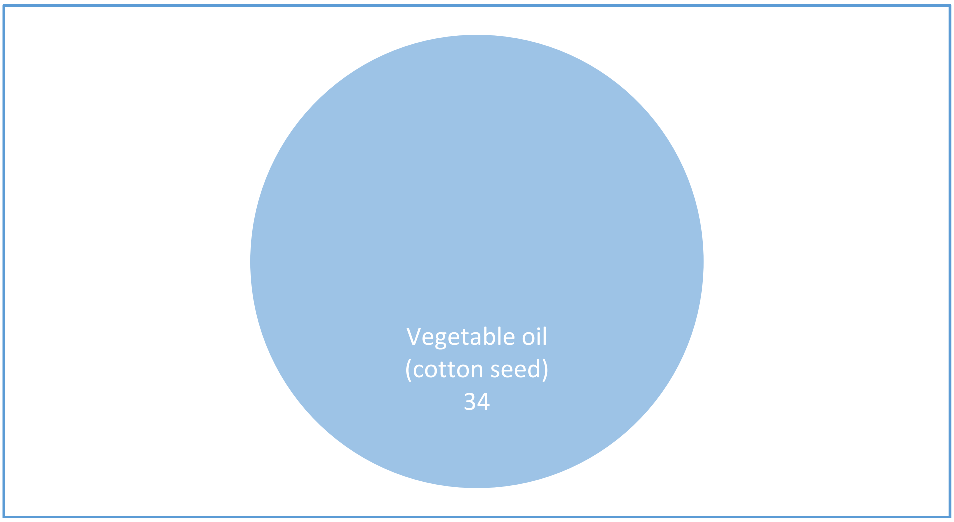


Figure 4: FeedKind protein Lifecycle Land Footprint (33.99 m^2/tonne of product)



Calysta recognises that procurement of electricity and natural gas from non-renewable sources has a greater environmental impact than the use of renewable sources. In order to assess how the use of renewable electricity or biogas would affect the FeedKind protein footprint, a range or scenarios were built into the product footprint model. The results of this will be discussed later in this report.

For every tonne of FeedKind protein that is produced, 10.41 tonnes of raw materials and inputs are required. The required materials each have a respective emission factor (reflecting their environmental impact per tonne), and the sum of these embodied emissions make up 19% of the overall carbon footprint. The majority of material inputs have a negligible impact on the overall footprint. The largest share of embodied emissions is from the supply of natural gas used in the fermenter. Although this gas is not combusted, and is instead metabolized by the microorganisms, there are emissions associated with the extraction and distribution of natural gas[3].

There is an extremely minor contribution to the footprint classed as 'Transport'. This refers to the carbon impact of transporting raw materials to the production facility. Where appropriate, it has been assumed that materials will travel by rail from New Orleans to Mobile, Alabama. As seen in figure 2, transport makes up less than 1% of the overall footprint.

2.2 Footprint Results: Water

Lifecycle analyses of product water footprints are significantly less established than carbon lifecycle analyses [14]. Therefore, this is an innovative approach being taken by Calysta in building the understanding of the environmental impacts of FeedKind protein.

The water footprint calculated is a volumetric measure and has not taken into account local impact, on both water quality and scarcity issues. The overall water footprint per tonne of FeedKind protein is 18.98m^3. As shown in figure 3 80% of this total is due to the embedded water in raw materials. However, this in itself may be misleading, as 81% of the raw material footprint is solely due to the vegetable oil content of FeedKind protein. Vegetable oil is already present in typical fishfeed, and is used as a binding agent for the pelletization of the product, improving transportability and product stability. It is likely that the vegetable oil content of FeedKind will reduce the total amount of additional vegetable oil added to the final feed product, therefore the net effect of this on the overall feed product will be low.

The high water factor for vegetable oil is associated with the water required to grow the vegetable. Alternate forms for the product that do not use vegetable oil can be explored which will reduce the water footprint significantly.

Other embedded water sources within the raw materials are from the ammonia and mineral salt solutions. However, as previously mentioned, these have a relatively small overall impact.

Energy also has an embedded water footprint, which may be easy to overlook. For FeedKind protein, this is embedded in the production of electricity. The primary factor that contributes to this is the water used in steam based turbine technology.

The final area in which water is consumed is in the operation of the facility, which contributes 5% of the water footprint. Water is constantly cycled within the fermenter, however much of this water is recycled throughout the process. It should also be noted that when metabolising methane, the microorganisms also produce water. The net effect of this is that only 0.99 m3 of water is consumed per tonne of product. This is primarily lost through evaporation when drying the product.

Water footprint is an important index by which to compare feed products. Typically agricultural plant and animal based feeds have a very high water footprint that is not sustainable in many water stressed parts of the world [15].

[3] Combusting methane produces carbon dioxide which has a global warming impact. However, the impact is not as great as if the methane were to be released directly into the atmosphere without combustion. This is due to methane having a greater global warming potential than carbon dioxide. By consuming methane and converting it to CO2, the global warming potential is decreased.

2.3 Product Footprint: Land Use

Much like lifecycle analyses or water impacts, land use footprints are an underutilised but important factor to consider when analysing the environmental impact of a product. In the context of animal feed this is especially important, as current agricultural practices are increasingly unsustainable, and farming land is replacing virgin forest [4]. One advantage stated by Calysta for FeedKind protein is that the production facility requires no agricultural land use. Similarly, in contrast to traditional fishing methods, there is no degradation of oceanic environments.

The land use footprint for FeedKind protein, as calculated by the footprint model, is $33.9m^2$ per tonne of FeedKind protein. As shown in figure 4, this is exclusively attributed to vegetable oil. There are no other significant land use footprints.

Given the high contribution of vegetable oil to both the water and land footprints of FeedKind protein, there may be reason to consider other suitable alternatives as mentioned above.

3 Potential for Change

3.1 Renewable Energy and Biogas

Calysta recognises that there is a significant environmental impact within the current production process, and are exploring alternative approaches. One feasible option is sourcing renewable energy to power the production facility.

As has been shown in this report, electricity contributes to the carbon footprint within Calysta's production site. Renewable energy could be purchased from a supplier, or generated directly on site. In either case, renewable energy could be used for 100% of electricity usage, or a smaller proportion.

In the default scenario where there is no renewable energy used, the carbon footprint for FeedKind protein is 5,819 kgCO_2e/tonne of product. Applying a scenario to the product footprint model in which 100% of electricity is generated from renewable sources results in the carbon footprint of FeedKind protein falling to 5,278 kgCO_2e/tonne of product. As mentioned in the evaluation of FeedKind protein's water footprint, renewable energy actually has a slightly larger impact than grid electricity. Therefore FeedKind protein's water footprint rises to 19.22 m^3/tonne of product, up from 18.98 m^3/tonne of product.

As discussed earlier within this report, natural gas usage has a significant contribution to the overall carbon footprint. The base case footprint assumes natural gas is from fossil based sources being supplied to the facility. The impact is due to carbon dioxide emissions released from the fermentation process and also the combustion of natural gas in the drying process. In total it contributes 4.4 tonnes of CO2e/tonne of product across the whole of FeedKind protein's footprint. Calysta has considered replacing natural gas with biogas in order to reduce the environmental impact of FeedKind protein.

Methane is the primary component within natural gas, but it is also the primary component of biogas. Biogas is generated from biogenic sources, for example during the decomposition of organic matter. The most common industrial sources of biogas are landfill gas and biogas from anaerobic digestion. In this report it is assumed that biogas is produced as a waste product from a separate process and has no value (for example as a waste gas from a landfill facility). Using the economic allocation method of greenhouse gas accounting (as in PAS2050), the resulting upstream emissions of biogas are also treated as zero.

Replacing all natural gas with biogas from a waste source would have a large impact on the overall carbon footprint of FeedKind protein. The embedded carbon in the gas released from the fermenter would fall to zero, as would the carbon dioxide released into the atmosphere as a result fermentation and the combustion of gas in the dryer. The net effect of this would be to reduce the lifecycle emissions of FeedKind protein to 2,274 kg CO_2e/tonne of product.

It is important to note that if biogas is purposefully manufactured to be sold, then it will have a carbon footprint in accordance with the economic allocation methodology above. For example such a process would have to take into account the greenhouse gas emissions associated with growing the crops that are used to produce the biogas in an anaerobic digester. This would influence the footprint, so it is important to consider the source of biogas if it were to be utilised in FeedKind protein's production.

A combined effort to utilise both renewable energy and biogas would lead to an overall reduction in the lifecycle emissions to 1,733 kgCO_2e/tonne of product. This is a 70% reduction from the initial level of 5,823 kgCO_2e/tonne of product.

3.2 Carbon Capture and Storage Potential

In addition to renewable energy sources, Calysta is investigating the potential of deploying carbon capture and storage (CCS) technology at their site to capture the carbon dioxide released during the fermentation process and exhaust gases from the drying unit. If CCS were to be more readily available in the future then using it in combination with biogas and renewable electricity would reduce the footprint of FeedKind protein to a negative value 2,790 kgCO_2 / tonne of product. In this scenario the upstream production of biogas will have removed CO_2 from the atmosphere.

Carbon capture and storage (CCS) is a developing technology in which carbon emissions from a process are captured and transferred to a secure storage location. The aim is to mitigate the carbon impact of industrial processes by preventing carbon emissions from entering the atmosphere.

It is important to note that at this time industrial scale CCS facilities are not yet in operation. The first CCS plant to be built in the US is the Kempler County carbon capture plant in Mississippi, which is current under construction.

Although CCS technology may currently not be feasible for Calysta's operations, there is certainly long term potential to utilise this technology. It is also assumed that any storage facilities will have no leakage for a sufficiently long period of time.

A full comparison of how renewable technology will affect the carbon footprint of FeedKind protein is shown in table A.

In all the scenarios below it is important to note that the resulting carbon dioxide emissions are much lower than if the methane were to be directly released into the atmosphere. Methane has a global warming potential 25 times greater than carbon dioxide, thus the 1.6427 tonnes of methane required per tonne of FeedKind would be equivalent to 41,068 kgCO_2e if it was directly released into the atmosphere. In this worst case scenario, the carbon benefit of utilising the methane is over 35 tonnes of CO_2e per tonne of product.

Waste or excess natural gas is also regularly combusted, or flared, during the extraction of fossil fuels. The purpose of this is to convert the gas into carbon dioxide, which is less harmful to the atmosphere than methane. If the equivalent volume of methane required for one tonne of FeedKind was instead flared, the resulting carbon impact would be 4,478 kgCO_2e. As shown in table A, this is higher than all but three of the scenarios presented. It is important to note that the overall product footprint for FeedKind shown in this table includes many more contributing factors than just the impact of natural gas.

Table A: Comparison of FeedKind protein's carbon footprint in a range of scenarios

	Biogas Percentage				
	0%	25%	50%	75%	100%
No Renewables	5,818	4,931	4,044	3,157	2,268
100% Renewable Electricity	5,278	4,390	3,503	2,616	1,729
100% Renewable Electricity + CCS	1,211	211	-789	-1,790	-2,790

4 Comparative Research

FeedKind protein has the potential to replace a number of conventional fish feed ingredients such as fish meal, fish oil, soya protein concentrate, hydrolysed chicken feather meal, chicken meal, pea protein concentrate, wheat gluten meal, blood meal (poultry) and purified amino acid products.

In this section an overview is provided of the water, land and carbon impacts associated with some of the main ingredients currently used in fish feed products. This data enables a comparison to be drawn on the benefits of replacing said ingredients with FeedKind protein

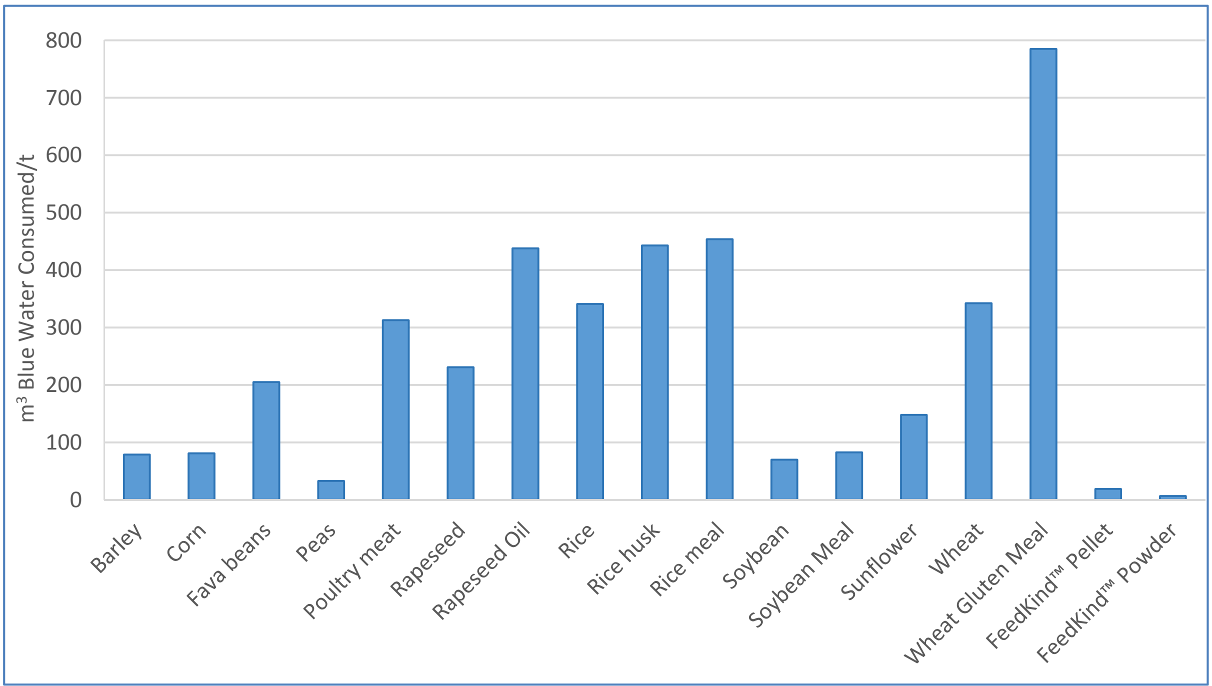
4.1 Water Consumption of Feed Ingredients:

Analysis of the water footprints of primary crops and crop derived products used as ingredients in fish feeds was completed using global average data published by UNESCO [15] and data from the EU Aquamax project [16] . Water consumption is divided into three flows, Blue, Green and Grey[4].

The consumption of blue water is arguably the most important element as this is the water resource for which the ingredients directly compete with other uses such as food crops and human consumption.

Figure 5 provides an overview of the blue water consumption of a selection of agricultural fish feed ingredients. Of the ingredients examined, wheat gluten meal had the largest total blue water footprint (785 m³/t).

Figure 5: Blue Water Consumption of Selective Fish Feed Agricultural Ingredients



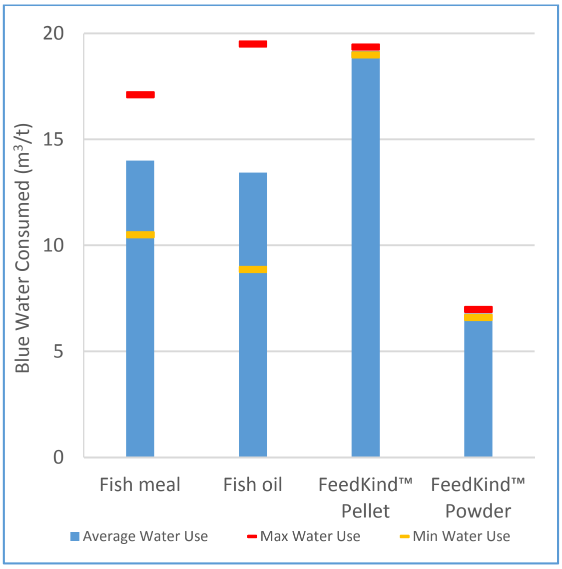
It is important to highlight that the water footprints can vary significantly depending on the geographical location within which the crop(s) are grown and/or processed. For example, blue water consumption for soybean production in the USA is approximately 92m³/tonne but in France it is approximately 447m³/tonne. There are a range of factors that would affect this, including the level of precipitation, rate of run off, climatic condition (humidity, wind speed etc.), competing demands from the water basin, ground conditions as well as the method of application. All of which would impact on the level of irrigation required.

[4] Blue water refers to fresh surface or ground water which is consumed and not immediately replaced. Green water refers to water from precipitation available in the soil that does not run off which evaporates or transpires through plants and Grey water is the volume of freshwater required to assimilate pollutants.

It is therefore vital that geographical factors are taken into account when determining the impacts avoided by the replacement of one ingredient with another. National level data is available from UNESCO, although to fully understand the impact a local assessment of the water basin is required.

As with agricultural ingredients, the source and location of the processing of fishmeal and oil ingredients affects their final water footprint. The average blue water consumption for fishmeal was 14.0m³/t and 13.43m³/t for fish oil (Figure 6) [16].

Figure 6: Water consumption of fishmeal & oil feed ingredients & FeedKind protein



Depending on the processing scenario, the water footprint of FeedKind protein in pellet form ranges from 18.98 to 19.35m³/t. Despite its consumption being on the high end of the range of the footprints of both fishmeal and fish oil (Figure 6), in all cases the water footprint is substantially less than all of the agricultural ingredients assessed (Figure 5). It is important to note that removal of the vegetable oil used in the pelletisation of FeedKind protein causes the associated water footprint to significantly fall to a range of 6.60 to 6.97m³/t (FeedKind Powder Figures 5 and 6).

Replacement of the vegetable oil used during pelletisation with oils from waste streams would also result in a water footprint significantly lower than either fish meal or fish oil.

Comparison against some of the more common agricultural feed ingredients shows that the blue water footprint of FeedKind protein, per tonne, is between 77% and 98% smaller[5]. A saving of this volume is likely to have a significant impact on reducing upstream water pressures.

[5] Soybean meal 76.6%, rapeseed oil 95.6%, wheat gluten meal 97.5%

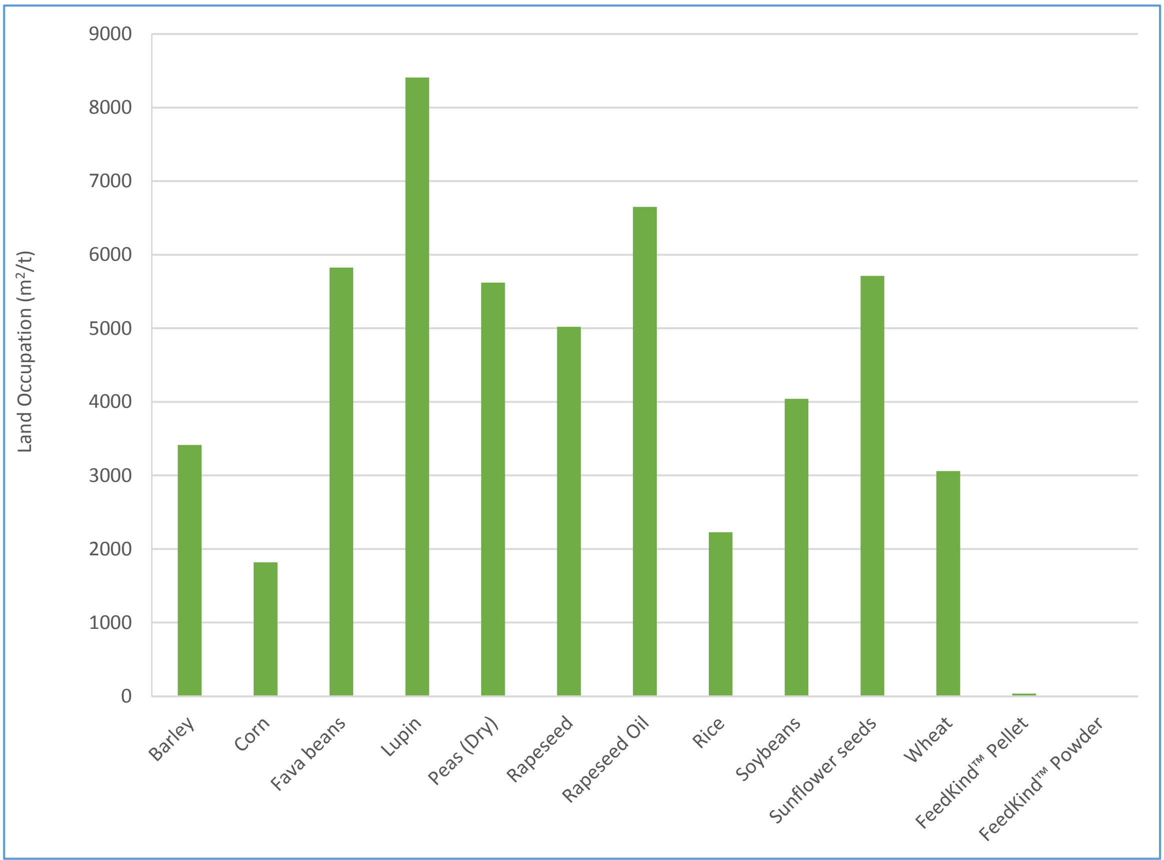
4.2 Land Use of Feed Ingredient:

The land use footprints associated with plant-based fish feed's ingredients comes from the space required for their cultivation and production.

There is limited data available for calculating the land required for the production and processing of the different ingredients used in fish feeds.

The Aquamax project [16] outlines land use required for some processed agricultural products. Whilst the FAO [17] provides global average data on the yield of different crops which have been used to determine the amount of space (m²) required to produce 1 tonne of agricultural ingredients in their unprocessed form (Figure 7).

Figure 7: Land Use of Selective Fish Feed Agricultural Ingredients



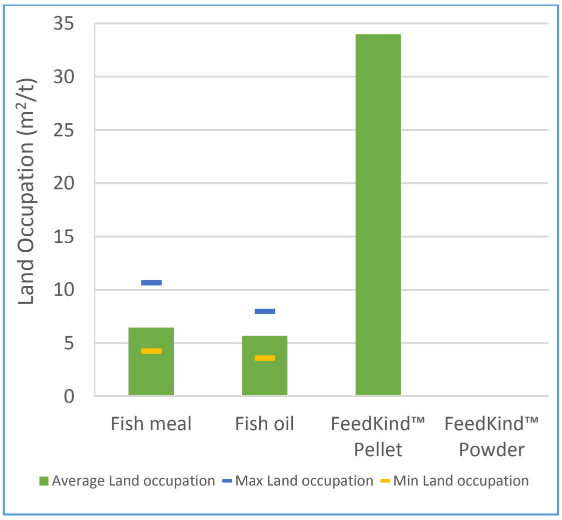
Land occupation of feed ingredients contributes to a much broader issue resulting from the limited availability of land for crop production - that of land use change.

In recent years, in order to meet the growing demand for food and non-food biomass, agricultural land has expanded at the expense of forests [4]. Land use change can increase the release of CO_2e emissions as a result of soil and vegetation disturbance, especially when followed by agriculture [4, 1]. Recent estimates report land use change being responsible for the release of 5.0-5.8 Gt of CO_2e/yr [1, 18].

Processes therefore that avoid land use could be argued to be indirectly preventing the release of carbon emissions by avoiding the exacerbation of land pressures.

The land use calculated for FeedKind protein originates entirely from the vegetable oil used as part of the final feed product. The land requirement that is therefore attributed to the final feed is 34m²/t (Figure 8).

Figure 8: Land occupation of fishmeal & oil feed ingredients & FeedKind protein™



This is significantly less than the land use of the agricultural ingredient assessed, and is due in part to the small quantity of vegetable oil used. The space required for the site within which the FeedKind protein is produced and processed is likely to be an immaterial contribution, and further will be located on industrial, rather than arable, land.

The land occupation of fishmeal and oil is very small in comparison to other ingredients, with FeedKind protein's vegetable oil footprint being 5 times greater than both these ingredients. The footprint of fishmeal and oil is based on wild-caught fish, whereas over 35% is derived from waste by-products of fish processed for human consumption [7].

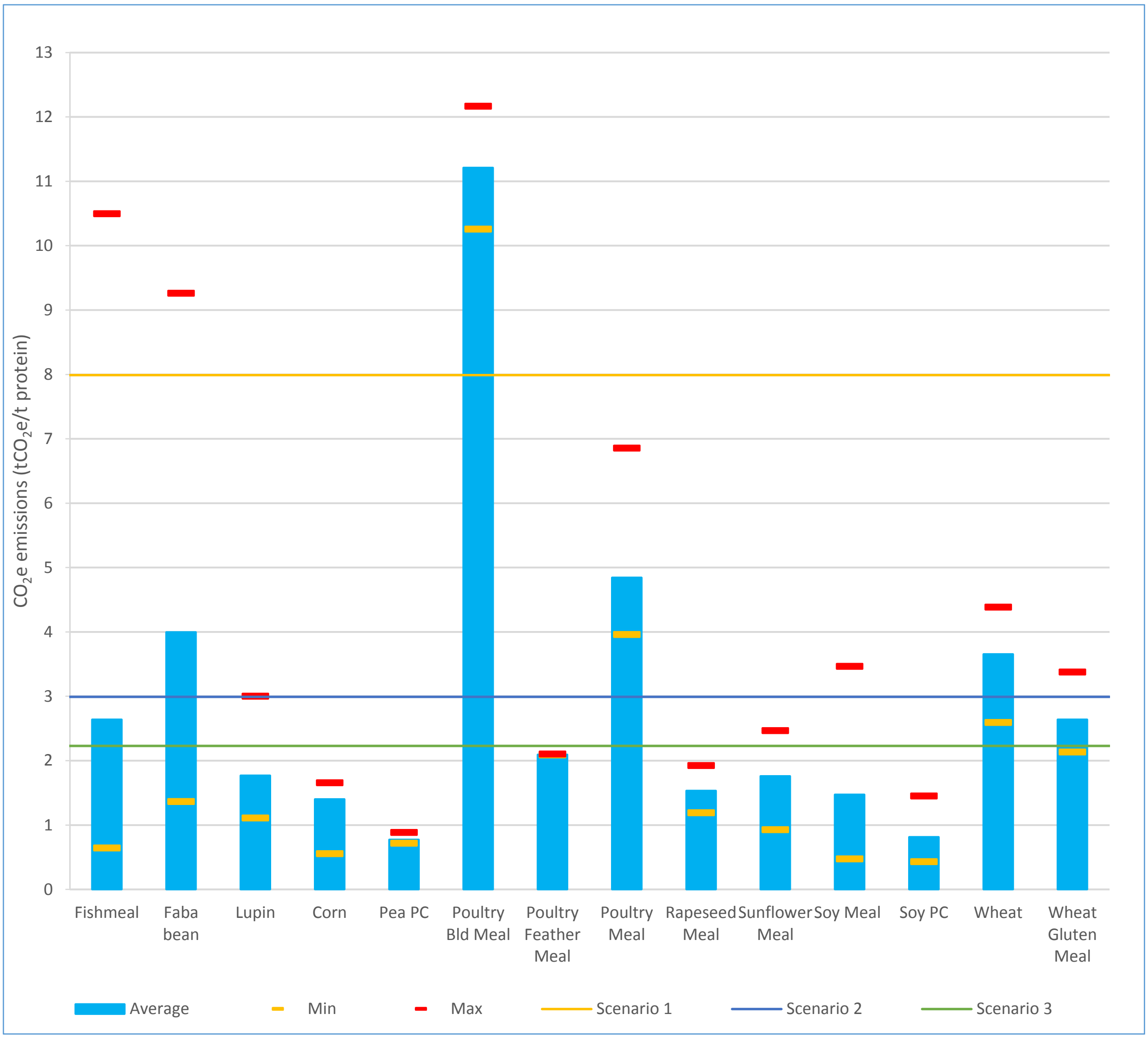
As seen with water consumption, the amount of space require to yield a tonne of a particular crop varies between regions and as such regional variations would need to be taken into account to accurately determine the true benefits of FeedKind protein substitution.

In addition changing the volume or source of vegetable oil used will also have a notable impact on the footprint of FeedKind protein. Using an oil from a crop that has a greater yield per m^2 would improve FeedKind protein's final footprint. In addition, as previously highlighted, making use of waste vegetable oil source could potentially avoid these impacts entirely.

4.3 CO_2e Emission of Protein Content of Feed Ingredients:

Considerable variation was observed in the CO_2e emission per tonne of protein between and within the different ingredients assessed (Figure 9). Fishmeal ingredients, which are notably affected by factors such as region and method of catch and processing, were particularly variable.

Figure 9: Comparison CO_2e Emission of per Tonne of Protein for Different Feed Ingredients & FeedKind protein Produced Under Varying Scenarios



Scenario 1: FeedKind protein™ Powder
Scenario 2: FeedKind protein™ 100% biogas
Scenario 3: FeedKind protein™100% biogas/100% Renewable Electricity

Despite high CO_2e emissions some ingredients are only used in very small volumes in feeds. E.g. Poultry blood meal (0.05 - 1.5%), Poultry meal (3.1 - 3.62%)[6]. Other ingredients associated with small CO_2e emissions are used in larger volumes, e.g. fishmeal (20.9 - 42.61%), fish oil (5.0 - 30.0%), wheat (7.0 - 17.0%).

The contribution an ingredient makes to the final feed product can have a significant impact on the feed's final CO_2e footprint of its protein content. It is important that this is taken into account when assessing the ingredients being replaced by FeedKind protein.

[6] Poultry meal and poultry blood meal are often bought as co-products therefore the actual footprint that can be attributed to them will likely be smaller.

Tonne for tonne CO_2e emissions of FeedKind protein powder derived under Scenario 1 (7.99 tCO_2e/t protein) are significantly higher than many of the other ingredients (Figure 9).

However, when biogas and/or renewables are used in FeedKind protein production, the CO_2e emissions of the FeedKind protein product are in line with other typical ingredients.

When 100% biogas is utilised (Scenario 2) total emissions fall to 2.99 tCO_2e/t protein. When 100% biogas and 100% renewable electricity is used (Scenario 3) FeedKind protein's total emissions are 2.23 tCO_2e/t protein.

Given these findings, without the use of renewables during production the direct replacement of solely the fishmeal and oil components of fish feed with FeedKind protein on a tonne for tonne basis would not result in a net reduction in total CO_2e emissions per tonne of protein. However, feed ingredients are generally included on the basis of their respective protein content, most of which are significantly lower than FeedKind protein. Therefore, one tonne of FeedKind protein generally displaces greater than one tonne of current feed ingredients. Therefore, it is more appropriate to compare ingredients as normalized by their protein content.

Table B provides a normalized comparison of some key fish feed ingredients to FeedKind protein in its powder and pelletised form. The differences between pellet and powder FeedKind protein are relatively small but arise from the use of vegetable oil as outlined earlier. The analysis shows that FeedKind protein can reduce the CO_2e emissions of the final feed by 20-30% relative to some grades of fishmeal.

Table B: Impacts of feed ingredients in relation to protein content

Ingredients	Protein content (%DM)	CO_2e emissions per kg of protein ($kgCO_2e/kg$)	Water consumption per kg of protein (m^3/kg)	Land occupation per kg of protein (m^2/kg)
FeedKind™ Pellet	71	2.648	0.029	0.052
FeedKind™ Powder	71	2.229	0.010	0.000*
Fish meal (medium)	64	2.640	0.024	0.011
Fish meal (low)	60	2.816	0.025	0.012
Soy protein concentrate	66	0.791	0.136**	6.655**

***No land occupation as no vegetable oil used**
****based on soybean water and land consumption**

5 Other considerations

In addition to the potential impacts discussed, there are other factors which should be considered when determining the potential benefits of using FeedKind protein as a feed for aquaculture.

Despite growth in aquaculture the global production of fishmeal and fish oil has remained relatively static or declining [19, 20] due mainly to more precautionary fishing of forage species. However, the increasing replacement of marine by vegetable ingredients has so far prevented this being a threat to the continuing expansion of the aquaculture industry.

It is predicted that any reduction in fishmeal and fish oil consumption will be replaced by plant based proteins and oils [1, 19] which may exacerbate the pressure on agricultural land (such as land use change) and continue to place fish feeds in direct competition with crops for human consumption, feeds and fuel production. This shift to the use of plant-based proteins is highlighted in a study by Nofima on Norwegian salmon farming. This study observed that farmed salmon's diet has shifted from 1990 with a 90 percent marine based diet to 2013 to a predominantly plant based diet where marine ingredients accounted for 30 percent [21].

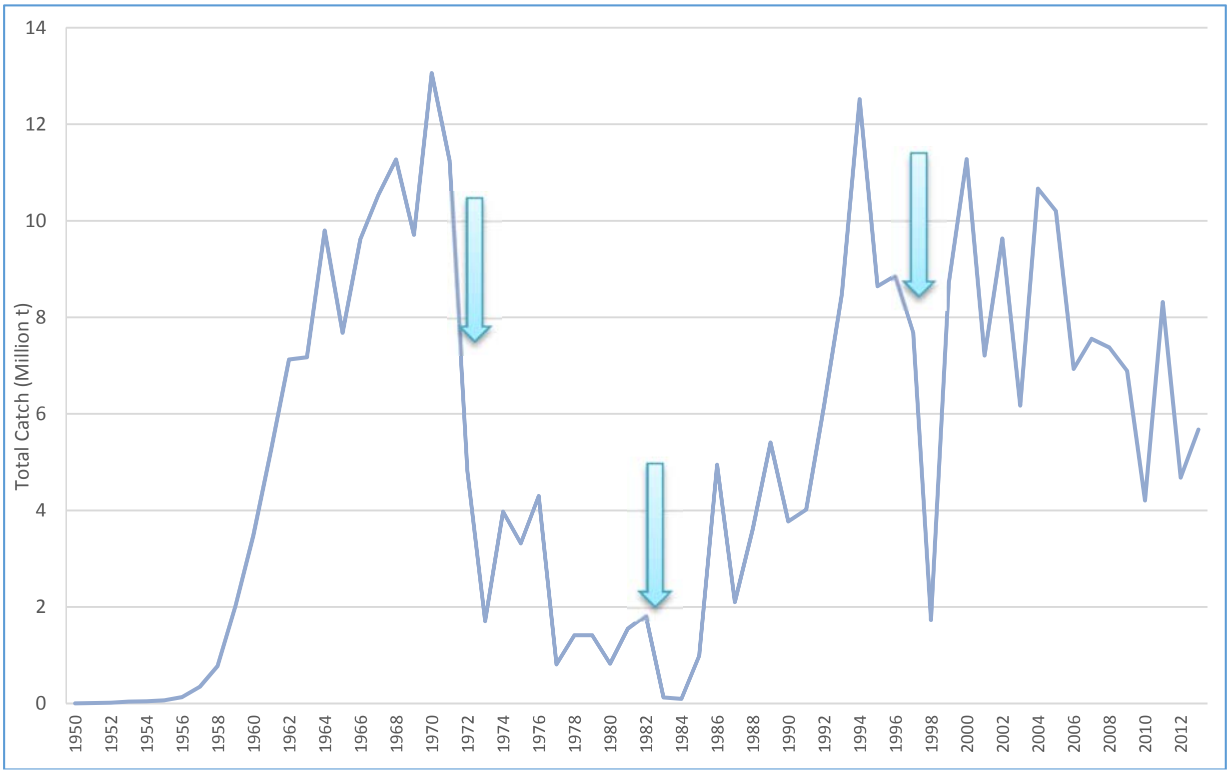
It is important to note that the partial substitution of marine raw materials has not been found to have any negative effect on growth, susceptibility to disease, or quality of the fish [2]. A minor proportion of fishmeal & fish oil is still retained to counter any anti-nutritional factors found in plant-based proteins (e.g. in soya), to provide essential lysine, methionine and also plus essential fatty acids.

The increased demand for fish based products, in particular fish oils from the nutraceutical sector [13] is helping to drive prices up.

Increased competition for this resource may mean feed producers are priced out of being able to source fishmeal and oils. Which would seriously threaten the industry's ability to maintain its expected growth.

35% of all fishmeal and fish oil is sourced from the Peruvian anchoveta [22]. The impact El Niño events have on this species has been widely reported [20, 22]. Figure 10 provides an overview of the total Peruvian anchoveta catch with major El Niño events highlighted.

Figure 10: Total Peruvian Anchoveta Catch (Million t) vs Major El Nino Events



During El Niño events a dramatic drop is observed in the total catch, the knock-on effect of this being a reduction in fishmeal and fish oil availability. This is compounded by the fact that a higher proportion of fish previously used for fishmeal (e.g. Jack Mackerel) are now being processed for direct human consumption [19].

The use of FeedKind protein could reduce the requirements of wild-caught fish for aquaculture. Because of the limited supply, fishmeal and fish oil are already being used more strategically by the industry [19, 20].

Therefore alternative sources such as FeedKind protein which do not compete with both plant-based and marine-based ingredients are essential as they facilitate the continued sustainable growth of the aquaculture industry.

FeedKind protein could not only be used to supplement any shortfall in fishmeal and fish oil availability, but could also enable the replacement of the alternative proteins, which in some cases represent the majority of the feed, (such as soya and rapeseed), avoiding any negative impacts associated with their production and use.

6 Conclusion

In conclusion when FeedKind protein is produced with both biogas and renewable electricity it has a carbon footprint that is comparable to or better than many other feed sources. However, evaluating the environmental impact based on purely the carbon footprint does not provide a complete picture of the potential benefits of the product. FeedKind protein has minimal land use and water requirements compared to many terrestrial based fish feed ingredients. Compared on this basis, FeedKind protein offers a significant advantage as land and water will become more valuable assets in the future when meeting the challenge of feeding a growing population.

Similarly as global fish stocks remain under severe pressure it is important to identify alternatives to fish meal.

The protein content of the feed is one of the most important factors to evaluate when considering alternatives to conventional fish feed ingredients. As FeedKind protein has a high protein content, its carbon footprint per tonne of protein can be comparable if not lower than many conventional fish feed ingredients, including fishmeal. However this is only when renewables are utilised in its production.

Finally, the future development of carbon capture and storage technology would enable FeedKind protein to provide a truly sustainable fish feed by providing feed that has a negative carbon footprint.

References

[1] World Reserach Institue, “Creating a Sustainable Food Future, World Resources Report 2013–14: Interim Findings,” 2013.

[2] MarineHarvest, “Salmon Farming Industry Handbook 2015,” 2015.

[3] World Bank, “Fish to 2030 Prospects for Fisheries and Aquaculture; Agriculture and Environmental Services Discussion Paper 03,” World Bank Report Number 83177-GLB, 2013.

[4] S. Bringezu, H. Schütz , W. Pengue , M. O´Brien, F. Garcia, R. Sims , R. Howarth, L. Kauppi, M. Swilling and J. Herrick, “Assessing Global Land Use: Balancing Consumption with Sustainable Supply. A Report of the Working Group on Land and Soils of the International Resource Panel,” UNEP, 2014.

[5] UN, Water Scarcity factsheet, 2013.

[6] Seafish, “The Seafish Guide To Aquaculture,” 2013.

[7] UN FAO, “The State of World Fisheries and Aquaculture; Opportunities and challenges,” Rome, 2014.

[8] Earth Policy Institute, “Farmed Fish Production Overtakes Beef, 2013, Avaialble at; http://www.earth-policy.org/plan_b_updates/2013/update114,” 2013. [Online].

[9] NOAA Fisheries website, Dec 2015, Available at; http://www.nmfs.noaa.gov/aquaculture/faqs/faq_aq_101.html#4howmuch.

[10] J. Boissy, J. Aubin, A. Drissi, H. M. van der Werf, G. J. Bell and S. J. Kaushik, “Environmental impacts of plant-based salmonid diets at feed and farm scales,” vol. 321, pp. 61 - 70, 2011.

[11] N. Pelletier and P. Tyedmers, “Feeding farmed salmon: Is organic better?,” vol. 272, pp. 399 - 416, 2007.

[12] N. Pelletier, P. Tyedmers, U. Sonesson, A. Scholz, F. Ziegler, A. Flysjo, S. Kruse, B. Cancino and H. Silverman, “Not All Salmon Are Created Equal: Life Cycle Assessment (LCA) of Global Salmon Farming Systems,” *Environ. Sci. Technol.*, vol. 43, pp. 8730 - 8736, 2009.

[13] J. Shepherd and E. Bachis, “Changing Supply And Demand for Fish Oil,” vol. 18, pp. 395 - 416, 2014.

[14] M. M. M. &. A. Y. Hoekstra, “A global Assessment of the Water Footprint of Farm Animal Products,” *Ecosystems*, pp. 401-415, 2012.

[15] M. M. Mekonnen and A. Y. Hoekstra, “The Green, Blue and Grey Water Footprint of Crops and Derived Crop Products,” UNESCO-IHE Institute for Water Education; Value of Water Research Report Series No.47, 2010.

[16] European Union, “Aquamax Project : Sustainable Aquafeeds to Maximise the Health Benefits of Farmed Fish for Consumers,” 2010.

[17] Food and Agriculture Organization of the United Nations, “FAOSTAT,” 2015. [Online]. Available: http://faostat.fao.org/.

[18] O. Edenhofer, R. Pichs-Madruga, Y. Sokona, S. Kadner, J. C. Minx, S. Brunner, S. Agrawala, G. Baiocchi, I. A. Bashmakov, G. Blanco, J. Broome, T. Bruckner, M. Bustamante, L. Clarke, M. Conte Grand, F. Creutzig, X. Creutzig, S. Dhakal, N. K. Dubash, P. Eickemeier, E. Farahani, M. Fischedick, M. Fleurbaey, R. Gerlagh, L. Gómez-Echeverri, S. Gupta, J. Harnisch, K. Jiang, F. Jotzo, S. Kartha, S. Klasen, C. Kolstad, V. Krey, H. Kunreuther, O. Lucon, O. Masera, Y. Mulugetta, R. B. Norgaard, A. Patt, N. H. Ravindranath, K. Riahi, J. Roy, A. Sagar, R. Schaeffer, S. Schlömer, K. C. Seto, K. Seyboth, R. Sims, P. Smith, E. Somanathan, R. Stavins, C. von Stechow, T. Sterner, T. Sugiyama, S. Suh, D. Ürge-Vorsatz, K. Urama, A. Venables, D. G. Victor, E. Weber, D. Zhou, J. Zou and T. Zwickel, “Technical Summary. In: Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change,” Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA., 2014.

[19] A. Chamberlin, “Fishmeal and Fish Oil –The Facts, Figures, Trends, and IFFO’s Responsible Supply Standard,” IFFO, 2011.

[20] A. Jackson, “Fishmeal & Fish Oil & its Role in Sustainable Aquaculture,” IFFO - International Aquafeed, Sept - Oct 2012.

[21] T. Ytrestøyl, T. Synnøve Aas and T. Åsgård, “Nofima: Resource utilisation of Norwegian salmon farming in 2012-2013; Report 36/2014,” 2014.

[22] IFFO, “Datasheet: The production of fishmeal and fish oil from Peruvian anchovy,” 2009.

[23] L. D. Anadon, M. Bunn, G. Chan, M. Chan, C. Jones, R. Kempener, A. Lee, N. Logar and V. Narayanamurti, “Transforming U.S. Energy Innovation,” Harvard Kennedy School Belfer Center, 2011.

[24] A. Sagar, H. De Coninck and D. Ockwell, “Options to facilitate collaborative climate technology R&D,” in *TEC meeting, May 28th, 2012*, 2012.

[25] K. Singh, “Innovation for a High-Energy Planet - Implementing Climate Pragmatism Framing Document Two,” Consortium for Science, Policy & Outcomes, Temple, Arizona, 2012.

[26] IEA, “Technology Roadmap: A Guide to Development and Implementation,” International Energy Agency, Paris, France, 2014.

[27] IEA, “World Energy Outlook,” International Energy Agency, Paris, 2015.

[28] ARENA, “Commercial Readiness Index for Renewable Energy Sectors,” Australian Renewable Energy Association, Sydney, 2014.

[29] NREL, “Strengthening Clean Energy Technology Cooperation under the UNFCCC: Steps toward Implementation,” National Renewable Energy Laboratory, Energy Research Centre of the Netherlands, UNEP Riso Centre, Oak Ridge, Tennessee, 2010.

[30] IEA, “Energy Technology Perspectives,” International Energy Agency, Paris, 2015.

[31] Green Energy Storage, “Market Trends for ESS,” 26 November 2015. [Online]. Available: http://www.greenenergystorage.eu/en/market-overview/.

[32] GBI Research, “Global Energy Storage Market to 2020 – Targeting Transportation Sector Applications, Advanced Batteries, Ultracapacitors and Fuel Cells all Set for Growth,” Global Business Intelligence, 2013.

[33] Navigant Research, “Compressed Air Energy Storage market forecast,” Navigant Research, 2013.

[34] IEA, “Energy Technology Perspectives,” International Energy Agency, Paris, 2012.

[35] Vision Gain, “Energy Storage Technologies (EST) Market 2015 - 2025,” Vision Gain, 2015.

[36] Ernst & Young, “Cost-benefit analysis for the comprehensive use of smart metering,” Ernst & Young, 2013.

[37] J. Chang, J. Pfeifenberger, K. Spees, M. Davis, I. Karkatsouli, L. Regan and J. Mashal, “The Value of Distributed Electricity Storage in Texas,” The Brattle Group, 2014.

[38] J. Aubin, E. Papatryphon, H. M. G. van der Werf and S. Chatzifotis, “Assessment of the environmental impact of carnivorous finfish production systems using life cycle assessment,” *Journal of Cleaner Production*, vol. 17, pp. 354 - 361, 2009.

[39] U.S. Soybean Export Council, “Soy Protein Concentrate For Aquaculture Feeds Technical Bulletin,” 2008.

[40] Feedipedia, “Feedipedia: Animal Feed Resources Information System,” 2015. [Online]. Available: www.feedipedia.org. [Accessed November 2015].

Table 1: Key Ingredient Comparison

Ingredients	Water Consumption (m^3/t)	Land Use (m^2/t)	Carbon Footprint (tCO_2e/t)
FeedKind™	18.98	33.99	6.27
FeedKind™ (100% biogas & renewables)	19.35	33.96	1.73
Fish meal	14.00	6.47	1.55
Fish oil	13.43	5.70	2.22
Soy meal	82.70	2793.17[¤]	0.68
Wheat Gluten Meal	785.00	4339.00[ʁ]	1.82
Rapeseed oil	438.00	6651.00	2.09
Poultry meal	313.00[¥]	<0.1[¥]	3.73

[¤] Based on land to yield 1 tonne soybean
[ʁ] Based on single value from Aquamax database
[¥] Based on water consumption and land use of feeds

The Carbon Trust is a world-leading not-for-profit group helping businesses, governments and the public sector to accelerate the move to a sustainable low-carbon economy through carbon reduction, energy-saving strategies and commercialising low-carbon technologies. We offer a range of tailored services, designed to meet the needs of businesses, governments and the public sector. By stimulating low-carbon action we contribute to green goals, including the lowering of carbon emissions, the development of low-carbon businesses, increased energy security and job creation.

- We advise businesses, governments and the public sector on their opportunities in a sustainable low-carbon world
- We measure and certify the environmental footprint of organisations, supply chains and products
- We develop and deploy low-carbon technologies and solutions, from energy efficiency to renewable power

www.carbontrust.com

020 7170 7000

The Carbon Trust is a company limited by guarantee and registered in England and Wales under Company number 4190230 with its Registered Office at: 4th Floor, Dorset House, 27-45 Stamford Street, London SE1 9NT

Published in the UK: April 2016

CARBON TRUST