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Impacts of the expansion of aquaculture on global agricultural markets and land use change

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Abstract

Aquaculture is one of the most rapidly growing food producing sectors. It has the potential to meet future seafood demand from a growing global population. However, the expansion of aquaculture has led to a continuous increase in demand for feed which has led to environmental issues. Fishmeal and fish oil are important ingredients in the feed given to carnivorous fish. They are accused of unsustainably exploiting fish stocks for feed instead of permitting their use as food for households in the least developing countries. As aquafeed accounts for about 50% of the total farming cost, the increasing prices of fishmeal and fish oil drive producers to look for cheaper and more sustainable alternatives. The improvement of feed technology is likely to replace fish meal and oil with plant-based alternatives. Thus, in terms of animal protein consumption for humans and crop demand for aquafeed, the expansion of aquaculture links seafood production with agricultural markets.

This purpose of this thesis is to assess and quantify the impact of aquaculture expansion on global agricultural markets and global land use via 2030 to 2050. A behavioral market model for fish sector and feed ingredients was developed extending the agricultural sector model, Common Agricultural Policy Regional Impact Modelling System (CAPRI), for quantitative analysis. The detailed coverage of the fish sector in the model permits the evaluation of various scenarios, such as diet shift, reforms of the European Union (EU) common fisheries policy (CFP), progress in feed technology, and a reallocation of fish used for fish feed to food.

The results of scenario 1 that represents a preference shift of animal protein from livestock products to seafood will lead to a 17% increase in seafood consumption globally. The implementation of scenario 2 where the CFP moves the EU fishery sector closer to maximum sustainable yield (MSY) and thereby permits an increased catch of 12% in the EU, which is primarily exported. Scenario 3-A which represents the technology needed to turn carnivorous fish to vegetarians, is found to have only a negligible impact on global land use change. Scenario 3-B banning the processing of fish caught to fish meal and oil results in a greater seafood supply as well as higher fish meal and oil prices by 16% and 13%, respectively. The reduced prices due to increased supply have increased seafood consumption in Africa by 15%. However, effects on global land use change are also negligible in this scenario.

Keywords*: fish markets, agricultural markets, impact assessment, CFP, fish sector model, CAPRI*

Zusammenfassung

Die Aquakultur ist eine der am schnellsten wachsenden Sektoren der Nahrungsmittelwirtschaft und hat das Potenzial, den zukünftigen Bedarf der wachsenden Weltbevölkerung an Meeresfrüchten zu decken. Die Ausweitung der Aquakultur hat jedoch auch zu einem kontinuierlichen Anstieg der entsprechenden Futtermittelnachfrage und zu Umweltproblemen geführt. Fischmehl und -öl sind wichtige Bestandteile im Futter für fleischfressende Fische. Sie werden dafür verantwortlich gemacht, dass Fischbestände als Futtermittel anstatt als Lebensmittel für Haushalte in den am wenigsten entwickelten Ländern genutzt werden. Da Futtermittel etwa 50% der gesamten Kosten für die Fischzucht ausmachen, stimulieren die steigenden Preise von Fischmehl und -öl die Produzenten dazu, nach billigeren und nachhaltigeren Alternativen zu suchen. Durch die Verbesserung der Futtertechnologie werden Fischmehl und -öl wahrscheinlich kontinuierlich durch pflanzliche Alternativen ersetzt werden. Eine expandierende Aquakultur ist somit über den tierischen Eiweißverbrauch für Menschen und die Nachfrage nach Futtermitteln mit den Agrarmärkten verbunden.

In dieser Arbeit sollen die Auswirkungen der Expansion der Aquakultur von 2030 bis 2050 auf die globalen Agrarmärkte und die globale Landnutzung bewertet und quantifiziert werden. Es wird ein Marktmodell für das Verhalten des Fisch- und zugehörigen Futtermittelsektors entwickelt, das das Agrarmodell CAPRI (Common Agricultural Policy Regional Impact Modeling System) für die quantitative Analyse erweitert. Dieses Fischsektormodell ermöglicht Szenarioanalysen zu veränderten Verbrauchsgewohnheiten, zu Reformen der gemeinsamen Fischereipolitik, zu Fortschritten in der Futtermitteltechnologie und zu einer politisch reglementierten Umwidmung der Fischverwendung von Futtermitteln zu Lebensmitteln.

Die Ergebnisse von Szenario 1, das eine Verlagerung von tierischem Eiweiß von tierischen Produkten zu Meeresfrüchten beinhaltet, würden weltweit zu einem Anstieg des Verbrauchs von Meeresfrüchten um 17% führen. In Szenario 2 erreicht die Gemeinsame Fischereipolitik eine bessere Orientierung am maximal nachhaltigen Ertrag und dadurch einen um 12% erhöhten Fang in der EU, der hauptsächlich exportiert wird. Szenario 3-A untersucht die Folgen einer Technologieänderung, so dass fleischfressende Fische weitgehend pflanzlich ernährt werden können, findet aber nur zu vernachlässigende Effekte auf die globale Landnutzung. Szenario 3-B, in dem die Verarbeitung von gefangenem Fisch zu Fischmehl und -öl verboten wird, führt zu einer höheren Versorgung mit Meeresfrüchten. Deren sinkenden Preise führen zu einem Verbrauchsanstieg von 15% bei Meeresfrüchten in Afrika. Gleichzeitig kommt es global zu

Preisanstiegen von 16% und 13% für Fischmehl und -öl. Die Auswirkungen auf die globale Landnutzung sind jedoch wie in den anderen Szenarien vernachlässigbar.

Keywords: *fish markets, agricultural markets, impact assessment, CFP, fish sector model, CAPRI*

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Abbreviations

ACRONYM	Definition
ACP	African, Caribbean and Pacific Group of States
Agg.	Aggregated
Aglink-COSIMO	Agricultural sector model of the OECD / FAO
B_{MSY}	MSY biomass level
CAP	Common Agricultural Policy
CAPRI	Common Agricultural Policy Regionalized Impact model
CAPTRD	Trend Projection tool for CAPRI
CES	Constant elasticity of substitution
CFP	Common Fishery Policy
CGE	Computational General Equilibrium
COCO	Complete and Consistent regional database of CAPRI
DDGS	Distiller's Dried Grains with Solubles
Diff	Difference
EAA	Essential Amino Acids
EU	European Union
EU MS	European Member States
EUROSTAT	Statistical Office of the European Communities
FAO	Food and Agriculture Organization of the United Nations
FAOSTAT	Statistical database provided by the Food and Agriculture Organization of the United Nations
FCR	Feed Conversion Ratio
FIFO	Fish-In Fish-Out Ratio
FIML	Fishmeal
FIML&FIOL	Fishmeal and fish oil
FIOL	Fish oil
FIOT	Fish waste
FISHSTAT	Statistical database provided by the FAO Fisheries and Aquaculture Department
F_{MSY}	Fishing at MSY
GHG	Green House Gas
GLOBIOM	Global Biosphere Management Model
ha	Hectare
IAA	Integrated Agriculture-Aquaculture system
IFPRI	International Food Policy Research Institute
IIASA	International Institute for Applied System Analysis

IMPACT	International Model for Policy Analysis of Agricultural Commodities and Trade
k	Kilo
LEI	Agricultural Economics Research Institute
MAGNET	Modular Applied GeNeral Equilibrium Tool
MEY	Maximum Economic Yield
mm	Million
MSY	Maximum Sustainable Yield
NPK	Nitrogen-Phosphorus-Potassium
NUTS	Nomenclature of Statistical Territorial Units
OECD	Organization for Economic Co-Operation and Development
PE	Partial equilibrium
SYML	Soybean meal
t	ton
TAC	Total Allowable Catch
USB	United Soybean Board
USDA	United States Department of Agriculture
UN	The United Nations

Chapter 1
Introduction

1.1 Motivation and research objective

In order to reduce confusion between capture fisheries, aquaculture is defined by the Food and Agriculture Organization of the United Nations (FAO, Edwards & Demaine, 1997) as "*Aquaculture is the farming of aquatic organisms, including fish, molluscs, crustaceans and aquatic plants. Farming implies some form of intervention in the rearing process to enhance production, such as regular stocking, feeding, protection from predators, etc. Farming also implies individual or corporate ownership of the stock being cultivated*."

Nearly all arable land is being utilized to feed the world. However, according to the press release by the United Nations (UN)[1], the global population is projected to reach 9.7 billion by 2050. Aquaculture, the fastest growing food sector, could significantly contribute to meeting the future food demand,

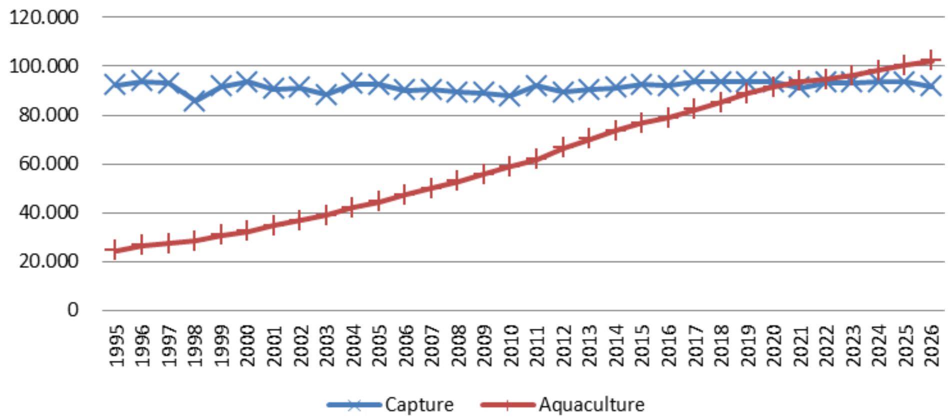
1 See webpage: http://www.un.org/en/development/desa/news/population/2015-report.html Last accessed on 06-02-2021

particularly the need for protein (Zurek et al., 2017). According to FAO (2014) and Moffitt and Cajas-Cano (2014), seafood makes up approximately 20% of animal protein and essential nutrients consumed by humans. Fish consumption is projected to be 138 million tons (mm) by 2020, 151.7 mm tons by 2030 (World Bank, 2013) and reach 215 mm tons by 2050 (Béné et al., 2015). The production of captured fisheries remained stagnant over the past two decades and is expected to be unchanged until 2026, as shown in Figure 1-1. At the same time, wild fish stocks have leveled off globally. According to FAO (2010), 53%, 28% and 3% of marine fish stocks were fully exploited, over-exploited or depleted in 2008, respectively. In 2011, 28.8% of marine fish stocks were estimated to have diminished to a biologically unsustainable level (FAO, 2014). Therefore, fishing in the sea is no longer a solution to meeting the increasing demand for seafood. According to Beveridge et al. (2012) and Kobayashi et al. (2015), nearly 40% of fish consumption was provided by fish farming and is projected to be 62% by 2023. Overall, aquaculture production has tripled in the past two decades (FAO–FISHSTAT, 2012) and is projected to exceed capture production after 2020 as shown in Figure 1-1. The World Bank[2] determined that two-thirds of food fish supply will be produced in fish farms by 2030. Currently, aquaculture production is dominated by Asia, which accounted

2 See press released by the World Bank: http://www.worldbank.org/en/news/press-release/2014/02/05/fish-farms-global-food-fish-supply-2030 Last accessed on 06-02-2021

for 91% of the total production by volume and 76% by value in 2013, respectively (Figure 1-2 and Figure 1-3). Among Asian countries, China is the biggest supplier and exporter accounting for approximately 60% of the world aquaculture production in the world.

Figure 1-1 FISHERIES – Agricultural OECD-FAO Outlook from 2017 to 2026 and meta-data back to 1995 (1000 t)



Source: OECDStat[3] (data extracted on 29 Oct 2018)

Though aquaculture's positive social-economic effects and advantages for meeting future seafood and protein demand are uncontested, there are also severe downsides in terms of aquaculture's environmental and social impacts such as pollution of ecosystem (David et al., 2009; Sara et al., 2011),

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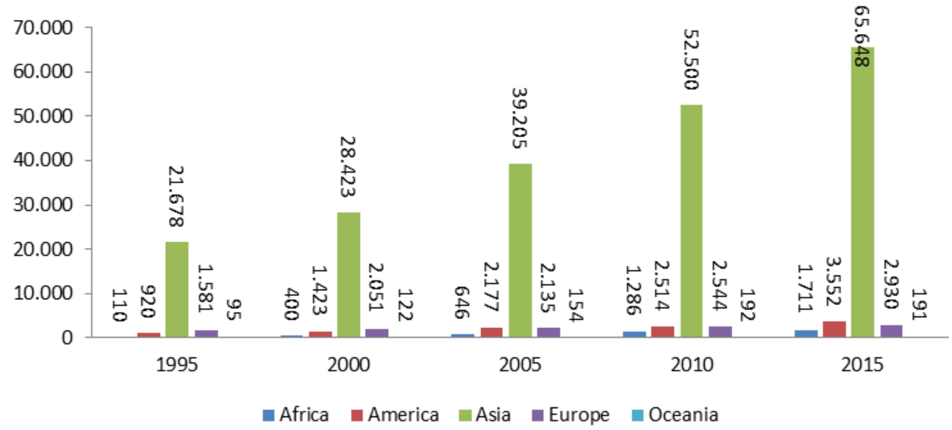
[3] This tool provides the database presented in the OECD-FAO Agricultural Outlook 2017-2026. For OECD countries, the data is accompanied by detailed meta-data. In most cases the data is going back to 1970 and extended to the latest year in the projections (currently 2026). Database was published in July 2017.

habitat destruction (Stokstad, 2010), salinization of groundwater (Paez-Osuna, 2001), health risks to consumers, and unemployment in capture fishery industry (Klinger & Naylor, 2012; Olsen, 2011) and competition with other agricultural sectors for the limited freshwater or land resources (Froehlich et al., 2018).

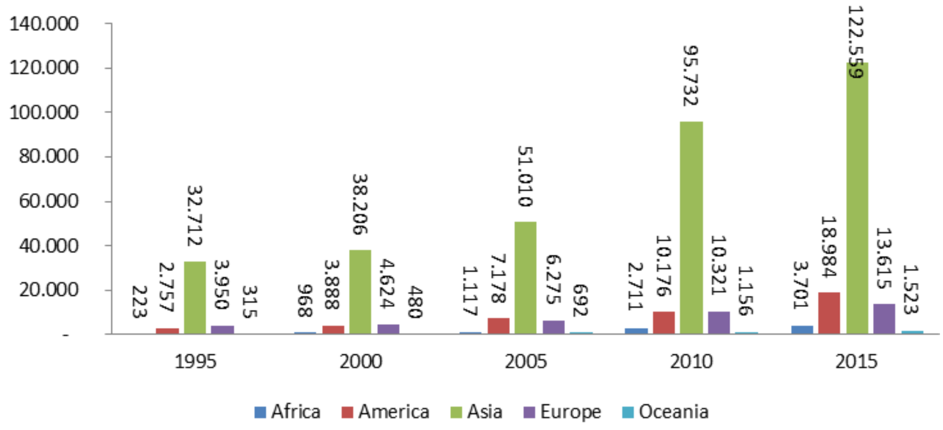
Figure 1-2 Aquaculture production in weight (1000 t) at continent level in 2013



Source: FAO FISHSTAT (data extracted from FishStatJ[4] on 29 Oct 2018)

[4] FishStatJ - Software for Fishery and Aquaculture Statistical Time Series (see installation instruction and data availability here: http://www.fao.org/fishery/statistics/software/fishstatj/en Last accessed on 29-10-2018

Figure 1-3 Aquaculture production in value (Millions USD) at continent level in 2013



Source: FAO FISHSTAT (data extracted from FishStatJ on 29 Oct 2018)

Since mainly fishmeal and fish oil (FIML&FIOL) extracted from captured wild fish are fed to farmed carnivores such as salmon, trout, tuna, sea bass, and sea bream (World Bank, 2013; Tacon & Metian, 2008; Tacon & Metian 2015), carnivore aquaculture is, in fact, a net consumer of captured fish rather than an alternative to the exploitation of nature marine fish resources. Further environmental problems arise from water pollution. Feed residuals under offshore fish nets and cages leach out and escapees can cause disease dispersion (Frankic & Hershner, 2003; Schlag, 2010; Klinger & Naylor, 2012; Ahmed & Thompson, 2019). In addition, nutritionists have raised concerns over the potential risks to human health from farmed fish that are fattened with artificial feed and the heavy reliance on antibiotics (Sapkota et al., 2008; Schlag, 2010; Aly & Albutti, 2014). The effects of the expansion of aquaculture on the competition for freshwater and land resources and resulting land use changes have rarely been discussed (Chang et al., 2016). Mangrove deforestation and the transformation of paddy rice farms for rearing aquaculture animals directly influence the land use change (Rahman et al., 2013; Arifanti et al., 2019). On the other hand, indirect land use results from growing crops that are used to produce fish feed (Froehlich et al., 2018). Technical developments in feeding material is among the crucial factors determining the future growth of aquaculture. Researchers have been searching for decades for more sustainable and cost-efficient alternatives to replace FIML&FIOL with plant-based protein and fat and turning carnivores into vegetarians (Powell, 2003). Examples include replacing high-protein distiller's dried grains with solubles (DDGS) as a suitable feed ingredient for omnivorous fish species (Hardy, 2010) and successfully compounding proteins and fats extracted from crops which can make up to 50% in the aqua feed for some carnivorous species. Generally, soybean meal (SYML) is the predominant alternative to FIML (Gatlin et al., 2007). Any expansion of aquaculture will be accompanied by an increasing demand for plant-based ingredients for fish feed and, consequently, lead to increased use of agricultural land.

When evaluating fishery policies, the issue of overfishing is of great importance. The European Commission states that 63% of total fish stocks are overexploited in European seas[5]. Within common fisheries policy (CFP), maximum sustainable yield (MSY) is one of the goals to be achieved in the near future with the management instrument by setting the annual single-stock total allowable catches (TACs) (Froese et al., 2018). This application of the CFP is likely to have a substantial impact on capture fisheries and aquaculture as well as the fish market in the EU. However, fishing at a MSY level suggested by CFP does not seem to result in satisfactory consequences in terms of the catch, stocks and profitability. An 80% MSY would result in the highest catch and profitability (Froese et al., 2018). In addition, as the EU plays a vital role in the global seafood trade (Belchior et al., 2016), the interaction between the EU fish supply with global fish markets as well as FIML&FIOL markets and the impacts of CFP on global seafood economy will require further discussion.

Aquaculture has been criticized because of its negative environmental impacts. Several models have been used to evaluate the environmental impact of aquaculture. They include life cycle assessments (LCA) (Klöpffer, 2005), the Farm Aquaculture Resource Management (FARM) model (Ferreira et al., 2009) and the Offshore Mari culture Escapes Genetics Assessment (OMEGA) (NOAA and ICF, 2012). Thus far, few economic models for analysis and scenario simulation of the complex

5 See webpage: https://ec.europa.eu/environment/marine/good-environmental-status/descriptor-3/index_en.htm Last accessed on 02 Feb. 2021

interrelationships between capture fisheries, aquaculture and land use exist. Such models are needed to provide sound policy advice on growing aquaculture and its effects on the agricultural sector and markets, both in the EU and globally.

Therefore, the goal of this thesis was to extend the standard CAPRI model version[6] by developing a behavioural fish and other aquatic animal market model (hereafter known as the fish market model).

The objective and central questions that were pursued and investigated specifically included the following:

(1) Extension of the standard CAPRI model version by developing a global fish market model with a focus on aquaculture

(2) What are the impacts of calorie intake gradually shifting away from livestock commodities (meat and dairy products) to seafood on the global food markets in 2030 in accordance with the USDA recommendation (430 Kcal/capita/day?

(3) What are the impacts of 80% of MSY implemented by the capture fisheries industry in the EU on the EU and global seafood and FIML&FIOL markets in 2030?

6 Note that the "standard CAPRI model version" in this thesis indicates the version described in the document that is written and edited by Britz and Witzke, 2012 (https://www.capri-model.org/docs/capri_documentation.pdf).

(4) What are the impacts of turning carnivorous fish to vegetarians on seafood markets and global land use change by shifting demand by fish feed for FIML&FIOL to soya cake and soya oil?

(5) What are the impacts of regulating captured fish used in FIML&FIOL production on the seafood markets and global land use?

1.2 Methodological approach

Within this study, a fish market model with the focus on aquaculture was developed to extend the current comparative static, spatial, economic agricultural sector CAPRI (Common Agricultural Policy Regional Impact) modelling system. The CAPRI fish market model permits the simultaneous simulation of effects of various fisheries, aquacultural and agricultural policies on global seafood and agricultural markets. The application of the CAPRI agricultural commodities used in fish feed production would benefit from the well-developed representation of agricultural supply behavior in the core CAPRI system. The measure of interaction between the aquacultural-agricultural sectors through aquafeed production is dependent on the technical parameters, feed conversion ratio (FCR) and ingredient-share. The FCR determines the quantity of fish feed required by the aquaculture industry, and ingredient-share describes the quantity of each CAPRI commodity used in fish feed production. Estimation and specification of the aquaculture supply relies on microeconomic theory and information derived from already existing modelling approaches. The optimal supply of each fish type required is determined to maximize the producer's profit. This implies that the decision for optimal demand for each feed ingredient is determined by its market price to minimize the producer's cost. For quantitative analysis, different seafood scenarios were simulated to investigate the objectives. The development of a reference scenario, a baseline for the seafood market, which assumes the continuation of the current situation via 2030 to 2050 was then conducted based on the statistical trend estimation.

1.3 Structure of the thesis

This thesis consists of seven chapters. **Chapter 1** introduces the necessity for the development of fish market model, research objectives and methodology used to analyze the global seafood and FIML&FIOL markets and the impacts on global land use change. **Chapter 2** gives a descriptive overview of global seafood and FIML&FIOL markets and a brief introduction of CFP, as well as fish feed, sustainability and land use demanded by aquaculture. **Chapter 3** introduces the data sources and elaborates on the consolidating process of global fish database. **Chapter 4** lists the seafood representation in existing economic models and describes the CAPRI fish market model structure including behavioural functions and the decision-making process. **Chapter 5** describes the reference scenario, the baseline of seafood and FIML&FIOL markets. In this chapter, the general baseline generation process applied in CAPRI are explained, and then the baseline results are summarized. **Chapter 6** defines and simulates four counterfactual scenarios. This chapter covers the quantitative analysis of the interaction between seafood and FIML&FIOL and agricultural market behaviour and interprets the individual results in detailed. Finally, this study allows for the comparison between the projection results presented in this thesis compared to the existing projections from models which were discussed in Chapter 4. **Chapter 7** summarizes the key findings of this study and provides a discussion of the limitations of the applied modelling approach. Suggestions for future research topics are highlighted in the end of this chapter.

Chapter 2
Global seafood markets, aquaculture feed and land use change

This chapter begins with an overview of the global seafood and FIML&FIOL markets, followed by a brief introduction of the CFP. The formulation of aquafeed is essential for aquaculture sustainability and farming costs. Replacing FIML and FIOL with plant-based meal and oil seems to be one solution which would solve both concerns. Aquaculture expansion is likely to drive an increasing demand for crops in fish feed production. Consequently, this demand shift is expected to lead to land use change. A considerable part of the content from section 2.3 to section 2.5 in this chapter is from Chang et al., 2016[7].

[7] Reference url: http://ageconsearch.umn.edu/record/244765

2.1 Global seafood market

Farming type and species

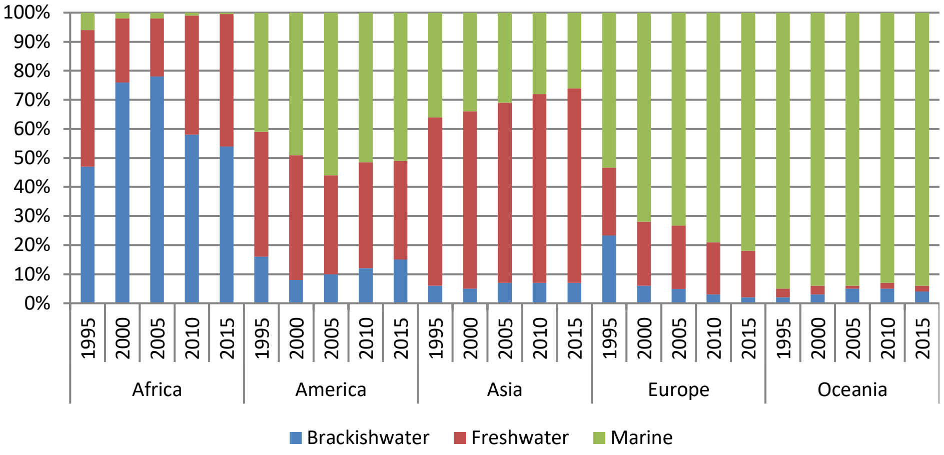
According to the FAO[8], aquaculture can be classified into three categories based on the environment where the end product is reared: Freshwater, brackish water and marine culture. Figure 2-1 shows that nearly all aquaculture farms in Africa are either in freshwater or brackish water. By contrast, the farmed seafood products in Oceania are produced in sea water. In Europe, the majority (80%) of aquatic animals are cultured in the ocean while about 70% of aquaculture production in Asia is from freshwater and brackish water. In America, aquaculture production is split equally between marine, freshwater or brackish water.

According to FAO[9], on-growing units are reared in ponds, tanks, enclosures, pens, cages, raceways, silos, barrages, rice-cum-fish paddies, hatcheries, nurseries, using rafts, ropes or stakes. Finfish culture accounts for approximately 50% of world aquaculture production. Figure 2-2 shows that, in 2014, the most farmed aquatic species was carp, which accounted for 38% of production by weight of aquatic species in China and India. With 22% of total production weight, mollusks were the second most produced species in 2014.

[8] See webpage: http://www.fao.org/fishery/cwp/handbook/j/en

[9] See webpage: http://www.fao.org/fishery/cwp/handbook/j/en

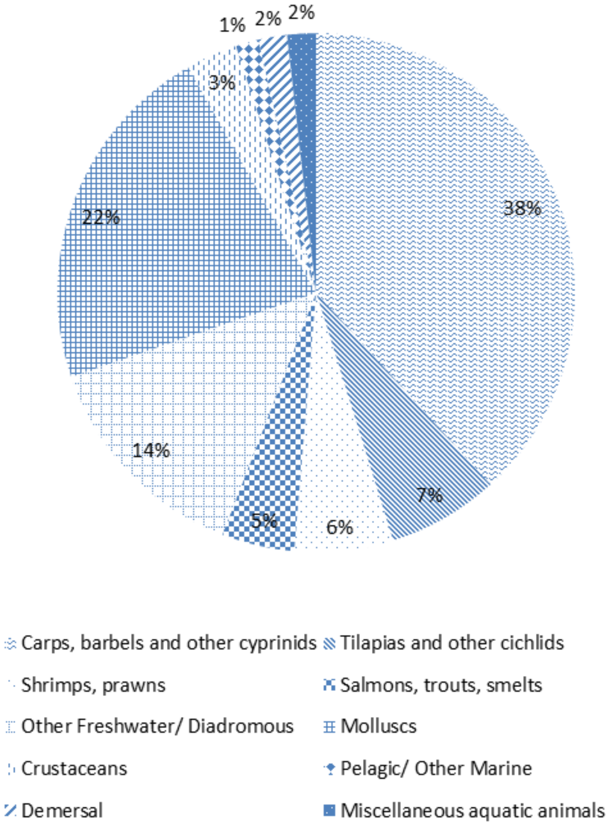
Figure 2-1 Production by farming environment at continent level



Source: FAO FISHSTAT (data extracted from FishStatJ on 29 Oct 2018)

The mollusk industry contributes considerably to aquaculture sustainability due to its non-feed and environmentally friendly characteristics (Klinger & Naylor, 2012; Froehlich et al., 2018). China is the biggest mollusk producer in the world. Shrimp and prawns are the third most farmed species (Figure 2-2), with shrimp ponds located mostly in China and Southeast Asian countries (Msangi et al., 2013). In the shrimp industry, crustacean farming is currently dominating and projected to grow to 9% of global aquaculture production by 2030 (Msangi et al., 2013). In addition, tilapia, pangasius, catfish, and salmonids are all very common and important cultured fish species. Tilapia, pangasius and catfish are freshwater herbivorous and omnivorous species, farmed primarily in China and Southeast Asia (Msangi et al., 2013). However, tilapia can also inhabit brackish water. Salmonids, a carnivorous marine species of high economic-value, provides an important economic contribution to the aquaculture industry in Europe and South America, where Norway and Chile are the biggest producers, respectively (Msangi et al., 2013).

Figure 2-2 The most farmed species worldwide (in volume) in 2014



Source: FAO FISHSTAT (data extracted from FishStatJ on 29 Oct 2018)

Asia

Asia dominates the world aquaculture production. Table 2-1 shows that the total aquaculture production in Asia was 65.65 mm tons in 2014, accounting for 89% of the total global aquaculture production. According to the FAO FISHSTAT, China is the biggest producer in Asia. In 2014, aquaculture production in China was 45.47 mm tons, accounting for 61.6% of the total global production, followed by 4.88 mm tons (6.6%) in India and 4.29 mm tons (5.8%) in Indonesia. Japan was the third largest aquaculture producer until 2003 but by 2014 Japan was ranked ninth in Asia. Compared to other continents, Asia has the highest proportion of freshwater aquaculture production. In 2014, the proportion of freshwater, brackish water and marine culture were 66.7%, 7.3% and 26%, respectively. Furthermore, mollusks are a very important aquatic category in Asia, accounting for 24% of total Asian and 20% of total global aquaculture production. In terms of value, the total Asian aquaculture production had a turnover of 122.56 billion U.S. dollars in 2014. Besides aquatic animals, aquatic plants play an important role in the aquaculture industry in Asia. The production of aquatic plants in Asia was 27.11 mm tons in 2014, accounting for 30.2% and 26.8% of Asian and global aquaculture production including aquatic plants, respectively. In addition, the aquatic plants produced in Asia account for more than 99.3% of its global production.

North and South America

As shown in Table 2-1, in 1995, the aquaculture production in America was only 920,000 tons, slightly more than half of the European production, However, in the following ten years the aquaculture industry in America increased markedly. In 2005 America produced more aquatic products (2.18 mm tons) than Europe (2.13 mm tons). In 2014 the total aquaculture production in America was 3.55 mm tons, accounting for approximately 4.8% of the total global production. Chile is currently the biggest producer in the Americas. Chile produced 1.21 mm tons of aquatic products in 2014, accounting for 34.1% of the total American production, followed by Brazil with 561,000 tons (15.8%) and the United States with 426,000 tons (12%). In fact, the United States was the biggest producer in America until surpassed by Chile in 2001. Moreover, in 2014 the proportion of aquaculture production in freshwater, brackish water and marine water in America was 34%, 14.6% and 51.4%, respectively. This shows the greater importance of marine aquaculture. A large part of marine aquaculture is in Chile, mainly focused on diadromous fish (salmonids) farming (approximately 70% of total Chilean aquaculture). Another quarter of aquaculture in Chile is shellfish farming. The aquaculture in Brazil is concentrated on freshwater fish. Both crustaceans and shellfish farming are important in America, accounting for one fifth and 15.2% of the total aquaculture production, respectively. The total value of aquaculture production in America in 2014 was calculated to be 19 billion U.S. dollars.

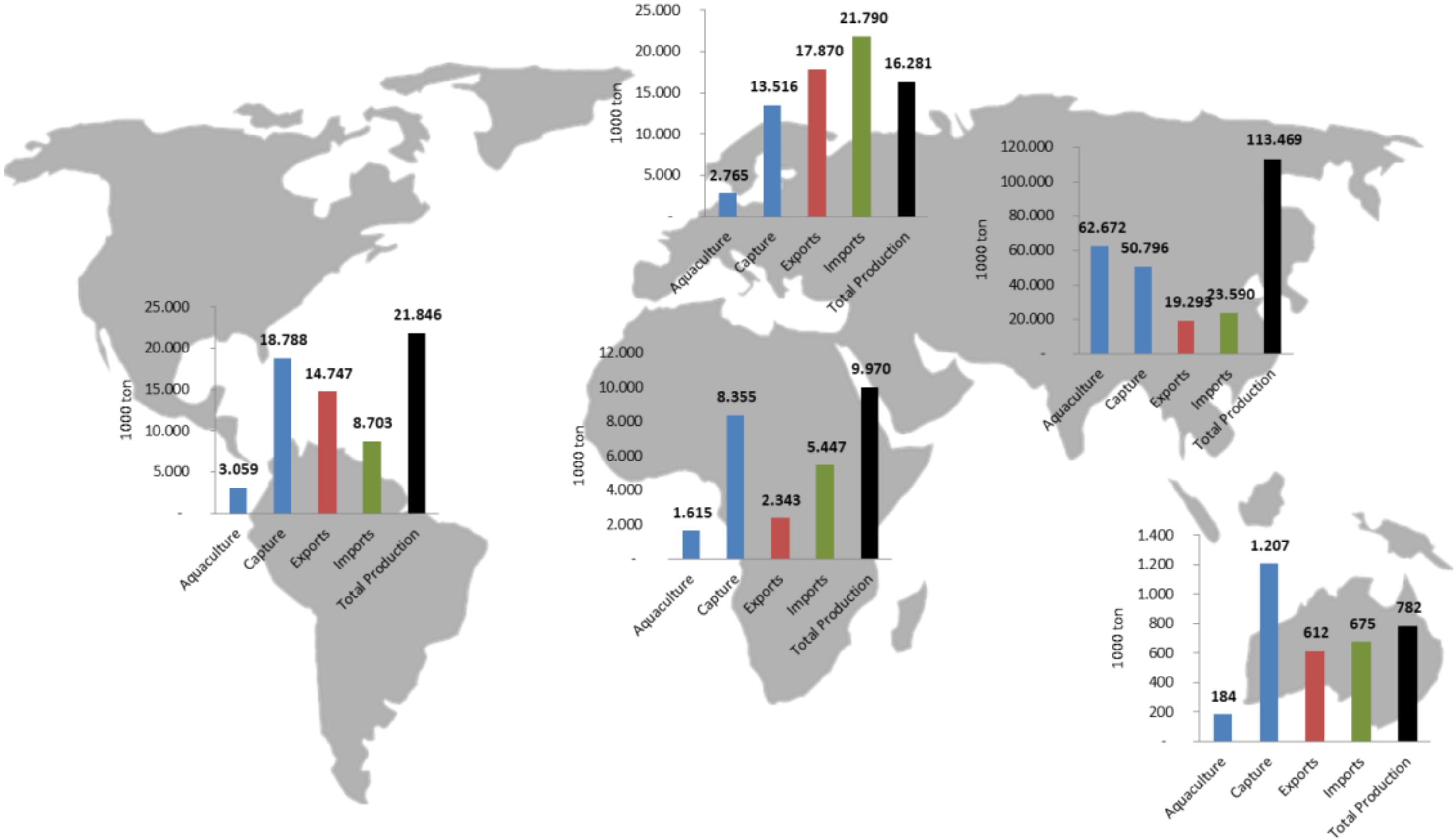
Europe

In 1995, aquaculture production in Europe was 1.58 mm tons, accounting for around 6.5% of the total global production. In 2005, European production was surpassed by American production. In 2014, Europe's share of global aquaculture production was reduced compared to the two prior decades, accounting for only about 3.9% (2.93 mm tons) of the world production. As the biggest aquaculture producer in Europe, Norway is well known for its salmonid farming technology and high quality of salmonid products. The aquaculture production in Norway was 1.33 mm tons in 2014, accounting for 45.4% of the total European production, followed by Spain with 282,000 tons (9.6%) and France with 204,000 tons (7%). France was the biggest European aquaculture producer in 1995 until Norway increased its salmon farming. Along with a proper natural environment and policy support, Norway became the leader of salmonid culture industry worldwide. In 2014, the shares of aquaculture produced in freshwater and brackish water and marine cages in Europe were 16.3%, 2.2% and 81.5%, which indicates that European aquaculture is highly reliant on marine culture. Moreover, mollusks account for around 21.6% of total European production. Based on the European commission, the most important aquaculture species in Europe are Atlantic salmon, sea bream (*Sparus aurata*), sea bass (*Dicentrarchus labrax*), Atlantic cod, mussels, oysters, carp (*Syprinus carpio*), trout (*Oncorhynchus mykiss*), sturgeon (*Acipenser baerii*), and eel. In addition, European aquaculture was valued at 13.62 billion U.S. dollars in 2014, which was slightly less than the value of aquaculture in America. Chile and Norway are both well-known suppliers of farmed salmonids and strongly promote their salmonid industry. In 1995, the production of salmonids in Chile (141,000 tons) was only half of Norway's (276.000 tons). However, in 2005, Chile had almost caught up with Norway (645,000 tons) producing 614,000 tons as well as delivering a higher unit value for salmonid production (4.65 and 3.23 U.S. dollars per ton for Chilean and Norwegian salmonids products, respectively). Compared to Norway, however, the production by Chile did not increase to a similar extent until 2014 (955,000 tons in Chile and 1.33 mm tons in Norway). The breakout of salmonid disease in Chile (Asche et al., 2009) may explain the lower amounts in Chile, and we can conclude that Chile is still a strong competitor for Norway.

Africa and Oceania

According to the information provided by FAO FISHSTAT, the aquaculture production in Africa and Oceania in 2014 reached 1.7 mm tons and 191,000 tons, respectively. Surprisingly, among all the continents, Africa has shown the most rapid growth in aquaculture production over the past twenty years. In 2014 there was more than a tenfold increase in African production compared to 1995. The biggest aquaculture producer in Africa is Egypt, and New Zealand is the biggest one in Oceania. Nearly all aquaculture in Africa is from inland water culture (99.5%), whereas most aquaculture in Oceania comes from marine aquaculture (93.8%). Moreover, the total value of aquaculture production in Africa and Oceania in 2014 was 3.7 and 1.52 billion U.S. dollars, respectively.

Figure 2-3 World seafood market in 2013 (1000 t)



Source: own illustration based on FISHSTAT data (data extracted from FishStatJ on 29 Oct 2018)

Table 2-1 Overview of global aquaculture production and value (1995-2014)

Unit: Production: ton/ Value: 1000USD

		1995	2000	2005	2010	2014
World Total	Production	24,383,041	32,418,528	44,317,019	59,036,142	73,832,107
	Value	39,957,095	48,165,321	66,272,495	120,095,443	160,382,576
Asia*	Production	21,677,578 (89%)	28,422,519 (88%)	39,204,651 (88%)	52,500,393 (89%)	65,648,289 (89%)
	Value	32,712,210 (82%)	38,205,560 (79%)	51,010,367 (77%)	95,732,422 (80%)	122,558,733 (76%)
Brackish water		6%	5%	7%	7%	7%
Freshwater		58%	61%	62%	65%	67%
Marine		36%	34%	31%	28%	26%
America*	Production	919,571 (4%)	1,423,434 (4%)	2,176,856 (5%)	2,514,222 (4%)	3,551,613 (5%)
	Value	2,756,538 (7%)	3,888,076 (8%)	7,178,289 (11%)	10,175,702 (8%)	18,984,352 (12%)
Brackish water		16%	8%	10%	12%	15%
Freshwater		43%	43%	34%	36%	34%
Marine		41%	49%	56%	51%	51%
Europe*	Production	1,580,907 (6%)	2,050,689 (6%)	2,134,904 (5%)	2,544,151 (4%)	2,930,128 (4%)
	Value	3,949,626 (10%)	4,623,899 (10%)	6,274,747 (9%)	10,320,894 (8,6%)	13,615,295 (8,5%)
Brackish water		28%	6%	5%	3%	2%
Freshwater		28%	22%	22%	18%	16%
Marine		64%	72%	74%	79%	82%
Africa*	Production	110,232 (0%)	399,628 (1%)	646,232 (1%)	1,285,634 (2%)	1,710,910 (2%)
	Value	223,239 (0,6%)	967,894 (2%)	1,117,210 (1,7%)	2,710,775 (2,3%)	3,701,068 (2,3%)
Brackish water		47%	76%	78%	58%	53,9%
Freshwater		47%	22%	20%	41%	45,6%
Marine		6%	2%	2%	1%	0,5%
Oceania*	Production	94,754 (0%)	122,258 (0%)	154,376 (0%)	191,741 (0%)	191,167 (0%)
	Value	315,483 (0,4%)	479,893 (0%)	691,881 (1,3%)	1,155,649 (1,1%)	1,523,128 (1,2%)

		1995	2000	2005	2010	2014
Brackish water		2%	3%	5%	5%	4%
Freshwater		3%	3%	1%	2%	2%
Marine		95%	94%	94%	93%	94%
World Total **	Production	6,849,215	9,306,042	13,503,584	18,992,860	27,306,965
	Value	2,643,064	2,909,380	3,887,269	5,641,903	5,637,415
World Total	Production	31,232,256	41,724,570	57,820,603	78,029,002	101,139,072
	Value	42,600,159	51,074,701	70,159,764	125,737,346	166,019,991

Remark: *: Production excluding aquatic plants; **: Production of aquatic plants)
Source: FAO FishStat (data extracted from FishStatJ on 29 Oct 2018)

2.2 Common fisheries policy (CFP)

"*The CFP is a set of rules for managing European fishing fleets and for conserving fish stocks.* […]" stated by European commission[10]. The CFP was first introduced in the 1970s, and updated in 2014 (Froese et al., 2018). The CFP has four main policy areas: a) fisheries management, b) international policy, c) market and trade policy and d) funding policy, which is designed to ensure environmentally, economically, and socially sustainable fishing and aquaculture.

Captured fisheries in the EU are regulated through the CFP with the use of various management tools. The principal aim of fisheries management in the EU was to ensure that the MSY must be achieved by 2020, at the latest. According to Marchal et al. (2016), multi-annual plans are implemented to manage fishing mortality and stock size. Input controls such as access to water, fishing effort and technical measures, and output controls, limit the number of fish from a particular fishery, particularly through TACs. Overall, the latest CFPs have been adapted to the available marine resources. However, the EU fishing fleet had and still has a much higher capacity than what should be sustainably fished and discarded (Latka et al., 2018). The quotas of TACs negotiated set exceed scientific advice, which has been

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[10] See webpage: https://ec.europa.eu/fisheries/cfp_en

shown overfishing. Carpenter et al. (2016) explain that seven out of ten TACs exceed scientific advice regarding fishing by an average of 20%. In the future, a more innovative management goal such as the Maximum Economic Yield (MEY) should be taken into consideration. The MEY results in a lower yield, but allows for more profitable fisheries and has lower environmental impacts (Farmery et al., 2014).

The EU has attempted to promote aquaculture production by reforming the CFP with supplements to fish policies. The Strategic Guidelines[11] for the sustainable development of EU aquaculture were introduced in 2013. In response to the Strategic Guidelines, member states were encouraged to develop national multiannual aquaculture plans. These plans included specific objectives on aquaculture production growth. Additionally, EU countries where asked to respond to four strategic priorities: a) reducing administrative burdens, b) improving access to space and water, c) increasing competitiveness, d) exploiting competitive advantages due to high quality, health and environmental standards (European Commission, 2016). In the period from 2013 to 2020, these objectives resulted in a combined aquaculture production increase of 437,000 tons (36%), of which 162,000 tons (25% increase) were freshwater fish, 133,000 tons (75%

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[11] https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:52013DC0229&from=EN Last accessed on 01-05-2021

increase) were of marine fish, and 142,000 tons were of mollusks (25% increase) (European Commission, 2016).

2.3 Aquaculture feed

According to Tacon and Metian (2015), in 2012, 24.3 mm tons of farmed fish (37% of the total global production excluding aquatic plants) relied on formulated aquaculture feed. The consumption of commercial fish feed is estimated at 39.6 mm tons and projected to grow to 87.1 mm tons by 2025. Aquafeed accounts for approximately 4% of total animal feed production in the world (Hardy, 2010; Tacon & Metian, 2008). However, it plays a vital role in the expansion of aquaculture as it accounts for roughly 50 percent of the total rearing costs (Rana et al., 2009; Zhuo et al., 2014).

Table 2-2 World production and price of Aquaculture and FIML&FIOL

Unit: Production: Thousand tons/ Price: USD

		1995	2000	2005	2010	2015*	2020*
Aquaculture (1)	Production	24,382	32,417	44,308	58,987	76,944	89,352
	World Price	1,603	1,472	1,464	1,972	2,183	2,041
Fish meal (2)	Production	6,874	6,970	6,436	4,492	4,701	5,009
	World Price	521	452	744	1,687	1,574	1,387
Fish oil (3)	Production	1,381	1,327	934	947	1,021	1,065
	World Price	457	262	719	1,122	1,731	1,639
FIML used in aquafeed (4)**		1,882	2,922	4,300	3,291	3,111	2,385
FIOL used in aquafeed (5)**		474	631	843	770	756	712
FIML used in aquaculture (4)/(2)		27%	42%	67%	73%	66%	48%
FIOL used in aquaculture (5)/(3)		34%	48%	90%	81%	74%	67%
Aquafeed used (6) **		7,484	14,782	23,812	34,647	48,874	66,636
FIML used in aquafeed		25%	20%	18%	9%	6%	4%
FIOL used in aquafeed		6%	4%	4%	2%	2%	1%

Note: The aquaculture production excludes aquatic plants
Source: * OECDStat,** (Tacon & Metian, 2008), (Chang et al., 2016)

FIML and FIOL are the best protein and oil sources because they contain sufficient nutrients for farming marine carnivorous species as well as the fry and fingerlings of freshwater omnivorous species (Council, 2011; Zhuo et al., 2014; Tacon & Metian, 2015). From 1995 to 2015, the average FIML and FIOL production reached 5.7- and one-mm tons, respectively. FIML production has declined steadily since 2000 and is projected to fall back to the 5 mm ton level in 2020, while FIOL production will fluctuate around the one mm ton level (Table 2-2). FIML&FIOL production are unlikely to meet the increasing demand of feed ingredients from rapidly growing aquaculture. Moreover, the price of FIML&FIOL exceeded 1000 USD per ton after 2007, which also drove producers to search for cheaper alternative ingredients. Advanced techniques of aquafeed production successfully reduced the need for FIML and FIOL for most of the farmed species. Moreover, this reduced aquaculture production costs, for some important carnivorous species, such as for salmon, where the proportion of FIML and FIOL in the feed were estimated to be reduced from 35% to 8% (FIML) and from 23% to 6% (FIOL) through 2020 (Tacon & Metian, 2008).

Freshwater aquaculture dominates the global aquaculture production. SYML, which is an important ingredient of fish feed (Zhuo et al., 2014) used to feed freshwater species, accounts for 50% to 60% of the feed ingredients (Gatlin III, 2002). In addition to soybeans, a large variety of crops such as peas, lupins, wheat, canola, rapeseed, corn, and cottonseed are used as protein and fat sources in aquatic feed (Gatlin et al., 2007; Enami, 2011). Plant protein and vegetarian oils have also been considered as an ecological and economical alternative for fish feed (Desai et al., 2012; Nasopoulou & Zabetakis, 2012). However, replacing FIML and FIOL with plant protein and oil is accompanied by several challenges (Hardy, 2010; Bandara, 2018), For example, some compounds contained in soybean may have a negative impact on the digestive process of fish (Francis et al, 2001; Dawood and Koshio, 2020), which in turn will lower the digestibility of nutrients and reduce feed conversion rates and fish growth (Refstie et al., 1998; Herman and Schmidt, 2016; Bandara, 2018; Krogdahl et al., 2020).

Nonetheless, SYML has emerged as the predominant alternative to FIML as one of the main aquafeed ingredients used in the current global aquaculture (Gatlin et al., 2007; Council, 2011). According to Paul and Keith (2002), 54 out of 358 cultured species are fed with soybeans. Even though some carnivorous species are still very sensitive to soy and can cope with a maximum of 15% soy in their feed, some species, such as the hybrid striped bass are able to handle a soybean content of 40% or higher (Paul & Keith, 2002; Rombenso et al., 2013; Novriadi, 2017). An experiment conducted by Arriaga-Hernández et al. (2021) shows that diets were formulated by replacing 30% of FIML with either SYML or soybean protein concentrate has the highest weight gain for white snook, *Centropomus viridis*. With respect to freshwater omnivorous species, Gatlin III, (2002) states that fish feed could contain even up to 60% SYML. Except for the digestion problems, SYML is a more sustainable and cheaper protein alternative when compared to FIML (Table 2-2). Research in alternative plant-based feed ingredients continues. In Norway, the salmon aquaculture industry cut its use of FIML&FIOL in the aquafeed and increased the shares of plant-based proteins from 22.2% to 40.3% (Naylor et al., 2021). Insect meal is also regarded as potential protein source that might be able to replace FIML (Sánchez-Muros et al., 2014). Moreover, recently researchers have pointed out the possibility of replacing fish oil through transgenic oilseed crop (Ruiz-Lopez et al., 2014; Betancor et al., 2015; Usher et al., 2015). The technological progress in aquafeed production will therefore likely result in an increased use of plants as protein and oil sources. The competition for land to produce soybeans for fish feed and other agricultural purposes will attract further attention in the near future.

2.4 Aquaculture sustainability

According to the definitions of aquaculture[12] and sustainability[13] by the FAO, sustainable aquaculture is "*the management and conservation, and the orientation of technological and institutional change in farmed aquatic organisms to ensure the satisfaction of human need for present and future generations in a way of environmental, economic and social development*." A few studies address animal welfare (Valenti et al., 2011) and consumer behaviour (Verbeke et al., 2007) in terms of sustainability, though measurement of both is very complex.

With respect to sustainability, aquaculture is considered a sustainable solution of compensate for the levelling off of marine resources to meet the increasing future demand of aquatic products (Kutty, 2010; Olsen, 2011). Since the 1980s, capture fishery has remained stagnant. In contrast,

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[12] See webpage: http://www.fao.org/3/X6941E/x6941e04.htm#bm04.1

[13] See webpage: http://www.fao.org/3/ai388e/AI388E05.htm

aquaculture has grown more than 30% making it a significant contributor to the world economy as well as creating numerous working opportunities. In fact, shellfish, which is approximately 30% of the aquaculture production, is non-fed species (Klinger & Naylor, 2012; Froehlich et al., 2018; Naylor et al., 2021). Therefore, Shumway et al., (2003) define shellfish farming as a “green industry” as well as an optimal environmentally sustainable form of aquaculture. Naylor et al. (2000) also point out that the production of some herbivorous species, such as carp have positive effects on fish supplies. However, aquaculture might also cause a severe reduction of marine fish stocks (Naylor et al., 2000; Naylor et al., 2021). Concerns have been raised over marine carnivorous finfish and shrimp farming because of their exploitation of marine fish stocks resulting from the high fish-in fish-out (FIFO) ratios. For example, in 1997, an average 1 kg of fish fed with formulated feed required 1.9 kg wild fish. Among the artificial feeds, salmon feed is comprised of 45% FIML and 25% FIOL and trout feed 35% and 20%, respectively. Based on information provided by Naylor et al., (2000), 1 kg weight gain for salmon and trout require 3.16 kg and 2.46 kg of wild fish, respectively. This indicates that carnivores in aquaculture consume much more wild fish than they gain in weight themselves, which is not sustainable because it exploits wild fish stocks. By 2006 the FIFO ratios declined to 4.9, 3.4, 3.5, 2.2, and 1.4 for farmed salmon, trout, eel, marine fish and shrimp respectively according to Tacon & Metian, (2008). Even though the FIFO ratios of those species further declined to 1.87, 1.82, 2.98, 1.25 and 0.82 in 2017 (Naylor et al., 2021), most of the cultured species still are net consumers of scarce ocean fish resources. Using captured small pelagic stocks as fish feed raises concerns about the negative environmental and ecological impacts on other predators in the food chain (Cury et al., 2011; Cashion et al., 2017) and also about social issues such as direct human consumption. In other words, the low value small pelagic fish are used to produce FIML instead of being consumed as a protein source by the low-income households locally (Tacon & Metian, 2009). Additionally, some farming types and species have raised concerns about their negative impacts on the environment (Naylor & Burke, 2005). The large scale offshore nets or cage farming of carnivores, such as salmon farming in Chile (Holmer, 2010) or shrimp farming in Thailand, might potentially destroy ocean and coastal resources through habitat destruction, waste disposal, exotic species, pathogen invasions, and using captured fish meat and oil as aquaculture feed (Naylor et al., 2000; Naylor et al., 2021). In addition, the replacement of the fish diet components by artificial ingredients in order to fatten the reared species at higher growth rates as well as the genetic engineering technique applied to farmed fish resulted in various unexpected concerns. For instance, the compound fish feed based on plant ingredients may contain insufficient essential amino acids (EAA) and fatty acids, and therefore the farmed fish flesh offers less essential nutrients (Hunter & Roberts, 2000; Naylor et al., 2021). Moreover, the safety of gene modified aquatic products has not yet been confirmed. Questions regarding whether or not farmed aquatic products are still healthy and provide suitable nutrients for daily intake have also been raised. Other considerations include water pollution by feed sedimentation, deforestation of mangroves, coastal damage for expanding shrimp farms, genetic pollution resulting from the escapees, disease dispersion to natural species, the overuse of antibiotics to reduce rearing mortality (Pauly et al., 2002; Naylor & Burke, 2005; Naylor et al., 2021). For some of these issues, using plant alternatives in fish feed production is considered to enhance sustainability.

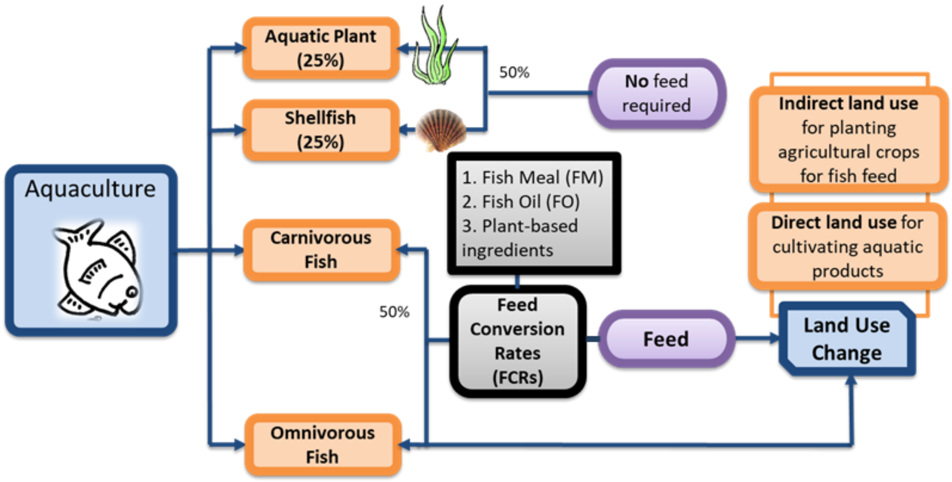
Recent research studies have used a multitude of indicators to evaluate the sustainability of aquaculture (Pullin et al. 2007; Valenti et al., 2011; Fezzardiet al., 2013; Valenti et al., 2018). Valenti et al., (2011) assessed aquaculture sustainability in three parts: economically, environmentally, and socially through computing indicators. Other assessments, for example of ecological and carbon footprint and energy use offer critical information and precise calculation to evaluate the impact of aquaculture on sustainability issues (Gyllenhammar and Häkanson 2005; Klöpffer, 2005; Vassallo et al. 2009). Beyond that, several models and monitoring systems have been developed to monitor aquaculture activities, access the influence of fish farming on the environment and simulate different scenarios to minimize environmental costs (Maroni, 2000; Cromey et al., 2002; Ferreira et al., 2009; NOAA & ICF, 2012). Additionally, the use of antibiotics in aquaculture has been a controversial topic, especially in developing countries. This is due to both the negative influences on ecological and biological systems, and harmful effects on human health through the food chain (Schlag, 2010; Aly & Albutti, 2014).

2.5 **Land use and its connection to aqua feed**

"*Different land uses will be competing for the available land*" (Lambin & Meyfroidt, 2011). For aquaculture, there is direct land use (land used directly for aquaculture ponds), rice-cum-fish paddies or Integrated Agriculture-Aquaculture system (IAA) systems, and indirect land use resulting from land used for aqua feed production.

Figure 2-4 indicates how aquaculture is interlinked with land use change. Cultured aquatic plant and shellfish farming are not directly relevant for land use change even though they account for half of the aquaculture production (25% each) according to Table 2-1. However, the other half, marine carnivores and omnivorous species impact land use change. Both marine carnivores and omnivorous species are linked to land use since a high percentage of fish feed is based on plant ingredients from agriculture. Additionally, many omnivorous species such as shrimp, carp, tilapia are farmed in ponds or IAA systems which are causally related to land use.

Figure 2-4: Linkage between aquaculture and land use change



Source: own illustration

Direct land use

Several aquaculture activities deem land as one of the most important inputs for production, such as pond rearing and coastal rafts, ropes and stakes' systems. Zhao et al., (2004), for example, stressed that land use for aquaculture ponds in Dongtan, Chonming Island, China amounted to more than 6%, 36% and 39% in 1990, 1997 and 2000, respectively. Ren et al., (2019) developed an approach to generate maps of coastal aquaculture ponds in China from 1984 to 2016. This analysis shows the area of ponds expanded by 10,463km^2, and more than 50% of the expansion was contributed by the loss of wetland (30%) and arable land (28%). Also, shrimp aquaculture has a considerable impact on land cover change (Alonso-Pérez et al., 2003; Ali, 2006; Bournazel et al., 2015; Jayanthi et al., 2018). In India, for example, the landscape under aquaculture has grown by 879% between 1988 and 2013, and 5.04% and 28.1% of the growth were contributed by the use of mangrove and agriculture land, respectively (Jayanthi et al., 2018). Another example is Damarpota in Southwestern Bangladesh where 79% (274 ha) of the rice fields of the village were transformed to shrimp ponds between 1985 and 2003 (Ali, 2006). The conversion not only happens between agricultural land and aquaculture but also natural mangrove forests are affected (Delgado et al., 2003; Hamilton, 2013; Lu et al., 2018). In Vietnam, shrimp farming caused wetland deterioration, where 440 ha (approximately 60%) of mangrove forests disappeared between 1986 and 1992 (Béland et al., 2006). During the period from mid-1970s to post-2004, Hamilton, (2013) estimated that aquaculture accounted for 28% of total mangrove loss resulting in about 544,000 ha of mangrove forest converted to aquaculture across eight nations including Indonesia, Brazil, India, Bangladesh, China, Thailand, Vietnam, and Ecuador. Direct competition for land resources between agriculture and aquaculture or the damage to forest land caused by aquaculture has been an important issue.

Rice-cum-fish paddies and integrated agriculture-aquaculture (IAA) systems

Rice-cum-fish paddies and IAA systems are ancient fish rearing practices in China. Prein (2002) defines them as an integrated farming method based on the diversification of agriculture in order to link subsystems. They also compose a special agro-landscape in other Asian countries and are usually taken into account as a part of an integrated ecosystem (Lu and Li, 2006) positively contributing to the environment because they recycle nutrients. They are usually extensive production systems with low input demand and low yields. Many Southeast Asian countries and China rely on the use of their own subsystems that serve as important protein sources for local households (ICLARM, 2001). Phong et al., (2011) compared the environmental impact of several IAA systems in the Mekong Delta of Vietnam using LCA and concludes that one kilogram of fish produced in orchard-based and low input fish systems has a 28% higher land use than rice-based and high input fish systems and rice-based and medium input fish systems.

Indirect land use and its linkage with aquafeed

"Although marine resources continue to have an important role in aquafeed, the use of plant-based ingredients has been increasing steadily, creating tighter connections between land and sea." (Naylor et al., 2021). Indirect

land use refers to the need of agricultural land derived from the demand for other products. The rapid growth of aquaculture is associated with land use for fish feed production (Henriksson et al., 2011). It is thought that the expected expansion of aquaculture will lead to an increasing demand for crops in the future.

Aquafeed plays a significant role in the most important issues linking aquaculture with agriculture, especially land use and sustainability. Aquafeed is composed of the main elements: FIML&FIOL and plant ingredients such as soybean, peas/lupins, wheat, canola, corn and cottonseed (Gatlin et al., 2007; Enami, 2011). These plants are processed as protein concentrated ingredients and fat sources in aquatic feed to replace FIML and FIOL. SYML is currently the predominant additive in world aquaculture (Zhuo et al., 2014), partly because of a dramatic increase in FIML and FIOL prices in 2006 and 2007. The world price of FIML rose from 744 USD to 1074 USD per ton in 2006, and the world price of FIOL rose from 812 USD to 1002 USD per ton in 2007 based on the data extracted from OECDStat[14], and therefore plant alternatives are increasingly used in compound fish feed as a more cost-efficient protein and oil sources (Hardy, 2010).

[14] OECD-FAO Agricultural Outlook 2017-2026: FISHERIES - OECD-FAO Agricultural Outlook 2017-2026. Retrieved from https://stats.oecd.org/ Last accessed on 02 May 2021

Global aquaculture production excluding aquatic plants is projected to reach 78.6 and 93.6 mm tons by 2020 and 2030, respectively (World Bank, 2013). The total estimated aquafeed production in 2006 was 25.4 mm tons and the total estimated feed used in 2020 is 66.6 mm tons, respectively (Tacon & Metian, 2008). With the technological advances in feed production, particularly in making plant protein digestible for carnivorous fish, the feed conversion ratio (FCR), which equals to consumption of fry matter from feed over weight gain (Refstie et al., 1998), and the reduction of consumption of FIML and FIOL for rearing species could be decreased. Note that apart from FIML, FIOL and plant ingredients there are also other minor additives used for fish feed. Since their share is not high and they do not constitute significant agricultural land use, the additives were not considered in this study. Table 2-2 shows that the percentage of plant ingredients in fish feed is projected to rise from 69% in 1995 to 95% in 2020. Thus, cost-efficient and sustainable feed ingredients extracted from plants will dominate the expansion of aquaculture in the future. Paul and Keith (2002) state that 54 out of 358 cultured species were fed with SYML at the time of publication. Usually, SYML is made from soybean cake by processing through crush and oil extraction and has soy oil as a co-product (Dalgaard et al., 2007). Salmonids (salmon and trout) can digest feed with a maximum share of SYML between 25% and 30%. Some authors believe that with technical progress, species like the hybrid striped bass will likely be able to handle up to 40% or even 50% once the important EAA requirements of target rearing species are evaluated because, to date, the feed formulations are normally on a crude protein basis (Paul and Keith, 2002; Rombenso et al., 2013; Naylor et al., 2021). For freshwater omnivorous species, Gatlin III, (2002) stresses that up to 60% of SYML could be contained in the feed. Aside from the technical nutrition or digestion problems, SYML is not only more sustainable but also a cheaper protein alternative compared to FIML and FIOL. Although the price of SYML has fluctuated between 250 USD/ton and 500 USD/ton since 2007 (except for 2012 when it was 550 USD), SYML is still much cheaper than FIML (more than 1500 USD/ton after 2010) based on the data extracted from OECDStat[15]. Until 2005, demand for SYML for farmed fish has risen from almost 0 to about 5 mm tons in China since a program funded by the United Soybean Board (USB) was implemented in 1995 (Gatlin et al., 2007). Consequently, land use changes due to the expansion of aquaculture and the rising demand for plant meal became an important issue. Expanding aquaculture in conjunction with maximum profit chasing behavior and technological progress of aquafeed will result in increasing demand for plant protein and oil that may lead to competition for land between soybeans for fish feed and other agricultural products.

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[15] OECD-FAO Agricultural Outlook 2017-2026: OECD-FAO Agricultural Outlook 1990-2027, by commodity. Retrieved from https://stats.oecd.org/ Last accessed on 02 May 2021

Chapter 3
Consolidation of global fish database

Economic fish and aquaculture modelling is still in its infancy. The lack of a comprehensive and consistent data set for the production and trade of fish and other fishery products has, thus far, curtailed modelling attempts. This chapter provides a methodology for addressing the present data gaps and for overcoming existing inconsistencies in order to create a database that may support modelling of the fish sector, illustrated at the case of the fish module in the CAPRI model. In order to avoid double counting with respect to FIML and FIOL production and trade, the available data are disentangling from key statistical sources by relying on a minimization of normalized least squares. The presented data correction procedure and the resulting database may be of further value for other models of global fish markets. Most of the content from section 3.1 to section 3.4 in this chapter has been previously published (Chang et al., 2018).

3.1 Fish data from FAO and its integration into the CAPRI fish module

The CAPRI fish module relies on data representing fish, other seafood, FIML&FIOL production and trade. The data sources referred to are both databases from the FAO, which provides two data sources for fish and fishery products (FIPS). These are the FAOSTAT FIPS Commodity Balance Sheets (CBS)[16] and FAO FISHSTAT[17]. FAOSTAT FAO FIPS CBS (hereinafter FAOSTAT) and FAO FISHSTAT (hereinafter FISHSTAT) contain series data covering the time period between 1990 and 2011 at country level.

FAOSTAT data are the key source for the global CAPRI database, which covers fish related commodities including "Aquatic Animals, others", "Aquatic Plants", "Cephalopods", "Crustaceans", "Demersal Fish", "Freshwater Fish", "Marine Fish, Other", "Pelagic Fish", "Mollusks", "Meat, Aquatic Mammals", "Fish Meal", "Fish Body Oil" and "Fish Liver Oil" and the market balance elements including "Production Quantity", "Import Quantity", "Export Quantity", "Feed", "Food" and "Other uses" etc..

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[16] http://www.fao.org/faostat/en/#data/FBS.

[17] FishStatJ - Software for Fishery and Aquaculture Statistical Time Series (see installation instruction and data availability here: http://www.fao.org/fishery/statistics/software/fishstatj/en Last accessed on 29-10-2018

Fish data in CAPRI used to be disaggregated into three fish groups but now these are extended to six fish groups. Regarding FIML and FIOL, the data from FAOSTAT only includes the amount processed from fish offal and wastes. CAPRI used FIML as one of the protein sources in the feed for terrestrial animals based on FAOSTAT data. However, FIML and FIOL obtained from captured fish is missing in these values, according to the FAOSTAT principle of recording products in primary product equivalents, meaning in the fish sector that production, trade and demand for FIML from pelagic fish, for example, is not booked as FIML but as pelagic fish. As the FIML quantities reported by FAOSTAT only refer to the part produced from waste material, the globally reported production quantities are considerably lower than the FIML demand of aquaculture. Therefore, we refer to the production and trade quantities of FIML and FIOL from FISHSTAT. FISHSTAT is a global database composed of four data sets: Global capture production (quantity), global aquaculture production (quantity and value), global commodities production and trade (quantity and value), and global production by production source (quantity). FISHSTAT provides the quantity data of fish and its processed products at country level and supplements FAOSTAT in four areas:

- Fishmeals and oils are two commodities in the set “global commodities production and trade” that replace the conceptually less suitable

FAOSTAT fishmeal data in the CAPRI database because of its better match with global aquaculture production data.

- The production data divided into capture and aquaculture from FISHSTAT is conveniently provided by the “FAOSTAT group”.
- The detailed information on species level from FISHSTAT helps to distinguish between fish for food and fish for FIML in the demersal fish category.
- The breakdown of the freshwater and diadromous fish category by species helps to specify regional FIML&FIOL requirements according to the share of predominantly carnivore fish types.

Despite offering a great level of detail, FISHSTAT data suffer from the lack of differentiation of several demand components such that it can only supplement, but not replace the FAOSTAT database.

In Figure 3-1 the integration of the two data sources in the CAPRI fish module and the interactions between fish and other agricultural markets are demonstrated. FAOSTAT provides data on the activity elements of the six fish groups. This figure illustrates the interaction between aquaculture and reduction fisheries through the FIML&FIOL processing from fish for feed (FEDM) and industrial and other uses (INDM). With feed conversion ratios and ingredient shares, the use of FIML and FIOL in feed for aquaculture is computable. Along with the increasing substitution of FIML and FIOL by crop meal and oil, the interaction between the fish sector and the agricultural sector is increasing.

In order to investigate aquaculture activities and to eliminate data inconsistencies, we calculated the share of cultured and captured fish in the total production from FISHSTAT (B1) and computed new quantities according to the production given by FAOSTAT (A1) as shown in Table 3-1.

Table 3-1 Fish activities, commodities and corresponding data sources

i = activities \ j = commodities	(A) FAOSTAT (FAO FIPS FBS)	(B) FAO FISHSTAT
Six fish groups based on FAO categories (1)	MAPR, IMPT, EXPT, HCOM, FEDM, INDM, STCM, PCRM = FEDM + INDM $Aquaculture = AQUAshare * MAPR$, $Captured = CAPshare * MAPR$	MAPR, AQTOTL, EXOG, $AQUAshare = \frac{aquaculture}{total\ production}$, $CAPshare = \frac{captured}{total\ production}$
FIML & FIOL (2)	MAPR, IMPT, EXPT, HCOM, FEDM, INDM, STCM, DOMM = MAPR + IMPT – EXPT, $HCOMshare = \frac{HCOM}{DOMM}$ $FEDMshare = \frac{FEDM}{DOMM}$, $INDMshare = \frac{FEDM}{DOMM}$	MAPR, IMPT, EXPT, DOMM1 = MAPR + IMPT – EXPT, $HCOM = HCOMshare * DOMM1$, $FEDM = FEDMshare * DOMM1$, $INDM = INDMshare * DOMM1$

Remarks: AQTOTL: total aquaculture production, IMPT: import, EXPT: export, FEDM: feed use, INDM: other use, PRCM: processing use, HCOM: human consumption, STCM: stock change, MAPR: marketable domestic production, EXOG: captured fish

Source: Own compilation

To estimate the composition of total domestic use for feed (FEDM), human consumption (HCOM), and other uses (INDM), we computed the share of each demand component in total domestic use (DOMM) from FAOSTAT

(Table 3-1, A2) and multiplied this by domestic use (DOMM1 = MAPR+ IMPT – EXPT) calculated in accordance with FISHSTAT (Table 3-1, B2), as the latter does not offer a decomposition by demand components.

Nearly 100% of FIML and 90% of FIOL is used in animal feed production, of which 70% of FIML and 80% of FIOL are produced for aquaculture feed (Tacon & Metian, 2008). As shown in Table 3-1, FAOSTAT data for 2006 to 2010 is used to calculate the different demand shares. The results for FIML support the literature findings, revealing a share of 97% going into animal feed production. With respect to FIOL, the FAOSTAT data indicates a demand share for human consumption of about 10%, for animal feed of 47% and 43% being determined for other uses. The latter two are aggregated because the assignment within the demand category 'other use' is unclear and commodities indicated for use as pet food or in tourism. This aggregation is also applied to the six fish categories. Furthermore, the quantity booked as "fish for feed use (FEDM)" is considered "fish for processing use (PRCM)" (for FIML and FIOL) and is therefore rebooked accordingly within the six fish groups.

The interaction between agricultural markets, aquaculture production and capture fisheries illustrated in the CAPRI model can be explained as follows: The linkage between FIML and FIOL production and their sources are shown in Equation 1.

The parameter $MAPR(f)$ represents the total FIML and FIOL domestic production in all regions over the full time period, originating from two sources. These are fish specifically used for reduction to FIML and FIOL ($PRCM(fg)$) and fish waste from human consumption that is partly again processed to FIML and FIOL. This quantity is derived from multiplying total human fish consumption ($HCOM(fg)$) with a waste ratio ($WR(fg)$) specific for each fish category.

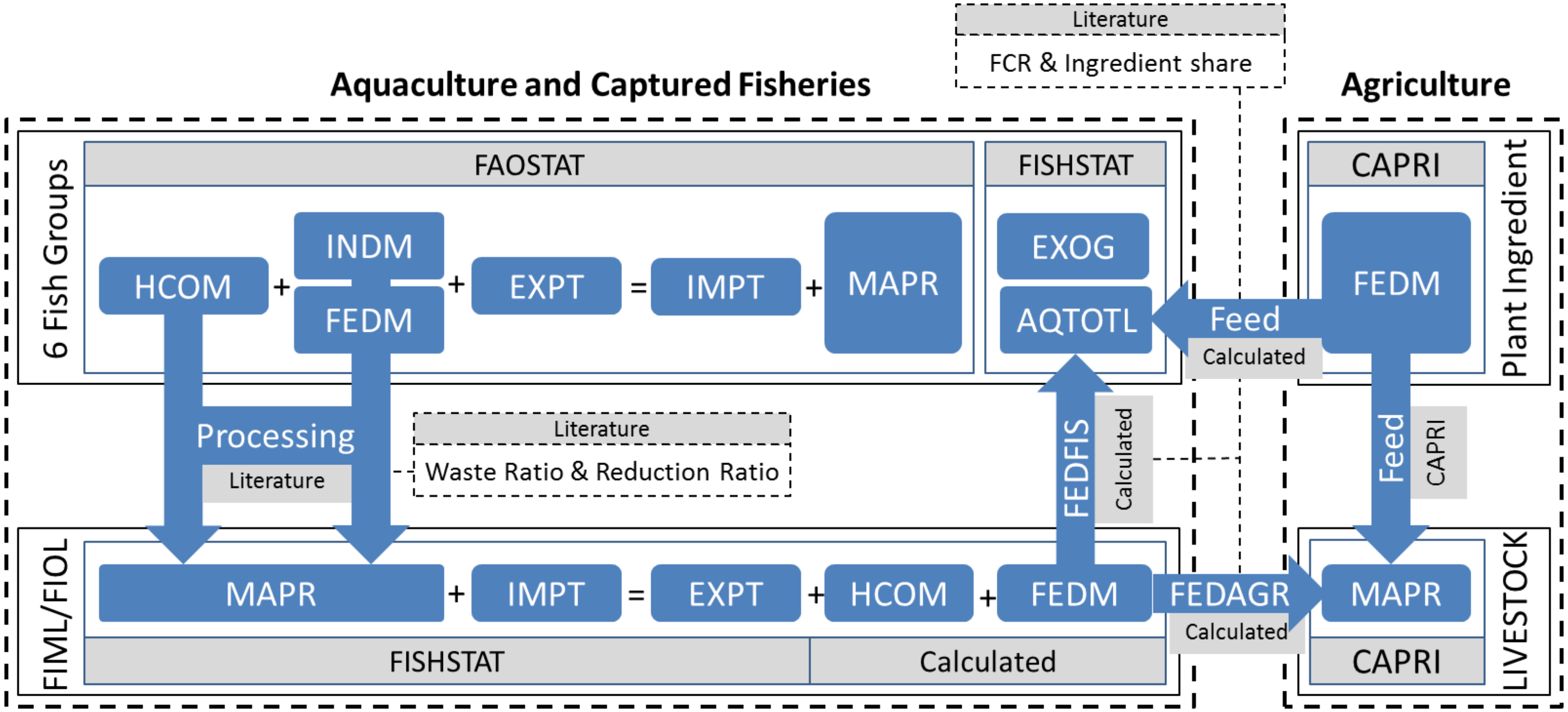
Subsequently, the total domestic production of FIML and FIOL can be calculated as the sum of these two quantities over all six fish categories (*fish*) multiplying the corresponding reduction ratios ($RR(fmol)$) (Equation 1).

Equation 1

$$MAPR(fmol) = \sum_{fish} \big(PRCM(fish) + HCOM(fish) * WR(fish)\big) * RR(fmol)$$

$$With\ fmol = fishmeal, fish\ oil;\ fish = CRUS, MOLS, FFIS, PFIS, DFIS, OFIS$$

Figure 3-1 Scheme of the CAPRI Fish Module, its linkage to the agricultural sector and data sources used



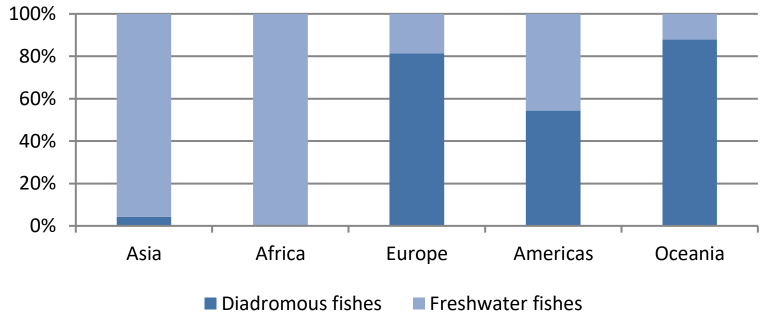
Remarks: AQTOTL: total aquaculture production, IMPT: import, EXPT: export, FEDM: feed use, INDM: other use, PRCM: processing use, HCOM: human consumption, STCM: stock change, MAPR: marketable domestic production, EXOG: captured fish, FEDFIS: feed for aquaculture, FEDAGR: feed for land animals

Source: Own illustration based on Heckelei et al., (2018) Due to the diverse diets of the fish species in freshwater and diadromous fish category, the constituents of feed for the different fish in this group requires particular attention. Generally, the major freshwater fish species, such as carp and tilapia, consume, on average, a vegetarian feed that contains up to 85% plant-based ingredients (Boyd & Polioudakis, 2006). In contrast, diadromous fish like trout and salmon require carnivorous feed with a share of FIML and FIOL of 35% and 15% to 20%, respectively (Tacon & Metian, 2008). In Figure 3-2 the proportion of freshwater fish production to diadromous fish production in 2005 is shown by continent. The high demand for plant-based feed ingredients of some fish species highlights once more the interdependencies of the fish and the agricultural sector.

To accurately project demand quantities of feed ingredients for freshwater and diadromous fish, countries were classified into three groups. These are carnivorous fish farming countries (group C) with a mainly diadromous fish production, vegetarian fish farming countries (group V) producing mostly freshwater fish species, or mixed farming regions (group M) as shown in Table 3-2. This classification is based on the fraction of carnivorous fish in the freshwater fish category for each country based on data from FISHSTAT (Table 3-2). A country that produces more than 70% carnivorous fish is assigned to group C, with less than 30% assigned to group V, and if the carnivorous fish share lies between 30% and 70% to group M. The introduction of the three categories allows for more accurate projections of future demand for FIML&FIOL and crop ingredients by aquaculture.

As shown in Table 3-2, in America, the ratio of freshwater and diadromous fish cultures are split. Among the American countries, Brazil specializes in freshwater fish farming (98%) such as carp which consume feed low in FIML and FIOL. In contrast, Chile farms only carnivorous salmonids. Most of the Asian countries focus on freshwater fish farming. However, Japan has a high diadromous fish production, and Taiwan and South Korea have an equal production of both (Table 3-2). In all African regions, freshwater fish dominate aquaculture production so that this also holds for the overall African continent. By convention, Oceania is differentiated into two sub-regions, Australia and New Zealand. Both are dominated by a diadromous aquaculture fish production. For the analysis in CAPRI, Oceania was treated as one diadromous fish farming region.

Figure 3-2 Distribution of vegetarian freshwater fish and carnivorous diadromous fish at continental level (2005)



Source: FAO FISHSTAT (data extracted from FishStatJ on 29 Oct 2018)

Table 3-2 Classification of countries by the share of carnivorous fish in FFIS

Group V (carnivorous fish production < 30%	Group C (carnivorous fish production > 70%)	Group M (carnivorous fish production > 30% and < 70%)
Africa		
Asia		
Other Asian countries	Japan	Taiwan, South Korea
America		
Brazil, other American countries	Uruguay, Chile, Peru, Canada	Bolivia, Argentina
Europe		
Croatia, Hungry, Romania, Ukraine, Russian Federation, Czech Republic	Other European countries	Bulgaria, Poland, Netherlands, Germany
	Oceania	

Source: Own compilation based on data from FAO FISHSTAT

3.2 Problem with available fish data

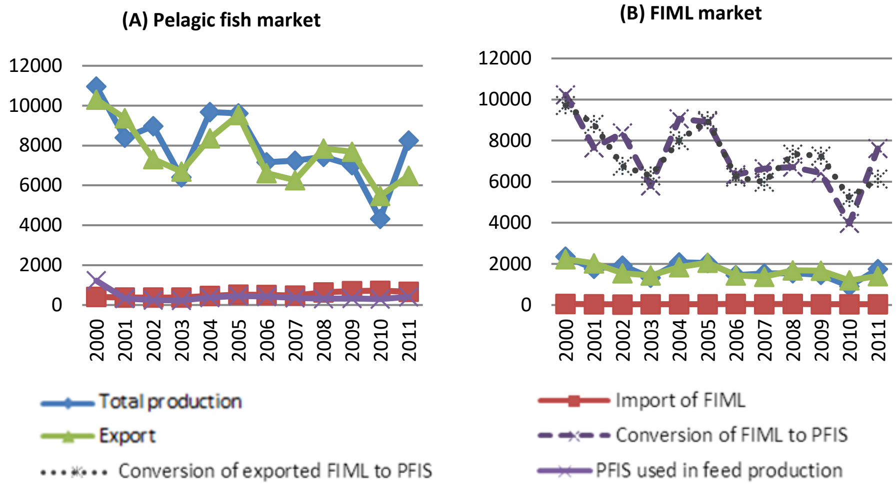
During the integration of the two data sources, we observe data gaps and inconsistencies in the given export and import quantities of each seafood category. These may also include the information of the export and import quantities of FIML and FIOL.

As mentioned before FAOSTAT market balances follow accounting rules unsuitable for modelling, as large amounts of fish that go into the processing industry, that can in fact, be converted into FIML and FIOL are classified as exports or imports of live fish.

The data problem is exemplified by one CAPRI region covering several countries in Middle and South America (RSA) namely Peru, Ecuador, Columbia, Costa Rica, Nicaragua, Panama, El Salvador, Guatemala, Honduras, and Bermuda (Figure 3-3). According to the left graph (A), which represents the pelagic fish market in this region, in 2010, the production and export of pelagic fish in this region amount to 10,966,000 and 10,311,000 tons, respectively (FAOSTAT). Peruvian anchovies are a crucial natural pelagic fish resource used as raw material in the FIML and FIOL industry in South America. Relying on the abundant Peruvian anchovy stock, this region is the biggest FIML and FIOL producing and exporting CAPRI region with FIML production and export quantities of 913,000 and 1,199,000 tons respectively (FISHSTAT). Converted back into live fish as shown in the right graph (B), which stands for the FIML market, the production of these amounts of processed FIML and FIOL requires 9,248,000 tons of pelagic fish. Therefore, we may conclude that the export values reported by FAOSTAT for pelagic fish are unreasonably high (when taken literally as exports of fish) in some cases and incompatible with the reported FIML and FIOL production from FISHSTAT. Thus, we adopt the export values for FIML and FIOL from FISHSTAT and combine those with FAOSTAT fish market balance data in CAPRI. However, to avoid double counting of trade in FIML and FIOL, we revised the FAOSTAT fish export quantities as explained in the following chapter.

Moreover, two inconsistencies are concerned to be consolidated. First, a reassignment of FIML and FIOL for animal feed was conducted. The feed quantity provided by FAOSTAT was based on the six fish categories which were directly assigned to feed use. Fish protein is generally included in the feed in the form of FIML and FIOL. Hence, we remove the “feed use” quantities and rebook them to “processing use” to represent the fish used as raw material to process FIML and FIOL. In the case of the considered region RSA, 9,248,000 tons were assigned to the processing use of pelagic fish. A second inconsistency stems from the integration of two data sources. For example, regarding the FIML and FIOL markets in the Netherlands in 2008, the data from FAOSTAT indicates that 92,000 tons of pelagic fish are used for feed. This implies that in the Netherlands some production of FIML from pelagic fish is likely to be taking place. However, FISHSTAT and Aidos et al. (2000) show zero production of FIML and FIOL in the Netherlands. This contradicts what was reported to be the amounts of fish used in feed production in FAOSTAT. A similar data situation is found for Germany, as data from FAOSTAT shows a large amount of FIML produced locally, which contradicts the zero production of FIML reported in FISHSTAT. In such cases where FISHSTAT reports zero FIML production but FAOSTAT gives nonzero use of fish for reduction, we given priority to FISHSTAT and rebook the quantities reported as feed use by FAOSTAT to human consumption.

Figure 3-3 Consolidation of fish data of CAPRI region RSA (1000 t)



Source: Own illustration based on CAPRI database (extracted on 18-03-2019)

3.3 Data correction

To correct the identified problems in the data obtained from FAO, several steps were undertaken to derive a consolidated data set that is suitable for fish sector modelling. In the following section how fish are correctly assigned to the processing industry while avoiding double counting of FIML and FIOL trade quantities is explained. Next, a minimization of normalized least squares model is applied. In this way, the two FAO data sources are integrated, data gaps filled and market balances can be closed. The whole procedure is applied to all regions in CAPRI over the time period between 1990 to 2011.

As previously mentioned, FIML and FIOL are two substantial inputs for the aquaculture industry. The raw materials for their production are mainly small pelagic fish. Péron et al., (2010) also list two demersal species (Norway pout and blue whiting) dominating in FIML and FIOL production. These two species are referred to in the numerator $DFIS\ used\ for\ FIML\ FIOL$ in Equation 2. Within the demersal fish group, only these two fish species require some data corrections. Furthermore, the same correction can be applied to the whole pelagic fish category.

First the traded FIML and FIOL quantities given from FISHSTAT are converted into equivalent live weight to obtain the total trade quantity that needs to be removed from the reported FAOSTAT trade of live fish. This reported trade that is corrected, is denominated as $Total\ raw\ materials\ of\ FIML\ FIOL(t0)$ in Equation 2 and represents the sum of the traded pelagic fish and the fraction of demersal fish usable as raw material in the FIML and FIOL production. Taking the ratio of the FIML trade expressed in live fish equivalent to the total trade "inflated" by this FIML trade gives a correction factor that may be applied to remove the FIML component, at least approximately, from the reported trade in pelagic and "fish meal suitable" demersal fish (Equation 3 and Equation 4).

Note that the amount of fish deducted from exports back to the processing industry ($PRCM$) of the corresponding seafood group must be added. The respective captured forage fish are first processed and then exported or imported in the form of FIML and FIOL. With respect to the imports, the imported amounts are deducted from the processing as these might be otherwise overstated (Equation 5).

Equation 2

$$Total\ raw\ materials\ of\ FIML\ FIOL(t0) = PFIS(t0) + DFIS(t0) * \frac{DFIS\ used\ for\ FIML\ FIOL}{total\ DFIS\ production}$$

With t0 = original export quantity (EXPT), original import quantity (IMPT)

Equation 3

$$PFIS(t1) = PFIS(t0) * (1 - \frac{PFIS(t0)/RR(FIML)}{Total\ raw\ materials\ of\ FIML\ FIOL(t0)})$$

With $t1$ *= consolidated export (EXPE), consolidated import (IMPE)*

Equation 4

$$DFIS(t1) = DFIS(t0) - DFIS(t0) * \frac{DFIS\ used\ for\ FIML\ FIOL}{total\ DFIS\ production}$$

Equation 5

$$PRCM1(g) = PRCM0(g) + ((EXPT(g) - IMPT(g)) - (EXPE(g) - IMPE(g))$$

With $g = pelagic\ fish, demersal\ fish$

The previous rebooking of FIML trade and the various other inconsistencies regarding technical constraints (detailed below) are the reason why establishment of a consistent data set requires a flexible procedure that is applicable to global time series at the country level. In the present study, minimization of normalized least squares model is applied (Equation 6).

To develop a consistent data set over time on the yield of fish, FIML&FIOL, feed production and market balances, we assigned weights and bounds to reduce the need for manual data corrections. We choose higher weights and tighter bounds for statistical data to be considered reliable. For example, the production of fishmeal from FISHSTAT. In contrast, we applied lower weights for items with higher uncertainties such as the demand composition for FIML&FIOL which had been estimated based on FAOSTAT shares applied to a FISHSTAT residual. The same idea is applied to technical coefficients taken from the literature which may be subject to fluctuations depending on the underlying methodology and the fish species investigated. The data consolidation procedure is applicable also to other periods of time (hence usable for next year's database update) or to another disaggregation of the global fish sector to regions and seafood items (hence usable also for other modelling systems).

Equation 6

$$Min\ v\_Obj = \sum_{i,j} \left(v\_Data_{\,i,j} - p\_Data_{\,i,j}\right)^2 \cdot wgt_{i,j}$$

$s,t.$

$$v\_Data_{i,j}{}^{LO} \leq v\_Data_{i,j} \leq v\_Data_{i,j}{}^{UP}$$

$With\ i = aquaculture\ and\ fishing\ activities\ (Table 8\ in\ the\ Annexes),$

$and\ j = fish\ and\ agricultural\ commodities\ (Table 9\ in\ the\ Annexes)$

With technical implementation there is also a need for constant region-specific scaling factors to avoid numerical problems, but these are just side issues in the presentation of the basic data consolidation methodology.

In the objective (Equation 6) we see that the squared deviations of the final solution values $v\_Data_{\,i,j}$, with i *and* j representing aquaculture or fishing related items and fish and agricultural commodities, respectively from their initial values $p\_Data_{\,i,j}$ have gaps or inconsistencies.

Gaps and inconsistencies are removed by additional restrictions (Equation 7 to Equation 18) for the estimation process. A list of the long texts of the following abbreviated subscripts is given in Table 8-1 and Table 8-2 in the Annexes.

In the equation system feed use has to be consistent with the crop ingredients, FIML and FIOL demanded for fish feed. Therefore Equation 7 requires that the feed conversion ratio level for each fish ($fish$), $FEED(fish)$, so the total feed quantity used to produce one ton of fish equals the sum of feed inputs of all feed ingredients used by this fish type:

Equation 7

$$FEED(fish) = \sum_{d} Ingredient\ Use(d, fish)$$

With d = fishmeal, fish oil, soya cake, soya oil, corn, wheat, rapeseed oil, sunflower oil, sunflower oil, barley, paddy rice, rape seed, rye and meslin and other animal waste use in fish feed

In Equation 8 $Ingredient\ Use(d, fish)$ represents the use of each feed ingredient per ton of produced fish multiplied by the (production) level of the respective fish type. This gives the total quantity of feed ingredients required by each fish type. The quantity of total feed required by aquaculture in one region, $FEDFIS(d)$, is the sum of these over all the fish types.

Equation 8

$$FEDFIS(d) = \sum_{fg} Ingredient\ Use(d, fish) \cdot AQTOTL(fish)$$

Total use of FIML&FIOL and crops for overall feed production is determined by the sum of the demanded ingredients for aquaculture feed

(*FEDFIS*) as well as for land animal feed (*FEDAGR*) in one region as shown in Equation 9.

Equation 9

$$FEDM(d) = FEDAGR(d) + FEDFIS(d)$$

The total production of seafood in each category is the sum of animals caught by fisheries ($EXOG(fish)$) and those farmed in aquaculture production systems ($AQTOTL(fish)$) (Equation 10). The former data is exogenously given.

Equation 10

$$MAPR(fish) = AQTOTL(fish) + EXOG(fish)$$

The market balance is shown in Equation 11. The sum of production (*MAPR*) and imports (*IMPT*) of each fish commodity must equal the sum of all demand components. In other words, the respective stock changes (*STCM*), exports (*EXPT*), human consumption (*HCOM*), feed use (*FEDM*), processing (*PRCM*), and other uses (*INDM*) must all be considered. Frequently, some components may be zero, such as human consumption for FIML and feed use for fresh fish.

Equation 11

$$MAPR(j) + IMPT(j) = STCM(j) + EXPT(j) + HCOM(j) + FEDM(j) + PRCM(j) + INDM(j)$$

3.4 Consolidated data (in comparison to original data)

We only apply the rebooking procedure explained in Section 3.3 to import and export of pelagic and demersal fish because these two groups include the most important fish species used as raw material in the fish processing industry. However, we consider that other fish (except for mollusks) are also raw material for FIML&FIOL production. These fish categories contribute comparably little to the fish used for animal feed and detailed information about their usage in feed is scarce. Therefore, we simply rebooked the share of fish that was reported as feed use by FAOSTAT to processing use for these fish categories, without further revision of trade data. This rebooking allows for that any fish used as feed to be converted to FIML and FIOL first.

As shown in Table 3-3, Peru is the biggest producer, as well as the biggest exporter of both FIML and FIOL in the world, Chile is the second biggest producer and exporter of FIML based on FISHSTAT. China is the largest importer of FIML.

Table 3-3 FIML and FIOL quantities (2006-2010 average) of the most relevant producing and trading countries (1000 t)

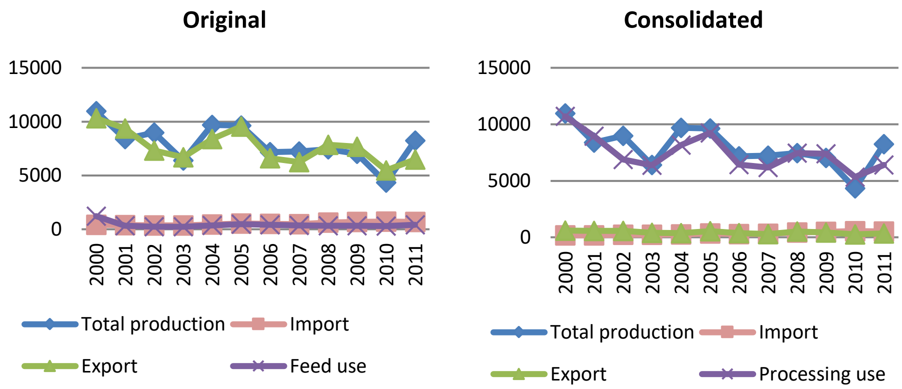
	Producer		Exporter		Importer	
	FIML	FIOL	FIML	FIOL	FIML	FIOL
1	Peru	Peru	Peru	Peru	China	Norway
	1,258	269	1,371	287	1,131	222
2	Chile	Chile	Chile	Denmark	Japan	Denmark
	624	166	485	140	336	128
3	Thailand	Denmark	Germany	Chile	Norway	Chile
	453	110	214	69	242	72
4	China	United States of America	Denmark	United States of America	Germany	China
	447	72	205	61	230	45
5	Denmark	Japan	Iceland	Iceland	Taiwan	Canada
	241	63	114	60	172	40

Source: FAO FISHSTAT

The effects of the data correction are particularly important for big exporters and importers including Peru, Chile, China, Iceland, and Norway. The correction of demersal fish data shows an impact mainly for countries that capture Norway pouts and blue whiting such as Denmark, Iceland, Norway, and the Faroe Islands. Here the comparison of the original data and the consolidated results from selected countries, namely the region RSA including Peru and other Middle and South American countries, China, Denmark, and Iceland are presented.

In Figure 3-4 the original FAOSTAT data for pelagic fish production, import, export, and feed use in the region RSA is contrasted to the data consolidated by the CAPRI system. As shown in the two graphs, the export quantity of live fish drops dramatically due to the deduction of the high export quantity of fishmeal, while the import quantity only decreases slightly. For example, in 2005, the exports of pelagic fish stated by FAOSTAT added up to 9,529,000 tons, and the value dropped to 544,000 tons after consolidation. In addition, the given feed use from the original data was replaced by processing use. When combining this replacement with the re-assignment of traded live fish to processed fish products, the consolidated processing use in RSA amounted to 9,248,000 tons in 2005, whereas the original feed use was only 464,000 thousand tons by FAOSTAT.

Figure 3-4 Original and consolidated fish data of region RSA (1000 t)

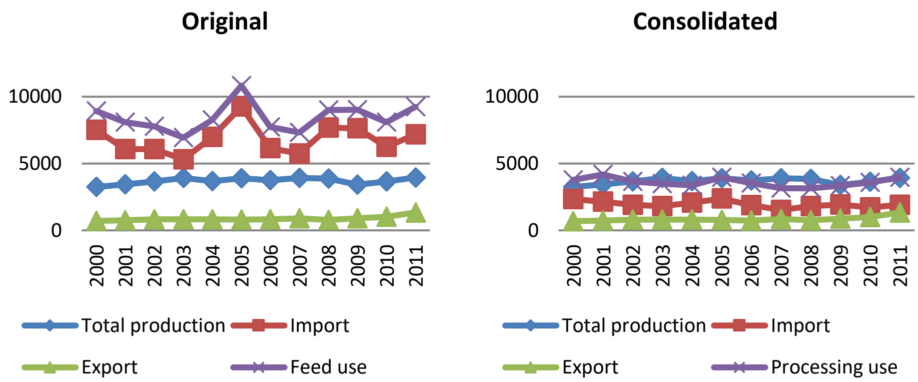


Source: Own illustration based on CAPRI database (extracted on 18-03-2019)

Not only does China have the biggest fish production in the world but it also has a substantial amount of FIML production. Furthermore, China is the biggest FIML importing country. Figure 3-5 shows the data comparison for

China. Although China has a large pelagic fish production, it also relies heavily on imports to meet its high demand of feed use. In 2005, the import, export and feed use of pelagic fish of China amount to 9,257,000, 810,000 and 10,829,000 tons, respectively. In comparison to the previous countries discussed, China's imports show a large decrease from 9,257,000 to 2,375,000 tons, and its exports dropped only slightly from 810,000 to 784,000 tons. This is due to China's high imports and low exports of FIML. Feed use in China in the year 2005 was reduced from 10,829.000 tons and converted to a processing use of only 3,974,000 tons.

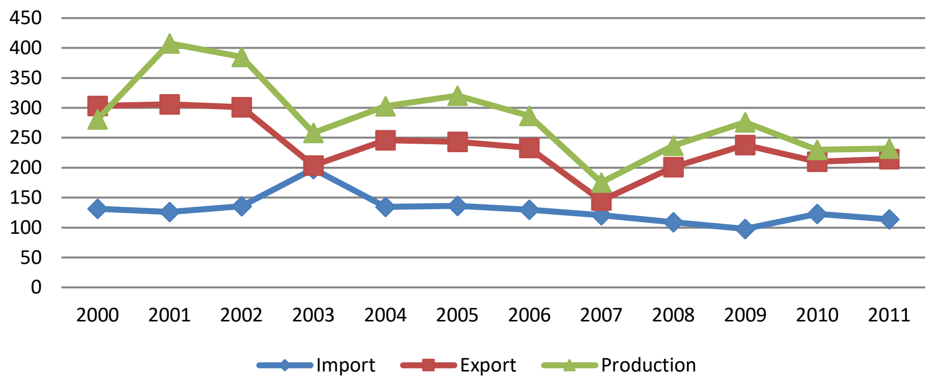
Figure 3-5 Original and consolidated fish data of China (1000 t)



Source: Own illustration based on CAPRI database (extracted on 18-03-2019)

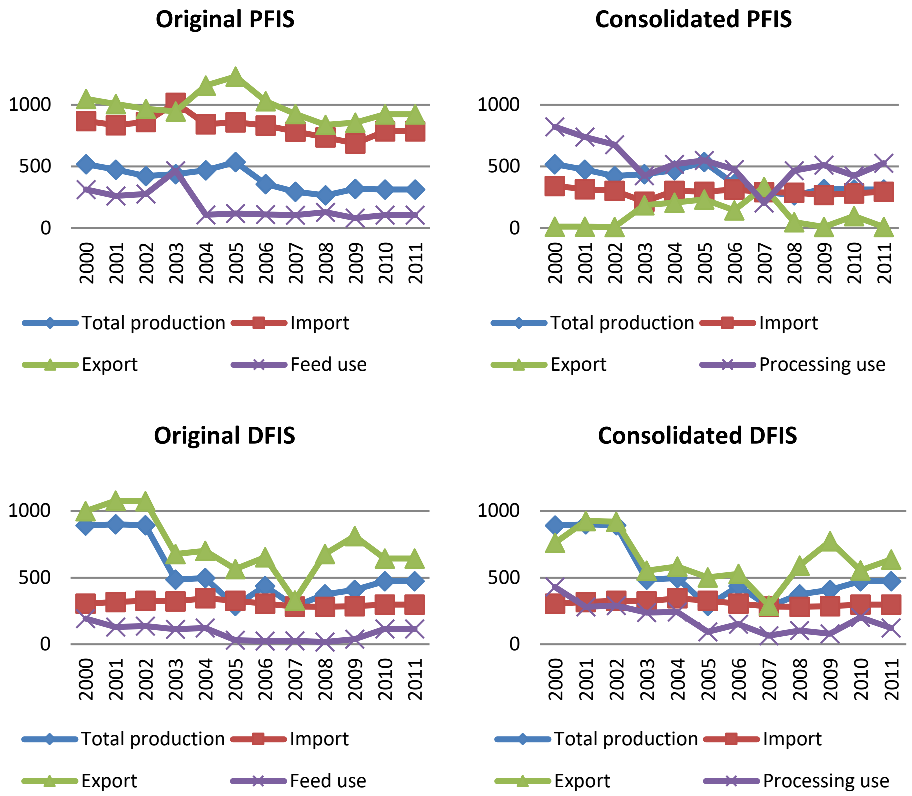
As the fifth biggest producer of FIML and the second biggest producer of FIOL, Denmark captures a large amount of pelagic forage fish, demersal fish species, Norway pout, and Blue whiting, which are used as raw material in its FIML&FIOL production industry. Therefore we reported the comparison of the data from FAOSTAT and the consolidated data from CAPRI for both, pelagic and demersal fish. The same procedure also applies to several countries, such as Iceland and Norway that capture the two demersal fish. Figure 3-7 shows the time series of the data comparison for pelagic fish produced and traded in Denmark. In 2005, the import, export and feed use of pelagic fish in Denmark was 857,000 1,229,000 and 108,000 tons, respectively. After consolidation, import and export values are adjusted to 294,000 and 232,000 tons, and feed use is replaced by a processing use of 550,000 tons. Moreover, an interesting phenomenon is found in the graphs of consolidated pelagic fish and demersal fish of Denmark in 2003 and 2007. Regarding the consolidated data for pelagic fish, the export is larger than the processing use. Although the gap is small, this differs from the rest of the time period examined. We conclude that this difference comes from the FIML market of Denmark which is presented in Figure 3-6. The absolute values of net trade of FIML in the two years were particularly small. The import and export quantities therefore decrease to a similar level. Thus, the consolidated trade data of fish are related to the trend of the trade data of FIML. Note that the original data for the pelagic fish market show hardly any relationship to the FIML market even though pelagic fish are the major constituent used in FIML production. As this relationship is present after the data correction, this indicates the data consistency gain from our approach. The movement of the values with respect to demersal is not comparably strong for Denmark. One reason may be that the two demersal species used for FIML&FIOL production account for only 14% of the total demersal fish production. The adjustment gains for demersal fish data are more transparent for Iceland as shown in Figure 3-8. The reason for this is that Iceland is the fifth biggest FIML&FIOL exporting country whose landings of Norway pout and blue whiting account for 35% of the total demersal fish production.

Figure 3-6 Production and trade quantity of fishmeal of Denmark (1000 t)



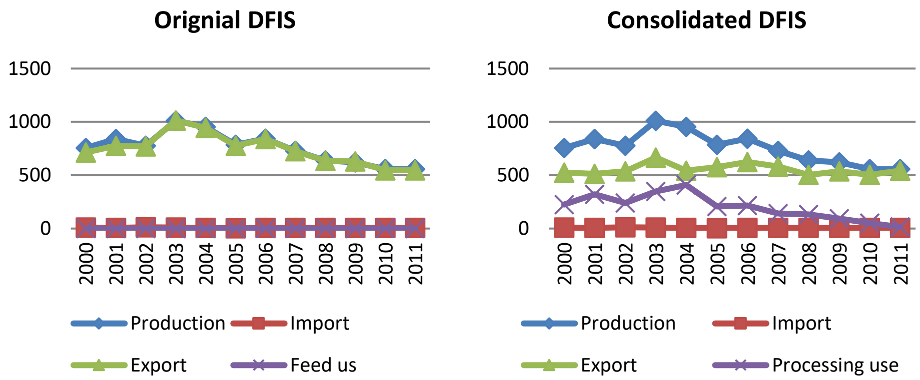
Source: Own illustration based on FAOSTAT database (extracted on 18-03-2019)

Figure 3-7 Original and consolidated fish data of Denmark (1000 t)



Source: Own illustration based on CAPRI database (extracted on 18-03-2019)

Figure 3-8 Original and consolidated fish data of Iceland (1000 t)



Source: Own illustration based on CAPRI database (extracted on 18-03-2019)

In Table 3-4, the original data of fish for feed use (1) and the consolidated data of fish for processing use (2) are shown for the top five FIML producing CAPRI regions for 2005. These values are further used as denominators in the computation of reduction ratios. The FIML production, based on FISHSTAT (3) is referred to as numerator. The two reduction ratios are computed based on the original data (RR(A)) and on the consolidated data (RR(B)) and are compared to the CAPRI reduction ratio (RR(C)) and the reduction ratios calculated based on Péron et al., (2010) (RR(D)). Table 3-4, shows the improved accuracy of the conversion between fish and fishmeal due to the consolidation in contrast to the original fish for feed use data. According to the original data, 464,000 tons of pelagic fish were used to produce 2,048,000 tons of FIML with the reduction ratio of 4.41 in the region RSA. This value has been disputed as it contradicts the reduction ratios stated by Msangi et al. (2013), Péron et al. (2010), and Tacon and Metian (2008). The computed ratio based on the consolidated quantities of processing use is relatively close to the reference values. The gaps between the computed reduction ratios and the reference values are reduced for Chile, China, and Denmark after the consolidation. The case of Thailand is extreme in that a reduction ratio of 1,95 indicates that FIML production of 473,000 tons would require only 243,000 tons of pelagic fish. This implies that other raw materials are being used to satisfy the needs of the FIML& FIOL industry, and that the gap is likely filled with trash fish (Péron et al., 2010).

The data consolidating procedures therefore contribute to filling the gaps in the CAPRI database. The results support that fish, FIML&FIOL markets are better integrated in the CAPRI database after the data consolidation.

Table 3-4 Comparison of reduction ratios computed based on original and consolidated database and from the literature (1000 t; Year 2005)

	FAOSTAT Original feed use (1)	RR(A) $\frac{(3)}{(1)}$	CAPRI Consolidated Processing use (2)	RR(B) $\frac{(3)}{(2)}$	FISHSTAT Fishmeal production (3)	RR(C)	RR(D)
RSA	464	4.41	9,248	0.22	2,048	0.23	0.22
Chile	911	0.95	3,939	0.22	866	0.23	0.24
Thailand	200	2.37	243	1.95	473	0.23	1.05
China	10,829	0.04	3,974	0.11	455	0.23	0.37
Denmark (PFIS+DFIS)	140	2.29	644	0.50	320	0.23	0.37

Remarks: RR(A) = Fishmeal production (3) / Original feed use (1); RR(B) = Fishmeal production (3) / Consolidated Processing use (2); RR(C): Reduction ratios used in CAPRI; RR(D): Reduction ratios calculated based on Péron et al., (2010)
Source: Own compilation

3.5 Fish market projection to 2050

As described in the earlier sections in this chapter, the available fish data from FAOSTAT and FISHSTAT through 2011 has been corrected and consolidated to provide a complete and consistent data set with the chosen base year 2008 for the CAPRI modelling system. The process of preparing a preliminary baseline projection for CAPRI are subject to a final baseline calibration procedure, which imposes a consistency of its final baseline in the calibration year with all constraints. The methodology required to obtain preliminary projections for the fish sector is described in this section. Expert supports are of importance in order to generate a baseline which is most predictive of the future. The consolidated global fish database has been extended to 2027 based on the OECD-FAO outlook (FISHERIES). This outlook provides projections only for selected regions[1] and aggregated fish quantity. Therefore, disaggregated information for all CAPRI regions and fish groups is not available. Thus, the growth factors are computed based on the aggregated level from the outlook and applied to the mapped CAPRI regions for all species. In the period from 2012 to 2027, the global fish databases will be updated to reflect the multiplication of growth factors and base year quantities.

The current OECD-FAO outlook ends in 2027. Trend estimation after 2027 consists of three stages for the selected regions based on the information provided by OECDStat. The first stage estimates an unconstrained trend curve based on the ex-post database covering the period from 1990 to 2027 at a global level. A simple linear regression (Equation 12) was implemented

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[1] Argentina (ARG), Australia (AUS), Brazil (BRA), Canada (CAN), Chile (CHL), Columbia (COL), Egypt (EGY), Ethiopia (ETH), NonEU_EU, Europe (EUE), EU28 (EUN), Indonesia (IDN), India (IND), Iran (IRN), Israel (ISR), Japan (JPN), Kazakhstan (KAZ), South Korea (KOR), Latin America (LAMA), Mexico (MEX), Malaysia (MYS), Nigeria (NGA), Pakistan (PAK), the Philippines (PHL), Rest Africa (RestAfr), Rest Asia (RestAsia), Russia (RUS), SUA (Saudi Arabia), Thailand (THA), Turkey (TUR), Ukraine (UKR), United Stated (USA), South Africa (ZAF), China (CHN)

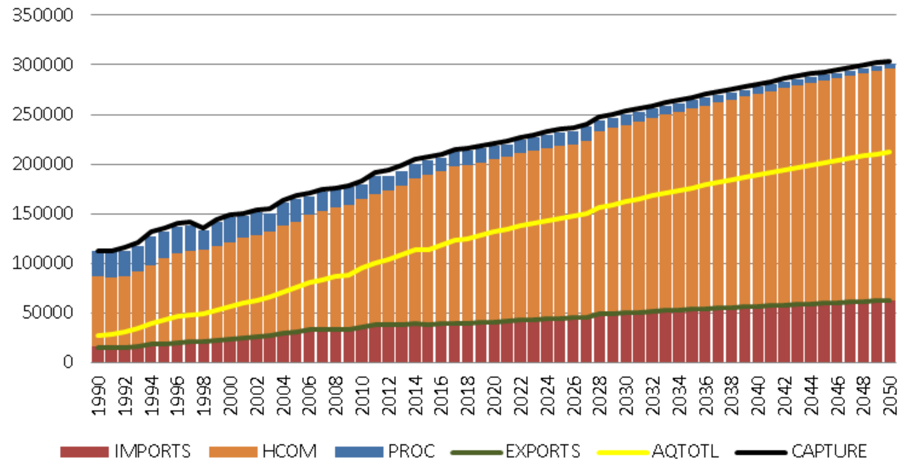
to project the global fish market associated with the single explanatory variable of global population from 2028 to 2050 (Annex Table 8-3 and Table 8-4). The whole period starting from 1990 based on the historical data and predicted values (from 2028) is illustrated in Figure 3-9.

Equation 12

$$y_{i,t} = \alpha_i + \beta_i x_{i,t} + \epsilon_{i,t}$$

y = global quantities of item i; i = AQTOTL, IMPT, EXPT, Demand, EXOG, HCOM, Crush and other use; α, β = estimated parameters; x = global population; t = 1990-2027

Figure 3-9 Trend of global fish market from 1990 to 2050 (1000 t) before correction

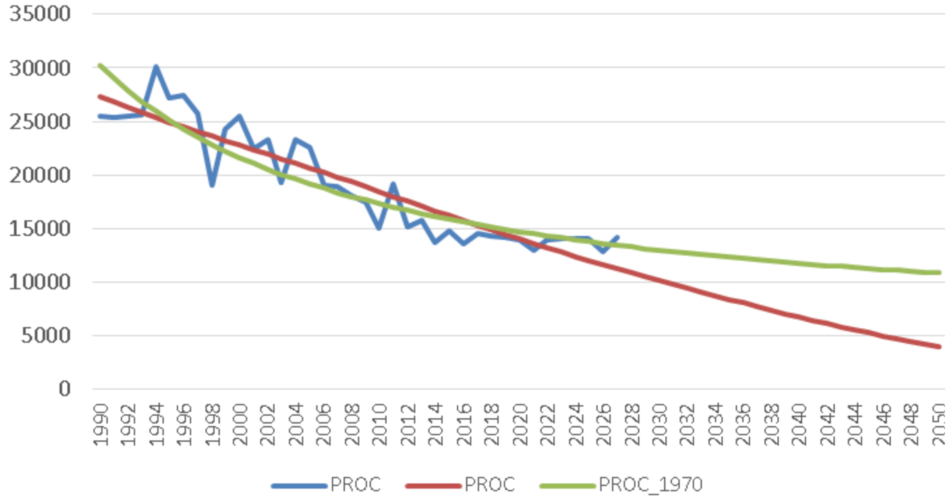


Source: Own illustration based on Table 8-2

The second step applies a multinomial logit model (Equation 13) to estimate the market shares for selected OECD regions in 2030, 2040 and 2050.

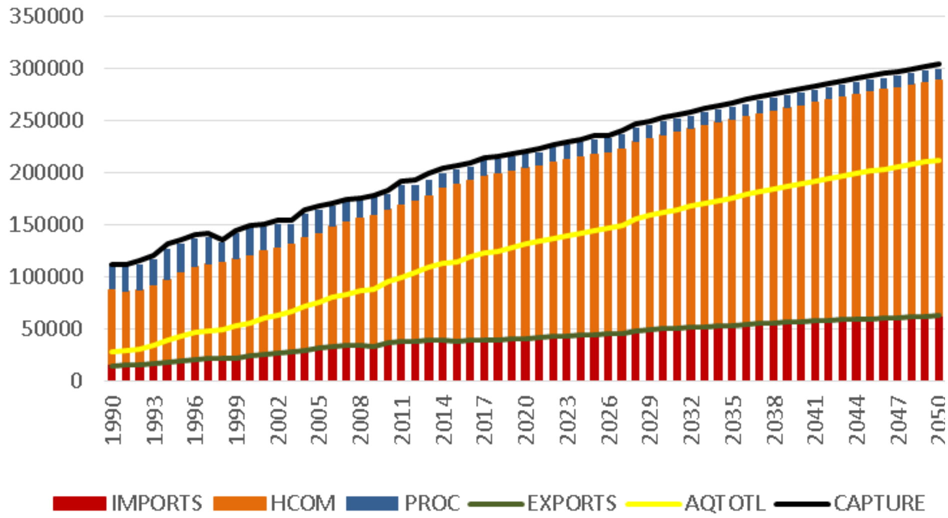
Assigning the coefficients in region r by $\alpha_{i,r}$ and $\beta_{i,r}$, we estimated the following model (Equation 13) for the quantity of each market item i in year t. However, the projection of global processing use displayed in Figure 3-9 is not conclusive when compared to the same method used for processing use. From 2012 to 2027 processing use was essentially stagnant, varying within a narrow margin around the mean (14,107,000 t) plus or minus 10% (12,648,000 t – 15,566,000 t) as shown in Figure 3-10 (blue line). Using a simple regression (Equation 12) to predict the trend of processing use results in a substantial quantity decline in 2050. The quantity of processing use determines the FIML&FIOL production, which are important elements in fish feed. A strong decline of processing use is therefore technically inconsistent with a strong increase in aquaculture production. The methodology requires modification. Otherwise, the final baseline calibration would need to strongly model the preliminary projections described in this section in order to impose technical consistency and in that case, may run into feasibility problems. In order to obtain a relatively reasonable projection, a hyperbolic function (Equation 13) was applied here exclusively for processing use. The projected results are displayed in Figure 3-10 (green line). The projected human consumption (HCOM) was residually computed given the new processing use (PROC) to ensure a closed global balances system in Figure 3-11.

Figure 3-10 Trend estimations of global processing use from 1990 to 2050 (1000 t)



Remark: PROC (red):, PROC_1970:
Source: Own illustration based on Table 8-2 and Table 8-14

Figure 3-11 Trend of global fish market from 1990 to 2050 (1000 t) after correction



Remark: HCOM: Human consumption, PROC: Processing use, AQTOTL: Total aquaculture production
Source: Own illustration based on Table 8-14

Equation 13

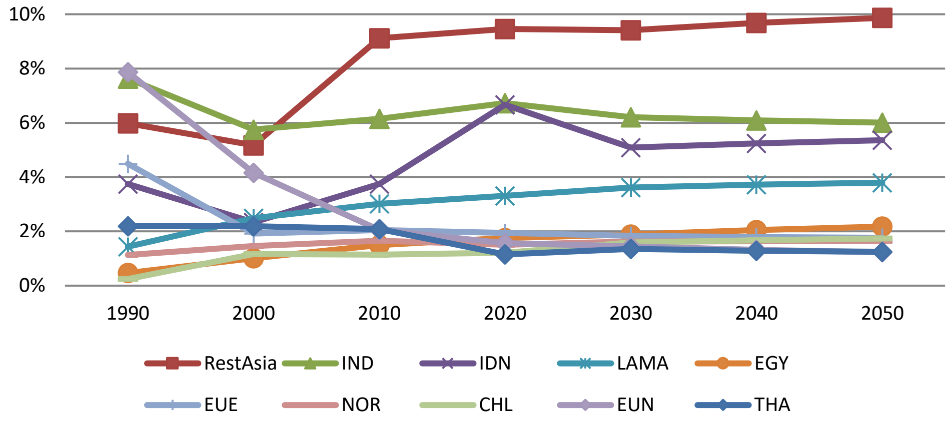
$$\ln\left(\frac{s_{i,r}}{s_{i,China}}\right) = \alpha_{i,r} + \beta_{i,r}\left(\frac{1}{t-1980}\right)$$

$$lny^{*}_{i,r,t} = \alpha_{i,r} + \beta_{i,r}\left(\frac{1}{t-1980}\right)$$

$s_{i,r}$: share of item i in region r (except for China), $s_{i,China}$: share of item i in China; $y^{*}_{i,r,t} = s_{i,r}/s_{i,China}$, r = regions; α, β = estimated parameters for each region

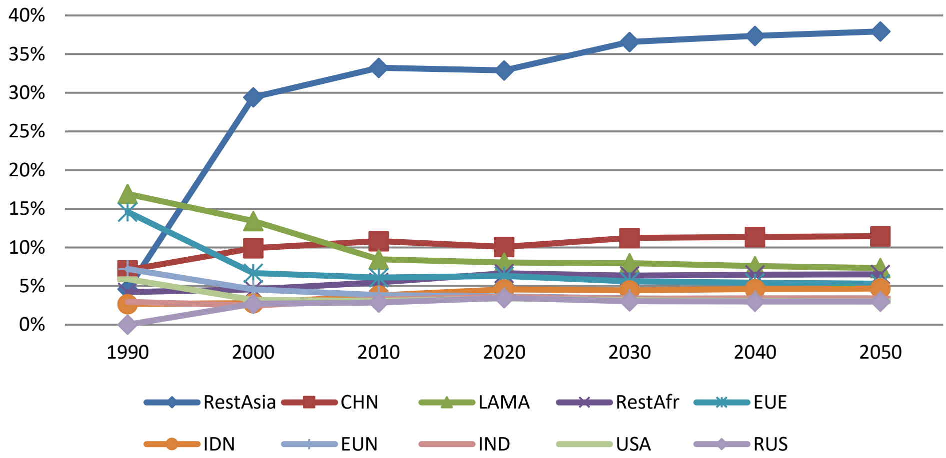
The particular specification for the trend component was chosen in order to obtain a stabilized trend over time. The constant term (1980) to subtract in the inner bracket was chosen subjectively because (1) it provides a suitable curvature to reflect the shifts in the OECD-FAO outlook posed with stabilization, thereafter and thus giving a conservative extrapolation to 2050. (2) if nothing were subtracted, then there would be no stabilizing effect left since all yearly indexes are relatively high. The transformed equation can be estimated using OLS, and the estimated parameters are displayed in Table 8-13 in the Annex. The estimation of $s_{i,China}$ is computed as $1/(\sum_r \exp\left(lny^{*}_{i,r,t}\right) + 1)$, and the estimated $s_{i,r}$ is equal to $\exp\left(lny^{*}_{i,r,t}\right) * s_{i,China}$. Subsequently the estimated quantity of each market item *i* in region *r* is the multiplication of the share of item *i* in region *r* and the global quantity of item *i*. Figure 3-12 to Figure 3-17 shows the trends of the market share for item *i* in the top ten producing, consuming or trading regions. China is the biggest aquaculture producer in the world, accounting for about half of global production. The share of aquaculture production in China is excluded in Figure 3-12 to give a better overview of the other producing regions. Figure 3-9 shows an increasing trend of aquaculture production (AQTOTL), meaning that both increasing and stagnant market shares in Figure 3-12 indicate increasing production over time. Although the market share of the EU decreases markedly over time, its aquaculture is still increasing slightly. In contrast, as the capture production remains unchanged in Figure 3-9, the quantity changes in regions over time depends on the trend of the share projection. Figure 3-13 shows that the rest of Asia region had the largest capture landings (35% - 40% of global catch) and gains increasing fishing harvest in 2050, while Latin America and the rest of Europe are expected to catch less.

Figure 3-12 Trend of share in aquaculture production from 1990 to 2050 for top ten producing regions (except for China)



Source: Own illustration based on Table 8-5

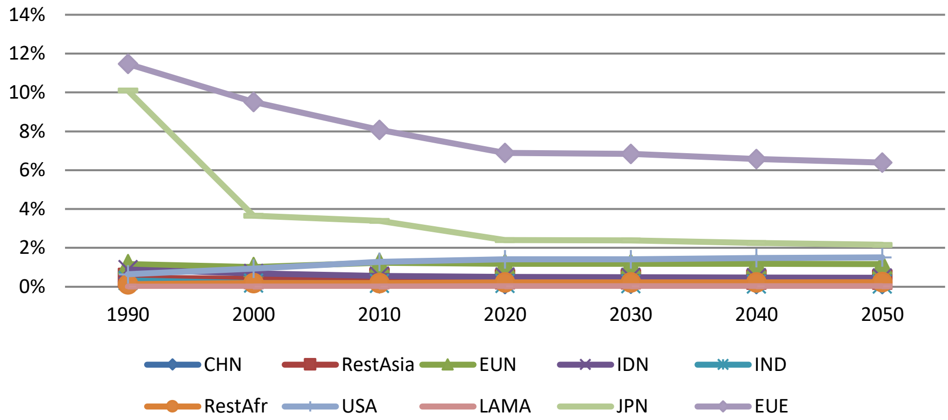
Figure 3-13 Trend of share in catch production from 1990 to 2050 for top ten producing regions



Source: Own illustration based on Table 8-9

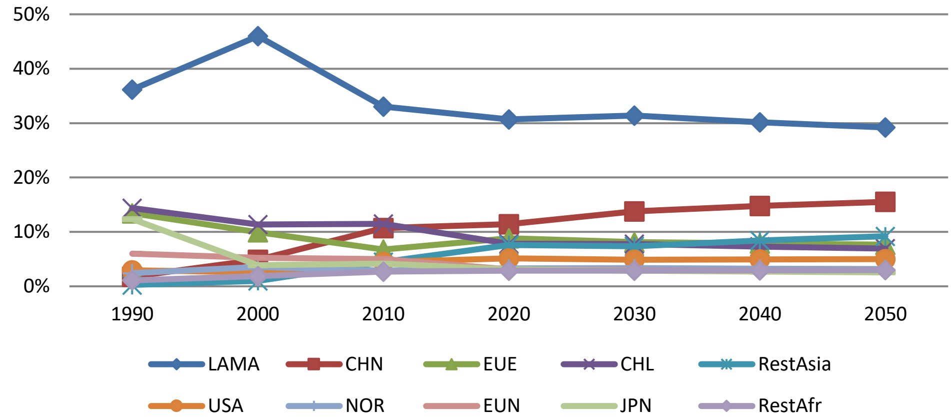
In terms of demand, Figure 3-9 shows a steady growth in seafood consumption, in contrast to the steady decline in processing use. Figure 3-14 shows a decreasing trend in shares in seafood consumption taking place in the EU and Japan. However, the computed seafood consumption quantities in these two regions are still assumed to increase through 2050 due to the growth in global demand. Latin America has obviously the largest FIML and FIOL production according to Figure 3-15, accounting for 30% of global processing use. The quantity of global processing use is expected to decrease from 10,000 tons in 2030 to about 4,000 tons in 2050. Therefore, although the trend of market share increases in China, the processing use quantity is decreasing over time.

Figure 3-14 Trend of share in human consumption from 1990 to 2050 for top ten consuming regions



Source: Own illustration based on Table 8-10

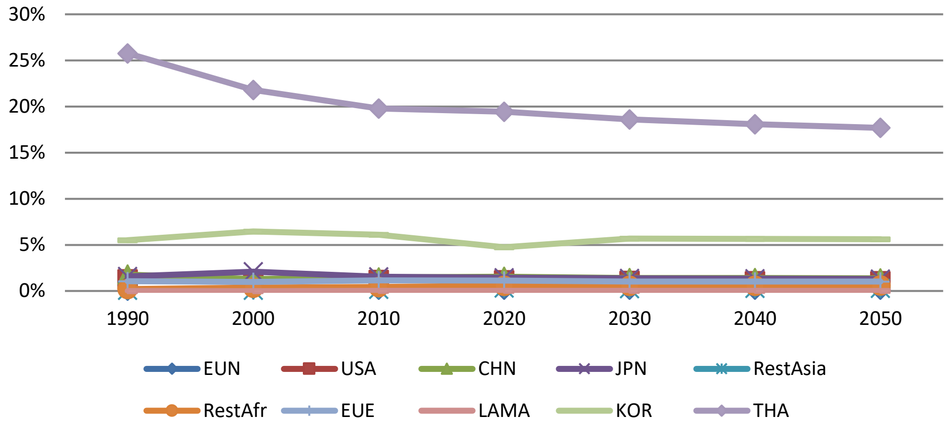
Figure 3-15 Trend of share in processing use from 1990 to 2050 for top ten consuming regions



Source: Own illustration based on Table 8-11

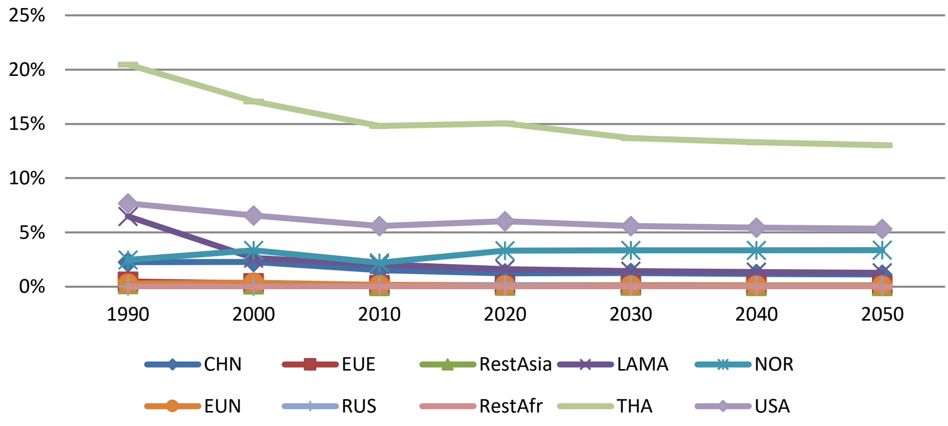
Figure 3-16 and Figure 3-17 displays the market shares of top ten importing and exporting countries. According to Figure 3-9, global imports are equal to global exports, and both show an increasing trend. Thailand is the biggest importer as well as biggest exporter in the world, accounting for 15% - 20% and 10% - 15% of global imports and exports, respectively. Although both Figure 3-16 and Figure 3-17 shows decreasing trends in Thailand, the trading quantities are increasing over time. The second biggest importer is South Korea, and the second biggest exporter is the US. Historical information and estimated results of trend of shares and quantities in production, demand and trade items are shown from Table 8-5 to Table 8-12 in the Annex.

Figure 3-16 Trend of share in imports from 1990 to 2050 for top ten importing regions



Source: Own illustration based on Table 8-7

Figure 3-17 Trend of share in exports from 1990 to 2050 for top ten exporting regions



Source: Own illustration based on Table 8-8

The final set of preliminary projections for the CAPRI baseline for the period from 2030, 2040 and 2050 was calculated based on the estimated global trend and regional market shares for the six market items. The projected data obtained for selected regions have been mapped to CAPRI regions for all fish species. The procedure for the growth factor computation that is applied through 2030 to the CAPRI base year is applied for subsequent projection years. As the final piece focuses only on fish market projections in 2030, 2040 and 2050, the gap between 2027 and 2030 is simply neglected. The quantities used for 2030 are from data from 2027 and the growth factors used were applied for 2040 and 2050. The final database covering the period from 1990 to 2027, 2030, 2040 and 2050 is complete for the baseline calibration phase in the CAPRI modelling system.

Chapter 4
The CAPRI fish model

In this chapter, an introduction to the concept and structure of the CAPRI modelling system is given. Section 4.1 introduces the existing economic models, including a representation of fish markets. Following this, the initial setting of seafood markets in the previous CAPRI system will be discussed in section 4.2. Then, the development of CAPRI fish model will be described in detail from section 4.3 to 4.5. Most of the content in this chapter has been published previously (Chang et al., 2016; Chang et al., 2018; Heckelei et al., 2018).

4.1 Seafood representation in existing economic models

The impact of the expansion of aquaculture on the environment has been addressed in multiple articles using different environmental models, such as the LCA (Klöpffer, 2005), the Farm Aquaculture Resource Management (FARM) model (Ferreira et al., 2009) or the Offshore Mariculture Escapes Genetics Assessment (OMEGA, NOAA and ICF, 2012), the Modeling–Ongrowing fish farm-Monitoring System (MOM, Maroni, 2000), Depositional Modeling (DEPOMOD, Cromey et al., 2002), and the Integrated Valuation of Environmental Services and Tradeoffs (InVEST) model[2]. Among the ten agriculture model intercomparison and improvement project models (AgMIP, Lampe et al., 2014), the International Model for Policy Analysis of Agricultural Commodities and Trade hosted at IFPRI, (IMPACT model[3]) was the only model which also considered aquatic products. Aside from IMPACT, AgLink-CoSiMo (FAO-OECD)[4] model features a completely structured fisheries sector (Chang et al., 2016). Currently, aquaculture, in fact the whole fishery sector, is under development within many of existing general equilibrium models or partial equilibrium models, i.e. the MAGNET (Modular Applied GeNeral

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[2] See webpage: https://naturalcapitalproject.stanford.edu/software/invest Last accessed on 02 May 2021

[3] See webpage: http://www.ifpri.org/program/impact-model Last accessed on 02 May 2021

[4] See webpage: http://www.agri-outlook.org/abouttheoutlook/ Last accessed on 02 May 2021

Equilibrium Tool) model and the GLOBIOM (Global Biosphere Management Model) model (Heckelei et al., 2018). In order to understand the methodological concepts and the specified features of CAPRI fish model relative to existing fish sector modelling approaches, four aforementioned economic models including IMPACT, AgLink-CoSiMo, MAGNET and GLOBIOM will be explicitly described here. These models, together with CAPRI, are currently the most developed and applied economic models with respect to fisheries. The features of the five selected economic models including general type, spatial and product differentiation, projection horizon and characteristics are introduced in this section, and displayed in Table 4-1.

IMPACT was developed at IFPRI and is a global, multimarket, partial equilibrium economic model. The World Bank (2013) implemented the IMPACT model for projecting global fish supply and demand and simulating six scenarios through 2030 in one of the first integrated aquaculture-agriculture reports called “Fish to 2030 – Prospects for Fisheries and Aquaculture” (Msangi et al., 2013). The IMPACT fish module includes 17 fish products, aggregated non-fish commodities for reducing the size of the model and 115 world regions. IMPACT can handle multiple fish species, fish feed and the relationship to the agricultural sector. Thus, IMPACT was the first large-scale economic model that included a comprehensive and comparably detailed fish module. Disadvantages of the model include a simplified model structure, an unrealistic market-clearing price, homogeneity assumptions and a lack of bilateral trade flows (Msangi et al., 2013). Particular attention is given to the link between aquaculture and land use through the consideration of aquafeed from plant-based ingredients. Therefore, IMPACT features a strong link between aquaculture and agriculture. Msangi et al., (2013) concluded that, compared to the IMPACT model, some general and partial equilibrium models, such as CGE models developed under the framework of the GTAP modelling consortium, the World Bank's Linkage model, the GLOBIOM model or the CAPRI model were better equipped to deal with some of the shortcomings of the IMPACT model. The fish module of the AgLink-CoSiMo Framework (FAO-OECD) was introduced by the FAO in 2010. AgLink-CoSiMo is a partial equilibrium model that simulates midterm projections for international agriculture and food markets. The fish model is a stand-alone model that can be linked to AgLink-CoSiMo through feed use. The goal of the combination of both models is to analyze the interaction between fisheries and agriculture. MAGNET has been developed at LEI Wageningen and is a multi-sector, multi-region and long-term computational general equilibrium model (Woltjer et al., 2014). The MAGNET model has been employed to evaluate the impact of agricultural and land policies on the global economy. According to Kuiper et al. (2018), the MAGNET database has been extended to model fishery sector to include four types of fish from wild capture fisheries, five types of fish from aquaculture and fish processing sectors. The aim for MAGNET is to capture the interaction between aquaculture and fisheries and, in particular, the FIML and fish seed produced from fisheries to aquaculture. In addition, given the competition between aquaculture and livestock, feed is explicitly modeled. GLOBOIM was developed at IIASA in 2007 and is a global recursive dynamic, partial equilibrium model (Rutten et al., 2016). Heckelei et al., (2018) report that the fish sector that has been developed under the GLOBIOM framework for constructing a module of seafood production, consumption, and trade at country-level globally. The goal calls for a link between the fish sector and the existing agricultural sector in GLOBIOM through the feed markets. On one hand, aquaculture consumes feed formulated from crops; on the other hand, FIM&FIOL extracted from fish is used in livestock feed.

Last, but not least, CAPRI has the potential to handle more complex structures and project medium term market developments. The CAPRI fish model focuses on forecast and evaluation of primarily economic impact of fisheries policies on global seafood, FIML&FIOL markets and additionally on agricultural market through aquafeed production. However, the environmental impact, such as greenhouse gas emission caused by the aquaculture activities, are not yet included. The detailed construction of the fish market and underlying behavioral functions will be introduced in the following sections.

Table 4-1 Overview of selected economic models covering fish and aquaculture markets

Model	Applied by	Sector	Spatial differentiation	Product differentiation	Time horizon	Further characteristics	References regarding fish sector
IMPACT (International Model for Policy Analysis of Agricultural Commodities and Trade)	IFPRI[1]	PE: Agriculture	115 regions EU aggregated	• 11 non-fish commodities • 17 Fish products • 3 feed ingredients incl. fishmeal & fish oil	2020 2030	Dynamic	(Delgado et al., 2003; Msangi et al., 2013)
AgLink-COSIMO	FAO[2]-OECD[3]	PE: Agriculture	56 world regions	• Fish, fishmeal, and fish oil		Recursive dynamic	(FAO, 2012)
CAPRI (Common Agricultural Policy Regional Impact)	ILR, University of Bonn[4]	PE: Agriculture	80 regions	• 6 Fish products • 14 feed ingredients incl. fishmeal & fish oil	2030 2050	• Exogenous catch • Comparative static	(Chang et al., 2016; Heckelei et al., 2017; Latka et al., 2018)
GLOBIOM (Global Biomass	IAASA[5]	PE: Forestry	27 FAO major fishing regions	• 10 fish commodities	2030 2040	Recursive dynamic	(Heckelei et al., 2018)

[1] International Food Policy Research Institute – IFPRI, Washington DC (USA). Available at: http://www.ifpri.org/ Last accessed on 24.06.2019

[2] Food and Agriculture Organization of the United Nations – FAO, Rome (Italy). Available at: http://www.fao.org/home/en/ Last accessed on 24.06.2019

[3] Organization for Economic Co-Operation and Development – OECD, Paris (France). Available at: https://www.oecd.org/ Last accessed on 24.06.2019

[4] University of Bonn, Bonn (Germany). Available at: https://www.ilr1.uni-bonn.de/en?set_language=en Last accessed on 24.06.2019

[5] International Institute for Applied System Analysis – IIASA, Laxenburg (Austria). Available at: http://www.iiasa.ac.at/ Last accessed on 24.06.2019

Model	Applied by	Sector	Spatial differentiation	Product differentiation	Time horizon	Further characteristics	References regarding fish sector
Optimization Model)		Agriculture		• 7 feed ingredients incl. 5 crop feed ingredients, fishmeal, and fish oil	2050		
MAGNET (Modular Applied GeNeral Equilibrium Tool)	LEI[6]	CGE	140 countries or regions	• 5 aquaculture groups • Fishmeal from processing	2030		(Kuiper et al., 2018)

Source: Own illustration based on Becker, (2011)

[6] Agricultural Economics Research Institute – LEI, The Hague (Netherlands). Available at: https://www.lei.wur.nl/en.htm Last accessed on 24.06.2019

4.2 General concept of CAPRI

The CAPRI model is a global, Europe focused, economic, comparatively static, spatial, partial equilibrium model with an almost exclusive focus on agricultural sector. The CAPRI modelling system is composed of two major modules. One set of regional programming models which represents the supply side of European regions and the global market module representing demand and bilateral trade for all regions and the supply side for NonEU_EUropean regions as well (Britz & Witzke, 2012). The fish market model is a part of the global market module and therefore does not offer regional disaggregation below country level. So far it treats European and NonEU_EUropean countries alike.

In general, the supply module determines agricultural supply of crops and animal products individually for all 28 EU countries and their sub-regions (NUTS2 regions). Those non-linear programming models in the supply module represent farming activities covering 50 products at regional or farm type level. The non-linear models combine a Leontief-technology for variable costs covering a low and high yield variant for the different production activities with a non-linear cost function which captures the effects of labor and capital on farmers’ decisions. Additionally, the supply module captures the premiums paid under the Common Agricultural Policy (CAP) and includes Nitrogen-Phosphorus-Potassium (NPK) balances as well as the animal feeding activities. Prices in the supply module are given exogenously by the market module (Britz and Witzke, 2012).

The market module in the CAPRI modelling system is global and spatial and about 50 agricultural and aquacultural products and 80 regions are covered. The supply functions in the market model depend on the producer prices for the agricultural sector and on the net revenues for the aquaculture sector. Total demand for each region is generally defined as the sum of food use (depending on income and consumer prices), processing use (depending on processing margin) and feed demand (depending on the feed prices and animal supply). The parameters are predominately taken from the literature or other modelling systems. The market module operates and delivers prices to the supply module. The final market equilibria are generated by the iterations between the two modules (Britz & Witzke, 2012). If the European supply models are not the focus of a study (such as in this one) the iterations may be omitted to obtain the market model results in a direct way.

Bi-lateral trade flows and prices are modeled based on the Armington assumptions (Armington, 1969) where a two level Armington system is applied. At the top-level domestic sales and imports of commodities are substituted as a function of the market prices and the average import prices. The next level then determines the import shares from different origins (Britz & Witzke, 2012).

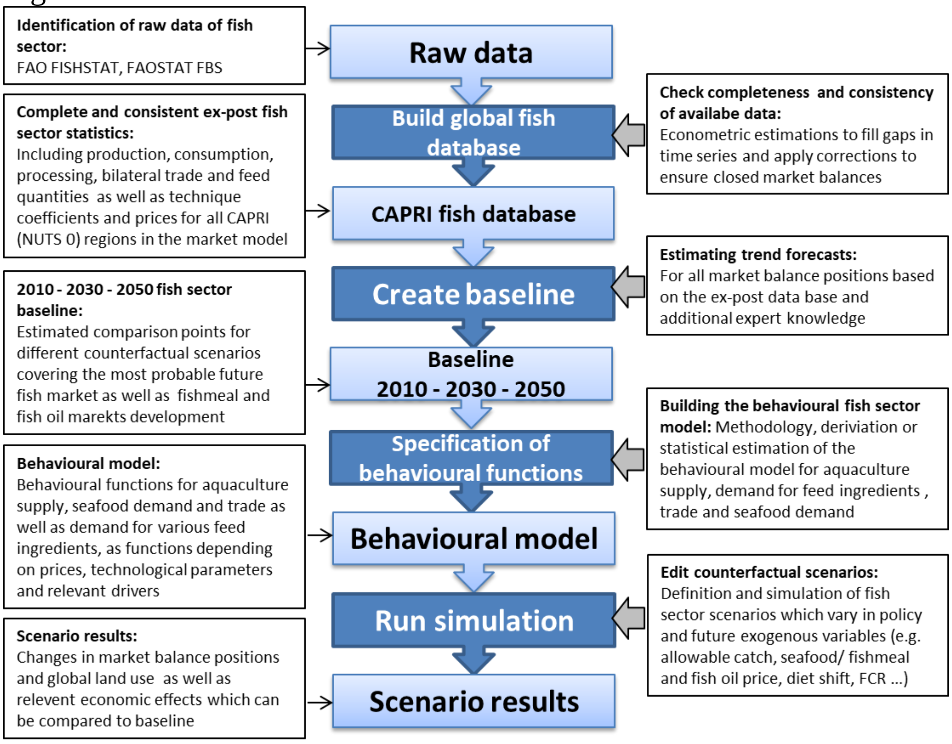
Applying the CAPRI model for scenario analysis first requires a reference scenario (baseline) for the simulation years, which are 2030 and 2050 in this study. The baseline is estimated based on the ex-post data and external expert projections. The ex-post database relies on well-documented, official, and harmonized data sources including FAOSTAT, OECDStat and EUROSTAT. Subsequently, the database is further consolidated to a complete and consistent set for use in the CAPRI modeling system. The construction of a global fish market database is described in detail in Chapter 3 with the baseline calibration phase (Chapter 5) whereas the behavioral models permit to run counterfactual scenarios. The new market equilibria are determined by the assumptions of various explanatory variables, as described in Chapter 6.

4.3 **Fish market construction in the model**

This study aims to extend the existing CAPRI system to incorporate a behavioral market model for the fish sector focusing on aquaculture which allows simulating various scenarios to access the impacts from the shocks implemented in the fish market. Therefore, the CAPRI fish market model led to an independent CAPRI version which consisted of a multitude of revisions to the core CAPRI system but also included various extensions such as the introduction of fish supply and aquafeed demand. The database extensions regarding aquatic animals, their by-product commodities and the required feed formulation, as well as the consolidation of the fish market database has been addressed in Chapter 3. The introduction of behavioral functions of seafood, FIML&FIOL supply as well as feed ingredient demand is addressed in the following section. Subsequently, the construction of a fish market baseline as well as the definition and evaluation of fish market or fisheries policy scenarios will be covered in Chapter 5. The workflow from the raw data until the execution of scenario simulation is visualized in Figure 4-1.

The CAPRI fish module is based on three decision making stages. At each level a distinct optimization objective is fulfilled to address a particular set of commodities (Table 4-2). Six fish categories are distinguished within the module: crustaceans (CRUS), mollusks (MOLS), freshwater and diadromous fish (FFIS), demersal fish (DFIS), pelagic fish (PFIS), and other marine fish (OFIS). Besides FIML and FIOL, twelve further categories, mainly crops, are differentiated as aquaculture feed ingredients. These are soya cake, maize, barley, wheat, paddy rice, rape seed, rape seed oil, rye and meslin, soya oil, sunflower seed, sunflower seed oil, and animal waste used in fish feed (FIOT).

Figure 4-1 Workflow towards CAPRI fish sector simulations



Source: Own illustration based on Becker, (2011)

Table 4-2 Commodities in each decision-making stage

	Optimization	Commodities
Level 1	Profit Maximization	Crustaceans, mollusks, freshwater and diadromous fish, demersal fish, pelagic fish, other marine fish
Level 2	Feed cost Minimization	Fishmeal, fish oil, aggregated crops
Level 3	Feed cost Minimization	Soya cake, maize, barley, wheat, paddy rice, rape seed, rape seed oil, rye and meslin, soya oil, sunflower seed, sunflower seed oil, animal waste used in fish feed

Source: Own compilation

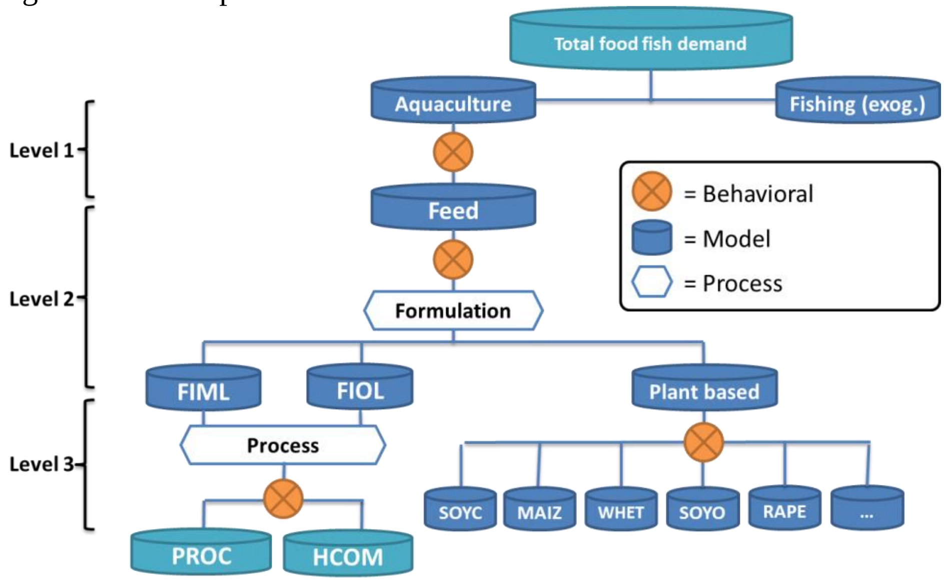
The three-level structure is described in the conceptual framework of the CAPRI fish market model shown in Figure 4-2. First, total fish supply is composed of fish from aquaculture and from capture. While fish supply from capture is based on exogenous information, aquaculture production is further modeled. At the first level, the fish producers' profit maximization problem is addressed to investigate how fish farmers determine the supply quantities of cultured fish.

Next, a cost minimization problem is set up to determine the input quantities for the feed needed in aquaculture production. First, the overall feed quantity in standard quantity and composition is technically determined by the feed conversion ratio specific to each fish type. Regarding the three major input categories, FIML, FIOL, and aggregated crops, relatively small substitution elasticity coefficients (between 0.5 and 1) are applied in the underlying CES production function. Thus, the composition of the main inputs in the feed formulation can only vary to a limited extent.

At the third level, mainly crop-based feed ingredients are disaggregated and assumed to be close substitutes to one another. Larger substitution elasticity coefficients are assigned to all feed crops referred to at this stage.

Besides the data regarding fish production and trade described in detail in Chapter 3.1, further technical information about the link between live fish, processing of FIML&FIOL, and fish feed was collected and included in the fish market model.

Figure 4-2 Conceptual framework of the CAPRI fish module



Source: Own illustration

According to Tacon and Metian (2008), FIML and FIOL account for 9.5% and 2.2% of the total aquaculture feed, by weight, in 2010, respectively. Aquaculture consumed 68% of FIML and 74% of FIOL of the total global consumption in 2012 (Tacon & Metian, 2015). Both products were extracted mainly from small pelagic forage fish, in particular, anchovies, mackerel and herring (Péron et al., 2010).

The FIML&FIOL industry relies highly on reduction fisheries. These are fisheries with catches targeted for processing into FIML&FIOL and not for direct human consumption. This accounts for approximately 20% to 30% of the total captured landings (Péron et al,, 2010). In addition, about 15% to 25% of FIML&FIOL production is based on fish processing waste (Msangi et al., 2013; Shepherd, 2012). The reduction ratio (RR) and the waste ratio (WR) are two important factors for computing FIML&FIOL production quantities and are therefore referred to in the data consolidation later on. The reduction ratio indicates how much FIML&FIOL can be obtained from a certain quantity of fish. The WR captures the share of fish initially designated for the food industry which is not suitable for human consumption so that it is further used in FIML&FIOL production.

On average, a ton of fish can be processed to roughly 225kg of FIML and 50kg of FIOL (Tacon & Metian, 2008). Accordingly, the global average reduction rates of FIML&FIOL are 0.225 and 0.05, respectively. WR vary by seafood group between 0.25 and 0.5 (Msangi et al., 2013) as shown in Table 4-3.

Table 4-3 FIML&FIOL processed from captured fish and fish waste

CAPRI fish groups	Reduction Ratio (Global Average)		Waste Ratio
	FIML	FIOL	
CRUS	0.23	0.05	0.45
MOLS	0	0	0
FFIS	0.23	0.05	0.25
PFIS	0.23	0.05	0.25
DFIS	0.23	0.05	0.29
OFIS	0.23	0.05	0.26

Remarks: Ratios for mollusks are not considered,
Sources: Msangi et al. (2013); Tacon and Metian (2008)

The FCR determines the overall feed quantity required to produce one ton of a given farmed seafood type. Table 4-4 shows that on average 1.4 tons of feed is required to produce one ton of crustaceans. As previously mentioned, FIML and FIOL are two substantial ingredients in the feed, in particular, for carnivorous groups such as crustaceans. However, the ingredients in fish feed are steadily being replaced by crop meal and oil due to increasing prices of fish-based products (Hardy, 2010).

Among the crop categories included in the CAPRI fish market model, soybean processing by-products are the predominate alternatives to FIML&FIOL. Consequently, the combination of fish-based and plant-based ingredients used in feed for various fish species determines how seafood markets interact with agricultural markets.

Table 4-4 Feed Conversion ratio (FCR) of the CAPRI fish group

#	CAPRI fish group	FAOSTAT description	FCR (1995-1999)	FCR (2000-2004)	FCR (2005-2009)	FCR (2010-2014)
1	CRUS	Crustaceans	1.4	1.4	1.4	1.4
2	MOLS	Cephalopods & Mollusks	-	-	-	-
3	FFIS	Freshwater fish & diadromous fish	0.9	0.9	1	1
4	DFIS	Demersal fish	1.3	1.3	1.3	1.3
5	PFIS	Pelagic fish	1.3	1.3	1.3	1.3
6	OFIS	Marine fish, other	1.3	1.3	1.3	1.3

Sources: Own calculations based on Boyd and Polioudakis (2006); Tacon and Metian (2008)

The feed formulation determines the crop use in feed production. Although there is heterogeneity within a single species of each CAPRI fish category, an assumption is made that the diet is uniform. The feed formulation chosen for crustaceans refers to shrimp feed. Mollusks are a filter non-fed seafood category and therefore have no feed demand. Pelagic, demersal, and other marine fish are mostly cultured in the ocean and are assumed to consume the same feed.

Freshwater and diadromous fish is an important but heterogeneous CAPRI fish category which accounts for the largest part (47%) of total aquaculture production. This category includes herbivorous and omnivorous fish such as carp, barbells and tilapia, and carnivorous fish such as sturgeon, eel, salmon, trout, smelts, and shad. According to Tacon and Metian (2008, 2015), the feed conversion ratio of herbivorous fish such as carp and tilapia ranges between 1.5 and 2, whereas the ratio of carnivorous fish like trout and salmon is between 1.3 and 1.5. Furthermore, about 30% of the farmed fish belong to non-fed filter-feeding species such as silver carp, bighead carp and invertebrates (FAO, 2018). This metric is accounted for by reducing the feed conversion ratio accordingly for this fish group.

4.4 Behavioral model for fish supply and feed demand

The total domestic fish supply, which is defined as the aggregation of aquaculture and capture production is shown in Figure 4-2. Capture production is determined exogenously and thus, aquaculture production represents the flexible part of the total supply function depending on assumptions of a given scenario. Therefore, the considerations of the following methodology relate exclusively to aquaculture supply.

The aim of analyzing producers' behavioral functions is to explore how farmers make the decision to produce the types of fish as discussed above and to use inputs in the production to obtain an optimal operating result under the assumption of competition. In other words, which combination of FIML, FIOL, different fish feed ingredients (agricultural crops) and FIOT should be used for the fish farmers. The decision-making process in determining optimal seafood supply and feed demand can be assessed by either the profit function or the cost function starting from the dual approach of the production theory (Fuss & McFadden, 2014). Profit function means the producers' profit as a function of input and output prices, while the cost function represents farmers' economic behavior which strives to minimize the producing cost subject to the given output quantities and input prices. Both profit maximizing and cost minimizing approaches should generate the same results with a suitable nesting, and the preference of either approach depends on the type of disaggregation of the behavioral functions in the specific model (Colman, 1983). As a complex market representation of seafood is being applied, we must disaggregate the full producer's problem of profit maximization with prices of seafood and feed ingredients, which are the variables that determine supply and demand quantities under market equilibrium conditions.

Next, the methodological considerations concerning aquaculture production technology are detailed to specify the underlying profit function.

Aquaculture supply

The profit function, determined by input and output prices, can be formulated depending on production margins subject to a quadratic cost function. In other words, fish farmers determine the optimal mix of the six CAPRI fish species, each valued at the corresponding net revenues. Net revenues basically assume the role of output prices due to our assumption of a fixed FCR. The calculation of profit maximizing aquafeed demand for individual feed ingredients is divided into two levels as shown in Figure 4-2. The total feed quantity is technically linked to profit maximizing aquaculture supply, allowing for total fish feed demand to be disaggregated into two feed demand stages.

1st level: Profit Maximization

Equation 14

$$\max \pi = \sum_i f_i \cdot P_i - \sum_i fcr_i \cdot f_i \cdot W_i - qV$$

Equation 15

$$s.t.\ \alpha_0 + \sum_i \alpha_i \cdot f_i + \sum_i \sum_j \alpha_{ij} \cdot f_i \cdot f_j = V$$

i = CRUS(1), MOLS(2), FFIS(3), DFIS(4), PFIS(5), OFIS(6)

q: input price vector, V: input vector, f_i: production quantity of fish type i, P_i: producer price of fish type i, fcr_i: feed conversion rates for fish type i, W_i: prices of formulated feed for fish type i, f_j: alias of f_i

The demand of total feed quantity (TFQ):

$$TFQ = \sum_i fcr_i \cdot f_i$$

The demand of total feed quantity (TFQ) of fish type i:

$$TFQ_i = fcr_i \cdot f_i$$

Supply of FIML, FIOL and FIOT

FIML and FIOL are by products processed from fresh fish (typically from capture) as well as from fish waste from human food consumption. In general, one ton of forage fish can be extracted to 225 kilograms of FIML and 50 kilograms of FIOL. Thereby, the supply of FIML&FIOL is technically determined, given processing use of feed fish and human consumption of food fish. The variable $PRDHCO(fmol)$ represents the production of FIML or FIOL from human consumption waste (Equation 16). First, the human consumption quantity of each fish category is multiplied by the WR to calculate the possible amount of food fish waste that might be used in FIML&FIOL production. Then the computed quantity is multiplied by the $RR(fmol)$ which is the reduction ratio to obtain the final quantity of fishmeal or fish oil.

Equation 16

$$PRDHCO(fmol) = \sum_{fg} HCOM(fish) \cdot WR(fish) \cdot RR(fmol)$$

With $fmol = fishmeal, fish\ oil$

The major source of raw materials for FIML&FIOL production is the small pelagic forage fish catch in the reduction fisheries as mentioned above. Therefore $PRDRED(fmol)$ refers to the production quantity of FIML or FIOL from the reduction of fish (PRCM) as shown in Equation 17.

Equation 17

$$PRDRED(fmol) = \sum_{fg} PRCM(fish) \cdot RR(fmol)$$

The total production of FIML&FIOL is derived from the aggregation of two sources, fish from human food waste and fish from reduction fisheries (Equation 18).

Equation 18

$$MAPR(fmol) = PRDHCO(fmol) + PRDRED(fmol)$$

Fish waste (FIOT) in the CAPRI fish model is the aggregate of heterogeneous and not statistically recorded material such as animal bone powder and shrimp head meal which are added in the fish feed formulation. Due to the lack of sufficient information, FIOT is assumed to be non-traded and unusable for the agricultural sector. Therefore, an ad-hoc semi-log form supply function (Equation 19) for FIOT is introduced in the CAPRI fish model with a low producer price ($PPRI_{FIOT}$). In addition, the assumption of a standard supply elasticity ($SUPELAS_{FIOT} = 1$)) is made.

Equation 19

$$\frac{PROD_{FIOT}}{Data\_PROD_{FIOT}} = SUPELAS_{FIOT} * \log(\frac{PPRI_{FIOT}}{Data\_PPRI_{FIOT}}) + 1$$

$PROD_{FIOT}$: Supply quantity, $SUPELAS_{FIOT}$: Supply elasticity of FIOT ($SUPELAS_{FIOT} = 1$), $Data\_PROD_{FIOT}$: original parameter of FIOT production, $Data\_PPRI_{FIOT}$: original parameter of FIOT producer price

Fish feed demand

The decision of the distribution among FIML, FIOL and aggregated cereal is done at the second level of the producers' problem, and among the individual cereals and FIOT at the third level. Here, demand quantities for individual feed ingredients are solved for implementing a cost minimization approach. The two levels are differentiated from the substitution elasticity assigned among the commodities as the feed ingredients are less flexible in substituting for each other at the second level than at the third level. The cost minimization responds to prices of FIML, FIOL and aggregated cereal at the second level and to the prices of individual cereals and FIOT at the third level. The cost minimizing demand quantity for fish feed used in aquaculture is given by Equation 23 and Equation 27. Both cost minimization problems rely on constant elasticity of substitution (CES) functions to represent the technical substitution possibilities, and the resulting demand quantities for feed ingredients are stated by the underlying cost minimization problem.

2nd level: Cost Minimization

Cost minimization for a given production level X, input quantities x and input prices w:

Equation 20

$$\min C = \sum_j x_j w_j$$

Equation 21

$$s.t.\ \alpha\left(\sum_j \sigma_j^{\rho-1} x_j^{\rho}\right)^{\frac{1}{\rho}} \geq X \quad \text{(CES)}$$

j: feed ingredients = FIML(1), FIOL(2) and aggregated plant-based ingredients(3) = SOYC, MAIZ, BARL, WHEA, RARI, RAPE, RAPO, RYEM, SOYO, SUNF, SUNO and FIOT

X: aggregate feed quantity for fish type i, w: input prices, σ: distributing parameter

$\rho = {\epsilon - 1}/{\epsilon}$ is the parameter related to the elasticity of substitution ϵ which are adopted in the CAPRI model (Britz and Witzke, 2012), α and σ are calibration parameters. Taking the first order conditions to optimize this problem gives the solution stated below.

Equation 22

$$x_j^* = X\sigma_j\left(\alpha^{\rho}\frac{W}{w_j}\right)^{\frac{1}{1-\rho}} \quad \text{for each } j = 1\ldots3$$

$$W^* = \left(\sum_j \tau_j w_j^{\frac{-\rho}{1-\rho}}\right)^{\frac{1-\rho}{-\rho}}$$

Here we can reparametrize the conditional demand equations using the elasticity of substitution, $\varepsilon = \frac{1}{1-\rho}$.

Equation 23

$$x_j^* = X\sigma_j\alpha^{\varepsilon-1}\left(\frac{P}{w_j}\right)^{\varepsilon}$$

On the second level, we assign a relatively small elasticity coefficient (between 0.5 and 1) within the 3 major ingredient groups with respect to the proportion of those ingredients used to the formulated feed is rather fixed.

3rd level: Between other feed materials (simplification)

In this stage, we neglect the energy contained in the different crops and the processed products that are used as feed ingredients and simply assume they substitute for each other and assign a larger elasticity coefficient (between 5 and 10).

On the third level, we basically duplicate the cost minimization for a given production level X' from the group 3, the aggregated plant-based feed use, with single input quantities of plant-based feed x' to be chosen, given input prices w':

Equation 24

$$\min C' = \sum_k x'_k w'_k$$

Equation 25

$$\text{s.t.}\ \beta\left(\sum_k \sigma'^{\gamma-1}_k x'^{\gamma}_k\right)^{\frac{1}{\gamma}} \geq X' \quad \text{(CES)}$$

k: Plant-based ingredients = SOYC, MAIZ, BARL, WHEA, RARI, RAPE, RAPO, RYEM, SOYO, SUNF, SUNO and FIOT

X′: aggregate feed quantity for fish type i, w′: input prices, σ′: distributing parameter

Equation 26

$$x'^{*}_k = X'\sigma'_k\left(\beta^{\gamma}\frac{W'}{w'_k}\right)^{\frac{1}{1-\gamma}} \quad \text{for each k = 1…12}$$

$$W'^{*} = \beta^{\gamma-1}\left(\sum_k \sigma'_k w'^{\frac{-\gamma}{1-\gamma}}_k\right)^{\frac{1-\gamma}{-\gamma}}$$

Here we can reparametrize the conditional demand equations using the elasticity of substitution, $\varepsilon' = \frac{1}{1-\gamma}$.

Equation 27

$$x'^{*}_k = X'\sigma'_k\beta^{\varepsilon'-1}\left(\frac{P'}{w'_k}\right)^{\varepsilon'}$$

4.5 Behavioral model for seafood demand and trade

To represent demand and trade of fish and FIML&FIOL in the CAPRI fish market model, the methodology used is that of a two stage demand system relying on the Armington assumption as already applied to other agricultural commodities in the standard CAPRI version (Britz & Witzke, 2012).

Within this methodological concept, the total domestic demand (Equation 28) is defined at the first stage as the aggregation of human consumption (food use), processing use and feed demand. Subsequently, the second stage applies a two level Armington assumption: That the total demand (Arm1) on the top level contains imports (Arm2) and domestic sales. The associated price, Armington 1 price (Arm1P), is basically the weighted average prices for goods consumed domestically as a function of the domestic market price and the average import price in accordance with Britz and Witzke (2012). At the lower level, the import shares from different origins are determined as a function of the average import price. The two functions are derived from CES utility functions. Arm1 and Arm2 define the aggregated utility of the top level and lower level corresponding to total demand (DOMM) and total imports, respectively. These assumptions address the issue that consumers will respond less to substitution between domestic and imported goods compared to substitution among goods from different import origins. The assigned substitution elasticity on the top level is, in general, smaller than for the lower level (Britz & Witzke, 2012). For seafood products, the substitution elasticity between domestic sales and imports and between import flows are 8 and 10, respectively.

Equation 28

$$DOMM = HCOM_{cpri,Y} + INDM_{mar} + FEDM_{Arm1p,\, supply_a}$$

cpri: consumer price, *Y*: income, *mar*: margin, *Arm1p*: Armington 1 Price

Within the CAPRI fish market model, the total domestic demand for seafood products is defined as the sum of human consumption and processing use (Equation 29) after the data from different sources has been processed to the final database in Chapter 3. FIML and FIOL are used mainly in aquafeed production. Total domestic demand for FIML is extended to cover the feed demand from aquaculture (FEDFIS) and from livestock (FEDAGR), which is determined by their Arm1 prices. The total demand for FIOL includes human consumption (about 10%), as well as feed demands from aquatic and land animals (Equation 30). FIOT is defined as cheap unknown ingredients used in the fish feed formulation, and its use in aquaculture equals to its total domestic demand (Equation 31).

Equation 29

$$DOMM_{fish} = HCOM_{fish} + PROC_{fish}$$

Equation 30

$$DOMM_{fmol} = HCOM_{fmol} + FEDM_{fmol} = HCOM_{fmol} + FEDFIS_{fmol} + FEDAGR_{fmol}$$

Equation 31

$$DOMM_{"FIOT"} = FEDFIS_{"FIOT"}$$

Sections 4.4 and 4.5 have described the derivation of the supply and demand functions of the aquatic and agricultural commodities within the fish sector. Subsequently, the calibration of all the behavioral functions was conducted to reproduce exactly the price quantity framework of the fish sector baseline.

Chapter 5
The reference scenario: CAPRI fish baseline

The reference scenario (hereafter, baseline) has to be defined to investigate the impacts of various scenarios using the new CAPRI fish model. A baseline is generated to "[…] *serve as a comparison point or comparison time series for counterfactual analysis*" (Britz & Witzke, 2012). Here the baseline represents a projection for 2030 and 2050 covering likely future development of the global agricultural and fish sectors under the status quo settings and includes future changes already foreseen. Moreover, it captures the interaction between technological, institutional, preference, and policy changes.

5.1 Baseline construction

The general estimation procedure of baseline relies on the established fish market database explained in Chapter 3. The fish market baseline generation relies first on the historical fish market database mainly from FAOSTAT and FISHSTAT from 1990 to 2011. The OECD-FAO outlook of fish and its by-product markets entered the baseline generation procedure to fill the gap for the period between 2012 and 2027. The procedure of trend estimation from 2028 onwards for the probable future of fish market through 2050 is reported in section 3.5. As stated in that section, the unrestricted global trend of 2030 and 2050 is determined by parameters generated from a simple model based on the ex-post database from OECDStat. The shares of the market items for each OECD region are estimated by implementing a multinomial logit model. Subsequently, the quantities of market items for individual regions are computed based on the global projection and the estimated shares. The different region coverage in OECD and CAPRI was studied with mapping after the projections in terms of OECD regions. Consistency constraints were added in the baseline calibration phase to ensure a closed market balance for both base year (2008) and simulation years (2010, 2030, 2050) in this study.

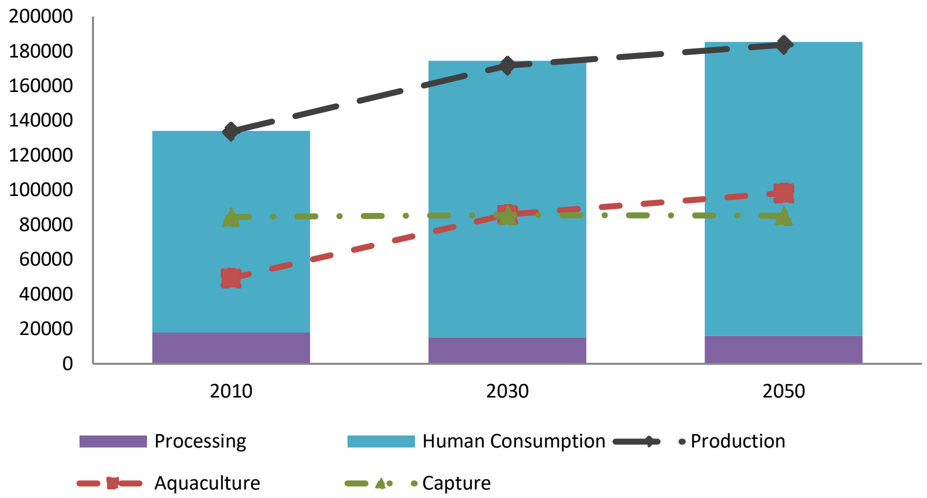
5.2 Results of the CAPRI fish baseline

The baseline of the CAPRI fish model will be described in detail in the following section focusing on the fish market, fish by-product (FIML&FIOL) markets, feed demand and single feed ingredient markets. The important quantity shifts in each market balance items in the projection years (2030, 2050) relative to the simulation year 2010 will be highlighted.

Fish market balance items and global fish trade

Figure 5-1 provides an overview of the fish market baseline in 2010, 2030 and 2050. Under the status quo setting, aquaculture growth is strong between 2010 and 2030 (increased by 75%), and then the growth slows down between 2030 and 2050 (only 14% from 2030 to 2050) while the capture production remains nearly stagnant for the whole period. Total fish production follows the trend of aquaculture production over time. The demand for food fish for human consumption, driven by the growing population, increases continuously until 2050. Meanwhile, the fish demand for processing use decreases by 15% in 2030 and recovers slightly by 2050.

Figure 5-1 Projection of global fish market (Baseline) (1000 t)



Source: CAPRI results extracted on 18-03-2019

Table 5-1 shows the fish market baseline from the simulation year 2010, 2030 to 2050 by continent (Europe is broken down to EU and NonEU_EU). Capture production is given exogenously from FAO FISHSTAT, OECDStat and our trend projection, which has been described in chapter 3.5. ASIA remains the biggest producer, consumer, and processer as well as trader over time, accounting for about 90%, 50%, 40%, 60%, 40% and 60% of global aquaculture production, catch, processing demand, human consumption, import and export, respectively. In general, aquaculture grows substantially in all regions over time. Apart from the Asian top seafood farming countries, Norway, and Chile are also top cultured FFIS producers located in NonEU_EU and MS_AM, respectively. Although the global catch quantity is nearly unchanged from 2010 to 2050, a 20% increase in growth is projected in AFRICA and ANZ in 2030. In contrast, MS_AM encounters a continuous loss in fishing production via 2030 to 2050 which explains the decreasing use of feed fish for FIML&FIOL production. In terms of processing use, Peru, Chile, China and Thailand are the top FIML&FIOL producers as mentioned above as they have abundant natural resources or wasted materials, such as trash fish in Thailand (Péron et al., 2010). Nevertheless, the substantial decreases in processing use of feed fish can be observed in EU, NonEU_EU and MS_AM. With respect to the demand for food fish, most of the regions excluding NonEU_EU increase their seafood consumption through 2050. It is shown that in NonEU_EU a substantial decrease in seafood consumption of 24% occurs by 2030 and recovers slightly by 2050.

Table 5-1 Baseline of fish market balance by continental (1000 t)

	Total production	Aquaculture	Capture	Processing use	Human consumption	Imports	Exports
			2010				
European Union	6651	1268	5382	1456	10793	9069	3470
Europe NonEU	10167	1430	8737	2217	6873	4850	5927
Africa	8131	970	7162	984	10484	4784	1447
North America	7426	753	6673	1194	10104	7426	3553
Middle and South America	11314	1437	9877	5589	3984	961	2702
Asia	89401	43250	46151	6530	73128	20203	29946
Australia and New Zealand	778	191	587	3	738		502
World	133867	49299	84568	17973	116104	47292	47547
			2030				
European Union	6883	1595	5288	997	11361	9982	4507
(Compared to 2010)	3.5%	25.8%	-1.8%	-31.5%	5.3%	10.1%	29.9%
Europe NonEU	11049	2187	8861	1533	5229	3985	8271
(Compared to 2010)	8.7%	52.9%	1.4%	-30.8%	-23.9%	-17.8%	39.6%
Africa	10280	1620	8660	965	13949	5522	888
(Compared to 2010)	26.4%	67.0%	20.9%	-1.9%	33.1%	15.4%	-38.7%
North America	8015	926	7088	1167	13637	10277	3487
(Compared to 2010)	7.9%	23.1%	6.2%	-2.3%	35.0%	38.4%	-1.9%
Middle and South America	12013	2450	9562	5111	6200	1985	2687
(Compared to 2010)	6.2%	70.5%	-3.2%	-8.6%	55.6%	106.6%	-0.5%
Asia	122534	77031	45503	5430	107784	21929	31251
(Compared to 2010)	37.1%	78.1%	-1.4%	-16.9%	47.4%	8.6%	4.4%
Australia and New Zealand	970	267	703	3	1110		499
(Compared to 2010)	24.8%	40.2%	19.8%	-0.1%	50.3%		-0.6%
World	171743	86077	85666	15206	159269	53680	51589

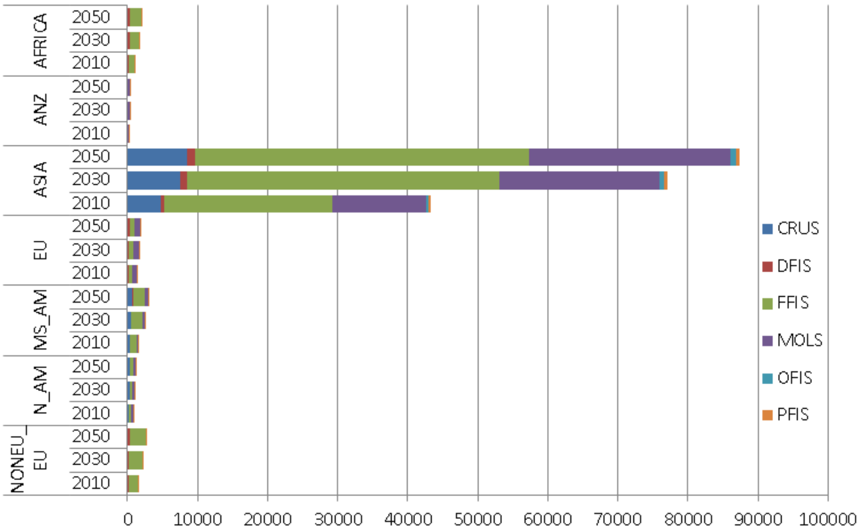
	Total production	Aquaculture	Capture	Processing use	Human consumption	Imports	Exports
(Compared to 2010)	28.3%	74.6%	1.3%	-15.4%	37.2%	13.5%	8.5%
2050							
European Union	6858	1884	4974	818	11240	9954	4754
(Compared to 2010)	3.1%	48.6%	-7.6%	-43.8%	4.1%	9.8%	37.0%
Europe NonEU	11410	2703	8706	1355	5832	3829	8051
(Compared to 2010)	12.2%	89%	-0.3%	-38.9%	-15.2%	-21.1%	35.9%
Africa	10860	1977	8883	1649	15404	6861	668
(Compared to 2010)	33.6%	103.8%	24.0%	67.6%	46.9%	43.4%	-53.9%
North America	7991	1111	6879	1406	13919	10830	3496
(Compared to 2010)	7.6%	47.7%	3.1%	17.7%	37.8%	45.9%	-1.6%
Middle and South America	11862	3024	8839	4185	6677	2199	3199
(Compared to 2010)	4.9%	110.4%	-10.5%	-25.1%	67.6%	128.9%	18.4%
Asia	133753	87383	46370	6830	114736	22104	34291
(Compared to 2010)	49.6%	102.0%	0.5%	4.6%	56.9%	9.4%	14.5%
Australia and New Zealand	1008	332	676	3	1367		440
(Compared to 2010)	29.6%	74.2%	15.2%	0.0%	85.2%		-12.3%
World	183741	98414	85327	16247	169174	55778	54899
(Compared to 2010)	36%	96%	1%	-8%	44%	14%	12%

Source: CAPRI results extracted on 18-03-2019

The baseline for individual fish species related to supply, demand, and trade from 2010 to 2050 is shown in from Figure 5-2 to Figure 5-5. Figure 5-2 shows the baseline for aquaculture production at the continental level where FFIS is observed as the most important farmed species group, and 87% of the FFIS production is contributed by ASIA (Table 8-15). FFIS also accounts for the largest part of aquaculture production in all regions. The second and the third most farmed species in the world are MOLS and CRUS, which are also mainly produced in ASIA, both accounting for about 90% of global production (Table 8-15). Moreover, Figure 5-2 also indicates that MOLS culture accounts for approximately 50% of the total EU aquaculture production. Figure 5-3 shows the baseline of capture production worldwide. Accordingly, ASIA has the highest catch for each species. Contrary to aquaculture, either PFIS or DFIS is the most caught species in all regions. In Africa, FFIS fishing is as important as PFIS fishing. Figure 5-4 displays the baseline for seafood consumption and demand for feed fish for processing use. It shows that FFIS is the most consumed species, and PFIS is the major species used for processing FIML&FIOL over time, which is in agreement with the observation and the content of Section 3.4. Due to the abundant small pelagic fish resource in MS_AM as mentioned above, a large part of PFIS caught in this region is for the purpose of FIML&FIOL processing purpose. Apart from Peru and Chile, the other big FIML&FIOL

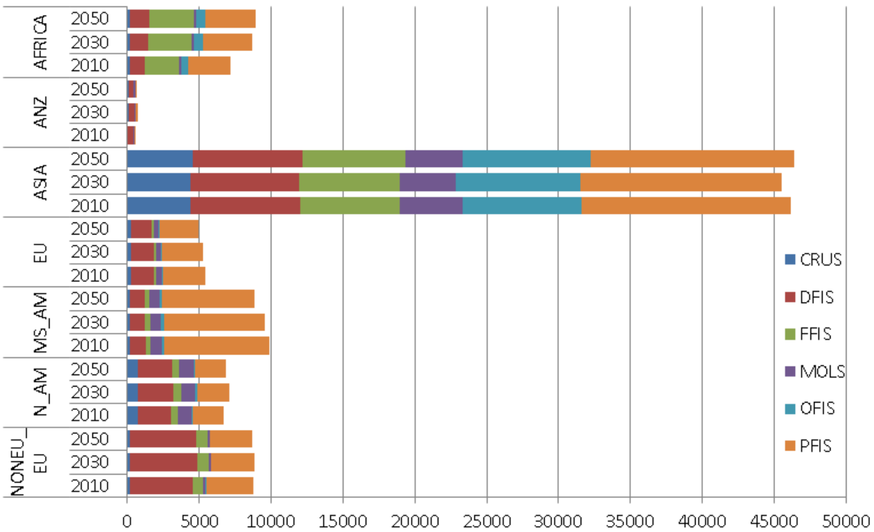
producing countries are located in Asia, and thereby the processing use in ASIA is also large. In terms of the baseline of fish trade, ASIA is the biggest importer and exporter as emphasized in Figure 5-5. Most of the regions except for NonEU_EU show increasing seafood imports over time and mainly in two species, PFIS and FFIS. In some regions this may result from an increasing imbalance between growth in human consumption compared to total production (reflecting higher net imports). But trade in fish may also be expected to grow due to increased globalization. Excluding ASIA, the major exported species are DFIS and PFIS globally. FFIS is the most farmed species in ASIA, its export quantity is as well the highest. Although the seafood consumption is growing rapidly in ASIA, the growth in ASIA's fish production is expected to keep pace. Consequently, ASIA will continue play a vital role as a seafood supplier in the world.

Figure 5-2 Baseline of aquaculture production by region and species (1000 t)



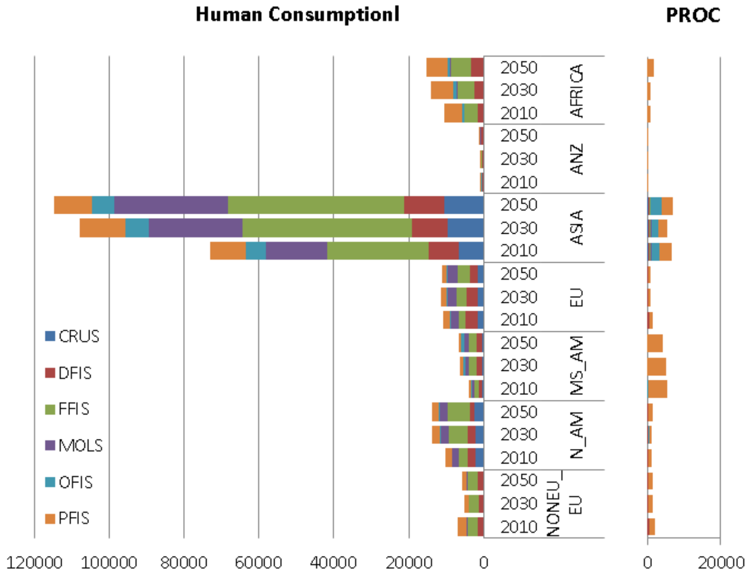
Remark: EU: European Union, NONEU: NonEU_EU member countries in Europe, N_AM: North America, MS_AM: Middle and south America, ANZ: Australia and New Zealand
Source: CAPRI results extracted on 18-03-2019

Figure 5-3 Baseline of capture production by region and species (1000 t)



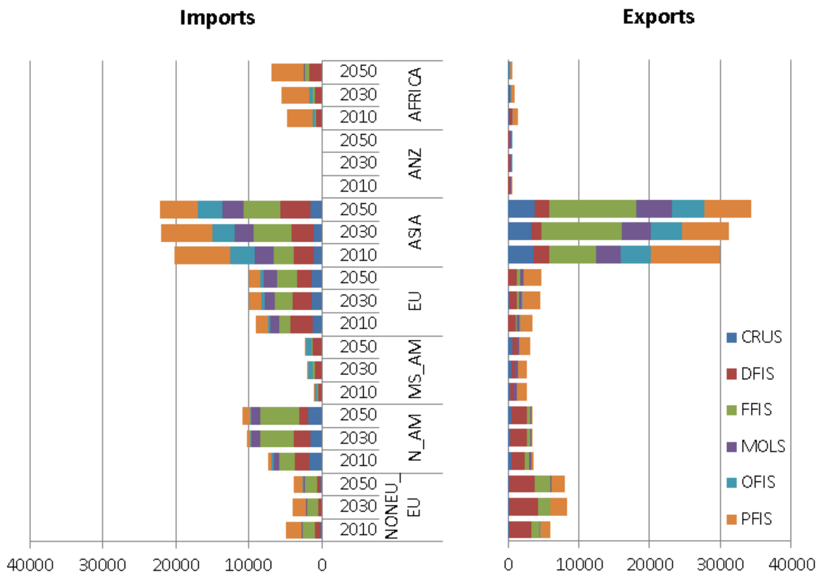
Remark: EU: European Union, NONEU: NonEU_EU member countries in Europe, N_AM: North America, MS_AM: Middle and south America, ANZ: Australia and New Zealand
Source: CAPRI results extracted on 18-03-2019

Figure 5-4 Baseline of seafood demand by region and species (1000 t)



Remark: EU: European Union, NONEU: NonEU_EU member countries in Europe, N_AM: North America, MS_AM: Middle and south America, ANZ: Australia and New Zealand
Source: CAPRI results extracted on 18-03-2019

Figure 5-5 Baseline of seafood trade by region and species (1000 t)



Remark: EU: European Union, NONEU: NonEU_EU member countries in Europe, N_AM: North America, MS_AM: Middle and south America, ANZ: Australia and New Zealand
Source: CAPRI results extracted on 18-03-2019

Table 5-2 demonstrates the FIML market baseline. Global FIML production is projected to decrease by 5.4% (227,000 tons) in 2050 compared to 2010. Among the seven regions listed in the table, ASIA and MS_AM rank top two producers whose productions are more than one mm tons while the other regions produce less than 500,000 tons. In the EU and NonEU_EU, a downward trend in fishmeal production from 2010 to 2050 of 25.7% and 33.3%, respectively is predicted (Table 5-2). Meanwhile, substantial growth in FIML production is expected in N_AM (24%), Africa (33.5%) and ANZ (69.1%) respectively. Although the percentage changes are substantial, the changes in production quantities in the aforementioned five continents are fairly small, given that they are not among the top producers. FIML is an important protein source used in animal, particularly, aquafeed. Table 5-2 shows an increasing proportion of FIML consumed by aquaculture from 2,850,000 tons (67.5% of total FIML production) in 2010 to 3,008,000 tons (75.3% of total fishmeal production) in 2050. On one hand, the shift of FIML use from livestock feed to aquafeed, as well as its growing demand for aquafeed production, can be explained by the rapid expansion of aquaculture, which has driven demand for FIML in the past two decades. On the other hand, the stagnant FIML production and its use in aquafeed compared to substantial aquaculture growth reflect the likelihood of improving feed efficiency and success in feed formulation with protein alternatives. FIML required by aquaculture generally increases in all regions except for ASIA by 2050 compared to 2010. Although the strongest growth occurs in the EU, about 92.5%, the quantity is rather small (78,000 tons). In contrast, FIML required by livestock generally decreases in all regions except for N_AM in 2050 compared to 2010. The strongest decline takes place in MS_AM about 51.6%, which is, however, small in terms of quantity (13,000 tons). ASIA shows a 12.5% decline of FIML used in aquafeed production in 2050 compared to 2010 although it shows a very strong growth in aquaculture of 102%. However, the combination of farmed species in ASIA is complex and not always reliant on commercial feed. As one can observe in Figure 5-2, the growth is mainly due to FFIS and MOLS production whose intake of FIML is either low or zero. In addition, the substantial increase of FIML prices (by about 24%, Table 8-17) and the existence of economical substitutes are likely to cause this result. In terms of the baseline of fishmeal trade, MS_AM is the top exporter over time, although the exporting quantity continuously decreases from 1,214,000 in 2010 to 902,000 tons in 2050 (by 25.7%).

NonEU_EU has the highest growth in FIML imports as well as the largest decline in FIML exports in both 2030 and 2050. This can be explained by strong growth in FFIS production, which is composed primarily of carnivorous species such as salmon and trout.

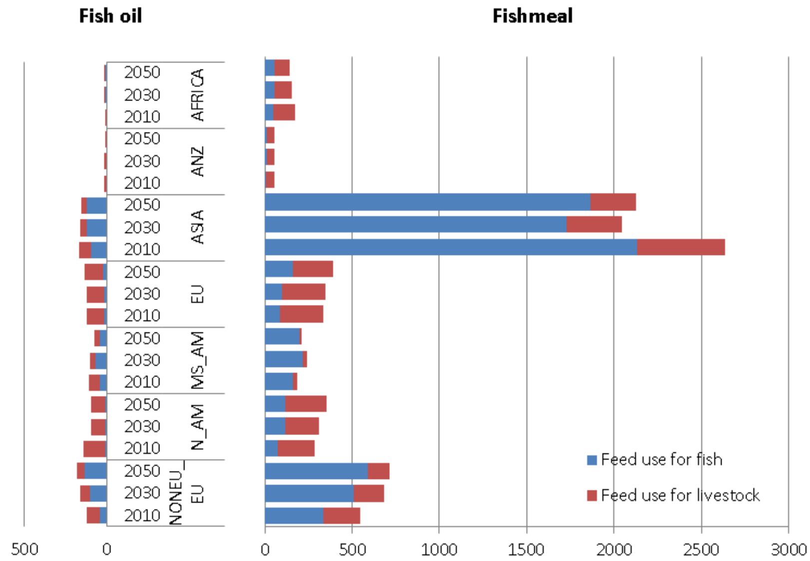
Table 5-2 Baseline of fishmeal market balance by region (1000 t)

	PROD	FEDAGR	FEDFIS	IMPT	EXPT
2010					
European Union	453	253	83	323	439
Europe, NonEU_EU	393	210	338	337	182
Africa	172	130	46	161	156
North America	271	213	75	105	89
Middle / South America	1272	24	164	129	1214
Asia	1625	500	2135	1330	320
Australia / New Zealand	38	45	8		10
World	4224	1374	2850	2385	2409
2030					
European Union	372	248	98	330	358
(Compared to 2010)	-18%	-2.3%	17.2%	2.4%	-18.6%
Europe. NonEU_EU	278	173	512	504	98
(Compared to 2010)	-29.1%	-17.5%	51.6%	49.8%	-46.3%
Africa	198	104	52	122	165
(Compared to 2010)	15.7%	-20.2%	12.9%	-24.2%	5.7%
North America	280	191	117	105	77
(Compared to 2010)	3.3%	-9.9%	55.9%	-0.2%	-13.5%
Middle / South America	1210	29	214	111	1079
(Compared to 2010)	-4.9%	21.8%	30.9%	-13.5%	-11.1%
Asia	1438	316	1728	910	305
(Compared to 2010)	-11.5%	-36.7%	-19.1%	-31.6%	-4.7%
Australia / New Zealand	57	45	8		18
(Compared to 2010)	48.8%	0.5%	2.7%		89.3%
World	3834	1106	2730	2084	2099
(Compared to 2010)	-9.2%	-19.5%	-4.2%	-12.6%	-12.9%
2050					
European Union	337	229	161	373	322
(Compared to 2010)	-25.7%	-9.8%	92.5%	15.8%	-26.8%
Europe. NonEU_EU	262	122	592	568	115
(Compared to 2010)	-33.3%	-41.7%	75.4%	68.8%	-36.6%
Africa	213	83	57	111	184
(Compared to 2010)	24%	-36%	22.3%	-31.2%	17.7%
North America	362	236	119	85	91
(Compared to 2010)	33.5%	10.9%	58.5%	-19.6%	3.1%
Middle / South America	1021	11	201	93	902
(Compared to 2010)	-19.8%	-51.6%	22.6%	-27.6%	-25.7%
Asia	1739	261	1868	802	410
(Compared to 2010)	7.0%	-47.8%	-12.5%	-39.7%	28.3%
Australia / New Zealand	64	45	11		21
(Compared to 2010)	69.1%	0.7%	31.9%		123.5%
World	3997	988	3008	2033	2045
(Compared to 2010)	-5.4%	-28.1%	5.6%	-14.8%	-15.1%

Remark: long texts of abbreviations are displayed in Table 8-1 and Table 8-2
Source: CAPRI results extracted on 18-03-2019

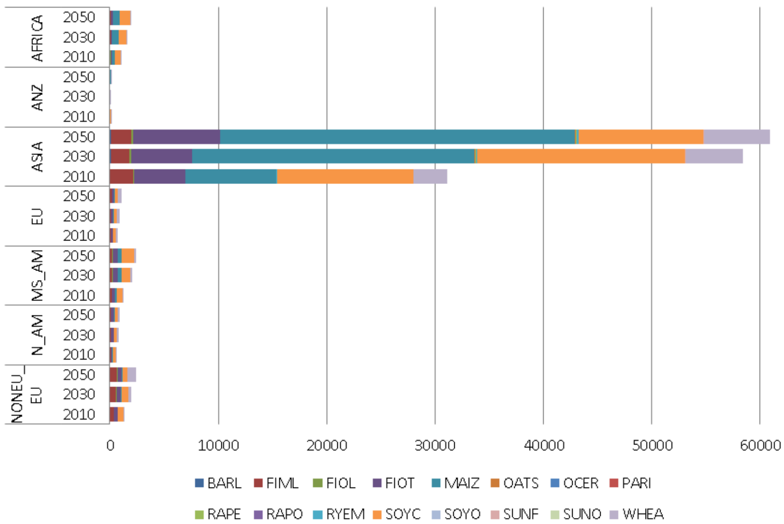
The baseline of the distribution of FIML&FIOL to animal feed use is shown in Figure 5-6. It can be observed that the use of FIML&FIOL in ASIA, MS_AM, and NonEU_EU is mostly distributed to aquafeed (displayed as "feed use for fish" in Figure 5-6). ASIA needs a large quantity of FIML to feed its significant aquaculture production. Norway and Chile are both top carnivorous FFIS producers, in particular, salmon and trout, which explains the reason why FIML required by aquaculture production in NonEU_EU (Norway) and MS_AM (Chile) accounts for more than 80% of their total use as animal feed. Although in the other four regions FIML&FIOL is mainly used in livestock feed, an increasing trend for the use of FIML&FIOL in aquafeed is shown. Figure 5-7 demonstrates the baseline of the ingredient used in aquafeed formulation. The increasing aquaculture production over time (Figure 5-2) drives the increasing demand for aquafeed through the rather fixed FCRs. ASIA requires the largest quantity of aquafeed as it dominates the world aquaculture production. Apart from FIML, it can be observed that FIOT, MAIZ, SOYC and WHEA are the most common ingredients used in the aquafeed production according to Figure 5-7. In addition, the use of MAIZ increases substantially in ASIA as a substitute for SOYC while the use of SOYC in aquafeed still dominates in AFRICA, EU, and MS_AM.

Figure 5-6 Baseline of use of FIML&FIOL in agriculture and aquaculture (1000 t)



Remark: EU: European Union, NONEU: NonEU_EU member countries in Europe, N_AM: North America, MS_AM: Middle and south America, ANZ: Australia and New Zealand
Source: CAPRI results extracted on 18-03-2019

Figure 5-7 Baseline of use of feed ingredients in fish feed formulation (1000 t)



Remark: EU: European Union, NONEU: NonEU_EU member countries in Europe, N_AM: North America, MS_AM: Middle and south America, ANZ: Australia and New Zealand
Source: CAPRI results extracted on 18-03-2019

Chapter 6
Scenario analysis

In this chapter, we investigate illustrative scenarios in order to accomplish the following tasks: First, to gain perspectives of the potential impact on fish and fish by-product markets resulting from changes in drivers of seafood supply, demand and policy implementation. Second, to obtain a better understanding of the sensitivities of the models used to assess changes in key parameters. The former CAPRI version included fish commodities in more aggregate form, without data consolidation and no fish sector specific behavioral functions applied. It assumed a linear fish supply without feed demand from cultured fish where the fish products only interact with market prices. In the CAPRI fish market model, the seafood supply considers an exogenously given captured quantity, endogenously derived aquaculture quantity, and feed supply. This way, the value of the development of the fish sector in current CAPRI modeling system, with rich detail in behavioral function, reveals the ways in which the expansion of aquaculture may drive changes in the agricultural sector.

6.1 Scenario definition

Three different scenarios simulated in this analysis were designed to inspect the central questions of this thesis addressed in Section 1.1.

Scenario 1 (*diet shift*) represents a situation where calorie intake shifts away from livestock commodities (meat and dairy products) to seafood. The livestock sector demands large quantities of resources such as land, water, and feed that play vital roles in global greenhouse gas (GHG) emissions (Grossi et al., 2018). The mitigation strategies stated by Grossi et al., (2018) focused on reducing emissions of the livestock sector while ensuring food and nutrition security for the growing population. The USDA (United States Department of Agriculture) [1] recommends the optimal consumption of animal product calories to be 430 Kcal/capita/day. To achieve the aims of reducing GHG emissions and sustaining sufficient energy and nutrition demand, we assumed that the total livestock calorie consumption level would be shifted to the recommended levels. Compared to high meat-eaters, fish-eaters have lower daily dietary GHG emissions (Scarborough et al., 2014). Seafood also provides essential animal protein and nutrients with additional health benefits. Therefore, we assumed the consumption of livestock product would decrease in all regions that consume livestock product calories beyond 430 Kcal/capita/day based on the USDA

[1] https://www.cnpp.usda.gov/USDAFoodPatterns

recommendations. A large amount of meat is currently consumed in the developed countries where this decrease is not likely to be realized immediately. The scenario is designed in a way that the decrease is phased in gradually in equal percentage steps from 2020 onwards and fully realized in 2070. In other words, no further decrease will take place after 2070. This scenario is designed to investigate the changes in global seafood markets when a 20%[2] decrease occurs by 2030. For example, the daily per capita calories consumed from livestock products in the U.S. is 968 Kcal, within which 538Kcal outpaces the recommended level. A 20% cut, which amounts to 108Kcal, is expected to take place by 2030. Initially, the 108Kcal was planned to shift from the livestock to the fish sectors. However, the daily per capita Kcal intake of seafood adds up to only 41Kcal. Therefore, a complete substitute of 108Kcal from livestock to seafood is not realistic and cannot be realized as the seafood supply is constrained by other resources in the CAPRI modelling system. The scenario thereby simulates a calorie shift which is limited by a maximum of 50% increase of the initial calorie intake from seafood in 2030. This means, with the cut of 108Kcal from livestock in the U.S., only about 20Kcal (50% of the baseline seafood calorie consumption, 41Kcal) will be moved to fish sector and the rest of the 88Kcal to other non-fish, non-meat food. This shift drives a substantial consumption

[2] A 20% cut is computed based on the formula: $\frac{Simulation\ Year - 2020}{2070 - 2020}$ with the simulation year 2030.

increase in seafood for the target regions and may consequently have sizeable impacts on global livestock and fish markets.

Contrary to the developed regions, Table 6-1 shows the average calorie consumption from livestock sector in AFRICA and ASIA are lower than the suggested calorie intake level; therefore, no shift should be generated here (except for some developed Asian countries). Based on the scenario design, the decrease in meat consumption for individual CAPRI region by 2030 is displayed in Table 8-20 where the examples show that the decrease in 2030 can be fully shifted in countries such as Norway and China or not at all in countries such as Ethiopia and Japan. In other words, although the calorie intake from the livestock sector is high in Norway and a cut of 67Kcal should be shifted, the maximum allowable shift of 87.5Kcal (half of baseline calorie intake from seafood = 50%*175Kcal) is even higher as Norway is one of the largest fish consumers. Japan, a representative of a developed country in Asia, has by contrary lower calorie intake from the livestock sector than the threshold but high calorie intake from seafood, and therefore no shift is needed.

Table 6-1 The calorie intake from livestock products and seafood

Region	Meat (1)	Other Animals (2)	Dairy (3)	Total (4)=(1)+(2)+(3)	(5)=(4)-430 Kcal	20% Cut in 2030 (5)*0.2	Fish
EU	464	50	407	920	490	98	45
NON_EU	262	49	252	563	133	26,6	30
AFRICA	82	10	58	150	-280	-56	24
N_AM	534	51	265	849	419	83,8	41
MS_AM	431	33	163	627	197	39,4	25
ASIA	189	35	124	347	-83	-16,6	48
ANZ	560	19	300	878	448	89,6	55
World	231	33	148	412	-18	-3,6	40

Remark: EU: European Union, NONEU: NonEU_EU member countries in Europe, N_AM: North America, MS_AM: Middle and south America, ANZ: Australia and New Zealand
Source: CAPRI results extracted on 18-03-2019 and own computation

Scenario 2 (CFP) represents the long-term target catch under the situation where "*Fishing mortality of 0.8* F_{MSY}[3] *is applied if the stock size is at or above half of 0.8* B_{MSY}[4]*. Below that level fishing mortality is declined linearly reduced to zero with a decrease in biomass.*" as defined by Froese et al., 2018. Overfishing endangers future seafood production and the income basis of workers in this industry (Allan et al., 2005; Quaas et al., 2012). The current EU Common Fisheries Policy (CFP, EC 2016) introduces the regulation that all fish stocks in EU waters should be harvested to maintain the biomass level producing the MSY latest by 2020. However, fishing at the fishing mortality leading to MSY level that is suggested by CFP does not seem to result in satisfactory consequences in

[3] Fishing at 80% of maximum sustainable yield level with respect to target fish species

[4] 80% of biomass level with respect to target fish species

terms of catch, stocks and profitability. Froese et al., 2018 simulate the scenario that fishing at 95% of MSY level takes place in the Northeast Atlantic and the Mediterranean from 2018 onwards. The results stress that fishing at MSY is likely to cause decreased stock replenishment and less profit compared to lower fishing mortality. Therefore, the 0.8 F_{MSY} scenario was chosen in this study as it would result in the highest catch and highest profitability in the four scenarios designed by Froese et al., (2018) although only 73% and 64% of the fish stocks in the Northeast Atlantic and the Mediterranean Sea respectively are predicted to rebuilt by 2030. The capture shift towards 80% of F_{MSY} for the represented fish species in 2030 was implemented based on the supplementary material provided by Froese et al., 2018 and is shown in Table 6-2. The detailed information and computing process are referred in the Annex (see Table 6-2 and Table 8-24). Adjusted for CAPRI baseline capture quantities and the fish species for the EU member states, fishing at 0.8 F_{MSY} implies that the changes in quantities in the fish sector module equal to the 0.8 F_{MSY} catch (80% scenario 2030 (1) in Table 6-2) subtracting the CAPRI baseline catch (Baseline 2030 (2) in Table 6-2). For example, in 2030, the baseline of PFIS catches in Denmark and France are 323,470 tons and 187,290 tons based on CAPRI results (Table 6-2). According to Froese et al. (2018), the catches of PFIS given by the 80% scenario to these two regions are 298,484 tons and 142,819 tons, respectively (Table 6-2). In addition, the catch quantities of the selected

PFIS species (detailed species displayed in Table 8-23) account for 100% and 45% of total PFIS landings for the two countries according to the calculation based on the information from FISHSTAT in 2008. For France this means that within the total PFIS catch quantity, only 64,269 tons of PFIS refers to the species selected by Froese et al. (2018). Instead of using total landings, which include irrelevant fish species from other regions for this scenario, this rule should be applied to all EU member countries for all three species. This explains the scenario in CAPRI in which the changes in catch quantities of PFIS for Denmark and France are -24,986 tons and -20,016 tons, respectively (Table 6-2).

Table 6-2 0.8 F_{MSY} catch and change of catch in absolute quantities (ton) in 2030

Species	PFIS				DIFS				CRUS			
EU members	80% Scenario 2030 (1)	Baseline 2030 (2)	% of selected species in total PFIS (3)	Change of catch 2030 (4)	80% Scenario 2030 (1)	Baseline 2030 (2)	% of selected species in total PFIS (3)	Change of catch 2030 (4)	80% Scenario 2030 (1)	Baseline 2030 (2)	% of selected species in total PFIS (3)	Change of catch 2030 (4)
Belgium	10369				16196	18980	37%	9173	1037	1450	9%	907
Denmark	298484	323470	100%	-24986	506262	353810	94%	173681	15397	15820	74%	3690
Estonia	96935	80940	100%	15995	1056	3650	34%	-185	0	10190	100%	-10190
Finland	142819	111440	100%	31379	838	920	94%	-27	0	510		0
France	64265	187290	45%	-20016	156955	188390	30%	100438	8577	17130	13%	6350
Germany	140146	152930	100%	-12784	70482	81960	64%	18028	36	18340	2%	-331
Greece	0	35140	3%	-1054	529	29020	23%	-6146	0	4960		0
Ireland	112348	127990	97%	-11802	41818	73830	49%	5641	8809	17640	52%	-364
Latvia	92417	140880	55%	14933	4026	6710	67%	-470	0	1660	100%	-1660
Lituania	32282	155600	17%	5830	2649	13500	76%	-7611	0	1200	100%	-1200
Netherlands	184560	258190	63%	21900	107000	122360	77%	12783	556	18430	4%	-181
Poland	209959	106360	81%	123807	17703	28200	48%	4167	0	7760		0
Portugal	76172	133100	11%	61531	19092	71400	18%	6240	231	2590		231
Spain	88653	467490	7%	55929	102053	301930	23%	32609	1684	16580	3%	1187
Sweden	240658	190910	100%	49748	34703	29940	89%	8056	4995	4150	91%	1219
UK	271038	261450	84%	51420	253015	196220	64%	127434	35193	79010	51%	-5102

Remark: (4) = (1)–(2)*(3)

Remark: PFIS: pelagic fish, DFIS: demersal fish, CRUS: crustaceans

Source: Own computation based on Froese et al., 2018 and van Zanten et al., 2019

Scenario 3 includes two sub-scenarios. The reduction fisheries are defined as the fisheries targeted for FIML&FIOL production (Asche & Tveterås, 2004). Fishing for feed instead of fishing for food has been criticized because of its negative impact on the local households due to the competition for the small pelagic fish between immediate human consumption and non-food use, in particular, in developing countries (Tacon & Metian, 2009). Small pelagic fish (known as feed fish) are the main resource for FIML&FIOL production and play an important role in feeding aquaculture. In addition, using low-value feed fish to feed high-value carnivorous farmed fish not only endangers the marine ecosystem, but the demand for feed fish for the rapidly growing aquaculture also increases farming costs. This raises the question as to whether or not carnivore aquaculture can be a sustainable food producing system. To investigate whether reducing the quantities of edible feed fish used in fish farming could enhance aquaculture sustainability, two scenarios are described in this section. First, **scenario 3-A** (*improved feed technology*) addresses the solution of turning carnivorous fish to vegetarians to achieve sustainable aquaculture as addressed by Powell (2003). This scenario represents a situation in which the technological innovation improves the feed efficiency for all farming species excluding MOLS (filter species). This innovation means those carnivores are capable of digesting feed in which fish-based ingredients are replaced with plant-based ingredients. Hence, improved feed technology triggers the demand for feed ingredients to shift from FIML&FIOL to crops. Up to 80% of FIML&FIOL in fish feed formulation can be substituted with soya cake and soya oil in 2050. In other words, the 3-A scenario indicates a decreased demand for FIML&FIOL and an increased demand for soya cake and soya oil. In contrast to the demand shock designed in scenario 3-A, **scenario 3-B** (*lower FIML&FIOL supply*) generates supply side shifts of FIML&FIOL. Feed fish is normally composed of low-value small pelagic and demersal fish species. Historically, feed fish was consumed as protein and fat sources and still is used as food by low-income households (Tacon & Metian, 2009). This scenario represents a decrease of 50% of the fish reduction which was originally destined for processing FIML&FIOL. In general, the cut is applicable to all CAPRI regions. However, due to the model's limitation, an adjustment is applied particularly to the top FIML&FIOL producers with respect to species listed in Table 6-3. Take the CAPRI region RSA as an example, the baseline of processing use of PFIS in 2050 is 2.5 mm tons as RSA is the biggest FIML&FIOL producing region while its human consumption of PFIS amounts to only 48,000 tons. A 50% shift of processing use, which is more than 1 mm tons, cannot be consumed locally as the consumption quantity per capita is constrained. This is the same for some other exceptional regions where implementing this kind of huge quantity shifts does not seem feasible in the model. Considering that a 50%

shift away from processing use in quantity is too large to be taken up by food demand, the shifts for those regions will be reduced to the amounts which are double the quantities of their original human consumption. Consequently, this 3-B scenario represents shifts within demand attributes (from processing use to human consumption) in the fish market which results in a shortage of supply in FIML&FIOL market.

Table 6-3 Top FIML&FIOL production regions where half of baseline PROC is larger than double baseline HCON

	DFIS	PFIS	OFIS
Denmark	X	X	
France	X		
Ireland		X	
Netherland		X	
United Kingdom			X
Norway	X		
Turkey		X	
Iceland		X	
South Africa		X	
India	X		
Pakistan	X		X
Vietnam			X
Thailand			X
Rest of south America (RSA)		X	
Chile		X	

Remark: DFIS: demersal fish, PFIS: pelagic fish, OFIS: marine fish, other
Source: own compilation

6.2 Scenario results

The simulation results of the counterfactual scenarios described in section 6.1 are addressed here with the focus on changes in seafood and FIML&FIOL markets and corresponding shifts in the single feed ingredient markets in compared to baseline. The impacts of the applied shocks, in particular for scenario 1 and scenario 3, on global land use change will be stressed in this section.

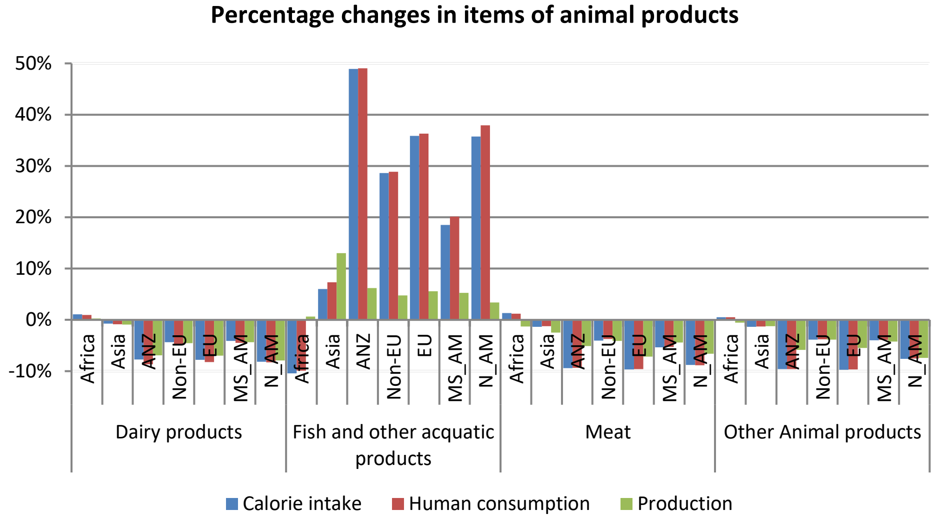
Changes in seafood and FIML&FIOL market balances and global trade

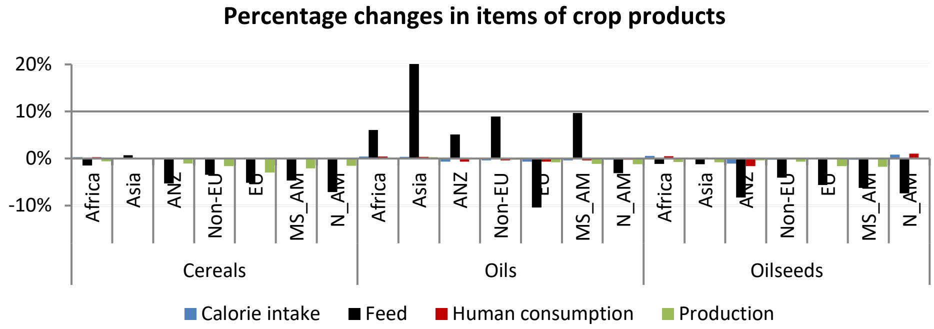
An overview of seafood and FIML&FIOL market balances at the global or continental level for each scenario is shown below. A more detailed view on market balances for each single species for each scenario is provided in the Annex in Chapter 8.

6.2.1 *Scenario 1*

Initially, we implement a scenario in which calorie intake from livestock commodities, meat and dairy products in particular, was shifted to seafood in a graded fashion. As described in the last section, a decrease in consumption of livestock products in regions that consume calories greater than 430 kcal/capita/day from this sector is assumed to occur by 2070 from 2020 onwards. This reflects a 20% cut by 2030 is generated. The complete results table addressing all quantity and percentage changes is in the Annex (Table 8-20). Figure 6-1 shows that the percentage changes for calorie intake are very similar to the changes in human consumption for all seven food groups based on the calorie conversion of each commodity group for the seven regions. According to changes in calorie intake from animal groups displayed in Figure 6-1, this calorie shift scenario has a large impact on human consumption and calorie intake in ANZ, EU and N_AM. In these regions calorie intake is decreased by more than 10% with respect to the livestock sector and increased by more than 30% in terms of the fish sector. Regions showing shifts of calorie intake from livestock to the fish sector are the target regions in this scenario. Figure 6-1 shows that AFRICA is the only exception. In the target regions, it is intuitive that the increasing demand of seafood resulted from the consumption shift triggers increasing seafood prices which encourages more fish supply. In contrast, the three livestock commodities (meat, other animal products and dairy products) suffer from the decreasing demand which drives declining prices. However, the shift impact is weakened due to the price effects. Being the only region that has performed oppositely, AFRICA consumes more meat and less fish resulting from the changes in prices. In addition, within the six target regions, ASIA is the only one that shows higher growth in production than consumption. This indicates that ASIA has the potential to export its seafood production to meet the increasing seafood demand from the rest of the world. Globally, on average this scenario results in an increase of 17% in seafood consumption (Table 6-4). It is of interest to assess whether the changes in animal commodities would drive changes in the crop commodities. As shown in Figure 6-1, the impact of this diet shift scenario on the production, human consumption and calorie intake with respect to the three crop groups are rather small at the continental level. After the calorie shifts take place in the target regions, a general increase in seafood consumption worldwide except for AFRICA is shown in Figure 6-1 and in Table 6-4. Capture production is set exogenously and fixed in the model. The production thereby reflects the contribution from aquaculture. This diet shift scenario translates to higher net revenue and lower processing margin of fish products in all regions as shown in Table 6-5, which motivates fish farmers to increase their supply for human consumption. Additionally, the supply of feed fish for processing use will be partially switched to food use. However, since no diet shift takes place in AFRICA, the significant increase in consumer prices due to strong demand overseas will drive African consumers to search for alternative protein sources which will yield lower seafood, but higher meat consumption (Figure 6-1). The increasing net revenue leads to increasing aquaculture production, and in AFRICA, increased seafood production will reduce net imports. (Table 6-4 and Table 6-5). Globally, this scenario leads to an increase of 21% in aquaculture production (Table 6-4). The percentage changes of human consumption, processing use and trade by 2030 compared to baseline are approximately 12%, -5%, 17% for imports and 18% for exports, respectively (Table 6-4).

Figure 6-1 Percentage changes of human consumption, production and calorie intake in the food commodity groups (%)





Remark: EU: European Union, NONEU: NonEU_EU member countries in Europe, N_AM: North America, MS_AM: Middle and south America, ANZ: Australia and New Zealand
Source: Results of CAPRI fish market version extracted on 21-03-2019

Table 6-4 Quantity and percentage changes in the fish market of scenario 1 compared to the baseline in 2030

Unit: 1000 t

	PROD	AQTOTL	PROC	HCON	Imports	Exports
EU	7266	1978	923	15488	14149	5004
	6%	24%	-7%	36%	42%	11%
NONEU_EU	11574	2713	1413	6738	5152	8575
	5%	24%	-8%	29%	29%	4%
AFRICA	10345	1685	890	12570	4414	1299
	1%	4%	-8%	-10%	-20%	46%
N_AM	8289	1200	975	18808	15100	3606
	3%	30%	-16%	38%	47%	3%
MS_AM	12645	3083	5092	7447	2754	2861
	5%	26%	0%	20%	39%	6%
ASIA	138503	93000	5224	115661	21388	39006
	13%	21%	-4%	7%	-2%	25%
ANZ	1031	328	3	1654		459
	6%	23%	-13%	49%		-8%
World	189653	103987	14521	178366	62958	60809
	10%	21%	-5%	12%	17%	18%

Remark: EU: European Union, NONEU: NonEU_EU member countries in Europe, N_AM: North America, MS_AM: Middle and south America, ANZ: Australia and New Zealand

Source: Results of CAPRI fish market version extracted on 21-03-2019

Table 6-5 Values and percentage changes in fish prices and net revenue of scenario 1 compared to the baseline in 2030

Unit: Euro/ton

	Producer price	Market price	Armington 1 Price	Consumer price	Processing margin	Net Revenue
EU	5068	4744	4452	4422	-4397	4754
	31%	25%	28%	27%	-37%	33%
NONEU_EU	4346	2160	2917	2958	-2167	3426
	30%	39%	43%	43%	-45%	35%
AFRICA	2410	2767	3131	3158	-2523	2021
	6%	19%	26%	25%	-42%	7%
N_AM	2866	2212	2904	2938	-2217	2420
	37%	42%	37%	37%	-50%	44%
MS_AM	3116	3757	3624	2980	-4126	2657
	31%	60%	54%	43%	-77%	37%
ASIA	2337	2015	2378	2378	-1935	2073
	27%	26%	26%	26%	-29%	30%
ANZ	6201		4441	4417	-3714	6046
	29%		39%	39%	-52%	29%
World	2484	1658	2790	2735	-2938	2193
	27%	25%	32%	30%	-54%	30%

Remark: EU: European Union, NONEU: NonEU_EU member countries in Europe, N_AM: North America, MS_AM: Middle and south America, ANZ: Australia and New Zealand

Source: Results of CAPRI fish market version extracted on 21-03-2019

As described above, the increasing demand for seafood in the end motivates increasing aquaculture production. Consequently, the demand for fish feed is growing. By contrast, the decreased livestock production shown in Figure 6-1 triggers decreasing demand for crops as feed for land animals. Table 6-6 provides details on the cost structure of fish feed used in fish farming. The unit value of plant-based feed, which is mainly fed to livestock, therefore, goes down. However, booming aquaculture demands increasing amounts of FIML&FIOL. FIML and FIOL are high value commodities and thereby result in a higher total unit value of fish feed. The demand for increased feed also adds to an increase in total feed cost.

Table 6-6 Net revenue analysis of scenario 1 compared to the baseline in 2030

Unit: Euro/ton

	Unit value of feed - [Euro]	Total Feed Quantity	Total Feed Cost	Unit value of plant-based feed - [Euro]
European Union	553	1154	638047	1006
	9.51%	28.70%	40.94%	-3.32%
Europe, NonEU_EU	1004	2568	2577294	1310
	13.50%	27.49%	44.69%	-1.70%
Africa	388	1730	671393	1053
	3.12%	5.04%	8.32%	-2.85%
North America	538	988	531103	930
	10.61%	28.31%	41.92%	-5.92%
Middle and South America	572	2502	1431272	1168
	10.24%	22.94%	35.53%	-5.65%
Asia	369	71396	26347810	1162
	5.73%	21.61%	28.58%	1.07%
Australia and New Zealand	508	100	50854	584
	10.48%	25.51%	38.66%	-2.45%
World	401	80439	32247774	1185
	6.89%	21.59%	29.97%	0.42%

Source: Results of CAPRI fish market version extracted on 21-03-2019

As a consequence, the decrease in livestock production causes a decrease in demand for plant-based feed ingredients. Globally, cereal, oilseeds and other arable field crops are important crop groups used in animal feed production. Table 6-7 shows that the feed demand for the three commodity groups decline by approximately 4%. This study is designed to assess whether this diet change scenario also influences global land use change. Table 6-8 shows that this scenario setting has a greater impact on land use change in North America due to the decreased feed demand for the crops which occurred due to a decline in livestock production. The changes are relatively small with respect to AFRICA and ASIA.

Table 6-7 Values and percentage changes (%) of Scenario 1 of market positions for the other agricultural commodity groups in 2030

	Production	Food	Processing	Feed use	Imports	Exports
Cereals	2137254	855467	244672	869123	132289	134050
	-1.19%	0.10%	0.89%	-3.37%	-0.32%	-0.38%
Oilseeds	357744	17318	326248	14179	74880	75259
	-1.10%	0.05%	-1.03%	-4.05%	-0.03%	-0.06%
Other arable field crops	394056	326559	20403	47094	10036	10111
	-0.44%	0.09%	0.11%	-4.18%	-1.01%	-1.02%
Veges / Permanent crops	1841682	1739623	40695	59126	63715	64222
	0.08%	0.17%	0.03%	-2.44%	-0.35%	-0.35%
All other crops	53054	4046	49003	6	3309	3312
	0.00%	0.17%	-0.02%	-10.23%	0.36%	0.36%
Oils	176337	85552	59417	1638	42929	43273
	-0.29%	0.01%	-0.18%	-7.43%	-0.45%	-0.45%
Oil cakes	225910	275	1241	224394	64619	65001
	-0.96%	0.29%	1.79%	-0.98%	3.51%	3.43%
Secondary products	789538	622045	46115	38684	20003	20109
	-0.04%	0.08%	0.08%	-1.80%	-0.19%	-0.19%

Source: Results of CAPRI fish market version extracted on 21-03-2019

Table 6-8 Percentage changes (%) of Scenario 1 of land used for the other agricultural commodity groups in 2030

	NONEU	AFRICA	N_AM	MS_AM	ASIA	ANZ	World
Cereals	-1.99%	-0.71%	-4.44%	-1.86%	-0.02%	-1.78%	-1.35%
Oilseeds	-0.87%	-0.88%	-3.82%	-1.75%	-0.43%	-1.47%	-1.48%
Other arable field crops	-2.79%	-0.30%	-2.91%	-0.59%	-0.26%	-4.30%	-0.70%
Vegetables and Permanent crops	-1.17%	-0.25%	-3.02%	-0.68%	0.32%	-1.43%	-0.06%
All other crops	-0.65%	-0.40%	-3.56%	0.04%	0.08%	-1.35%	-0.32%
Meat	0.14%	-0.07%	-0.26%	0.14%	0.21%	0.82%	0.03%
Other Animal products	-0.10%	-0.08%	-2.04%	-0.28%	-0.30%	-0.74%	-0.29%
Oils		-0.16%	-1.21%	-0.53%	0.03%	-1.18%	-0.11%
Secondary products	-1.19%	-0.39%	-2.73%	0.55%	-0.03%	-1.05%	-0.01%

Remark: EU: European Union, NONEU: NonEU_EU member countries in Europe, N_AM: North America, MS_AM: Middle and south America, ANZ: Australia and New Zealand
Source: Results of CAPRI fish market version extracted on 21-03-2019

6.2.2 *Scenario 2*

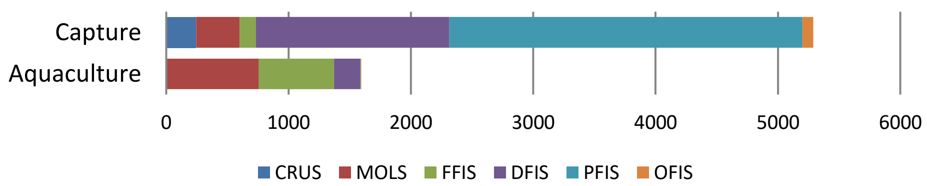
As shown in Figure 6-2, the EU production is dominated by fisheries, which produce three times the aquaculture production quantity. Capture quantities vary greatly between EU member states. As shown in Figure 6-3, capture quantities in the 2030 reference scenario range from 115,000 tons in Finland to 901,000 tons in Spain. The TACs[1] of 0.8 MSY constrain the catches for each EU country as shown in Table 6-2. The 0.8 MSY affects only the

[1] The total allowable catches (TACs) defined by OECD is "*a catch limit set for a particular fishery, generally for a year or a fishing season. TACs are usually expressed in tonnes of live-weight equivalent but are sometimes set in terms of numbers of fish.*"

CRUS, PFIS and DFIS groups, and therefore the allocation of fishing quantities for each country can be increased or decreased compared to the reference scenario in 2030. This is particularly true for CRUS, PFIS and DFIS.

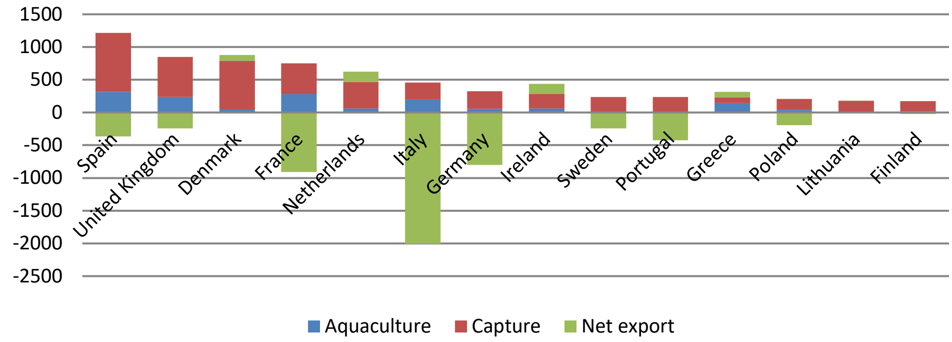
Capture quantities are given exogenously and not affected by fish price changes in the reference scenario. At the 0.8 MSY level, capture increases in half of the EU member states. Table 8-21 shows that the most substantial increase of total catch takes place in Poland (about 77%) and the least in Germany (2%) while there will be a decreased catch in Lithuania (-1%), Ireland (-3%), and Greece (-20%). This is due to the underlying scenario defined in the last section. About one third of the EU countries are not subject to restrictions applied to any of those in the scenario design. The increase or decrease in total capture in the 0.8 MSY scenario for each country depends on the reference level of capture and the composition of total capture such as the respective importance of PFIS and DFIS.

Figure 6-2 Sources of fish production in the EU (Baseline 2030) (1000 t)



Source: Results of CAPRI fish market version extracted on 18-03-2019

Figure 6-3 Production and net export (including reexport) of the EU top 15 producers (Baseline 2030) (1000 t)



Source: Results of CAPRI fish market version extracted on 18-03-2019

The 0.8 MSY scenario has negligible effects on the market balance items of the aggregate food sector. Table 6-9 presents the results of market balance items for the fish sector which confirms this statement. As we expected, this 0.8 MSY scenario increases self-sufficiency and reduces the EU seafood trade deficit. Table 6-9 shows that fishing at 80% of F_{MSY} would permit capture production in 2030 to be approx. 858,000 tons (12%) higher than in the reference scenario. This is a meaningful and realistic target (Froese et al., 2018) and close to the Maximum Economic Yield (MEY)[2] catches estimated by Holt (2009). This production increase is comprised of a 7,600 ton (3%) in crustaceans, a 490,000 ton (31%) increase in demersal (bottom-living) fish species and a 360,000 ton (12%) increase in catches of pelagic

[2] As described in section 2.2, MEY implies a lower yield objective but allows for more profitable fisheries and leads to lower environmental impacts (Farmery et al., 2014).

fish species (living higher in the water column). In this scenario, total seafood production increases compared to the 2030 reference. As a consequence of this fishing scenario, aquaculture production declined by 1%. This can be explained by the combination of simultaneous effects. Capture increased by 16% in the EU in this scenario which increases domestic supply and results in lower domestic prices. The decreased fish prices drive fish farmers to reduce their aquaculture production. The marked supply increase outpaces domestic consumption and translates into a strong growth of fish exports (13%). Imports of aquatic products (or seafood) declined (2.5%) but a drop-in price stimulates human consumption of these products only slightly (0.15%).

While meat, cereal and oilseed production do not shift as a consequence of the implemented 0.8 MSY measures (Table 6-9), EU FIML&FIOL production and trade are slightly affected. The changes in FIML quantities and prices are summarized in Table 6-10. As FIOL changes follow a similar pattern, these are not shown. EU FIML production does not reveal large changes, however, the allocation of FIML for feed use changes by 2.1% (increase of 3.1% in feeding land animals and a decrease of 1.4% in feeding aquaculture). In the capture policy scenario, the decline in aquaculture production leads to a shift of FIML usage from aquaculture feed to land animal feed.

Table 6-9 CAPRI results as absolute values and relative change of 0.8 MSY compared to baseline for EU average in 2030

Unit: Quantity: 1000 t; Price: Euro/t

	Total seafood production	Aquaculture production	Captured production	Processing use for FIML&FIOL
Baseline	6883	1595	5288	997
0.8 MSY	7724	1579	6146	994
	12,2%	-1%	12,2%	0%
	Seafood consumption	**Cereals consumption**	**Seafood imports**	**Seafood exports**
Baseline	11361	77852	9982	4507
0.8 MSY	11364	77849	9725	5091
	0%	0%	-2,6%	13%
	Oilseeds consumption	**Meat consumption**	**Seafood producer price**	**Seafood consumer price**
Baseline	2395	43929	3867	3485
0.8 MSY	2394	43922	3819	3413
	0%	0%	-1.3%	-2,1%

Source: Results of CAPRI fish market version extracted on 18-03-2019

Table 6-10 CAPRI FIML results as absolute value and relative change after 0.8 MSY compared to the baseline for EU average in 2030

Unit: Quantity: 1000 t; Price: Euro/t

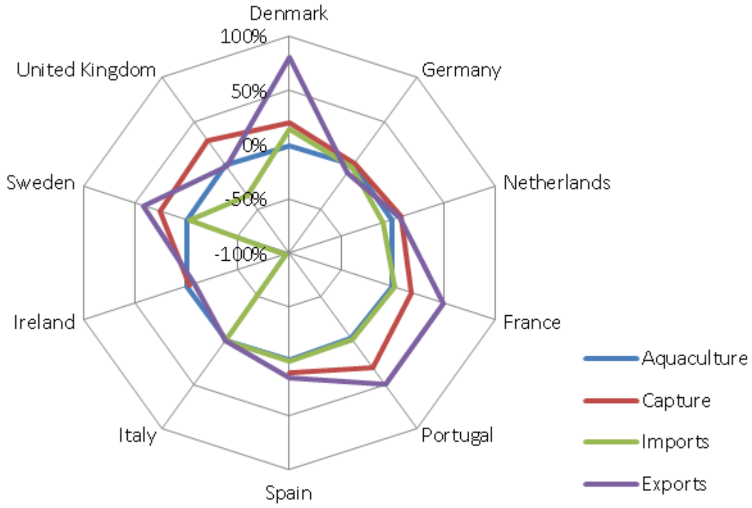
	Total production	Feed use for land animals	Feed use for aquaculture	Imports
Baseline	372	248	98	330
MSY	374	255	96	337
	0,7%	3,1%	-1,4%	1,9%
	Exports	**Producer price**	**Market price**	**Armington 1 price**
Baseline	358	1374	833	2266
MSY	359	1345	818	2230
	0,5%	-2,1%	-1,8%	-1,6%

Source: Results of CAPRI fish market version extracted on 18-03-2019

Figure 6-4 shows the percentage changes of fish market compared to the baseline for the top ten seafood producers in the EU in 2030. Portugal benefits from the 0.8 MSY policy with the highest increase of total catch of 30%, however, its aquaculture production is only slightly affected with a decrease of 3%. Sweden, the UK, and Denmark all have increases in their catches of over 20%. Wherever it is strong, the growth in catch generally contributes to the net exports for those countries.

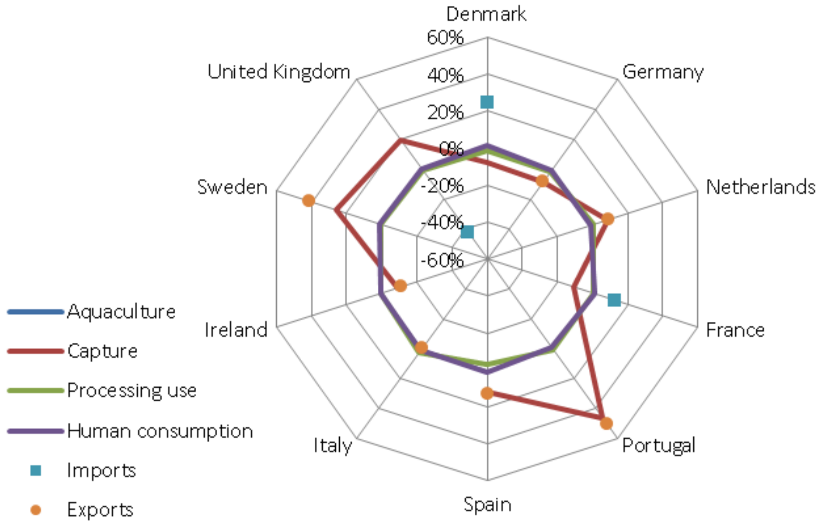
The impact of TACs applied to CRUS on total catch in the EU is very small. Figure 6-5 and Figure 6-6 disentangle the impact from the catches of PFIS and DFIS. As a consequence of the 0.8 MSY scenario, catches of PFIS substantially increase in Portugal (50%) and Sweden (26%) while the catches of DFIS greatly increase in France (52%), the UK (65%) and Denmark (49%) compared to baseline. However, the change in catches in both species have a negligible impact on processing use and human consumption and only affect trade. In terms of policy impacts on aquaculture production, a decrease by about 6% in the DFIS catches in Denmark, France, Portugal, Spain, Italy and the U.S. is displayed in Figure 6-6. The decision of reducing aquaculture production is derived from the declined net revenue (Table 6-11).

Figure 6-4 Impact of 0.8 MSY on the top 10 EU fishing producers



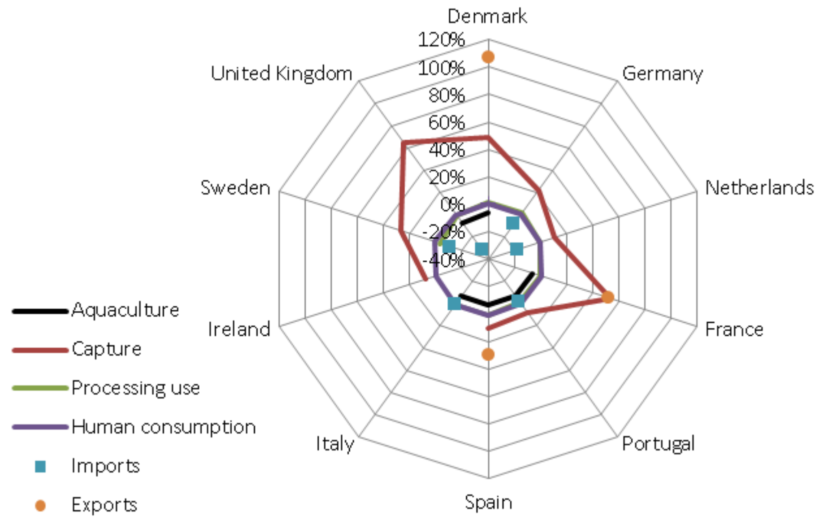
Source: Results of CAPRI fish market version extracted on 18-03-2019

Figure 6-5 Impact of 0.8 MSY in PFIS on the top 10 EU fishing producers



Source: Results of CAPRI fish market version extracted on 18-03-2019

Figure 6-6 Impact of 0.8 MSY in DFIS on the top 10 EU fishing producers



Source: Results of CAPRI fish market version extracted on 18-03-2019

Table 6-11 Impact of 0.8 MSY on aquaculture net revenue for the top 10 EU fishing producers

	Total seafood products	Demersal fish	Pelagic fish
Denmark	3325	3096	3860
	-1.8%	-9.3%	0.0%
Germany	3377	3860	3860
	-0.2%	0.0%	0.0%
Netherlands	3772	3860	3860
	-0.2%	0.0%	0.0%
France	3747	3126	3860
	-0.4%	-9.3%	0.0%
Portugal	3514	3133	3860
	-3.7%	-9.2%	0.0%
Spain	3672	2955	2447
	-1.4%	-9.7%	-7.0%
Italy	3637	3026	3860
	-0.9%	-9.5%	0.0%
Ireland	3723	3860	3860
	-0.2%	0.0%	0.0%
Sweden	3422	3860	3860
	-0.2%	0.0%	0.0%
United Kingdom	3378	1976	3860
	-0.2%	-13.2%	0.0%

Source: Results of CAPRI fish market version extracted on 18-03-2019

As shown in Table 6-2, aquaculture production decreases slightly or stays nearly constant in the MSY scenario compared to the 2030 baseline for all EU member states. The changes in the 0.8 MSY scenario has almost no effect on fish sectors outside the EU. The increase of total EU catches contributes only by 1% increase to the global catches.

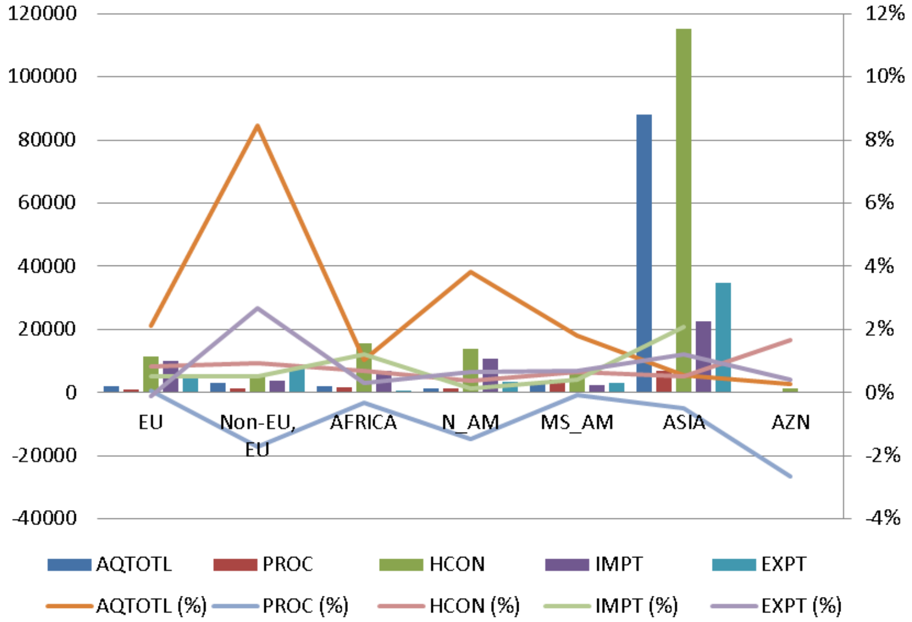
6.2.3 *Scenario 3*

Feed is a crucial factor that determines aquaculture production. The combination of ingredient shares corresponding to own CAPRI fish groups are displayed in Table 8-26. FIML and FIOL are two important fish by-product ingredients used in fish feed production, in particular, for carnivorous species. Scenario 3 investigates the impacts of shocks applied to FIML&FIOL market on the global fish market, specifically in aquaculture production and trade in 2050. In addition, the impact of scenario 3-A which substitutes “fish-based ingredients” with “crop-based ingredients” on global land use change will also be assessed in this section.

3-A

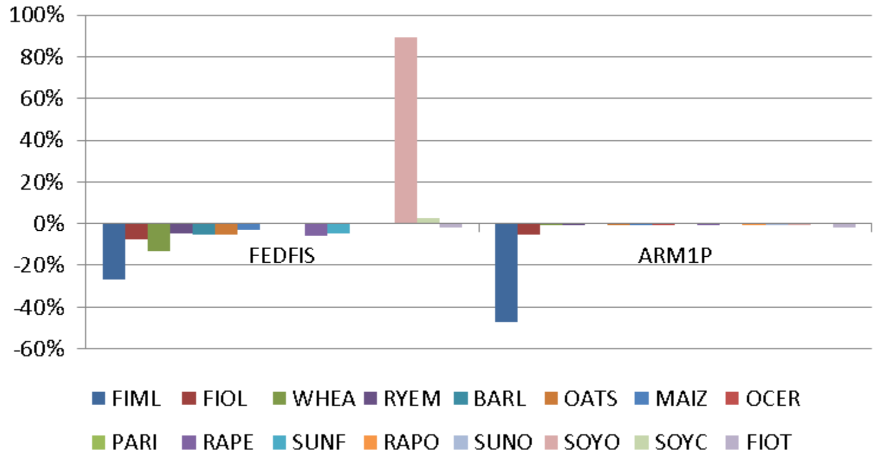
Under the assumptions described above, scenario 3-A replaces FIML&FIOL with soya cake and soya oil which leads to an increase in aquaculture production in general at the continent level (Figure 6-7). This can be explained by the increasing net revenues that give farmers incentives to increase their production. As displayed in Figure 6-8 and Table 8-28, the decline in demand of FIML&FIOL under this scenario setting results in lower FIML and FIOL (Armington 1) prices which decrease by about 47% and 5% respectively at the global level. The changes in prices subsequently affect the global consumption quantities of FIML and FIOL to 2197,000 and 319,000 tons (declines by about 27% and 7.6%, respectively) in aquaculture production. The design of high substitution elasticity within the plant-based ingredients in the model allows for the substitution of soya cake and soya oil with the other ingredients depending on own prices. Generally, FIML and FIOL are high-value fish-based ingredients compared to the crop-based commodities. The assumption is that advanced feed technology will lead to better digestion of crops and lower feed demand and costs. in particular for carnivorous fish. Globally, the total feed quantity would decline by about 3%, and the unit value of feed (Euro/t) decrease by about 15%. As described in section 3.1, FFIS is a mixture of herbivores (such as carp) and carnivores (salmon and trout etc.) depending on the region studied. The regions categorized in Group C in Table 3-2 will have differentiated profit structure from the regions assigned to Group V or Group M. Thereby, in terms of changes with respect to species, CRUS, PFIS, DFIS, and OFIS as well as FFIS in group C (Table 3-2) are defined as carnivorous species that are assumed to have similar diets containing high proportion of FIML and FIOL. The impact of this scenario on the production and feed costs for those species are comparatively large. Farmers will benefit from the lower feed costs in carnivore aquaculture derived from the substantially decreased FIML price. Globally, the unit value of aggregated feed for CRUS, PFIS, DFIS, and OFIS decreases by more than 30% while the unit value of their plant-based part increase by 5% to 11% compared to the baseline. In terms of individual regions, the impacts of this scenario on aquaculture production and feed costs are larger for the regions which focus on carnivore farming. For example, countries such as Norway or Canada, where the carnivorous FFIS production accounts for more than 70% of its total FFIS production are assigned to group C. More precisely, more than 95% of cultured fed fish produced by the two countries are carnivorous species, and their aggregated net revenues would increase by 16% and 2%. In contrast, for regions in Asia such as Bangladesh, Vietnam, Indonesia, and Thailand, herbivore farming suffers from increasing crop prices. The effects coming from opposing directions of net revenues of herbivorous FFIS and carnivorous FFIS offset the production growth. On average, the global unit value of fish feed would decrease by about 20% while the global aquaculture production stays nearly unchanged compared to baseline. This can be explained by a small increase of 1% in net revenue. Although aquaculture production of carnivorous fish is increased due to the increasing net revenue, the aggregated quantity is still small compared to the herbivorous fish. Consequently, the impact of scenario 3-A on global net revenue and market items vary between -1% and 1%. Nevertheless, turning carnivores to vegetarians translates into increasing demand for soya cake and soya oil particularly for carnivore aquaculture. The use of soya cake in CRUS, PFIS, DFIS, and OFIS production is increased by 24%, 7%, 8%, and 21% respectively compared to baseline. In terms of regional changes, the quantities of soya cake used in fish feed in the EU, NonEU_EU, AFRICA, N_AM, ASIA and ANZ are increased by 13%, 26%, 1%, 17%, 2%, and 23%, respectively, and MS_AM is the only region showing a decrease of 2% as displayed in Table 8-28. The changes are influenced by the use of soya cake in livestock feed, which accounts for more than 90% of total feed demand globally. In general, the decline in soya cake used in livestock feed production is larger than in total feed use. This results in the increased uses in fish feed for most of the regions except for MS_AM. The ultimate aim of this study is to investigate the impact of "turning carnivorous fish to vegetarians" on global land use change because there is an important connection between the aquacultural and agricultural sectors since they compete for land resources. Considering that fish feed accounts for only approximately 4% of total animal feed production in the world (Hardy, 2010; Tacon & Metian, 2008), this scenario still shows negligible impact on the land use change of other agricultural sectors as shown in Table 6-12.

Figure 6-7 Quantity (1000 t) and percentage change (%) in fish market items of scenario 3-A in 2050



Remark: AQTOTL: Total aquaculture production, PROC: Processing use, HCON: Human consumption, IMPT: Imports, EXPT: Exports
Source: Results of CAPRI fish market version extracted on 18-03-2019

Figure 6-8 Percentage change (%) of plant-based ingredients used in aquaculture feed and their Armington 1 prices (Euro/t)



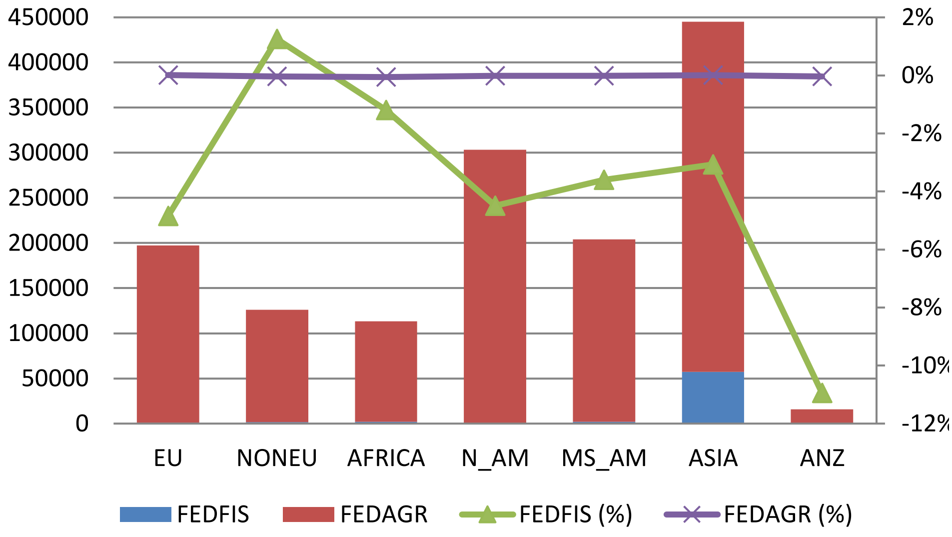
Remark: long texts of abbreviations are displayed in Table 8-1 and Table 8-2
Remark: FEDFIS: Feed for aquaculture, ARM1P: Armington 1 price
Source: Results of CAPRI fish market version extracted on 18-03-2019

Table 6-12 Percentage changes (%) of Scenario 3-A of land used for the other agricultural commodity groups in 2050

	NONEU	AFRICA	N_AM	MS_AM	ASIA	ANZ	World
Cereals	-0.04%	-0.01%	-0.02%	-0.05%	-0.07%	-0.09%	-0.04%
Oilseeds	-0.00%	0.11%	0.01%	0.02%	0.02%	0.04%	-0.00%
Other arable field crops	-0.00%	-0.01%	-0.01%	0.00%	-0.00%	-0.03%	-0.00%
Vegetables and Permanent crops	-0.01%	-0.02%	-0.01%	-0.01%	-0.02%	-0.03%	-0.01%
All other crops	-0.01%	0.00%	-0.00%	0.00%	0.00%	-0.03%	-0.01%
Meat	-0.00%	-0.00%	-0.00%	-0.00%	0.02%	0.00%	-0.00%
Other Animal products	0.01%	0.00%	0.00%	0.00%	0.01%	-0.00%	0.01%
Oils		-0.02%	-0.02%	-0.02%	-0.02%	-0.02%	

Remark: NONEU: NonEU_EU countries in Europe, N_AM: North America, MS_AM; Middle and South America, ANZ: Oceania
Source: Results of CAPRI fish market version extracted on 18-03-2019

Figure 6-9 Quantity (1000 t) and percentage changes (%) of aggregated plant-based ingredients used in livestock (FEDAGR) and aquaculture (FEDFIS) in 2050 by continent



Remark: long texts of abbreviations are displayed in Table 8-1 and Table 8-2
Remark: NONEU: NonEU_EU countries in Europe, N_AM: North America, MS_AM; Middle and South America, ANZ: Oceania; FEDFIS: Feed for aquaculture
Source: Results of CAPRI fish market version extracted on 18-03-2019

Table 6-13 Changes of feed conversion ratios by fish species in 2050

CAPRI fish groups	Baseline	Scenario 3-A	(%)
Fish and other acquatic products	0.71	0.68	-5%
Crustaceans	1.27	1.12	-12%
Fresh water and diadromous fish	0.98	0.95	-3%
Demersal fish	1.23	1.06	-14%
Pelagic fish	1.30	1.07	-18%
Other marine fishs	1.22	0.97	-20%

Source: Results of CAPRI fish market version extracted on 18-03-2019

3-B

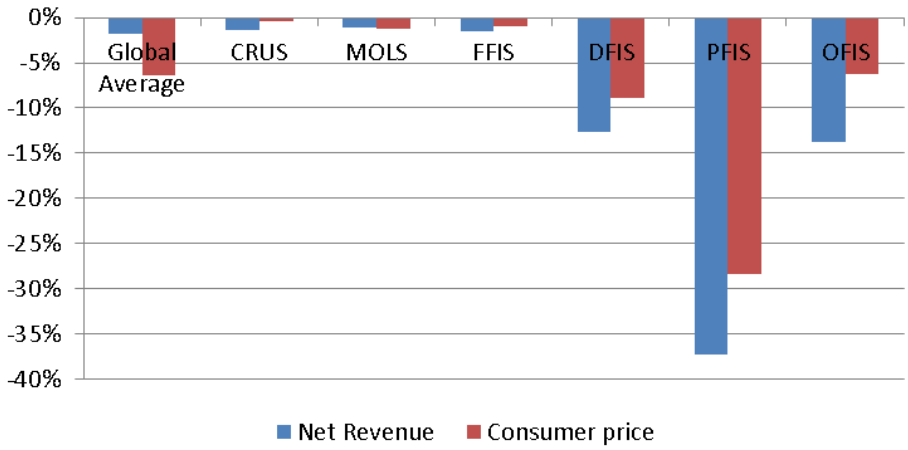
Seafood is of great importance to food and nutrition security as it provides essential animal protein and nutrients to human beings. Small pelagic fish are considered as important food source in poor regions. However, it is also the main resource for FIML&FIOL production to feed aquaculture. Fishing for feed instead of fishing for food is a critical issue when considering the level of malnutrition and starvation in developing countries (Tacon & Metian, 2009). Scenario 3-B investigates a hypothetical situation in which 50% of processing demands for the feed fish are cut for all regions except for some top FIML&FIOL producers. For those exceptional regions, a twofold increase in human consumption is applied as shown in Table 6-3. The decrease in processing use allows for feed fish to be used for direct human consumption, but it is unclear which specific policies would support this scenario. Small pelagic fish is the major raw material for FIML&FIOL production and categorized in CAPRI PFIS group. Globally, PFIS accounts for 70% (11 mm tons) of total processing demand, followed by OFIS (18%, 3 mm tons) as shown in Table 6-14. The cut therefore results in a substantial impact on the PFIS market. The PFIS originally destined for processing use enters the food fish market and translates to an excess supply of seafood which drives down consumer prices as well as reduces net revenue by 28% and 37%, respectively (Figure 6-10). Consequently, human consumption of PFIS increases by 24%, and its aquaculture production decreases by 25%. In terms of total global seafood demand, the design of scenario 3-B results in a decrease of 24% in processing use and an increase in human consumption by 4% (Table 8-30).

Table 6-14 The impacts of scenario 3-B on aquaculture production, processing use and human consumption in 2050 (1000 t)

	Aquaculture		Processing use		Human consumption	
	Baseline	Scenario 3-B	Baseline	Scenario 3-B	Baseline	Scenario 3-B
Total	98414	96990	16247	12382	169174	176059
CRUS	9497	9256	197	49	15375	15252
MOLS	30765	30487	230	81	36981	36868
FFIS	54669	54165	311	124	66521	66198
DFIS	2116	1922	1216	789	20750	22932
PFIS	523	393	11445	8975	21355	26373
OFIS	845	767	2849	2364	8192	8437

Remark: long texts of abbreviations are displayed in Table 8-1 and Table 8-2
Source: Results of CAPRI fish market version extracted on 18-03-2019

Figure 6-10 Percentage changes (%) of in net revenue and consumer prices



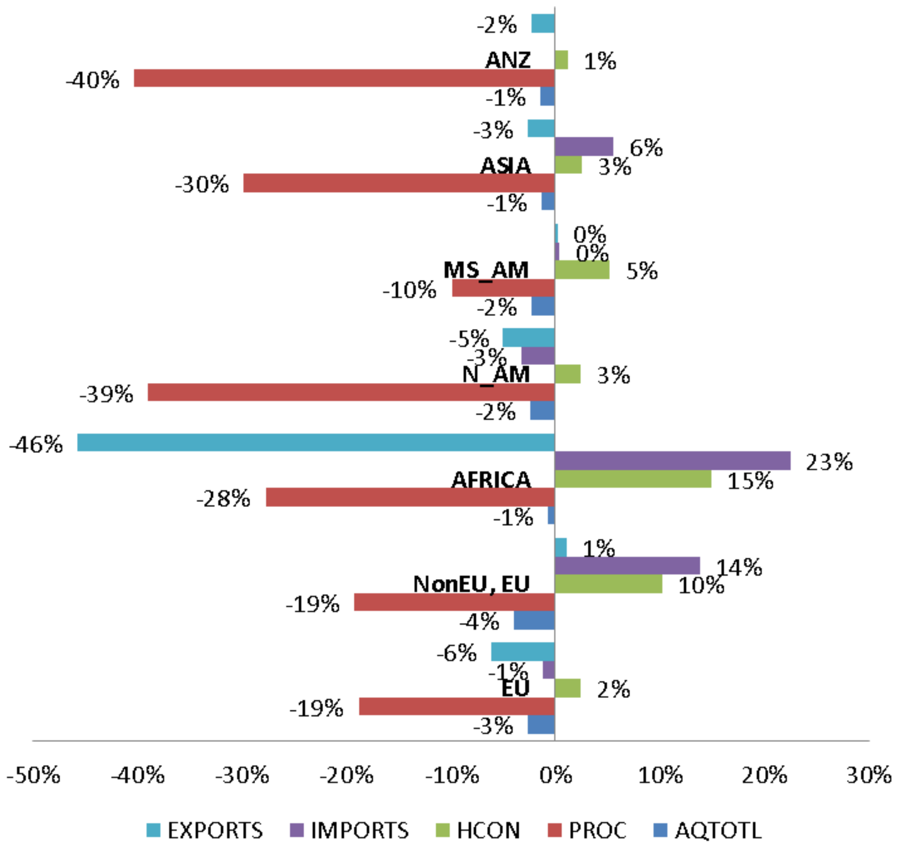
Remark: long texts of abbreviations are displayed in Table 8-1 and Table 8-2
Source: Results of CAPRI fish market version extracted on 18-03-2019

Considering the impact on the regions, especially for the developing countries, AFRICA benefits from the scenario setting and has the highest increase (15%) in human consumption, followed by NonEU_EU of 10% (Figure 6-11). This study aims to investigate the impacts of scenario 3-B on the top FIML&FIOL producing countries and African regions. As can be seen, in Chile the fish used in FIML&FIOL processing decreases by 19% and human consumption increases by 18%. However, although RSA is the biggest FIML&FIOL producer, the changes in its processing use and human consumption are just -4% and 2% respectively. When comparing Chile's baseline with that of RSA, we observe that both regions have high processing demands, mainly for PFIS (1,404,000 tons in Chile and 2,593,000 tons in RSA) while their human consumption for PFIS is far lower

(128,000 tons in Chile and 39,000 tons in RSA). When a shift of doubled baseline PFIS consumption is implemented, the shift in Chile and RSA are 384,000 tons and 117,000 tons respectively, which accounts for 27% and 5% of their processing demands and explains the substantial differences. Tacon and Metian (2009) addressed the issue of the role played by small pelagic forage fish in food and nutrition security, especially for the developing countries of Africa and the Sub-Saharan region. Africa in the CAPRI model is broken down into five regions: Nigeria, Ethiopia, South Africa, Africa least developed countries (LDCs), and Africa rest. Nigeria and Ethiopia have no processing demand for any fish group; however, the change of human consumption in Nigeria is 38% and 0% in Ethiopia. This can be explained by their different seafood intake structures. The baseline seafood consumption in Nigeria is 2,783,000 tons while it is only 136,000 tons in Ethiopia. In Nigeria, PFIS and DFIS account for 30% and 36% of total seafood consumption while they account only for 7% and 0% respectively in Ethiopia. Hence, the effects of decreasing PFIS and DFIS prices (by 28% and by 12% respectively) in Nigeria are substantial as its human consumption of PFIS and DFIS relies on imports increasing by 66% and 50%. The same effects in Ethiopia, in contrast, can be neglected. The results in Africa LDCs show that 57% of the seafood consumption is from FFIS and 13% from PFIS. As 62% of domestic use of PFIS goes to the processing in this region, the scenario effects can be substantial in the PFIS market. This is reflected by the changes in processing use and human consumption which are -40% and 31% respectively. In Africa rest, 74% of seafood consumption is from PFIS. However, only 8% of domestic use of PFIS goes to processing. The change in processing use of PFIS is 39% based on this scenario setting, and the change in human consumption of PFIS is 25% driven by the decreasing consumer price (32%). The increasing demand of PFIS is met by increasing net import here.

For FIML&FIOL markets, lack of raw material means a shortage of FIML&FIOL supply. At the global level, the decreases in FIML and FIOL production by 17% and by 14% are shown respectively which generates higher FIML&FIOL prices in international markets. The results show that the Armington 1 prices of fishmeal and fish oil increase by 16% and 13%. Fish farmers will tend to reduce the use of FIML&FIOL and search for more economical alternatives. Consequently, the use of plant-based ingredients increases as expected. The changes of FIML and FIOL used in aquaculture are -18% (-107,000 tons) and -13% (-42,000 tons). The total use of plant-based ingredients increases by 1,634,000 tons (2.5%), of which MAIZ has the largest growth by 655,000 tons (2%), followed by WHEA by 568,000 tons (5%) and soya cake by 297,000 tons (2%). The use of these crops in the feed for livestock is slightly influenced by price effects driven by the aquaculture feed use demand. In general, the aggregated changes of those plant-based ingredients in total feed use are very small. The impacts of this scenario are therefore tiny on global land use change (Table 6-17).

Figure 6-11 Percentage changes (%) of market balance items by continent



Remark: long texts of abbreviations are displayed in Table 8-1 and Table 8-2

Remark: NONEU: NonEU_EU countries in Europe, N_AM: North America, MS_AM; Middle and South America, ANZ: Oceania

Source: Results of CAPRI fish market version extracted on 18-03-2019

Table 6-15 Quantity (1000t) and percentage changes of Scenario 3-B in AQTOTL, PROC and HCON for specific regions

	Baseline			Scenario 3-B		
	AQTOTL	PROC	HCON	AQTOTL	PROC	HCON
Chile	1174	1440	526	1136	1166	624
				-3,2%	-19,0%	18,7%
RSA	793	2624	931	785	2531	949
				-1,0%	-3,5%	1,9%
Africa	1977	1649	15404	1964	1193	17702
				-0,7%	-27,7%	14,9%
Nigeria	303		2783	297		3835
				-2,0%		37,8%
Ethiopia			136			135
						0,0%
South Africa	6	171	621	6	301	635
				-2,0%	76,4%	2,2%
Africa LDC nes	226	923	4257	223	549	4471
				-1,7%	-40,5%	5,0%
Africa rest (mostly ACP)	51	300	4770	49	183	5620
				-3,6%	-38,9%	17,8%

Remark: RSA: rest of Middle and South America
Remark: AQTOTL: aquaculture production, PROC: processing use and HCON: human consumption
Source: Results of CAPRI fish market version extracted on 18-03-2019

Table 6-16 Quantity (1000 t) or values (Euro/t) and percentage changes in production, price and use in livestock/ aquaculture feeds of scenario 3-B in 2050

	Fishmeal		Fish oil	
	Scenario 3-B	% change compared to baseline	Scenario 3-B	% change compared to baseline
Production	3337	-16,5%	609	-14,2%
Armington 1 Price	2843	16,4%	2191	12,7%
Feed use for land animals	881	-10,8%	278	-13,1%
Feed use for aquaculture	2474	-17,8%	302	-12,7%

Source: Results of CAPRI fish market version extracted on 18-03-2019

Table 6-17 Percentage changes (%) of Scenario 3-B of land used for the other agricultural commodity groups in 2050

	NONEU	AFRICA	N_AM	MS_AM	ASIA	ANZ	World
Cereals	-0.01%	-0.01%	0.01%	0.01%	0.03%	0.01%	-0.01%
Oilseeds	-0.02%	-0.02%	0.01%	0.02%	-0.00%	-0.03%	-0.02%
Other arable field crops	-0.08%	-0.09%	-0.03%	-0.03%	-0.02%	-0.06%	-0.08%
Vegetables and Permanent crops	-0.04%	-0.11%	-0.01%	-0.02%	-0.03%	-0.03%	-0.04%
All other crops	-0.00%	0.03%	0.00%	0.00%	0.00%	-0.01%	-0.00%
Meat	-0.00%	-0.00%	-0.00%	-0.01%	-0.01%	-0.01%	-0.00%
Other Animal products	-0.01%	0.00%	-0.00%	-0.01%	-0.00%	-0.01%	-0.01%
Oils	-0.01%	-0.01%	0.01%	0.01%	0.03%	0.01%	-0.01%

Remark: NONEU: NonEU_EU countries in Europe, N_AM: North America, MS_AM; Middle and South America, ANZ: Oceania

Source: Results of CAPRI fish market version extracted on 18-03-2019

Chapter 7
Summary

The “Blue Revolution”, farming from land to ocean, is taking place to meet the increasing demand for food and protein resulting from population expansion. However, the rapidly growing aquaculture not only competes for land and water with other food producing sectors but also exploits ocean resources by consuming wild fish as well in the form of FIML&FIOL, which raises concerns over its sustainability. In 1995, the percentage of plant ingredients used in formulated fish feed was 80 - 90% for freshwater omnivorous species and approximately 30 - 40% for marine carnivorous species. As a result of searching for cost-efficient and sustainable fish feed ingredients, the proportion of plant sources increased to 60 - 70% of feed for cultured carnivores in 2010. By 2050, up to 80% of FIML&FIOL is expected to be replaced by plant protein and plant oil for carnivores. The impact that these developments are likely to have on global land use, food production and environment were assessed in this thesis. The results described lays the foundation for identifying (1) the complex relationships between

aquaculture and land use, (2) the main sustainability concerns, and (3) suitable model frameworks and applications.

In the present study, the difficulties we faced in the modeling work based on previously published data were addressed in a generic data consolidation strategy which is applicable to other data needs and raw data as well. Although there are still elements missing in the integrated time series database, the preliminary consolidation does help to eliminate double counting problems, to reflect the relationships between fish and FIML&FIOL markets and to capture the flow from fish to feed and vice versa correctly. The data analysis does not only provide a comprehensive database, but it reveals also a consistent data structure of fish and other relevant markets and eases the data integration between fish and other sectors in CAPRI.

Rapidly growing aquaculture has led to a continuous increase in fish feed demand. Due to the concerns over rearing costs and sustainable aquaculture production, the increasing demand for plant-based ingredients to substitute FIML&FIOL is motivated by the growth of fish feed markets. Thus, seafood production, in particular, from aquaculture, is closely connected to agricultural markets. The objective and central questions that were studied specifically:

(1) Extension of the standard CAPRI model version by developing a global fish market model with a focus on aquaculture

(2) What are the impacts of calorie intake gradually shifting away from livestock commodities (meat and dairy products) to seafood on the global food markets in 2030 in accordance with the USDA recommendation (430 Kcal/capita/day?

(3) What are the impacts of 80% of MSY implemented by the capture fisheries industry in the EU on the EU and global seafood and FIML&FIOL markets in 2030?

(4) What are the impacts of turning carnivorous fish to vegetarians on seafood markets and global land use change by shifting demand by fish feed for FIML&FIOL to soya cake and soya oil in 2050?

(5) What are the impacts of regulating captured fish used in FIML&FIOL production on the seafood markets and global land use?

7.1 Modeling approach

A behavioral market model for fish and fish by-product markets is developed extending the core CAPRI modeling system for the quantitative analysis used in this thesis. This modified CAPRI version incorporates behavioral functions for seafood demand and aquaculture supply in a more detailed species disaggregation, depending on changes of consumer prices and net revenues, respectively. Fish feed ingredients considered for aquaculture production are 11 different CAPRI crop commodities (soya cake, soya oil, corn, wheat, rapeseed oil, sunflower oil, sunflower oil, barley, paddy rice, rapeseed, rye and meslin) and FIOT as well as fish by-products (FIML&FIOL). The total feed demand is the aggregation of aquaculture production per species multiplied with the respective FCR. The demand for single feed ingredient is broken down to a two-stage approach depending on the prices of individual feed ingredients and the substitution elasticities between them. The feed costs are covered in the net revenues for different species which determines the aquaculture supply. This structure allows the modified CAPRI fish version to enhance the link between the aquaculture sector and the agriculture sector. It permits the analysis of the impact of global and European fisheries policies on aquaculture and agriculture sectors as well as fish by-product markets, globally or in the EU.

7.2 Key findings and conclusions

Different scenarios were designed to answer these research questions. Therefore, the reference scenario (fish baseline) represents a projection for the years 2030 and 2050 predicting probable future development of the global agricultural and fish sectors under the status quo settings and includes future changes that are foreseen. The counterfactual scenarios simulated in the analysis deviate from the baseline by (1) introducing calorie intake shifts away from livestock commodities to seafood (2) implementing 0.8 MSY policy (3) turning carnivorous fish to vegetarians (4) banning small pelagic fish caught for processing FIML&FIOL.

Impacts on global seafood market

In the near future, the growth of the global fish supply will rely mainly on the aquaculture expansion as the captured quantities are always given at a fixed level of approximately 85 mm tons. In contrast, the global aquaculture supply increases from 49 mm tons in 2010 to 86 mm tons in 2030 (by 75% compared to 2010) to 98 mm tons 2050 (by 14% compared to 2030). The global fish demand comes from seafood consumption and processing use. Due to the growing population, seafood consumption should increase from 116 mm tons in 2010 to 159 mm tons in 2030 (by 37% compared to 2010) to 169 mm tons in 2050 (by 6% compared to 2030). The processing demand first declines from 18 mm tons in 2010 to 15 mm tons in 2030 and then increases slightly to 16 mm tons in 2050. ASIA is the largest fish supplier, consumer, and trader in the world at all times.

A 20% decrease in calorie intake from the livestock sector that exceeds 430 Kcal/day/capita for the target regions in 2030 triggers decreases in human consumption and calorie intake of livestock products in nearly all regions except for AFRICA. This scenario results in increased global seafood consumption by 17.1%. Hardly any shift takes place in ASIA and AFRICA as their average calorie intake is lower than the threshold for most countries (exceptions are displayed in Table 8-20). ASIA is the only continent that has an excess supply to export its seafood production. AFRICA benefits from the decreased prices of meat and dairy products; however, it suffers from high world seafood prices which will reduce seafood consumption by 10% and increase aquaculture production by 52%.

The implementation of 0.8 MSY in the EU by 2030 has negligible impact on the global fish market as the total EU fish production accounts for only about 4% of the total world production. However, since the EU relies heavily on its capture fisheries industry, the impact of the policy shows an increase of 12% on the total EU catch in 2030. Although a substantial increase in the catch in the EU occurs, due to policy effects, without a corresponding growth in consumption the production is eventually exported.

Turning carnivorous fish to vegetarians implies a demand shift while banning fish caught for processing FIML&FIOL shows a supply shift in the FIML&FIOL markets in 2050. The former shock has negligible impacts on the global fish market. However, the latter shows a strong impact on global processing use (decrease by 24%). Here, regulating fishing for feed leads to a large increase in human consumption (15%). As PFIS and DFIS are the main resources use in FIML&FIOL processing, the assumption as well heavily affects the markets of these two species. The changes of aquaculture production, processing use and human consumption for PFIS and DFIS are -25%, -22%, 24% and -9%, -35%, and 10%, respectively.

Impact on global FIML and FIOL market

The trends of processing demands projected in section 3.5 have been used to assess the future development of FIML&FIOL production. As one might expect the production of FIML will decline from 4.2 mm tons in 2010 to 3.8 mm tons in 2030 and then increase slightly to 4 mm tons in 2050. Similarly, FIOL production is declining from 803,000 tons in 2010 to 720,000 tons in 2030 to 710,000 tons in 2050. Although the quantity of FIML used in aquafeed stays at a rather fixed level, the proportion in total animal feed (including livestock feed) should increase from 68% in 2010 to 75% in 2050.

The scenario results show that the shift of calorie intake from the livestock sector to the fish sector has small impacts on global FIML&FIOL markets. As processing demand and human consumption waste are the main sources of FIML&FIOL production, the combined effects of decreased processing use and increased human consumption result in small increases in global FIML and FIOL production by 1% and 6% respectively. However, the increasing aquaculture production drives higher demand of FIML&FIOL for aquafeed production. The uses of FIML and FIOL in aquafeed increase by 11% and 27% while the Armington 1 prices of those two ingredients increase by 29% and 6%, respectively.

Scenario 3 stresses the changes in the FIML&FIOL markets. The scenario results show that replacing FIML and FIOL with SOYA and SOYO in 2050 leads to lower FIML and FIOL world prices by 47% and 5% respectively due to the lower demands compared to baseline. The final uses of FIML and FIOL decrease by 27% and 8% respectively compared to baseline. Banning fish caught use for processing FIML&FIOL in 2030 reduces the raw materials for FIML&FIOL production, and thereby the production of FIML and FIOL decline by 17% and 14%. The supply shortage results in increasing FIML and FIOL prices by 16% and 13%.

Impacts on global agricultural market

The scenario results show shifting calorie intake of meat and dairy products to seafood causes an excess supply of livestock products. Thus, producers reduce their production of the land animal products due to the lower net revenues. Along with the decrease in livestock production, lower demand for crops in particular for cereal (-3%), oilseed (-4%), other arable field crops (-4%), and oil (-7%) for livestock feed production. Although “All other crops” decrease by 10% compared to baseline, the quantity of feed use is rather small (6,000 tons).

The idea of turning carnivorous fish to vegetarians leads to increasing demands of SOYC and SOYO specifically for carnivorous fish. The use of soya cake in feeding CRUS, PFIS, DFIS and OFIS fish groups are increased by 24%, 7%, 8%, and 21%, respectively.

Banning fish caught used for FIML&FIOL production leads to higher FIML and FIOL prices. Producers will look for cheaper plant-based alternatives. However, the impact is not substantial. The total use of plant-based ingredients increases by 2.5%, with MAIZ having the largest growth (655,000 tons), followed by WHEA (568,000 tons) and SOYC (297,000 tons).

Impacts on global land use change

Global land use change is an essential issue in our study. The results of the diet shift scenario show larger effects in North America. However, the two sub-scenarios in scenario 3 that investigate both the connection between the aquaculture sector and the agriculture sector through demand for plant-based ingredients in aquafeed have shown negligible effects on global land use change.

7.3 Limitations and research outlook

Although this thesis has successfully addressed the objectives we proposed in the beginning, there still exist some data issues that have not been fully solved. The following limitations must be considered when interpreting the results of the described modeling approach:

First, the information of captured fisheries is given exogenously in the model neglecting the interaction between captured fisheries and aquaculture by the competition for seafood market share and corresponding changes in fish prices but also by the demand for small pelagic fish caught to feeding farmed fish. It is of importance to take the spatial geographic structure of ocean area into account in the model for further study of global captured fisheries. Besides captured fisheries, our data consolidation does not yet include bilateral trade flow data as this would add another layer of complexity that has been deferred to the future.

Second, the classification of fish into the six groups in CAPRI does not sufficiently explain the complex diet components and the human consumption preferences. In particular, freshwater and diadromous fish are both categorized in the CAPRI FFIS group, which includes both low-value herbivores and high-value carnivores that cannot be sufficiently distinguished. Additionally, nearly all pelagic fish are considered as raw material for the FIML&FIOL industry in this study. However, high-value fish such as some tuna species are grouped with pelagic fish, but the former are too valuable to be used to produce animal feed.

Third, we explain how we corrected the quantity data. However, with the quantity relationships in the fish sector corresponding price and processing margins are required. These have not been worked out, with the same rigor as the quantities have, at this stage, and it still needs to be done along with future applications of the extended CAPRI system to fish sector issues that are increasingly important in the global bioeconomy.

Finally, given the results of the models, it is likely that remarkable environmental impact will come from increasing fisheries and aquaculture activities globally. As the refined CAPRI fish version not yet include the information of GHG emission caused by both activities, further extension of the model will provide a useful tool for better assessment of the impact of climate change on future seafood production. Moreover, climate change has a growing impact on fish habitation behavior worldwide. A further model extension with respect to the impact of climate change on seafood supply would be useful.

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Chapter 8
ANNEX

8.1 Supplemented information for Chapter 3: Fish market projection to 2050

Table 8-1 Abbreviations of activities used in Chapter 3

i													
AQTOTL	IMPT	EXPT	FEDM	INDM	PRCM	HCOM	MAPR	EXOG	STCM	FEDAGR	FEDFIS	YLDFML	YLDFOL
AQCRUS	AQMOLS	AQFFIS	AQPFID	AQDFIS	AQOFIS	PrdHCO	PrdRED	YldHCO					

Remark: AQTOTL: total aquaculture production, IMPT: import, EXPT: export, FEDM: feed use, INDM: other use, PRCM: processing, HCOM: human consumption, STCM: stock change, FEDAGR: feed use for agriculture, FEDFIS: feed use for aquaculture, PrdHCO: production of FIML and FIOL from human consumption waste, PrdRED: production of FIML and FIOL from reduction fisheries, YldHCOM: yield ratios of production of FIML and FIOL from human consumption waste, MAPR: domestic production, EXOG: captured fisheries, YldFML and YldFOL: yield ratios of production of FIML and FIOL from reduction fisheries

Table 8-2 Abbreviations of commodities used in Chapter 3

j																				
fg						*d*														
		g				*f*														
CRUS	MOLS	FFIS	PFIS	DIFS	OFIS	FIML	FIOL	SOYC	MAIZ	WHEA	RYEM	BARL	OATS	PARI	RAPE	SUNF	RAPO	SUNO	SOYO	FIOT

Remark: CRUS: crustaceans, MOLS: mollusks, FFIS: freshwater and diadromous fish, PFIS: pelagic fish, DIFS: demersal fish, OFIS: other marine fish, SOYC: soya cake, SOYO: soya oil, MAINZ: corn, WHEA: wheat, RAPO: rapeseed oil, SUNF: sunflower oil, SUNO: sunflower oil, BARL: barley, RARI: paddy rice, RAPE: rape seed, RYEM: rye and meslin, FIOT: other animal waste use in fish feed

Table 8-3 OLS estimated parameters of Equation 12

	Intercept	Population	R Square	Observations
IMPT	-42538,5	0,011021	0,958425	38
EXPT	-43631,1	0,011108	0,966056	38
AQTOTL	-171551	0,033663	0,993304	38
EXOG	85963	0,00061	0,047669	38
HCOM	-145190	0,039707	0,994252	38
Crush	56648,36	-0,00552	0,850224	**38**

Source: own estimation based on Equation 12

Table 8-4 Trend of global fish market, computation based on Equation 12 and Table 8-3

Time	IMPT	EXPT	AQTOTL	EXOG	HCOM	Crush	POP
1990	15608	14656	13085	84680	71206	25464	27429
1991	16018	14988	13726	83722	69851	25366	28762
1992	15964	15424	15410	85222	70846	25546	30327
1993	16846	16753	17799	86605	74369	25600	29999
1994	18253	18388	20840	92149	78980	30141	33865
1995	19043	18808	24382	92361	85844	27246	31053
1996	20273	20006	26541	93829	89415	27461	31273
1997	21023	21044	27322	93096	91138	25735	29173
1998	21378	21117	28413	85761	92583	19043	21880
1999	22514	21982	30731	91602	94843	24227	27859
2000	24029	23502	32418	93551	96949	25498	29350
2001	25826	25298	34614	90769	99424	22497	26358
2002	26993	26072	36786	91060	100971	23261	27359
2003	27611	27290	38913	88290	103842	19270	23484
2004	29953	29306	41909	92843	107678	23345	28087
2005	31521	31118	44298	92465	110328	22561	27256
2006	33929	33177	47257	90165	114686	19030	23494
2007	34900	33574	49941	90448	118250	18899	23738
2008	35087	33736	52915	89472	121473	18086	22283
2009	34742	32794	55691	89180	124518	17490	22068
2010	36818	36013	58962	87815	127685	15054	20149
2011	38787	37885	61796	92168	130313	19108	24498
2012	37460	37564	66443	89513	135819	15136	20221
2013	38048	38637	70156	90567	139591	15716	21484
2014	39758	39608	73667	91252	146171	13657	19084
2015	39288	38119	76055	92624	149660	14779	20367
2016	39502	38797	80027	90769	153217	13583	18671
2017	40406	39738	83105	92318	156813	14550	19340
2018	40426	39736	85232	91245	158492	14334	18667
2019	40726	40136	87992	90389	160919	14107	18045
2020	41283	40793	90883	89591	163491	13923	17466
2021	41679	41289	93293	88167	165558	12911	16284
2022	42659	42369	95112	89809	167951	13959	17252
2023	43034	42844	96980	90053	169961	13991	17254

Time	IMPT	EXPT	AQTOTL	EXOG	HCOM	Crush	POP
2024	43860	43770	98504	90317	171648	14024	17257
2025	44291	44301	100458	90508	173698	14048	17251
2026	45139	45149	102070	88824	174930	12824	15947
2027	45852	45862	103713	90964	177343	14173	17316
2028	48836	48469	107559	91020	184030	10849	15028
2029	49578	49217	109825	91061	186703	10477	14659
2030	50310	49955	112061	91102	189341	10110	14295
2031	51032	50683	114267	91142	191942	9748	13937
2032	51744	51401	116442	91181	194508	9391	13583
2033	52446	52108	118587	91220	197037	9040	13234
2034	53138	52806	120700	91258	199531	8693	12890
2035	53820	53493	122783	91296	201988	8351	12552
2036	54491	54170	124836	91333	204408	8014	12218
2037	55153	54837	126856	91370	206792	7683	11889
2038	55804	55493	128845	91406	209138	7356	11566
2039	56444	56139	130801	91441	211444	7035	11248
2040	57073	56773	132722	91476	213711	6720	10935
2041	57691	57396	134609	91510	215937	6410	10628
2042	58298	58007	136462	91544	218122	6106	10327
2043	58892	58606	138279	91577	220265	5808	10032
2044	59475	59194	140059	91609	222365	5516	9742
2045	60046	59769	141803	91641	224422	5230	9458
2046	60605	60332	143510	91672	226435	4950	9181
2047	61152	60883	145180	91702	228405	4676	8909
2048	61686	61422	146812	91731	230330	4408	8644
2049	62208	61949	148408	91760	232213	4146	8384
2050	62719	62463	149967	91789	234051	3890	8131

Remark: AQTOTL: Aquaculture production, EXOG: capture production, HCOM: human consumption, Crush: processing use, POP: population, IMPT: Imports, EXPT: Exports
Source: own computation based on Equation 12, Table 8-3 and Table 8-4

Table 8-5 Historical (1990–2020) and projected (2030–2050) shares of aquaculture production (AQTOTL)

Region	1990	2000	2010	2020	2030	2040	2050
ARG	0,00%	0,01%	0,00%	0,00%	0,00%	0,00%	0,00%
AUS	0,09%	0,09%	0,12%	0,13%	0,12%	0,12%	0,12%
BRA	0,15%	0,51%	0,67%	0,78%	0,90%	0,97%	1,02%
CAN	0,31%	0,38%	0,26%	0,24%	0,25%	0,24%	0,24%
CHL	0,24%	1,16%	1,14%	1,21%	1,59%	1,68%	1,74%
COL	0,08%	0,18%	0,13%	0,12%	0,13%	0,13%	0,13%
EGY	0,46%	1,01%	1,49%	1,75%	1,89%	2,05%	2,18%
ETH	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%
EUE	4,49%	1,92%	2,05%	1,94%	1,83%	1,79%	1,76%
EUN	7,87%	4,15%	2,05%	1,56%	1,45%	1,32%	1,23%
IDN	3,75%	2,33%	3,74%	6,67%	5,08%	5,24%	5,35%
IND	7,63%	5,75%	6,14%	6,72%	6,20%	6,09%	6,01%
IRN	0,20%	0,12%	0,36%	0,46%	0,43%	0,46%	0,49%
ISR	0,11%	0,06%	0,03%	0,02%	0,02%	0,02%	0,02%

Region	1990	2000	2010	2020	2030	2040	2050
JPN	6,04%	2,26%	1,17%	0,74%	0,69%	0,61%	0,56%
KAZ	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%
KOR	2,83%	0,87%	0,77%	0,60%	0,54%	0,50%	0,47%
LAMA	1,44%	2,48%	3,01%	3,31%	3,61%	3,72%	3,79%
MEX	0,17%	0,16%	0,20%	0,25%	0,26%	0,26%	0,27%
MYS	0,40%	0,45%	0,61%	0,26%	0,29%	0,28%	0,27%
NGA	0,06%	0,08%	0,33%	0,37%	0,34%	0,37%	0,40%
NOR	1,13%	1,45%	1,66%	1,51%	1,62%	1,64%	1,65%
NZL	0,21%	0,25%	0,18%	0,13%	0,13%	0,13%	0,12%
PAK	0,08%	0,04%	0,23%	0,19%	0,21%	0,22%	0,23%
PHL	2,85%	1,17%	1,21%	1,00%	0,90%	0,85%	0,82%
PRY	0,00%	0,00%	0,00%	0,01%	0,01%	0,01%	0,01%
RestAfr	0,06%	0,09%	0,26%	0,36%	0,34%	0,37%	0,40%
RestAsia	5,98%	5,17%	9,12%	9,46%	9,41%	9,68%	9,87%
RUS	0,00%	0,22%	0,20%	0,23%	0,20%	0,20%	0,19%
SUA	0,01%	0,02%	0,04%	0,06%	0,05%	0,05%	0,06%
THA	2,19%	2,19%	2,09%	1,15%	1,35%	1,29%	1,24%
TUR	0,04%	0,23%	0,27%	0,30%	0,37%	0,40%	0,42%
UKR	0,00%	0,09%	0,04%	0,02%	0,02%	0,02%	0,01%
USA	2,37%	1,35%	0,81%	0,51%	0,50%	0,45%	0,42%
ZAF	0,03%	0,01%	0,01%	0,01%	0,00%	0,00%	0,00%
CHN	48,72%	63,73%	59,62%	57,91%	59,25%	58,82%	58,48%

Remark: ARG: Argentina, AUS: Australia, BRA: Brazil, CAN; Canada, CHL: Chile, COL: Colombia, EGY: Egypt, ETH: Ethiopia, EUE: rest of Europe, EUN: European union 28, IDN: Indonesia, IND: India, IRN: Iran, MYS: Malaysia, NGA: Nigeria, NOR: Norway, NZL: New Zealand, PAK: Pakistan, PHL: the Philippines, PRY: Paraguay, RestAfr: Rest of Africa, RestAsia: Rest of Asia, RUS: Russia, SUA: Saudi Arabia, THA: Thailand, TUR: Turkey, UKR: Ukraine, USA: the US, ZAF: South Africa, CHN: China
Source: own estimation based on Equation 13

Table 8-6 Historical (1990–2020) and projected (2030–2050) shares of total demand (Human consumption (HCOM) + processing use (Crush) + other use)

Regions	1990	2000	2010	2020	2030	2040	2050
ARG	0,18%	0,23%	0,15%	0,14%	0,14%	0,13%	0,13%
AUS	0,32%	0,31%	0,41%	0,37%	0,37%	0,37%	0,37%
BRA	0,84%	0,80%	1,08%	1,08%	1,08%	1,09%	1,09%
CAN	0,86%	0,62%	0,52%	0,49%	0,47%	0,45%	0,44%
CHL	4,46%	2,70%	1,56%	0,87%	0,89%	0,79%	0,73%
COL	0,09%	0,14%	0,16%	0,20%	0,21%	0,21%	0,22%
EGY	0,45%	0,70%	1,09%	1,27%	1,27%	1,33%	1,38%
ETH	0,00%	0,01%	0,01%	0,03%	0,02%	0,03%	0,03%
EUE	11,05%	5,21%	3,84%	2,91%	2,90%	2,72%	2,59%
EUN	9,93%	8,48%	7,65%	6,45%	6,38%	6,14%	5,97%
IDN	2,50%	3,15%	4,23%	5,97%	5,45%	5,62%	5,75%
IND	3,38%	3,65%	4,74%	5,34%	5,04%	5,09%	5,12%
IRN	0,25%	0,30%	0,44%	0,62%	0,55%	0,57%	0,58%
ISR	0,09%	0,09%	0,10%	0,10%	0,10%	0,10%	0,10%
JPN	11,98%	7,02%	4,89%	3,30%	3,33%	3,08%	2,92%
KAZ	0,00%	0,04%	0,05%	0,04%	0,04%	0,04%	0,04%

Regions	1990	2000	2010	2020	2030	2040	2050
KOR	2,35%	1,73%	1,86%	1,68%	1,67%	1,63%	1,59%
LAMA	14,19%	13,47%	7,79%	6,71%	6,69%	6,29%	6,01%
MEX	1,22%	0,92%	1,11%	1,21%	1,11%	1,11%	1,10%
MYS	1,00%	1,20%	1,24%	1,08%	1,09%	1,08%	1,07%
NGA	0,96%	0,59%	1,39%	1,03%	1,14%	1,16%	1,17%
NOR	0,89%	0,97%	0,60%	0,43%	0,46%	0,43%	0,41%
NZL	0,10%	0,15%	0,11%	0,10%	0,11%	0,11%	0,11%
PAK	0,38%	0,38%	0,28%	0,27%	0,25%	0,24%	0,23%
PHL	2,07%	1,62%	1,96%	1,58%	1,60%	1,56%	1,53%
PRY	0,01%	0,02%	0,01%	0,02%	0,02%	0,02%	0,02%
RestAfr	3,72%	3,42%	4,06%	4,55%	4,32%	4,33%	4,33%
RestAsia	5,68%	6,21%	8,78%	9,09%	8,99%	9,14%	9,24%
RUS	0,00%	2,25%	2,27%	1,61%	1,62%	1,54%	1,48%
SUA	0,08%	0,10%	0,19%	0,22%	0,22%	0,23%	0,24%
THA	2,10%	2,02%	1,38%	1,15%	1,19%	1,13%	1,09%
TUR	0,34%	0,42%	0,42%	0,27%	0,30%	0,29%	0,28%
UKR	0,00%	0,46%	0,39%	0,27%	0,31%	0,31%	0,30%
USA	6,20%	5,23%	4,97%	4,69%	4,58%	4,46%	4,37%
ZAF	0,44%	0,36%	0,38%	0,42%	0,40%	0,40%	0,39%
CHN	11,86%	25,05%	29,88%	34,45%	35,70%	36,81%	37,60%

Remark: ARG: Argentina, AUS: Australia, BRA: Brazil, CAN; Canada, CHL: Chile, COL: Colombia, EGY: Egypt, ETH: Ethiopia, EUE: rest of Europe, EUN: European union 28, IDN: Indonesia, IND: India, IRN: Iran, MYS: Malaysia, NGA: Nigeria, NOR: Norway, NZL: New Zealand, PAK: Pakistan, PHL: the Philippines, PRY: Paraguay, RestAfr: Rest of Africa, RestAsia: Rest of Asia, RUS: Russia, SUA: Saudi Arabia, THA: Thailand, TUR: Turkey, UKR: Ukraine, USA: the US, ZAF: South Africa, CHN: China

Source: own estimation based on Equation 13

Table 8-7 Historical (1990–2020) and projected (2030–2050) shares of import (IMPT)

Region	1990	2000	2010	2020	2030	2040	2050
ARG	0,04%	0,24%	0,14%	0,17%	0,16%	0,16%	0,16%
AUS	1,28%	1,15%	1,19%	1,16%	1,09%	1,07%	1,05%
BRA	1,77%	1,29%	1,47%	1,53%	1,42%	1,40%	1,39%
CAN	1,57%	2,09%	1,55%	1,45%	1,39%	1,34%	1,30%
CHL	0,09%	0,10%	0,18%	0,33%	0,28%	0,29%	0,30%
COL	0,21%	0,35%	0,42%	0,58%	0,57%	0,58%	0,59%
EGY	1,07%	0,98%	1,15%	1,11%	1,03%	1,03%	1,03%
ETH	0,00%	0,00%	0,00%	0,00%	0,01%	0,01%	0,01%
EUE	5,49%	6,45%	6,10%	4,74%	5,69%	5,66%	5,63%
EUN	25,77%	21,82%	19,78%	19,44%	18,62%	18,08%	17,68%
IDN	0,05%	0,20%	0,69%	0,61%	0,65%	0,74%	0,82%
IND	0,00%	0,02%	0,06%	0,08%	0,15%	0,19%	0,23%
IRN	0,00%	0,02%	0,23%	0,17%	0,14%	0,15%	0,15%
ISR	0,46%	0,37%	0,35%	0,39%	0,35%	0,34%	0,33%
JPN	18,50%	16,91%	9,24%	7,75%	7,66%	7,14%	6,79%
KAZ	0,00%	0,19%	0,20%	0,15%	0,21%	0,22%	0,23%
KOR	1,72%	3,32%	3,69%	4,10%	4,40%	4,50%	4,58%
LAMA	3,82%	3,85%	5,07%	5,87%	5,59%	5,67%	5,72%
MEX	0,21%	0,38%	0,80%	1,35%	1,38%	1,55%	1,68%

Region	1990	2000	2010	2020	2030	2040	2050
MYS	1,62%	1,49%	1,29%	1,03%	1,03%	0,98%	0,95%
NGA	4,52%	1,36%	4,08%	1,97%	2,24%	2,19%	2,16%
NOR	0,76%	1,81%	0,53%	0,53%	0,53%	0,50%	0,48%
NZL	0,14%	0,12%	0,15%	0,11%	0,11%	0,11%	0,11%
PAK	0,00%	0,00%	0,01%	0,03%	0,03%	0,03%	0,04%
PHL	0,96%	0,69%	0,50%	0,75%	0,65%	0,63%	0,62%
PRY	0,00%	0,01%	0,01%	0,01%	0,01%	0,01%	0,01%
RestAfr	4,66%	3,99%	4,72%	6,50%	5,94%	6,01%	6,06%
RestAsia	5,81%	5,48%	6,39%	7,11%	6,53%	6,50%	6,47%
RUS	0,00%	2,10%	3,07%	1,76%	2,87%	2,99%	3,07%
SUA	0,30%	0,35%	0,64%	0,77%	0,75%	0,79%	0,81%
THA	3,15%	2,72%	4,07%	3,64%	3,73%	3,69%	3,66%
TUR	0,12%	0,19%	0,25%	0,26%	0,24%	0,24%	0,24%
UKR	0,00%	1,19%	1,18%	1,07%	1,26%	1,28%	1,29%
USA	14,44%	12,73%	12,24%	12,80%	12,21%	12,00%	11,84%
ZAF	0,43%	0,16%	0,38%	0,86%	0,61%	0,64%	0,66%
CHN	1,03%	5,86%	8,18%	9,79%	10,49%	11,28%	11,87%

Remark: ARG: Argentina, AUS: Australia, BRA: Brazil, CAN; Canada, CHL: Chile, COL: Colombia, EGY: Egypt, ETH: Ethiopia, EUE: rest of Europe, EUN: European union 28, IDN: Indonesia, IND: India, IRN: Iran, MYS: Malaysia, NGA: Nigeria, NOR: Norway, NZL: New Zealand, PAK: Pakistan, PHL: the Philippines, PRY: Paraguay, RestAfr: Rest of Africa, RestAsia: Rest of Asia, RUS: Russia, SUA: Saudi Arabia, THA: Thailand, TUR: Turkey, UKR: Ukraine, USA: the US, ZAF: South Africa, CHN: China

Source: own estimation based on Equation 13

Table 8-8 Historical (1990–2020) and projected (2030–2050) shares of export (EXPT)

Region	1990	2000	2010	2020	2030	2040	2050
ARG	2,26%	2,29%	1,53%	1,24%	1,26%	1,19%	1,13%
AUS	0,48%	0,33%	0,15%	0,16%	0,13%	0,12%	0,12%
BRA	0,26%	0,23%	0,10%	0,11%	0,10%	0,10%	0,09%
CAN	6,49%	2,64%	2,07%	1,61%	1,45%	1,35%	1,28%
CHL	2,47%	3,35%	2,21%	3,31%	3,36%	3,37%	3,37%
COL	0,30%	0,37%	0,17%	0,14%	0,13%	0,12%	0,12%
EGY	0,02%	0,00%	0,03%	0,10%	0,06%	0,07%	0,07%
ETH	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%
EUE	20,47%	17,09%	14,80%	15,06%	13,68%	13,31%	13,04%
EUN	7,68%	6,57%	5,60%	6,02%	5,61%	5,45%	5,34%
IDN	2,05%	1,95%	2,76%	3,30%	2,99%	3,00%	3,01%
IND	0,96%	1,77%	2,09%	2,56%	2,44%	2,51%	2,55%
IRN	0,01%	0,03%	0,12%	0,18%	0,18%	0,20%	0,22%
ISR	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%
JPN	2,65%	0,88%	1,54%	1,65%	1,37%	1,34%	1,31%
KAZ	0,00%	0,08%	0,10%	0,08%	0,08%	0,08%	0,08%
KOR	3,32%	1,98%	1,89%	0,89%	0,94%	0,88%	0,84%
LAMA	8,70%	10,07%	8,04%	8,88%	9,07%	8,91%	8,79%
MEX	0,65%	0,65%	0,45%	0,39%	0,39%	0,37%	0,37%
MYS	1,21%	0,57%	0,75%	0,51%	0,51%	0,49%	0,47%
NGA	0,04%	0,01%	0,06%	0,03%	0,03%	0,03%	0,03%
NOR	5,53%	7,94%	7,04%	6,22%	6,04%	5,92%	5,83%
NZL	1,76%	1,56%	1,06%	0,81%	0,80%	0,75%	0,71%

Region	1990	2000	2010	2020	2030	2040	2050
PAK	0,45%	0,36%	0,35%	0,43%	0,37%	0,37%	0,36%
PHL	0,93%	0,78%	0,69%	0,86%	0,68%	0,67%	0,66%
PRY	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%
RestAfr	4,21%	5,61%	4,04%	4,55%	4,37%	4,29%	4,23%
RestAsia	7,50%	7,03%	9,71%	10,92%	10,48%	10,61%	10,69%
RUS	0,00%	5,04%	4,18%	5,82%	4,82%	4,76%	4,71%
SUA	0,01%	0,01%	0,09%	0,10%	0,10%	0,12%	0,14%
THA	6,46%	5,59%	5,97%	3,96%	4,33%	4,17%	4,06%
TUR	0,21%	0,16%	0,20%	0,45%	0,36%	0,38%	0,39%
UKR	0,00%	0,34%	0,21%	0,05%	0,04%	0,04%	0,03%
USA	9,14%	4,36%	4,21%	4,12%	3,96%	3,81%	3,71%
ZAF	0,49%	0,64%	0,42%	0,38%	0,35%	0,34%	0,33%
CHN	3,32%	9,72%	17,39%	15,09%	19,49%	20,88%	21,92%

Remark: ARG: Argentina, AUS: Australia, BRA: Brazil, CAN; Canada, CHL: Chile, COL: Colombia, EGY: Egypt, ETH: Ethiopia, EUE: rest of Europe, EUN: European union 28, IDN: Indonesia, IND: India, IRN: Iran, MYS: Malaysia, NGA: Nigeria, NOR: Norway, NZL: New Zealand, PAK: Pakistan, PHL: the Philippines, PRY: Paraguay, RestAfr: Rest of Africa, RestAsia: Rest of Asia, RUS: Russia, SUA: Saudi Arabia, THA: Thailand, TUR: Turkey, UKR: Ukraine, USA: the US, ZAF: South Africa, CHN: China

Source: own estimation based on Equation 13

Table 8-9 Historical (1990–2020) and projected (2030–2050) shares of capture (EXOG)

Region	1990	2000	2010	2020	2030	2040	2050
ARG	0,59%	0,62%	0,57%	0,55%	0,57%	0,56%	0,55%
AUS	0,22%	0,13%	0,13%	0,10%	0,10%	0,10%	0,09%
BRA	0,66%	0,45%	0,55%	0,50%	0,50%	0,50%	0,50%
CAN	1,74%	0,67%	0,66%	0,59%	0,55%	0,53%	0,52%
CHL	5,47%	2,91%	1,88%	1,40%	1,37%	1,26%	1,19%
COL	0,13%	0,09%	0,06%	0,06%	0,06%	0,05%	0,05%
EGY	0,27%	0,26%	0,27%	0,23%	0,25%	0,24%	0,24%
ETH	0,01%	0,01%	0,01%	0,04%	0,03%	0,03%	0,04%
EUE	14,59%	6,69%	6,08%	6,31%	5,59%	5,42%	5,29%
EUN	7,20%	4,55%	3,82%	3,67%	3,39%	3,25%	3,16%
IDN	2,67%	2,78%	3,78%	4,55%	4,46%	4,58%	4,67%
IND	2,95%	2,48%	3,29%	3,59%	3,35%	3,39%	3,41%
IRN	0,26%	0,26%	0,31%	0,53%	0,45%	0,47%	0,48%
ISR	0,01%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%
JPN	10,14%	3,43%	2,87%	2,11%	1,96%	1,83%	1,74%
KAZ	0,00%	0,02%	0,03%	0,03%	0,03%	0,03%	0,03%
KOR	2,62%	1,23%	1,21%	0,90%	0,90%	0,86%	0,83%
LAMA	16,91%	13,42%	8,45%	8,05%	7,94%	7,57%	7,32%
MEX	1,44%	0,89%	1,07%	1,17%	1,05%	1,05%	1,04%
MYS	1,01%	0,87%	1,01%	1,15%	1,08%	1,09%	1,09%
NGA	0,33%	0,30%	0,43%	0,53%	0,52%	0,54%	0,56%
NOR	1,70%	1,83%	1,88%	1,53%	1,54%	1,51%	1,49%
NZL	0,37%	0,37%	0,31%	0,29%	0,30%	0,29%	0,29%
PAK	0,50%	0,42%	0,32%	0,37%	0,33%	0,32%	0,32%
PHL	1,96%	1,30%	1,75%	1,53%	1,50%	1,48%	1,47%
PRY	0,01%	0,02%	0,01%	0,01%	0,01%	0,01%	0,01%

Region	1990	2000	2010	2020	2030	2040	2050
RestAfr	4,21%	4,58%	5,47%	6,65%	6,34%	6,45%	6,53%
RestAsia	4,59%	29,42%	33,21%	32,88%	36,58%	37,37%	37,93%
RUS	0,00%	2,69%	2,86%	3,46%	3,02%	3,01%	2,99%
SUA	0,04%	0,03%	0,05%	0,05%	0,05%	0,05%	0,05%
THA	2,65%	2,03%	1,27%	1,01%	1,06%	1,00%	0,96%
TUR	0,40%	0,34%	0,34%	0,24%	0,26%	0,25%	0,24%
UKR	0,00%	0,26%	0,15%	0,04%	0,05%	0,05%	0,04%
USA	5,89%	3,19%	3,08%	3,41%	3,15%	3,08%	3,03%
ZAF	0,57%	0,44%	0,44%	0,42%	0,42%	0,41%	0,41%
CHN	7,06%	9,91%	10,82%	10,07%	11,24%	11,36%	11,45%

Remark: ARG: Argentina, AUS: Australia, BRA: Brazil, CAN; Canada, CHL: Chile, COL: Colombia, EGY: Egypt, ETH: Ethiopia, EUE: rest of Europe, EUN: European union 28, IDN: Indonesia, IND: India, IRN: Iran, MYS: Malaysia, NGA: Nigeria, NOR: Norway, NZL: New Zealand, PAK: Pakistan, PHL: the Philippines, PRY: Paraguay, RestAfr: Rest of Africa, RestAsia: Rest of Asia, RUS: Russia, SUA: Saudi Arabia, THA: Thailand, TUR: Turkey, UKR: Ukraine, USA: the US, ZAF: South Africa, CHN: China
Source: own estimation based on Equation 13

Table 8-10 Historical (1990–2020) and projected (2030–2050) shares of human consumption (HCOM)

Region	1990	2000	2010	2020	2030	2040	2050
ARG	0,26%	0,30%	0,17%	0,15%	0,16%	0,15%	0,14%
AUS	0,46%	0,40%	0,45%	0,39%	0,39%	0,38%	0,37%
BRA	1,17%	1,01%	1,24%	1,18%	1,18%	1,18%	1,17%
CAN	0,89%	0,69%	0,56%	0,51%	0,50%	0,48%	0,46%
CHL	0,32%	0,19%	0,18%	0,17%	0,16%	0,15%	0,15%
COL	0,13%	0,19%	0,19%	0,23%	0,23%	0,23%	0,24%
EGY	0,65%	0,94%	1,29%	1,42%	1,42%	1,47%	1,51%
ETH	0,01%	0,02%	0,01%	0,03%	0,03%	0,03%	0,03%
EUE	10,10%	3,66%	3,40%	2,40%	2,39%	2,25%	2,16%
EUN	11,47%	9,52%	8,08%	6,89%	6,84%	6,58%	6,39%
IDN	3,59%	4,19%	4,81%	6,12%	5,67%	5,76%	5,83%
IND	4,39%	4,49%	5,06%	5,60%	5,30%	5,30%	5,30%
IRN	0,30%	0,31%	0,47%	0,63%	0,56%	0,58%	0,59%
ISR	0,13%	0,12%	0,12%	0,11%	0,11%	0,11%	0,11%
JPN	11,84%	8,21%	4,98%	3,39%	3,48%	3,22%	3,04%
KAZ	0,00%	0,05%	0,06%	0,04%	0,09%	0,11%	0,12%
KOR	2,75%	2,12%	2,06%	1,83%	1,79%	1,74%	1,69%
LAMA	5,32%	4,21%	4,12%	4,19%	4,03%	3,95%	3,89%
MEX	1,43%	0,97%	1,06%	1,17%	1,06%	1,04%	1,03%
MYS	1,17%	1,42%	1,26%	1,16%	1,15%	1,13%	1,11%
NGA	1,39%	0,79%	1,64%	1,15%	1,27%	1,28%	1,29%
NOR	0,26%	0,22%	0,19%	0,16%	0,16%	0,15%	0,15%
NZL	0,10%	0,08%	0,08%	0,07%	0,07%	0,07%	0,07%
PAK	0,31%	0,33%	0,25%	0,23%	0,22%	0,21%	0,20%
PHL	3,01%	2,18%	2,31%	1,77%	1,79%	1,73%	1,68%
PRY	0,02%	0,03%	0,02%	0,02%	0,02%	0,02%	0,02%
RestAfr	4,85%	4,01%	4,31%	4,79%	4,51%	4,48%	4,46%
RestAsia	6,99%	7,26%	8,81%	8,70%	8,64%	8,68%	8,70%
RUS	0,00%	2,53%	2,37%	1,63%	1,70%	1,62%	1,57%
SUA	0,12%	0,14%	0,23%	0,24%	0,25%	0,26%	0,26%

Region	1990	2000	2010	2020	2030	2040	2050
THA	1,53%	1,88%	1,22%	1,05%	1,10%	1,05%	1,01%
TUR	0,45%	0,49%	0,36%	0,25%	0,27%	0,26%	0,25%
UKR	0,00%	0,61%	0,46%	0,31%	0,99%	1,20%	1,38%
USA	7,51%	6,04%	4,96%	4,52%	4,40%	4,24%	4,12%
ZAF	0,49%	0,27%	0,22%	0,27%	0,24%	0,24%	0,23%
CHN	16,46%	30,03%	32,88%	37,14%	37,85%	38,68%	39,26%

Remark: ARG: Argentina, AUS: Australia, BRA: Brazil, CAN; Canada, CHL: Chile, COL: Colombia, EGY: Egypt, ETH: Ethiopia, EUE: rest of Europe, EUN: European union 28, IDN: Indonesia, IND: India, IRN: Iran, MYS: Malaysia, NGA: Nigeria, NOR: Norway, NZL: New Zealand, PAK: Pakistan, PHL: the Philippines, PRY: Paraguay, RestAfr: Rest of Africa, RestAsia: Rest of Asia, RUS: Russia, SUA: Saudi Arabia, THA: Thailand, TUR: Turkey, UKR: Ukraine, USA: the US, ZAF: South Africa, CHN: China
Source: own estimation based on Equation 13

Table 8-11 Historical (1990–2020) and projected (2030–2050) shares of crush (processing use / PRCM)

Region	1990	2000	2010	2020	2030	2040	2050
AUS	0,02%	0,03%	0,27%	0,23%	0,31%	0,35%	0,38%
BRA	0,13%	0,18%	0,29%	0,30%	0,30%	0,30%	0,31%
CAN	0,32%	0,14%	0,26%	0,22%	0,19%	0,18%	0,18%
CHL	14,38%	11,37%	11,50%	7,81%	7,80%	7,29%	6,94%
EUE	13,43%	9,97%	6,76%	8,82%	8,14%	7,86%	7,65%
EUN	6,00%	5,25%	4,98%	3,10%	3,00%	2,81%	2,68%
IDN	0,07%	0,02%	0,16%	0,18%	0,14%	0,14%	0,14%
IND	1,04%	1,03%	1,52%	3,94%	2,73%	2,86%	2,94%
IRN	0,15%	0,32%	0,36%	0,60%	0,51%	0,53%	0,55%
JPN	12,36%	3,88%	4,18%	3,10%	2,87%	2,69%	2,56%
KOR	1,37%	0,43%	0,79%	0,48%	0,44%	0,41%	0,39%
LAMA	36,17%	45,98%	33,05%	30,67%	31,40%	30,14%	29,20%
MEX	0,78%	0,88%	1,75%	1,91%	1,75%	1,81%	1,86%
MYS	0,56%	0,55%	0,57%	0,57%	0,59%	0,58%	0,58%
NOR	2,42%	3,56%	2,87%	3,32%	3,33%	3,26%	3,20%
NZL	0,10%	0,41%	0,35%	0,38%	0,50%	0,54%	0,56%
PAK	0,56%	0,58%	0,62%	0,67%	0,62%	0,61%	0,60%
RestAfr	1,09%	1,86%	2,69%	2,89%	2,87%	2,94%	2,99%
RestAsia	0,26%	0,98%	4,47%	7,60%	7,37%	8,40%	9,21%
RUS	0,00%	1,42%	1,88%	1,83%	1,51%	1,46%	1,42%
THA	3,62%	2,74%	2,95%	2,13%	2,28%	2,18%	2,10%
TUR	0,08%	0,23%	0,90%	0,59%	0,62%	0,67%	0,70%
USA	2,97%	2,58%	4,44%	5,14%	4,88%	4,95%	4,99%
ZAF	0,35%	0,73%	1,64%	2,06%	2,09%	2,25%	2,36%
CHN	1,78%	4,88%	10,74%	11,44%	13,75%	14,78%	15,52%

Remark: ARG: Argentina, AUS: Australia, BRA: Brazil, CAN; Canada, CHL: Chile, COL: Colombia, EGY: Egypt, ETH: Ethiopia, EUE: rest of Europe, EUN: European union 28, IDN: Indonesia, IND: India, IRN: Iran, MYS: Malaysia, NGA: Nigeria, NOR: Norway, NZL: New Zealand, PAK: Pakistan, PHL: the Philippines, PRY: Paraguay, RestAfr: Rest of Africa, RestAsia: Rest of Asia, RUS: Russia, SUA: Saudi Arabia, THA: Thailand, TUR: Turkey, UKR: Ukraine, USA: the US, ZAF: South Africa, CHN: China
Source: own estimation based on Equation 13

Table 8-12 Historical (1990–2020) and projected (2030–2050) shares of other use

Region	1990	2000	2010	2020	2030	2040	2050
CAN	8,24%	2,40%	0,48%	0,63%	0,55%	0,47%	0,42%
CHL	5,20%	0,97%	2,27%	2,85%	2,63%	2,40%	2,23%
EUE	11,31%	9,31%	5,06%	0,48%	1,21%	0,95%	0,80%
EUN	14,79%	7,30%	6,68%	1,42%	1,84%	1,53%	1,34%
IDN	0,11%	0,76%	3,78%	26,20%	10,76%	13,14%	15,08%
JPN	12,96%	1,16%	5,17%	0,00%	0,82%	0,64%	0,53%
KOR	2,96%	1,88%	0,38%	0,00%	1,26%	1,12%	1,02%
LAMA	5,97%	3,22%	14,04%	18,51%	14,50%	14,31%	14,10%
MEX	0,16%	0,03%	0,02%	0,00%	0,01%	0,01%	0,01%
MYS	1,61%	0,62%	3,04%	0,00%	0,57%	0,52%	0,48%
NOR	1,01%	0,44%	3,07%	0,00%	0,76%	0,69%	0,64%
RestAfr	2,84%	0,53%	2,57%	0,91%	1,01%	0,89%	0,80%
RestAsia	20,67%	7,07%	15,08%	21,65%	17,21%	16,64%	16,17%
RUS	0,00%	1,66%	1,13%	0,00%	0,96%	0,87%	0,81%
THA	0,38%	0,00%	0,00%	1,71%	0,24%	0,24%	0,25%
USA	8,31%	5,01%	7,47%	11,39%	9,49%	9,16%	8,89%
CHN	0,00%	54,93%	21,63%	14,24%	36,17%	36,43%	36,45%

Remark: ARG: Argentina, AUS: Australia, BRA: Brazil, CAN; Canada, CHL: Chile, COL: Colombia, EGY: Egypt, ETH: Ethiopia, EUE: rest of Europe, EUN: European union 28, IDN: Indonesia, IND: India, IRN: Iran, MYS: Malaysia, NGA: Nigeria, NOR: Norway, NZL: New Zealand, PAK: Pakistan, PHL: the Philippines, PRY: Paraguay, RestAfr: Rest of Africa, RestAsia: Rest of Asia, RUS: Russia, SUA: Saudi Arabia, THA: Thailand, TUR: Turkey, UKR: Ukraine, USA: the US, ZAF: South Africa, CHN: China

Source: own estimation based on Equation 13

Table 8-13 Estimated parameters of market items for OECD regions

	AQTOTL		Demand		Import		Export	
	$\hat{\alpha}$	$\hat{\beta}$	$\hat{\alpha}$	β	$\hat{\alpha}$	β	$\hat{\alpha}$	β
ARG	-9,421723525	-3,704719369	-6,002934758	23,51114818	-4,636949058	21,93468535	-3,530732527	39,69509555
AUS	-6,112707759	-4,258401334	-4,776265279	10,41311238	-2,830415894	28,2363209	-5,888241556	45,50673797
BRA	-3,691165686	-24,90161841	-3,637406791	6,908117515	-2,515147138	25,743385	-6,05388762	40,52690567
CAN	-5,567317032	5,023949054	-4,740531632	20,41383595	-2,675584585	32,58839043	-3,451626147	42,78169021
CHL	-3,261868508	-17,77798595	-4,571664557	43,86245106	-3,787623096	7,37945653	-2,15354593	19,7067102
COL	-6,114997276	-0,234218721	-5,178753161	1,202866599	-3,21470209	15,20128632	-5,863369835	44,53144606
EGY	-2,900920796	-27,32720503	-3,230358487	-5,354173568	-2,76423527	22,21244681	-5,557341219	-11,4023272
ETH	-14,00198746	12,05786378	-6,985231469	-16,13894767	-6,994519134	-28,55870128	-7,968420738	-52,46195325
EUE	-3,563325277	4,355344712	-3,088800525	28,95360529	-1,083776378	23,60545821	-0,932225483	28,90967618
EUN	-4,232601764	26,01758739	-2,137252884	20,73447205	-0,038172841	30,57721971	-1,82394129	28,87814538
IDN	-2,228632942	-11,36645096	-1,872820346	-0,373210581	-2,434075156	-17,02250187	-2,260456206	19,25517926
IND	-2,320286576	3,174805878	-2,0849276	6,395215523	-3,136243887	-56,11358912	-2,327388425	12,43409787
IRN	-4,482344329	-21,6422512	-4,177682425	0,061031909	-4,422602823	4,178990183	-4,349306942	-16,71444257
ISR	-8,503584948	26,44212555	-6,144572051	12,53810584	-4,02968494	31,48700382	-10,31605569	36,72474644
JPN	-5,120116218	33,41343321	-3,021574353	32,52526831	-1,172461325	42,92051883	-3,213094874	27,79068402
KAZ	-11,20629331	24,66078348	-7,008014041	9,479761547	-3,987325081	2,631434401	-6,045884657	27,92563781
KOR	-5,148664778	22,36761571	-3,419925308	17,98353001	-1,162300495	14,64628066	-3,858804075	41,59306618
LAMA	-2,579209476	-10,91284071	-2,229897718	27,77584267	-0,982331051	17,66875576	-1,282296908	25,83621172
MEX	-5,256696369	-8,872020803	-3,688587023	11,11989166	-1,774302902	-12,62477824	-4,539294561	31,16011851
MYS	-5,525072588	10,2623686	-3,734797819	12,43756148	-3,019857344	34,75747186	-4,368296806	36,59477043
NGA	-4,588854948	-28,11823666	-3,521393206	3,735153766	-2,10105797	27,77851456	-6,707754697	15,3883422
NOR	-3,482924877	-5,818233415	-4,92771113	29,23205661	-3,816898216	41,98227547	-1,707073508	26,7797361
NZL	-6,395262114	14,75296406	-6,03332077	11,88495855	-5,108152423	27,58794963	-4,016966085	41,23018402
PAK	-5,286209062	-17,92770661	-5,3971195	21,31692589	-4,690789277	-66,43049118	-4,478540789	25,98470527
PHL	-4,46162487	13,76823317	-3,428913375	16,07209285	-3,353253448	28,29152853	-3,900286675	27,52820411
PRY	-7,640770999	-52,41090554	-8,02659974	14,81066814	-7,606465493	22,2037228	-14,56660559	57,37550122
RUS	-5,823674454	7,730271122	-3,590107259	24,76718647	-1,487036714	9,530900934	-1,886169469	24,44843117
RestAfr	-4,567019971	-29,39292664	-2,282980916	8,546044013	-0,93119636	18,08485524	-2,017484406	26,14649358
RestAsia	-1,628993101	-10,53022	-1,467128396	4,428402118	-0,935922228	23,08019551	-0,960563727	16,98079492
SUA	-6,612852719	-23,07575954	-5,003699541	-4,153825023	-2,800856629	8,307977068	-4,72007157	-25,84390808
THA	-4,021973423	11,98233442	-3,901064104	25,19673404	-1,529618584	24,77565464	-2,139564796	31,74352337
TUR	-4,56536933	-25,86701805	-5,172141274	19,80087345	-4,109883059	16,02761392	-4,101990165	5,07652313
UKR	-9,021177074	48,32380237	-5,101079237	18,50938036	-2,473140488	17,72111525	-7,698509151	80,55346334

USA	-5,312320657	26,79480229	-2,399259532	17,24521832	-0,389899582	27,08960019	-2,228333988	31,69342108
ZAF	-9,97139754	25,98529191	-4,747943856	12,82593791	-3,025927373	9,302012512	-4,715423632	35,40855261
	EXOG		**Demand**		**Crush**		**Other use**	
	$\hat{\alpha}$	$\hat{\beta}$	$\hat{\alpha}$	β	$\hat{\alpha}$	β	$\hat{\alpha}$	β
ARG	-3,166371114	9,641533145	-5,966031903	24,38400777	NA	NA	-13,52213348	15,10429
AUS	-5,019760369	15,64960947	-4,824946008	11,95384747	-3,504170736	-13,70250077	NA	NA
BRA	-3,225132307	5,993828561	-3,61367327	7,188742312	-4,15625663	16,5392851	-14,38648832	54,0014
CAN	-3,319955519	15,4095667	-4,704523778	18,52486119	-4,922739946	31,70439674	-5,186118217	50,00752
CHL	-2,674655354	28,62462196	-5,871138647	19,76810207	-1,399170696	41,57532103	-3,221333586	29,9905
COL	-5,645691138	16,84580945	-5,139806315	2,004625515	-6,008453292	-18,15165862	-16,53226631	70,35243
EGY	-3,957308278	6,621760032	-3,193105675	-4,495686992	-9,260615785	46,87472223	-13,75290014	33,96236
ETH	-5,315603875	-29,52761503	-6,948327243	-15,26587967	NA	NA	NA	NA
EUE	-0,954313349	12,82358416	-3,236520151	23,64177953	-1,166363539	32,10265271	-4,8726701	73,73762
EUN	-1,506276747	15,32818823	-2,077090197	18,33917211	-2,347465548	41,29386074	-4,129921409	57,67181
IDN	-0,825752869	-4,915001899	-1,932807722	1,746172907	-4,945138553	16,45994194	-0,057939418	-57,7273
IND	-1,20621935	-0,264365901	-2,096356272	6,545369605	-1,77920613	8,194704575	-3,846274123	35,61816
IRN	-3,072163924	-6,876410893	-4,188743821	-1,085589777	-3,462966523	8,348674387	-2,521824919	-180,479
ISR	-9,763480388	31,16726062	-6,112758004	13,47375129	NA	NA	16,88349134	-687,639
JPN	-2,241058127	24,82975363	-2,984701487	29,90090535	-2,383280366	40,81091155	-5,322335034	76,76309
KAZ	-6,230630369	7,901620375	-5,139470475	-42,85954729	NA	NA	NA	NA
KOR	-2,89076772	18,49468558	-3,374000149	16,19135451	-4,278048292	42,11758379	-4,118718296	38,11878
LAMA	-0,696908191	17,47649401	-2,488623996	12,4000611	0,148835288	33,83153834	-1,039317398	6,270425
MEX	-2,466093018	4,885455312	-3,795412474	10,96573535	-2,283068015	11,13687291	-9,708732222	67,09312
MYS	-2,362515655	0,874238472	-3,723569985	11,31347424	-3,666521161	25,98145293	-4,830892149	34,42557
NGA	-2,911026642	-7,918382522	-3,48448898	4,608221769	NA	NA	NA	NA
NOR	-2,174065614	9,236004182	-5,817006808	17,4336852	-1,975440046	27,78664093	-4,484109075	31,14126
NZL	-3,826532672	10,01102903	-6,540096021	15,00108035	-3,308046718	-0,572023317	-13,68224752	52,16739
PAK	-3,727879436	10,10610009	-5,503820422	17,30136748	-3,63025417	26,46148878	NA	NA
PHL	-2,133361315	5,847994221	-3,392046975	16,94537023	NA	NA	-9,498690187	-3,87762
PRY	-7,004692653	9,789557302	-7,989683759	15,6833182	NA	NA	-14,38935676	10,0338
RUS	-1,40747136	4,65582295	-3,52019554	20,93821089	-2,85900562	32,59503254	-4,255403077	31,08583
RestAfr	-0,536823821	-1,761550688	-2,290072805	8,09179598	-1,848762197	14,08348681	-4,423945691	42,42681
RestAsia	1,241397099	-3,050789869	-1,582719062	5,285776906	-0,268449693	-17,76505849	-0,987495351	12,24314
SUA	-5,510696075	1,315298151	-4,962436367	-3,459587003	-10,61192371	46,14447784	-8,816400822	-17,5403
THA	-2,768736381	20,44598314	-3,944054213	20,14313121	-2,507274642	35,60990867	-4,887384355	-6,92977
TUR	-4,049997779	13,64538867	-5,374024885	21,99724329	-3,125305151	1,579687594	-8,161363023	62,51888

UKR	-6,221866898	43,73084517	-2,599417514	-52,23650992	NA	NA	-4,116376728	NA
USA	-1,479307229	10,40843217	-2,50803351	17,83296918	-1,380764807	17,18242235	-1,593944273	12,80129
ZAF	-3,44774603	7,499939554	-5,392673002	17,44076993	-1,881398039	-0,12986695	-19,72066741	110,6404

Remark: ARG: Argentina, AUS: Australia, BRA: Brazil, CAN; Canada, CHL: Chile, COL: Colombia, EGY: Egypt, ETH: Ethiopia, EUE: rest of Europe, EUN: European union 28, IDN: Indonesia, IND: India, IRN: Iran, MYS: Malaysia, NGA: Nigeria, NOR: Norway, NZL: New Zealand, PAK: Pakistan, PHL: the Philippines, PRY: Paraguay, RestAfr: Rest of Africa, RestAsia: Rest of Asia, RUS: Russia, SUA: Saudi Arabia, THA: Thailand, TUR: Turkey, UKR: Ukraine, USA: the US, ZAF: South Africa, CHN: China

Source: own estimation based on Equation 13

Table 8-14 Projected quantities for market items from 2030 to 2050 (1000 t)

	Aquaculture production			Capture			Total demand			Import		
	2030	2040	2050	2030	2040	2050	2030	2040	2050	2030	2040	2050
ARG	5	6	7	523	515	508	287	302	315	79	90	99
AUS	135	161	183	92	89	87	754	829	891	548	608	657
BRA	1006	1286	1533	459	457	455	2197	2442	2645	714	800	870
CAN	280	324	360	504	486	473	955	1015	1065	698	763	817
CHL	1783	2224	2607	1251	1155	1090	1807	1776	1762	139	165	187
COL	146	172	193	51	49	47	420	475	522	287	333	372
EGY	2113	2721	3263	223	222	221	2582	2991	3336	519	588	644
ETH	0	0	0	28	31	34	49	58	67	3	4	5
EUE	2053	2379	2646	5095	4957	4860	5909	6104	6274	2863	3229	3529
EUN	1621	1748	1846	3084	2976	2900	12983	13784	14447	9365	10318	11092
IDN	5695	6955	8028	4063	4194	4290	11088	12631	13921	329	425	512
IND	6950	8086	9016	3048	3098	3134	10269	11437	12403	75	110	145
IRN	487	615	728	413	429	441	1116	1269	1398	69	83	95
ISR	23	25	26	1	1	1	200	219	234	176	194	208
JPN	774	814	845	1789	1672	1593	6788	6929	7061	3856	4077	4256
KAZ	1	2	2	24	23	23	79	88	94	103	125	143
KOR	603	658	701	823	786	760	3407	3651	3852	2213	2571	2871
LAMA	4048	4936	5691	7233	6929	6719	13623	14129	14562	2814	3237	3588
MEX	290	351	403	959	958	957	2270	2489	2669	695	885	1054
MYS	325	369	405	981	993	1002	2226	2430	2597	516	561	597
NGA	385	497	597	476	496	511	2315	2601	2839	1125	1252	1354
NOR	1815	2176	2479	1400	1379	1363	945	975	1001	269	285	298
NZL	149	167	181	272	268	264	221	242	259	55	62	67
PAK	235	293	344	301	296	292	504	534	559	13	20	26
PHL	1009	1134	1232	1363	1357	1353	3250	3505	3714	325	361	390
PRY	11	16	20	11	11	11	32	35	37	4	5	5
RestAfr	383	497	599	5777	5901	5991	8794	9725	10492	2987	3430	3799
RestAsia	10548	12846	14799	33328	34187	34813	18313	20530	22369	3285	3711	4061
RUS	229	263	290	2750	2749	2749	3292	3448	3580	1444	1706	1928
SUA	56	71	85	42	43	43	449	518	576	379	449	509
THA	1512	1708	1865	967	917	883	2433	2545	2639	1877	2108	2298
TUR	412	528	631	234	227	222	613	653	685	119	138	154
UKR	21	21	21	49	43	39	641	686	722	634	730	809
USA	559	602	634	2872	2816	2778	9317	10008	10577	6144	6849	7424
ZAF	5	6	6	378	375	372	814	888	948	308	365	413
CHN	66392	78066	87704	10237	10395	10508	72687	82699	91062	5279	6440	7445
	Export			Human consumption			Processing use			Other		
	2030	2040	2050	2030	2040	2050	2030	2040	2050	2030	2040	2050
ARG	631	673	707	299	318	334	0	0	0	0	0	0
AUS	67	70	73	731	810	875	32	24	15	0	0	0
BRA	51	55	57	2230	2512	2744	30	20	12	0	0	0
CAN	726	767	799	940	1019	1084	19	12	7	23	20	18
CHL	1676	1911	2106	300	324	344	788	490	270	110	101	95
COL	67	71	73	437	501	554	0	0	0	0	0	0
EGY	30	38	45	2688	3148	3537	0	0	0	0	0	0
ETH	1	2	2	51	62	71	0	0	0	0	0	0
EUE	6834	7557	8145	4519	4818	5062	823	528	298	51	40	34
EUN	2800	3096	3337	12956	14060	14961	304	189	104	77	65	57
IDN	1493	1705	1880	10740	12318	13635	14	9	5	450	554	639
IND	1218	1423	1595	10039	11331	12400	276	192	115	0	0	0
IRN	90	116	139	1063	1231	1372	51	36	21	0	0	0
ISR	1	1	1	208	229	247	0	0	0	0	0	0
JPN	683	758	819	6588	6879	7120	290	181	100	34	27	23
KAZ	40	45	48	178	237	292	0	0	0	0	0	0
KOR	472	500	523	3393	3709	3966	45	28	15	53	47	43
LAMA	4529	5059	5492	7624	8439	9107	3174	2025	1136	607	603	598
MEX	194	213	228	2005	2230	2415	177	122	72	0	0	0
MYS	257	277	293	2170	2410	2608	60	39	22	24	22	20
NGA	16	19	21	2410	2738	3010	0	0	0	0	0	0
NOR	3018	3361	3640	302	329	351	336	219	125	32	29	27
NZL	400	424	444	140	153	164	50	36	22	0	0	0

	Aquaculture production			Capture			Total demand			Import		
	2030	**2040**	**2050**	**2030**	**2040**	**2050**	**2030**	**2040**	**2050**	**2030**	**2040**	**2050**
PAK	186	208	225	412	449	479	63	41	23	0	0	0
PHL	342	380	410	3383	3688	3938	0	0	0	0	0	0
PRY	0	0	0	33	36	39	0	0	0	0	0	0
RestAfr	2185	2438	2645	8531	9579	10444	290	198	116	42	37	34
RestAsia	5233	6021	6677	16361	18545	20355	745	565	358	720	702	686
RUS	2408	2702	2944	3223	3468	3667	153	98	55	40	37	34
SUA	52	69	84	468	546	612	0	0	0	0	0	0
THA	2163	2369	2536	2077	2240	2373	231	147	82	10	10	11
TUR	178	213	243	516	553	583	63	45	27	0	0	0
UKR	22	21	20	1873	2572	3238	0	0	0	0	0	0
USA	1977	2166	2319	8335	9061	9653	493	332	194	397	386	377
ZAF	177	192	203	462	503	536	211	151	92	0	0	0
CHN	9738	11856	13689	71657	82665	91883	1390	993	604	1514	1536	1545

Remark: ARG: Argentina, AUS: Australia, BRA: Brazil, CAN; Canada, CHL: Chile, COL: Colombia, EGY: Egypt, ETH: Ethiopia, EUE: rest of Europe, EUN: European union 28, IDN: Indonesia, IND: India, IRN: Iran, MYS: Malaysia, NGA: Nigeria, NOR: Norway, NZL: New Zealand, PAK: Pakistan, PHL: the Philippines, PRY: Paraguay, RestAfr: Rest of Africa, RestAsia: Rest of Asia, RUS: Russia, SUA: Saudi Arabia, THA: Thailand, TUR: Turkey, UKR: Ukraine, USA: the US, ZAF: South Africa, CHN: China

8.2 Reference scenario (Baseline) results tables

Table 8-15 Baseline (reference scenario) of fish markets in quantity (1000 t)

		Aquaculture production			Catch			Processing use			Food use			Imports			Exports		
Region	**Species**	**2010**	**2030**	**2050**	**2010**	**2030**	**2050**	**2010**	**2030**	**2050**	**2010**	**2030**	**2050**	**2010**	**2030**	**2050**	**2010**	**2030**	**2050**
EU	ACQU	1268	1595	1884	5382	5288	4974	1456	997	818	10793	11361	11240	9069	9982	9954	3470	4507	4754
EU	CRUS				248	244	229	1	1	1	1507	1573	1570	1312	1408	1396	52	78	55
EU	MOLS	602	758	864	362	356	335	10	4	4	1869	2173	2564	1195	1457	1772	280	393	403
EU	FFIS	497	615	712	137	135	127	9	4	5	1884	2740	3204	1549	2381	2816	291	386	447
EU	DFIS	164	212	286	1608	1579	1485	418	255	305	3316	3055	2190	2927	2605	1962	965	1087	1239
EU	PFIS	3	4	9	2936	2886	2714	983	712	482	1847	1419	1298	1721	1744	1600	1831	2502	2544
EU	OFIS	3	6	13	91	89	84	36	21	23	371	401	414	365	387	407	51	61	67
NONEU	ACQU	1430	2187	2703	8737	8861	8706	2217	1533	1355	6873	5229	5832	4850	3985	3829	5927	8271	8051
NONEU	CRUS				170	165	163	1	0	1	164	145	169	138	112	153	143	131	146
NONEU	MOLS	6	10	14	151	155	152	16	12693	42979	199	173	191	106	90	119	49	71	85
NONEU	FFIS	1273	1912	2351	729	831	828	0	15	1	2696	2616	2725	1776	1630	1771	1082	1743	2224
NONEU	DFIS	141	252	322	4376	4661	4593	688	140	374	1378	1058	1358	742	348	456	3193	4062	3638
NONEU	PFIS	6	6	9	3245	3013	2935	1512	1367	970	2297	1168	1279	2000	1756	1250	1442	2240	1945
NONEU	OFIS	4	7	8	66	36	36	0	0	0	140	69	110	88	49	80	43542	23	15
AFRICA	ACQU	970	1620	1977	7162	8660	8883	984	965	1649	10484	13949	15404	4784	5522	6861	1447	888	668
AFRICA	CRUS	12	22	26	128	154	159				119	173	215	50	70	109	71	72	80
AFRICA	MOLS	4	9	12	155	175	174				63	133	203	30	74	108	127	125	91
AFRICA	FFIS	785	1351	1647	2355	2996	3120				3333	4532	5351	205	213	595	23346	43551	47058
AFRICA	DFIS	168	237	289	1100	1310	1347	0	1	1	1603	2333	3201	681	931	1595	345	145	29
AFRICA	PFIS	1	1	2	2938	3415	3453	981	963	1644	4600	5807	5752	3492	3864	4372	850	511	430
AFRICA	OFIS				485	610	630	24139	32143	16893	766	970	682	325	369	82	42	29403	26
N_AM	ACQU	753	926	1111	6673	7088	6879	1194	1167	1406	10104	13637	13919	7426	10277	10830	3553	3487	3496
N_AM	CRUS	143	264	305	717	723	695	17533	46753	1	2160	2152	2425	1690	1532	1815	389	366	390
N_AM	MOLS	215	228	280	929	996	966	27	25	20	1645	2126	2257	827	1139	1172	299	212	140
N_AM	FFIS	390	429	520	491	526	511				2539	5014	5778	2209	4527	5351	551	468	604
N_AM	DFIS	1	1	2	2291	2491	2408	260	384	191	1984	2252	1334	1947	2385	1310	1996	2241	2196
N_AM	PFIS	3	5	5	2153	2259	2207	905	705	1194	1550	1892	1868	581	512	991	281	179	142
N_AM	OFIS				91	92	92	1	52	1	225	201	258	172	183	191	38	21	24
MS_AM	ACQU	1437	2450	3024	9877	9562	8839	5589	5111	4185	3984	6200	6677	961	1985	2199	2702	2687	3199

Region	Species	Aquaculture production			Catch			Processing use			Food use			Imports			Exports		
		2010	2030	2050	2010	2030	2050	2010	2030	2050	2010	2030	2050	2010	2030	2050	2010	2030	2050
MS_AM	CRUS	373	540	737	193	191	180	49	32568	43619	297	284	259	25	18	15	245	461	671
MS_AM	MOLS	192	367	535	766	758	708	44927	1	1	572	858	1094	57	86	115	442	353	263
MS_AM	FFIS	865	1530	1739	360	354	345				1299	2087	2145	112	222	106	38	18	45
MS_AM	DFIS	7	11	12	1068	1046	996	46	48	48	993	1492	1691	458	975	1229	493	493	497
MS_AM	PFIS	1	1	1	7326	7050	6454	5403	5005	4103	502	850	694	33	138	47	1454	1334	1705
MS_AM	OFIS				165	164	155	90	52	31	321	630	792	276	546	686	29	43736	18
ASIA	ACQU	43250	77031	87383	46151	45503	46370	6530	5430	6830	73128	107784	114736	20203	21929	22104	29946	31251	34291
ASIA	CRUS	4668	7487	8422	4400	4397	4509	198	184	192	6493	9576	10592	1163	1106	1634	3539	3230	3781
ASIA	MOLS	13363	22846	28814	4360	3967	3965	465	226	196	16338	25022	30410	2566	2605	2835	3486	4171	5008
ASIA	FFIS	24052	44660	47630	6922	6992	7201	186	202	305	27091	45237	47213	2788	5103	4987	6486	11316	12301
ASIA	DFIS	586	994	1206	7613	7515	7652	404	488	298	8135	9628	10550	2685	3100	4092	2344	1494	2103
ASIA	PFIS	293	364	490	14581	13977	14145	3300	2453	3049	9569	12135	10117	7698	6919	5077	9704	6673	6546
ASIA	OFIS	288	679	821	8275	8654	8897	1977	1877	2791	5502	6186	5854	3304	3096	3478	4388	4366	4551
ANZ	ACQU	191	267	332	587	703	676	43499	43468	43499	738	1110	1367				502	499	440
ANZ	CRUS	4	6	7	40	48	46				108	151	145				21	29921	33086
ANZ	MOLS	130	192	246	76	91	87				116	171	262				182	228	235
ANZ	FFIS	52	62	70	23437	13241	43556				61	84	106				14	34274	14
ANZ	DFIS				336	403	388				235	342	425				280	243	182
ANZ	PFIS	4	6	6	114	137	132	43499	43468	43499	163	302	347				0	0	0
ANZ	OFIS	1	2	3	17	20	19				55	60	82				27485	27061	1
World	ACQU	753	926	1111	84568	85666	85327	17973	15206	16247	116104	159269	169174	47292	53680	55778	47547	51589	54899
World	CRUS	143	264	305	5896	5923	5981	251	191	197	10848	14055	15375	4379	4245	5123	4461	4352	5130
World	MOLS	215	228	280	6799	6497	6388	519	266	230	20802	30654	36981	4781	5450	6121	4865	5553	6226
World	FFIS	390	429	520	10998	11838	12136	194	221	311	38903	62311	66521	8639	14076	15626	8474	13970	15646
World	DFIS	1	1	2	18392	19006	18869	1816	1316	1216	17644	20160	20750	9439	10344	10644	9616	9765	9883
World	PFIS	3	5	5	33294	32737	32040	13086	11208	11445	20528	23574	21355	15524	14935	13338	15561	13438	13313
World	OFIS				9190	9665	9912	2107	2005	2849	7380	8517	8192	4530	4630	4925	4570	4510	4701

Remark: EU: European Union, NONEU: NonEU_EU member countries in Europe, N_AM: North America, MS_AM: Middle and south America, ANZ: Australia and New Zealand
Source: Results of CAPRI fish market version extracted on 18-03-2019

Table 8-16 Database table of baseline (reference scenario) for FIML&FIOL markets in quantity (1000 t)

		Production			Food use			Use in livestock feed			Use in aquafeed			Imports			Exports		
		2010	**2030**	**2050**	**2010**	**2030**	**2050**	**2010**	**2030**	**2050**	**2010**	**2030**	**2050**	**2010**	**2030**	**2050**	**2010**	**2030**	**2050**
EU	FIML	453	372	337				253	248	229	83	98	161	323	330	373	439	358	322
EU	FIOL	141	109	97	33	34	20	102	101	112	17	17	23	145	145	147	133	102	90
NONEU	FIML	393	278	262				210	173	122	338	512	592	337	504	568	182	98	115
NONEU	FIOL	105	59	55	3	2	2	84	59	48	40	101	135	115	153	175	93	51	46
AFRICA	FIML	172	198	213				130	104	83	46	52	57	161	122	111	156	165	184
AFRICA	FIOL	27	31	34	4	4	3	5	4	3	4	7	7	14	14	14	27	31	34
N_AM	FIML	271	280	362				213	191	236	75	117	119	105	105	85	89	77	91
N_AM	FIOL	97	119	126	1	1	1	129	85	88	10	12	9	78	32	33	35	53	61
MS_AM	FIML	1272	1210	1021				24	29	11	164	214	201	129	111	93	1214	1079	902
MS_AM	FIOL	286	262	217	7	5	5	63	36	30	45	66	43	60	53	39	231	208	178
ASIA	FIML	1625	1438	1739				500	316	261	2135	1728	1868	1330	910	802	320	305	410
ASIA	FIOL	144	135	176	73	17	14	73	37	32	93	120	123	170	133	99	76	93	106
ANZ	FIML	38	57	64				45	45	45	8	8	11				10	18	21
ANZ	FIOL	3	5	5	1	0	0	13	9	7	3	4	4				3	5	5
RSA	FIML	716	727	583				3	4	1	29	33	38	19	16	19	703	706	564
RSA	FIOL	149	151	121	1	1	1				2	3	3	3	3	3	149	150	120
CHN	FIML	579	492	424				25	12	5	1001	647	681	458	194	292	11	26	27
CHN	FIOL	46	48	77	1	1	0	1	1	1	44	74	79	30	54	32	30	26	29
THAI	FIML	518	388	598							427	392	565	13	62	36	104	59	70
THAI	FIOL	7	5	7	1	1	1	1	1	1	14	13	13	16	15	14	7	5	7
World	FIML	4224	3834	3997				1374	1106	988	2850	2730	3008	2385	2084	2033	2409	2099	2045
World	FIOL	803	720	710	122	64	45	469	331	320	212	326	345	581	529	508	598	543	520

Remark: EU: European Union, NONEU: NonEU_EU member countries in Europe, N_AM: North America, MS_AM: Middle and south America, ANZ: Australia and New Zealand
Source: Results of CAPRI fish market version extracted on 18-03-2019

Table 8-17 Baseline of 13 feed ingredients used in world aquaculture (% changes compared to 2010) (1000 t)

Commodities	Feed use for aquaculture			Armington 1 Price (EURO)		
	2010	2030	2050	2010	2030	2050
Wheat	3602	6211	7675	209	249	331
		72%	113%		19%	58%
Rye and meslin	27	88	112	148	185	248
		231%	318%		25%	68%
Barley	34	102	129	173	207	287
		203%	283%		20%	66%
Oats	32	92	112	147	181	238
		188%	250%		23%	62%
Grain maize	8959	27167	34062	172	212	280
		203%	280%		24%	63%
Other cereals				178	207	292
Paddy rice						
Rape seed	26	88	106	311	359	443
		241%	314%		15%	42%
Sunflower seed	25	87	124	295	340	447
		246%	392%		15%	51%
Rape oil				912	960	1205
Sunflower oil				872	893	1118
Soya oil	0	0	1	830	827	1068
Soya cake	14604	22014	14609	313	402	518
		51%	0%		28%	65%
FIOT	5686	6977	9457	14	18	22
		23%	66%		24%	52%
Total plant based	**32995**	**62827**	**66387**			
		190%	201%			
Fishmeal	2850	2730	3008	1993	1966	2442
		-4.22%	5.55%		-1.38%	22.51%
Fish oil	212	326	345	1303	1548	1945
		53.69%	62.68%		18.79%	49.19%
Total feed quantity	**36057**	**65884**	**69740**			
		183%	193%			

Source: Results of CAPRI fish market version extracted on 18-03-2019

Table 8-18 Total use of plant-based ingredients and FIML&FIOL by continents (% changes compared to 2010)

Region	Total plant based			Total feed quantity		
	2010	2030	2050	2010	2030	2050
European Union	615	782	894	716	897	1078
		127%	145%		125%	151%
Europe, NonEU_EU	954	1392	1674	1331	2005	2401
		146%	176%		151%	180%
Africa	947	1588	1891	998	1647	1955
		168%	200%		165%	196%

Region	Total plant based			Total feed quantity		
	2010	2030	2050	2010	2030	2050
North America	494	641	767	578	770	896
		1	2		133%	155%
Middle and South America	1021	1756	2136	1230	2035	2380
		172%	209%		165%	193%
Asia	28911	56602	58952	31138	58450	60942
		196%	204%		188%	196%
Australia and New Zealand	53	67	73	154	196	207
		127%	138%		128%	135%

Source: Results of CAPRI fish market version extracted on 18-03-2019

Table 8-19 Baseline of 13 feed ingredients used in feeding five CAPRI fish species (% changes compared to 2010) (1000t)

Commodities	2010					2030					2050				
	CRUS	FFIS	DFIS	PFIS	OFIS	CRUS	FFIS	DFIS	PFIS	OFIS	CRUS	FFIS	DFIS	PFIS	OFIS
Wheat	2791	398	270	101	42	4280	628	805	220	279	4862	1240	925	313	335
						53%	58%	198%	119%	562%	74%	212%	243%	211%	694%
Rye and meslin	4	22	1	0	0	12	70	2	0	4	14	84	4	5	5
						208%	222%	170%			242%	287%	536%		
Barley	5	27	1	0	0	15	80	3	0	4	17	97	4	5	7
						202%	192%	153%			248%	254%	225%		
Oats	6	25	1	0	0	15	69	3	0	5	17	81	3	4	7
						162%	174%	330%			197%	222%	325%		
Grain maize	6	8951	1	0	0	18	27137	6	0	5	25	34013	10	5	9
						205%	203%	370%			321%	280%	701%		
Other cereals															
Paddy rice															
Rape seed	4	20	1	0		14	68	2	0	4	15	79	2	5	6
						212%	230%	222%	106%		236%	286%	249%		
Sunflower seed	4	20	1	0		15	66	2	0	4	17	90	5	6	6
						268%	225%	216%	105%		325%	344%	728%		
Rape seed oil															
Sunflower seed oil															
Soya oil		0					0	0				1	0		
							13%					192%			
Soya cake	668	13394	572	67	90	2157	19348	567	56	155	1218	12737	677	77	168
						223%	44%	-1%	-16%	73%	82%	-5%	18%	15%	87%
Fishwaste, unknown	2218	3022	282	95	69	3737	2256	553	171	260	4716	3543	682	201	316
						68%	-25%	96%	81%	278%	113%	17%	142%	112%	360%
Total plant based	5707	25881	1129	264	201	10263	49723	1942	450	719	10901	51966	2312	620	858
						80%	92%	72%	71%	257%	91%	101%	105%	135%	326%
Fishmeal	1149	1230	195	130	146	985	1389	182	50	124	1102	1431	269	52	155

Commodities	2010					2030					2050				
	CRUS	FFIS	DFIS	PFIS	OFIS	CRUS	FFIS	DFIS	PFIS	OFIS	CRUS	FFIS	DFIS	PFIS	OFIS
						-14%	13%	-7%	-62%	-15%	-4%	16%	38%	-60%	6%
Fish oil	64	127	12	6	3	82	198	24	6	16	82	210	27	7	20
						28%	56%	89%	4%	487%	28%	65%	115%	10%	617%
Total feed Quantity	6920	27237	1337	400	350	11330	51311	2148	506	859	12085	53607	2607	678	1032
						64%	88%	61%	27%	145%	75%	97%	95%	70%	195%

Remark: CRUS: Crustaceans, FFIS: Freshwater and diadromous fish, PFIS: Pelagic fish, DFIS: Demersal fish, OFIS: Other marine fish

Source: Results of CAPRI fish market version extracted on 18-03-2019

8.3 Counterfactual scenario results tables

8.3.1 *Scenario 1*

Table 8-20 The baseline and changes in calories intake from livestock and seafood sectors (1000 t)

Regions	Calories intake from livestock in 2030 (1)	430 Kcal threshold	20% Cut in 2030 (2)	Calories intake from seafood in 2030 (3)	% change in consuming livestock in 2030 (4)	% change in consuming seafood in 2030 (5)
Belgium and Luxemburg	1065	635	127	55	-12	50
Demark	1139	709	142	36	-12	50
Germany	1070	640	128	25	-12	50
Greece	867	437	87	28	-10	50
Spain	947	517	103	64	-11	50
France	1017	587	117	49	-12	50
Ireland	848	418	84	50	-10	50
Italy	819	389	78	72	-9	50
Netherlands	913	483	97	30	-11	50
Austria	1035	605	121	29	-12	50
Portugal	934	504	101	126	-11	50
Sweden	995	565	113	78	-11	50
Finland	1108	678	136	60	-12	50
UK	824	394	79	29	-10	50
Czech Republic	907	477	95	48	-11	50
Hungry	703	273	55	18	-8	50
Poland	962	532	106	23	-11	50
Slovenia	879	449	90	33	-10	50
Slovak Republic	714	284	57	31	-8	50
Estonia	1083	653	131	55	-12	50
Lithuania	914	484	97	206	-11	47
Latvia	846	416	83	81	-10	50
Cyprus	1158	728	146	85	-13	50
Malta	914	484	97	112	-11	50
Bulgaria	372	-58	-12	23		
Romania	606	176	35	19	-6	50
Norway	766	336	67	175	-9	38
Turkey	228	-202	-40	6		
Albania	488	58	12	15	-2	50
Macedonia	394	-36	-7	14		
Serbia	527	97	19	18	-4	50
Montenegro	570	140	28	28	-5	50
Croatia	778	348	70	94	-9	50
Bosnia and Herzegovina	301	-129	-26	15		
Kosovo	180	-250	-50	61		

Regions	Calories intake from livestock in 2030 (1)	430 Kcal threshold	20% Cut in 2030 (2)	Calories intake from seafood in 2030 (3)	% change in consuming livestock in 2030 (4)	% change in consuming seafood in 2030 (5)
Western Balkans	425	-5	-1	22		
Mediterranean countries	250	-180	-36	20		
Uruguay and Paraguay	647	217	43	13		
Mercosur associated	629	199	40	53		
Switzerland	906	476	95	1	-11	50
Rest of Europe	948	518	104	216	-11	48
Russia	742	312	62	62	-8	50
Ukraine	655	225	45	10	-7	50
Belarus	966	536	107	14	-11	50
Kazakhstan	748	318	64	10	-9	50
Former Soviet Union excl. Russia	450	20	4	5	-1	50
Morocco	231	-199	-40	44		
Middle East	326	-104	-21	24		
Nigeria	74	-356	-71	16		
Ethiopia	80	-350	-70	1		
South Africa	333	-97	-19	11		
Africa LDCs	143	-287	-57	18		
Africa Rest	123	-307	-61	64		
India	252	-178	-36	3		
Pakistan	524	94	19	4	-4	50
Bangladesh	61	-369	-74	27		
China	544	114	23	92	-4	25
Japan	424	-6	-1	75		
Malaysia	390	-40	-8	189		
Indonesia	97	-333	-67	81		
Taiwan	631	201	40	51	-6	50
South Korea	435	5	1	127	0	1
Vietnam	295	-135	-27	22		
Thailand	275	-155	-31	75		
Asian and Oceania LDC	167	-263	-53	72		
Asian and Oceania REST	225	-205	-41	17		
Australia and New Zeeland	878	448	90	55	-10	50
USA	968	538	108	41	-11	50
Canada	769	339	68	40	-9	50
Mexico	571	141	28	42	-5	50
Argentina	739	309	62	10	-8	50
Brazil	809	379	76	26	-9	50
Middle and South America ACP	328	-102	-20	45		

Regions	Calories intake from livestock in 2030 (1)	430 Kcal threshold	20% Cut in 2030 (2)	Calories intake from seafood in 2030 (3)	% change in consuming livestock in 2030 (4)	% change in consuming seafood in 2030 (5)
Rest of Middle and South America	428	-2	0	10		
Tunisia	265	-165	-33	18		
Algeria	199	-231	-46	5		
Egypt	226	-204	-41	25		
Israel	758	328	66	43	-9	50
Venezuela	632	202	40	47	-6	50
Chile	729	299	60	44	-8	50
Uruguay	790	360	72	19	-9	50
Paraguay	557	127	25	10	-5	50
Bolivia	439	9	2	84	0	2

Remark: $(4) = \frac{-(2)}{(1)}\%$; $(5) = \max\left(0, \min\left(50, \frac{(2)}{(3)} * 100\right)\right)$

Source: Results of CAPRI fish market version extracted on 18-03-2019

8.3.2 *Scenario 2*

Table 8-21 Baseline of the market balance items of the EU member countries in 2030 (reference for Figure 6-3 sort by total production) (1000t)

EU Members	Aquaculture	Capture	Net export	Imports	Exports
Spain	316	901	-364	893	529
United Kingdom	238	612	-241	527	286
Denmark	49	741	89	122	211
France	278	472	-908	1123	215
Netherlands	62	405	154	147	301
Italy	198	259	-2005	2087	82
Germany	54	271	-799	948	149
Ireland	60	227	149	6	155
Sweden	10	228	-244	363	119
Portugal	8	226	-424	546	122
Greece	143	89	84	43	127
Poland	42	165	-193	200	7
Lithuania	4	172	8	2	10
Finland	18	155	-22	127	105
Latvia	1	156	105	2	107
Estonia	1	99	56	9	65
Croatia	27	52	-50	57	6
Czech Republic	27	4	-169	169	0
Hungary	20	7	-53	53	0
Belgium		23	-229	229	0
Romania	18	5	-110	110	0
Bulgaria	7	11	-33	40	6
Cyprus	4	3	-33	33	
Malta	3	1	-28	28	0
Austria	3	1	-128	128	0
Slovak Republic	1	2	-60	60	
Slovenia	1	1	-27	27	

Source: Results of CAPRI fish market version extracted on 18-03-2019

Table 8-22 Approach MSY for EU countries (unit: ton)

	Appr MSY (EU+ NonEU_EU)	EU landings	Appr MSY (EU)	Belgium	Denmark	Estonia	Finland	France	Germany	Greece	Ireland	Latvia	Lituania	Netherlands	Poland	Portugal	Spain	Sweden	UK
Atlantic herring	1249537	39%	487715	5545	89941	21294	65150	24437	43449	0	8266	11945	3641	57390	32565	17	17	69670	54386
Atlantic Cod	896427	13%	119517	1289	19840	592	470	8818	16049	297	1356	2258	1486	3632	9084	4808	13139	7632	28424
Blue whiting (=Poutassou)	776391	17%	131935	0	17995	0	0	12337	6895	0	13689	0	0	21586	0	4478	27328	4373	23256
Atlantic mackerel	773842	46%	356308	457	26968	151	0	13791	18734	0	60856	112	112	28073	1285	5594	27081	4393	168701
European sprat	348412	92%	320817	18	49505	33213	14972	255	18179	0	0	40113	14510	255	85127	0	0	62755	1913
Haddock Kolja	353939	16%	56115	398	3731	0	0	7640	1491	0	4119	0	0	183	0	0	0	412	38140
Pollock	306049	14%	43513	62	2902	0	0	22115	9270	0	285	0	0	110	0	0	0	399	8371
Capelin	53600	0%	252	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
European plaice	249428	86%	215121	12715	59681	0	0	11116	10152	0	2397	0	0	64762	1612	100	100	1777	50708
European hake	115670	96%	111181	624	4831	0	0	56830	234	0	3331	0	0	512	0	2670	30421	238	11490
Atlantic horse mackerel	210984	89%	187150	14	16148	0	0	4795	8380	0	26496	0	0	35131	0	44453	40061	764	10908
Sandeels (=Sandlances)	139354	76%	106038	0	100026	0	0	0	153	0	0	0	0	0	0	0	0	3673	2187
European pilchard (=Sardine)	45065	100%	45064	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Beaked redfish	43008	8%	3599	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

	Appr MSY (EU+ NonEU_EU)	EU landings	Appr MSY (EU)	Belgium	Denmark	Estonia	Finland	France	Germany	Greece	Ireland	Latvia	Lituania	Netherlands	Poland	Portugal	Spain	Sweden	UK
Norway pout	390000	49%	191812	0	191634	0	0	0	38	0	0	0	0	139	0	0	0	0	0
Atlantic redfishes nei	0	30%	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Norway lobster	36989	96%	35642	555	4621	0	0	4595	19	0	4719	0	0	286	0	124	902	1337	18483
Anglerfishes nei	58296	100%	58294	3210	2036	0	0	25096	1079	0	2741	0	0	928	0	520	4952	12	17721
Northern prawn	83721	22%	18163	0	12316	0	0	0	0	0	0	0	0	41	0	0	0	4544	1261
Ling	48932	23%	11261	54	924	0	0	2961	590	0	525	0	0	6	0	4	1965	20	4209

Source: Froese et al., 2018 and Hannah van Zanten et al., 2019

Table 8-23 Species mapping between CAPRI fish groups and Froese et al., 2018

PFIS		DFIS		CRUS	
Code	*Species*	*Code*	*Species*	*Code*	*Species*
HER	Atlantic herring	COD	Atlantic Cod	NEP	Norway lobster
MAC	Atlantic mackerel	WHB	Blue whiting (=Poutassou)	PRA	Northern prawn
SPR	European sprat	HAD	Haddock Kolja		
CAP	Capelin	POK	Pollock		
HOM	Atlantic horse mackerel	PLE	European plaice		
PIL	European pilchard (=Sardine)	HKE	European hake		
		SAN	Sandeels (=Sandlances) nei Tobisfiskar		
		REB	Beaked redfish		
		NOP	Norway pout		
		RED	Atlantic redfishes nei		
		ANF	Anglerfishes nei		
		LIN	Ling		

Source: own compilation based on Froese et al., 2018 and FAOSTAT group definition

Table 8-24 Percentages of approach MSY and the aggregation to CAPRI species for EU countries (%)

Species	CAPRI species	MSY	Belgium	Denmark	Estonia	Finland	France	Germany	Greece	Ireland	Latvia	Lituania	Netherlands	Poland	Portugal	Spain	Sweden	UK	Other EU
Atlantic herring	PFIS	870792	1.1%	18.4%	4.4%	13.4%	5.0%	8.9%	0.0%	1.7%	2.4%	0.7%	11.8%	6.7%	0.0%	0.0%	14.3%	11.2%	0.0%
Atlantic Cod	DFIS	213083	1.1%	16.6%	0.5%	0.4%	7.4%	13.4%	0.2%	1.1%	1.9%	1.2%	3.0%	7.6%	4.0%	11.0%	6.4%	23.8%	0.3%
Blue whiting (=Poutassou)	DFIS	236988	0.0%	13.6%	0.0%	0.0%	9.4%	5.2%	0.0%	10.4%	0.0%	0.0%	16.4%	0.0%	3.4%	20.7%	3.3%	17.6%	0.0%
Atlantic mackerel	PFIS	323380	0.1%	7.6%	0.0%	0.0%	3.9%	5.3%	0.0%	17.1%	0.0%	0.0%	7.9%	0.4%	1.6%	7.6%	1.2%	47.3%	0.0%
European sprat	PFIS	567749	0.0%	15.4%	10.4%	4.7%	0.1%	5.7%	0.0%	0.0%	12.5%	4.5%	0.1%	26.5%	0.0%	0.0%	19.6%	0.6%	0.0%
Haddock Kolja	DFIS	110590	0.7%	6.6%	0.0%	0.0%	13.6%	2.7%	0.0%	7.3%	0.0%	0.0%	0.3%	0.0%	0.0%	0.0%	0.7%	68.0%	0.0%
Pollock	DFIS	72732	0.1%	6.7%	0.0%	0.0%	50.8%	21.3%	0.0%	0.7%	0.0%	0.0%	0.3%	0.0%	0.0%	0.0%	0.9%	19.2%	0.0%
Capelin	PFIS	7492	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
European plaice	DFIS	201089	5.9%	27.7%	0.0%	0.0%	5.2%	4.7%	0.0%	1.1%	0.0%	0.0%	30.1%	0.7%	0.0%	0.0%	0.8%	23.6%	0.0%
European hake	DFIS	95482	0.6%	4.3%	0.0%	0.0%	51.1%	0.2%	0.0%	3.0%	0.0%	0.0%	0.5%	0.0%	2.4%	27.4%	0.2%	10.3%	0.0%
Atlantic horse mackerel	PFIS	299184	0.0%	8.6%	0.0%	0.0%	2.6%	4.5%	0.0%	14.2%	0.0%	0.0%	18.8%	0.0%	23.8%	21.4%	0.4%	5.8%	0.0%
Sandeels (=Sandlances) nei Tobisfiskar	DFIS	284911	0.0%	94.3%	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	3.5%	2.1%	0.0%
European pilchard (=Sardine)	PFIS	155887	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Beaked redfish	DFIS	5125	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Norway pout	DFIS	96245	0.0%	99.9%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Species	CAPRI species	MSY	Belgium	Denmark	Estonia	Finland	France	Germany	Greece	Ireland	Latvia	Lituania	Netherlands	Poland	Portugal	Spain	Sweden	UK	Other EU
Atlantic redfishes nei	DFIS	19681	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Norway lobster	CRUS	66528	1.6%	13.0%	0.0%	0.0%	12.9%	0.1%	0.0%	13.2%	0.0%	0.0%	0.8%	0.0%	0.3%	2.5%	3.8%	51.9%	0.0%
Anglerfishes nei	DFIS	9420	5.5%	3.5%	0.0%	0.0%	43.1%	1.9%	0.0%	4.7%	0.0%	0.0%	1.6%	0.0%	0.9%	8.5%	0.0%	30.4%	0.0%
Northern prawn	CRUS	9986	0.0%	67.8%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.2%	0.0%	0.0%	0.0%	25.0%	6.9%	0.0%
Ling	DFIS	14453	0.5%	8.2%	0.0%	0.0%	26.3%	5.2%	0.0%	4.7%	0.0%	0.0%	0.0%	0.0%	0.0%	17.5%	0.2%	37.4%	0.0%
	PFIS		10369	298484	96935	142819	64265	140146	0	112348	92417	32282	184560	209959	76172	88653	240658	271038	0
	DFIS		16196	506262	1056	838	156955	70482	529	41818	4026	2649	107000	17703	19092	102053	34703	253015	616
	CRUS		1037	15397	0	0	8577	36	0	8809	0	0	556	0	231	1684	4995	35193	0

Source: Own compilation based on Froese et al., 2018 and Hannah van Zanten et al., 2019

Table 8-25 Values and percentage changes (compared to baseline) of market items for scenario 2 (1000 t; %)

EU members	PROD	AQTOTL	Catch	Processing use	Food use	Imports	Exports
EU28	7724	1579	6146	994	11364	9725	5091
	13%	-16%	24%	22%	1%	-2%	7%
Belgium	33		33	4	248	219	0
	52%		52%	-10%	11%	-2%	
Denmark	942	48	894	584	116	139	381
	25%	-16%	28%	26%	-3%	175%	71%
Germany	329	54	276	17	1108	931	137
	4%	-12%	8%	24%	5%	6%	9%
Austria	3	3	1	2	129	128	0
	-10%	-12%	1%	4%	-5%	-5%	0%
Netherlands	502	62	439	25	287	133	323
	11%	-12%	15%	37%	23%	48%	11%
France	837	278	559	7	1654	1147	322
	10%	-13%	26%	19%	-5%	-4%	55%
Portugal	302	8	294	11	646	538	184
	35%	-23%	38%	29%	-23%	-27%	65%
Spain	1303	312	991	43	1540	892	612
	6%	-17%	17%	0%	5%	-3%	-4%
Greece	222	136	86	11	137	42	116
	-17%	-26%	3%	6%	8%	4%	-31%
Italy	456	197	259	2	2462	2090	82
	-4%	-15%	6%	2%	13%	18%	17%
Ireland	281	60	221	11	127	0	143
	-1%	-12%	3%	28%	10%	-97%	-14%
Finland	204	18	186	4	191	127	136
	23%	-12%	28%	0%	-26%	-34%	40%
Sweden	297	10	287	45	437	353	168
	32%	-12%	34%	-5%	-23%	-28%	69%
United Kingdom	1023	238	785	156	930	345	282
	21%	-12%	37%	48%	-2%	-29%	2%
Czech Republic	31	27	4	4	196	169	0
	-10%	-12%	6%	-33%	5%	7%	43%
Estonia	116	1	115	15	30	9	81
	23%	-21%	23%	-22%	-14%	37%	68%
Hungary	27	20	7	4	77	53	0
	-15%	-20%	6%	-34%	-7%	-5%	
Lithuania	174	4	170	15	153	8	14
	4%	-20%	5%	7%	35%	381%	-65%
Latvia	171	1	171	7	45	2	121
	16%	-22%	16%	7%	41%	217%	10%
Poland	335	42	293	3	398	197	131
	61%	-20%	89%	-18%	30%	25%	138%
Slovenia	2	1	1	2	27	27	0
	-14%	-21%	6%	0%	-16%	-15%	
Slovak Republic	3	1	2		63	60	
	-7%	-20%	6%		1%	1%	
Croatia	79	27	52	1	129	57	6

EU members	PROD	AQTOTL	Catch	Processing use	Food use	Imports	Exports
	-9%	-28%	5%	23%	23%	49%	-67%
Cyprus	6	4	3	4	35	33	
	-7%	-16%	6%	7%	-10%	-9%	
Malta	4	3	1	12	20	28	0
	-12%	-17%	6%	-10%	-10%	-15%	
Bulgaria	18	7	11	1	50	40	6
	-6%	-20%	6%	172%	-22%	-25%	-17%
Romania	22	18	5	4	129	111	0
	-16%	-20%	6%	-32%	0%	2%	

Source: Results of CAPRI fish market version extracted on 18-03-2019

8.3.3 *Scenario 3*

Scenario 3-A

Table 8-26 Feed ingredient share

		RYEM	*BARL*	*OATS*	*MAIZ*	*RAPE*	*SUNF*	*PARI*	*WHEA*	*RAPO*	*SUNO*	*SOYO*	*SOYC*	*FIML*	*FIOL*	*FIOT*
1995																
CRUS	**World**	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.272	0.001	0.001	0.001	0.25	0.19	0.02	0.258
FFIS	**RegHigh**	0.001	0.001	0.001	0.001	0.001	0.001	0.06	0.321	0.001	0.001	0.001	0.23	0.3	0.08	
FFIS	**RegMed**	0.001	0.001	0.001	0.36	0.001	0.001	0.001	0.002	0.001	0.001	0.001	0.37	0.15	0.03	0.079
FFIS	**RegLow**	0.001	0.001	0.001	0.36	0.001	0.001	0.001	0.002	0.001	0.001	0.001	0.42	0.1	0.03	0.079
DFIS	**World**	0.001	0.001	0.001	0.001	0.001	0.001	0.06	0.321	0.001	0.001	0.001	0.23	0.3	0.08	
PFIS	**World**	0.001	0.001	0.001	0.001	0.001	0.001	0.06	0.321	0.001	0.001	0.001	0.23	0.3	0.08	
OFIS	**World**	0.001	0.001	0.001	0.001	0.001	0.001	0.06	0.321	0.001	0.001	0.001	0.23	0.3	0.08	
2000																
CRUS	**World**	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.272	0.001	0.001	0.001	0.25	0.19	0.02	0.258
FFIS	**RegHigh**	0.001	0.001	0.001	0.001	0.001	0.001	0.06	0.321	0.001	0.001	0.001	0.23	0.3	0.08	
FFIS	**RegMed**	0.001	0.001	0.001	0.36	0.001	0.001	0.001	0.002	0.001	0.001	0.001	0.39	0.13	0.03	0.079
FFIS	**RegLow**	0.001	0.001	0.001	0.36	0.001	0.001	0.001	0.002	0.001	0.001	0.001	0.45	0.07	0.03	0.079
DFIS	**World**	0.001	0.001	0.001	0.001	0.001	0.001	0.06	0.321	0.001	0.001	0.001	0.23	0.3	0.08	
PFIS	**World**	0.001	0.001	0.001	0.001	0.001	0.001	0.06	0.321	0.001	0.001	0.001	0.23	0.3	0.08	
OFIS	**World**	0.001	0.001	0.001	0.001	0.001	0.001	0.06	0.321	0.001	0.001	0.001	0.23	0.3	0.08	
2005																
CRUS	**World**	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.272	0.001	0.001	0.001	0.25	0.19	0.02	0.258
FFIS	**RegHigh**	0.001	0.001	0.001	0.001	0.001	0.001	0.06	0.321	0.021	0.001	0.021	0.23	0.28	0.06	
FFIS	**RegMed**	0.001	0.001	0.001	0.36	0.001	0.001	0.001	0.002	0.001	0.001	0.001	0.39	0.13	0.03	0.079
FFIS	**RegLow**	0.001	0.001	0.001	0.36	0.001	0.001	0.001	0.002	0.011	0.001	0.001	0.45	0.07	0.01	0.089
DFIS	**World**	0.001	0.001	0.001	0.001	0.001	0.001	0.06	0.321	0.021	0.001	0.021	0.23	0.28	0.06	

		RYEM	BARL	OATS	MAIZ	RAPE	SUNF	PARI	WHEA	RAPO	SUNO	SOYO	SOYC	FIML	FIOL	FIOT
PFIS	**World**	0.001	0.001	0.001	0.001	0.001	0.001	0.06	0.321	0.021	0.001	0.021	0.23	0.28	0.06	
OFIS	**World**	0.001	0.001	0.001	0.001	0.001	0.001	0.06	0.321	0.021	0.001	0.021	0.23	0.28	0.06	
									2010							
CRUS	**World**	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.272	0.001	0.001	0.001	0.32	0.12	0.02	0.258
FFIS	**RegHigh**	0.001	0.001	0.001	0.001	0.001	0.001	0.06	0.321	0.001	0.001	0.041	0.25	0.28	0.04	
FFIS	**RegMed**	0.001	0.001	0.001	0.36	0.001	0.001	0.001	0.002	0.001	0.001	0.001	0.39	0.13	0.03	0.079
FFIS	**RegLow**	0.001	0.001	0.001	0.36	0.001	0.001	0.001	0.002	0.001	0.001	0.026	0.48	0.04	0.005	0.079
DFIS	**World**	0.001	0.001	0.001	0.001	0.001	0.001	0.06	0.321	0.001	0.001	0.041	0.25	0.28	0.04	
PFIS	**World**	0.001	0.001	0.001	0.001	0.001	0.001	0.06	0.321	0.001	0.001	0.041	0.25	0.28	0.04	
OFIS	**World**	0.001	0.001	0.001	0.001	0.001	0.001	0.06	0.321	0.001	0.001	0.041	0.25	0.28	0.04	

Remark: long texts of abbreviations are displayed in Table 8-1 and Table 8-2

Source: Results of CAPRI fish market version extracted on 18-03-201

Table 8-27 Net revenue and unit value of feed for scenario 3-A (compared to baseline) (Euro/t; %)

Items	Net Revenue					Unit value of total fish feed					Unit value of plant-based ingredients in fish feed				
Species	**CRUS**	**FFIS**	**DFIS**	**PFIS**	**OFIS**	**CRUS**	**FFIS**	**DFIS**	**PFIS**	**OFIS**	**CRUS**	**FFIS**	**DFIS**	**PFIS**	**OFIS**
EU		4634	4593	4215	4342		413	354	687	758		359	317	392	357
		5%	7%	17%	21%		-44%	-47%	-46%	-54%		7%	9%	12%	46%
NONEU_EU		2851	2845	1649	2474		744	541	548	821		677	519	464	800
		15%	7%	30%	3%		-41%	-36%	-54%	-11%		-5%	1%	3%	-4%
AFRICA	3720	2258	2036	1943		568	423	382	478		422	417	378	479	
	9%	2%	1%	6%		-40%	-11%	-9%	-16%		7%	1%	1%	1%	
N_AM	1807	2640	2031	1237		246	406	532	374		225	371	440	364	
	11%	6%	14%	3%		-48%	-36%	-30%	-11%		23%	6%	3%	1%	
MS_AM	2482	2790	2037	543		389	443	526	709		353	417	515	659	
	4%	1%	14%	850%		-40%	-22%	-56%	-42%		7%	2%	2%	28%	
ASIA	2050	2080	1638	2214	2179	245	363	323	296	328	225	357	308	277	300
	2%	0%	17%	6%	18%	-40%	-6%	-42%	-32%	-49%	9%	1%	7%	6%	12%
Norway	5540	5502	6585	4681	4895	543	366		352	862	156	280		254	133
	3%	2%	0%	6%	2%	-39%	-38%		-43%	-42%	-1%	9%		14%	-1%
Chile	3769	2924	3015	7667	2484		847	864		1151		787	866		1198
	0%	16%	7%	0%	6%		-41%	-19%		-12%		-9%	-2%		0%
Bangladesh	2075	2141	1926	2298	2087		432	296				386	292		
	0%	2%	4%	0%	0%		-28%	-25%				4%	4%		
China	2729	1650	3300	1544	2268	215	1098			119	20	806			54
	0%	-1%	0%	0%	1%	-46%	0%			-42%	-6%	0%			-2%
ANZ	2268	1790	1505	2317	2344	210	341	308	306	332	200	342	295	307	305
	-1%	0%	21%	7%	22%	-18%	-5%	-44%	-33%	-54%	2%	0%	8%	4%	14%
World	2083	2188	2258	2254	2223	256	382	359	309	340	234	370	342	283	307
	3%	1%	9%	7%	18%	-40%	-12%	-38%	-33%	-48%	9%	1%	5%	7%	12%

Remark: long texts of abbreviations are displayed in Table 8-1 and Table 8-2

Remark: EU: European Union, NONEU: NonEU_EU member countries in Europe, N_AM: North America, MS_AM: Middle and south America, ANZ: Australia and New Zealand

Source: Results of CAPRI fish market version extracted on 18-03-2019

Table 8-28 Values and percentage change (%) of the quantity use (1000 t) and Armington 1 price (Euro/t) of single ingredients in fish feed (compared to baseline)

		FIML	FIOL	WHEA	RYEM	BARL	OATS	MAIZ	OCER	PARI	RAPE	SUNF	RAPO	SUNO	SOYO	SOYC	FIOT
EU	FEDAGR	704	122	38782	3988	47058	10426	46236	21317		926	2973	362	193	345	23712	
		208.1%	9.6%	0.2%	0.2%	-0.1%	0.1%						0.1%	0.1%	0.3%	-0.2%	
	FEDFIS	78	19	262				78							2	353	155
		-51.4%	-17.7%	-20.6%				-12.4%							89.5%	12.7%	-3.2%
	Arm1P	1571	2138	283	252	289	221	303	286		473	456	1257	1262	1113	509	13
		-43.2%	-4.5%	-0.1%	-0.1%		-0.1%						-0.1%	-0.1%	-0.1%	0.1%	-3.2%
NONEU_EU	FEDAGR	270	54	38210	5989	37797	4848	26966	2585		1158	761	14		1	5905	
		120.5%	12.4%				-0.1%						0.1%		0.1%	-0.7%	
	FEDFIS	364	128	758	3	4	3	109								499	319
		-38.6%	-4.7%	-6.9%	-4.3%	-6.2%	-4.1%	-17.6%								26.4%	-1.3%
	Arm1P	1316	1743	403	238	264	231	276	302		482	491	1321	1022	969	498	23
		-47.6%	-5.4%	-0.2%	-0.1%	-0.1%	-0.1%	-0.1%				-0.1%	-0.1%	-0.1%	-0.1%	0.8%	-1.2%
AFRICA	FEDAGR	102	4	4508	171	4665	57	71529	19329							11108	
		22.3%	2.8%		0.1%		0.1%		-0.1%							-0.6%	
	FEDFIS	35	7	104	3	5		603								952	201
		-39.1%	-2.5%	-3.9%	-1.5%	-0.8%		-3.5%								0.5%	-0.6%
	Arm1P	1180	2375	373	275	366	294	304	314		559	436	1467	1086	1204	546	23
		-47.8%	-5.1%	-0.1%	-0.1%							0.3%	-0.1%	-0.4%	-0.1%	0.1%	-0.6%
N_AM	FEDAGR	283	90	11346	394	15228	4392	191801	34532		515	1142				43349	
		19.8%	2.7%	0.3%	0.2%							0.2%				-0.1%	
	FEDFIS	69	8	149				70								280	233
		-41.9%	-14.4%	-28.2%				-6.8%								16.6%	-4.4%
	Arm1P	1158	1692	291	274	270	249	257	254		380	360	1249	1257	1100	508	22
		-42.3%	-5.3%	-0.2%	-0.1%	-0.1%					-0.1%		-0.1%	-0.1%	-0.1%	0.1%	-4.3%
MS_AM	FEDAGR	14	31	1119	88	373	883	95854	16494							87255	
		23.2%	2.5%		0.1%	0.1%											

		FIML	FIOL	WHEA	RYEM	BARL	OATS	MAIZ	OCER	PARI	RAPE	SUNF	RAPO	SUNO	SOYO	SOYC	FIOT
	FEDFIS	123	41	98		2	2	344								1181	433
		-38.9%	-4.8%	-16.6%		-16.2%	-16.3%	-6.2%								-1.9%	-2.5%
	Arm1P	1308	1765	331	257	284	273	256	271		364	384	1184	1104	1003	528	21
		-47.6%	-6.1%	-0.1%				-0.1%	-0.1%		-0.1%	-0.1%	-0.1%	-0.1%	-0.1%	0.2%	-2.5%
ASIA	FEDAGR	279	35	18468	1860	19147	549	308078	10757		1765	2675				24494	
		7.0%	8.1%	0.1%	-1.4%	0.1%	-0.1%		-0.2%							-0.1%	
	FEDFIS	1521	111	5297	100	112	101	31742			100	118				11681	7889
		-18.6%	-9.4%	-13.0%	-5.1%	-5.5%	-5.1%	-3.1%			-5.7%	-4.9%				1.6%	-2.1%
	Arm1P	1178	1740	323	271	299	270	293	279		428	456	1146	1148	1108	513	22
		-51.6%	-6.5%	-0.3%	-0.1%	0.7%	-0.1%	-0.3%	-0.1%		-0.1%	-0.1%		-0.1%	-0.1%	0.2%	-2.1%
ANZ	FEDAGR	56	8	4726		4548	952	501	5004		1					126	
		23.0%	3.1%	0.1%		-0.1%		0.4%	-0.1%		0.2%					-0.5%	
	FEDFIS	8	4	8				24								14	19
		-27.4%	-16.7%	-30.9%				-19.7%								23.3%	-4.8%
	Arm1P	1473	1840	317	273	291	294	262	282		481	480	1400	1209	1040	515	22
		-45.3%	-5.8%	-0.4%	-0.1%	-0.1%	-0.1%	-0.1%	-0.4%		-0.1%	-0.2%			-0.1%	0.2%	-4.7%
World	FEDAGR	1707	343	117160	12491	128815	22107	740965	110018		4365	7551	377	193	345	195948	
		72.9%	7.1%	0.1%	-0.1%								0.1%	0.1%	0.3%	-0.1%	
	FEDFIS	2197	319	6676	106	122	106	32969			100	118			2	14960	9251
		-27%	-7.6%	-13%	-5%	-5.5%	-5.3%	-3.2%			-5.7%	-4.9%			89.5%	2.4%	-2.2%
	Arm1P	1287	1842	330	248	287	238	280	292		442	447	1204	1116	1067	519	21
		-47%	-5.3%	-0.2%	-0.1%	0.1%	-0.1%	-0.1%	-0.1%		-0.1%		-0.1%	-0.2%	-0.1%	0.2%	-2.1%

Remark: long texts of abbreviations are displayed in Table 8-1 and Table 8-2

Remark: EU: European Union, NONEU: NonEU_EU member countries in Europe, N_AM: North America, MS_AM: Middle and south America, ANZ: Australia and New Zealand

Source: Results of CAPRI fish market version extracted on 18-03-2019

Table 8-29 Impacts of Scenario 3-A on land use change in percentage by CAPRI regions (compared to baseline)

CAPRI region	CERE	OILS	OAFC	VGPM	OCRP	MEAS	OANP	OILP
Europe, NonEU_EU	-0.04%	-0.00%	-0.00%	-0.01%	-0.01%	-0.00%	0.01%	
Switzerland	0.00%	-0.01%	-0.00%	-0.00%		0.00%	-0.00%	
Rest of Europe		-0.08%	-0.08%			-0.01%	0.00%	
Russia	-0.04%	-0.02%	-0.00%	-0.03%	-0.02%	0.00%	0.01%	
Ukraine	-0.03%	0.01%	0.00%	-0.00%	0.01%	0.02%	0.02%	
Belarus	-0.03%	-0.00%	-0.01%	-0.01%	-0.00%	0.00%	0.01%	
Kazachtan	-0.07%	-0.04%	-0.03%	-0.02%	-0.04%	-0.01%	0.02%	
other Former Soviet Union countries	-0.03%	-0.01%	-0.01%	-0.01%	-0.01%	0.00%	0.00%	
Morocco	-0.02%	-0.02%	-0.01%	-0.02%	-0.00%	0.00%	0.00%	-0.02%
Mediterranean countries	-0.01%	-0.01%	-0.00%	-0.01%	-0.00%	-0.00%	0.00%	-0.01%
Tunesia	-0.00%	-0.01%	0.01%	-0.00%	0.00%	-0.00%	0.00%	-0.01%
Algeria	-0.01%	-0.03%	-0.00%	-0.01%	-0.01%	0.00%	0.00%	-0.01%
Egypt	-0.01%	-0.01%	-0.00%	-0.01%	-0.00%	-0.00%	0.00%	
Israel	-0.01%	-0.01%	0.01%	0.00%	0.01%	0.00%	0.01%	-0.05%
Middle East	-0.02%	0.01%	-0.00%	-0.01%	-0.00%	-0.00%	0.00%	-0.01%
Africa	-0.01%	0.11%	-0.01%	-0.02%	0.00%	-0.00%	0.00%	-0.02%
Nigeria	-0.01%	0.02%	0.01%	-0.02%	0.01%	0.01%	0.02%	-0.01%
Ethiopia	-0.01%	0.00%	0.00%	0.00%	0.00%	0.01%	0.00%	
South Africa	-0.00%	0.35%	0.02%	0.05%	0.02%	-0.10%	0.10%	
Africa LDC nes	-0.01%	-0.00%	-0.01%	-0.01%	0.00%	0.01%	-0.01%	-0.02%
Africa rest	-0.02%	-0.01%	-0.02%	-0.04%	-0.01%	0.00%	0.00%	-0.04%
North America	-0.02%	0.01%	-0.01%	-0.01%	-0.00%	-0.00%	0.00%	-0.02%
USA	-0.02%	0.01%	-0.01%	-0.01%	-0.01%	-0.00%	0.00%	-0.04%
Canada	-0.05%	-0.00%	-0.02%	-0.02%	-0.01%	0.01%	0.00%	
Mexico	-0.01%	-0.00%	-0.01%	-0.01%	-0.00%	0.00%	0.00%	-0.02%
Middle and South America	-0.05%	0.02%	0.00%	-0.01%	0.00%	-0.00%	0.00%	-0.02%
Middle and South Americs, ACP	-0.01%	0.02%	0.01%	0.00%	0.00%	0.01%	0.01%	-0.01%
Mercosur	-0.06%	0.02%	0.01%	-0.00%	0.00%	-0.01%	-0.00%	-0.02%
Brazil	-0.04%	0.04%	-0.00%	-0.00%	0.00%	-0.01%	-0.00%	-0.02%
Argentina	-0.10%	0.02%	0.03%	-0.01%	-0.01%	-0.00%	0.00%	-0.02%
Uruguay and Paraguay	-0.04%	0.01%	0.03%	-0.01%	-0.00%	-0.01%	0.00%	-0.02%
Paraguay	-0.05%	0.01%	0.03%	-0.01%	-0.00%	-0.01%	0.00%	-0.02%
Uruguay	-0.03%	-0.01%	0.02%	-0.01%	-0.01%	-0.01%	-0.00%	
Mercosur associated	-0.06%	0.00%	-0.02%	-0.02%	-0.00%	-0.00%	0.02%	-0.03%
Venezuela	-0.06%	0.02%	-0.01%	-0.02%	-0.00%	-0.00%	0.02%	-0.02%
Bolivia	-0.06%	0.00%	-0.00%	-0.01%	-0.00%	-0.00%	0.01%	
Chile	-0.08%	-0.01%	-0.04%	-0.03%	-0.03%	-0.01%	0.02%	-0.04%
Rest of Middle and South America	-0.01%	0.02%	0.00%	-0.00%	0.00%	0.00%	0.00%	-0.01%
Asia	-0.07%	0.02%	-0.00%	-0.02%	0.00%	0.02%	0.01%	-0.02%
India	-0.03%	0.02%	0.00%	-0.00%	0.00%	0.02%	0.02%	

CAPRI region	CERE	OILS	OAFC	VGPM	OCRP	MEAS	OANP	OILP
Pakistan	-0.05%	0.07%	0.03%	-0.00%	0.00%	-0.00%	0.00%	
Bangladesh	-0.01%	-0.01%	0.00%	-0.01%	0.01%	0.01%	0.01%	
China	-0.10%	0.02%	-0.04%	-0.02%	-0.01%	0.03%	0.02%	0.00%
Japan	0.25%	0.06%	0.03%	0.05%	0.03%	-0.06%	0.01%	
Malaysia	-0.21%			-0.06%	-0.05%	0.04%	0.01%	-0.06%
Indonesia	-0.04%	0.00%	-0.01%	-0.03%	-0.00%	0.01%	0.02%	-0.01%
Taiwan	-0.07%		-0.00%	-0.02%	0.00%	0.15%	0.07%	
South Korea	-0.02%	0.02%	0.02%	-0.00%	0.00%	0.01%	0.01%	
Viet nam	-0.45%	0.33%	0.18%	-0.01%	0.02%	0.13%	0.10%	
Thailand	-0.36%	0.10%	0.07%	0.02%	0.05%	0.30%	0.25%	0.05%
Australia and New Zealand	-0.09%	0.04%	-0.03%	-0.03%	-0.03%	0.00%	-0.00%	-0.02%
World	-0.04%	0.03%	-0.01%	-0.01%	0.00%	0.00%	0.00%	-0.02%

Remark: CERE: Cereals, OILS: oilseeds, OAFC: other arable field crops, VGPM: vegetables and permanent crops, ORCP: all other crops, MEAS: meat; OANP: other animal products, OILP: oils

Source: Results of CAPRI fish market version extracted on 18-03-2019

Scenario 3-B

Table 8-30 Impacts of scenario 3-B on fish market items - values (1000 t) and percentage changes (%) compared to baseline

Regions	Species	Aquaculture	Processing use	Food use	Imports	Exports
EU	ACQU	1836	664	11515	9834	4463
		-2.6%	-18.8%	2.5%	-1.2%	-6.1%
	CRUS		0	1563	1388	54
			-56.1%	-0.4%	-0.6%	-2.3%
	MOLS	856	2	2540	1747	396
		-0.9%	-55.8%	-0.9%	-1.4%	-1.8%
	FFIS	700	2	3188	2803	439
		-1.7%	-54.1%	-0.5%	-0.5%	-1.8%
	DFIS	262	250	2227	1770	1040
		-8.5%	-17.9%	1.7%	-9.8%	-16.1%
	PFIS	7	398	1576	1735	2482
		-27.2%	-17.5%	21.4%	8.4%	-2.4%
	OFIS	11	13	421	392	53
		-12.3%	-44.1%	1.6%	-3.7%	-20.3%
NONEU	ACQU	2598	1095	6432	4360	8137
		-3.9%	-19.2%	10.3%	13.9%	1.1%
	CRUS		0	164	148	147
			-70.2%	-2.8%	-2.9%	0.5%
	MOLS	13	1	190	111	86
		-1.1%	-93.2%	-0.7%	-6.7%	2.0%
	FFIS	2279	0	2708	1764	2163
		-3.1%	-52.4%	-0.6%	-0.4%	-2.7%
	DFIS	291	256	1417	459	3670
		-9.6%	-31.7%	4.3%	0.7%	0.9%
	PFIS	6	838	1842	1796	2058
		-28.2%	-13.7%	44.0%	43.6%	5.8%
	OFIS	8	0	112	81	13

Regions	Species	Aquaculture	Processing use	Food use	Imports	Exports
		-3.5%	-48.1%	1.7%	1.0%	-8.2%
AFRICA	ACQU	1964	1193	17702	8411	363
		-0.7%	-27.7%	14.9%	22.6%	-45.6%
	CRUS	26		210	105	80
		-2.4%		-2.3%	-3.6%	0.6%
	MOLS	12		200	105	91
		-1.1%		-1.6%	-3.1%	-0.1%
	FFIS	1636		5312	572	15
		-0.7%		-0.7%	-3.9%	37.0%
	DFIS	288	0	3760	2156	30
		-0.2%	-65.8%	17.5%	35.1%	3.7%
	PFIS	2	1192	7527	5389	125
		-4.0%	-27.5%	30.9%	23.3%	-71.0%
	OFIS		1	692	85	21
			-71.0%	1.6%	3.3%	-18.2%
N_AM	ACQU	1086	859	14266	10483	3323
		-2.3%	-38.9%	2.5%	-3.2%	-5.0%
	CRUS	295	0	2394	1780	375
		-3.4%	-74.9%	-1.3%	-2.0%	-3.8%
	MOLS	277	3	2232	1136	143
		-1.1%	-86.1%	-1.1%	-3.1%	1.7%
	FFIS	509		5723	5297	594
		-2.2%		-1.0%	-1.0%	-1.7%
	DFIS	1	36	1409	1210	2175
		-10.2%	-81.0%	5.6%	-7.6%	-0.9%
	PFIS	4	820	2247	868	13
		-23.2%	-31.4%	20.3%	-12.4%	-90.7%
	OFIS		0	261	192	23
			-71.1%	1.2%	1.0%	-3.5%
MS_AM	ACQU	2954	3773	7021	2209	3207
		-2.3%	-9.9%	5.2%	0.4%	0.3%
	CRUS	722	1	253	14	662
		-2.1%	-74.2%	-2.3%	-9.2%	-1.3%
	MOLS	512	0	1069	108	259
		-4.2%	-75.7%	-2.3%	-6.1%	-1.5%
	FFIS	1712		2121	108	44
		-1.6%		-1.2%	1.4%	-2.7%
	DFIS	8	15	1778	1268	479
		-30.3%	-69.4%	5.1%	3.2%	-3.6%
	PFIS	1	3748	1006	46	1747
		-38.3%	-8.6%	44.8%	-2.3%	2.4%
	OFIS		9	795	665	16
		-71.80%	0.27%	-3.14%	-9.18%	
ASIA	ACQU	86226	4797	117738	23340	33401
		-1.3%	-29.8%	2.6%	5.6%	-2.6%
	CRUS	8207	48	10532	1498	3634
		-2.6%	-75.1%	-0.6%	-8.3%	-3.9%
	MOLS	28573	76	30385	2749	4827
		-0.8%	-61.3%	-0.1%	-3.0%	-3.6%
	FFIS	47260	121	47043	4927	12224
		-0.8%	-60.3%	-0.4%	-1.2%	-0.6%
	DFIS	1072	233	11918	5466	2040

Regions	Species	Aquaculture	Processing use	Food use	Imports	Exports
		-11.1%	-21.9%	13.0%	33.6%	-3.0%
	PFIS	368	1978	11784	5458	6209
		-24.9%	-35.1%	16.5%	7.5%	-5.2%
	OFIS	745	2341	6075	3242	4467
		-9.2%	-16.1%	3.8%	-6.8%	-1.8%
ANZ	ACQU	327	2	1383		430
		-1.4%	-40.3%	1.2%		-2.3%
	CRUS	7		135		9
		-2.2%		-7.2%		2.1%
	MOLS	244		252		236
		-0.9%		-3.7%		0.4%
	FFIS	68		102		14
		-1.6%		-3.7%		1.6%
	DFIS			422		170
				-0.8%		-6.3%
	PFIS	5	2	391		0
		-19.4%	-40.3%	12.8%		-69.7%
	OFIS	3		81		1
		-5.1%		-1.1%		-13.7%
World	ACQU	96990	12382	176059	58636	53323
		-1.5%	-23.8%	4.1%	5.1%	-2.9%
	CRUS	9256	49	15252	4933	4960
		-2.5%	-75.0%	-0.8%	-3.7%	-3.3%
	MOLS	30487	81	36868	5956	6038
		-0.9%	-64.7%	-0.3%	-2.7%	-3.0%
	FFIS	54165	124	66198	15470	15492
		-0.9%	-60.2%	-0.5%	-1.0%	-1.0%
	DFIS	1922	789	22932	12330	9605
		-9.2%	-35.1%	10.5%	15.8%	-2.8%
	PFIS	393	8975	26373	15291	12633
		-24.9%	-21.6%	23.5%	14.6%	-5.1%
	OFIS	767	2364	8437	4657	4595
		-9.2%	-17.0%	3.0%	-5.4%	-2.3%

Remark: long texts of abbreviations are displayed in Table 8-1 and Table 8-2

Remark: EU: European Union, NONEU: NonEU_EU member countries in Europe, N_AM: North America, MS_AM: Middle and south America, ANZ: Australia and New Zealand

Source: Results of CAPRI fish market version extracted on 18-03-2019

Table 8-31 Impacts of scenario 3-B on FIML&FIOL market items - values (1000 t) and percentage changes (%) compared to baseline

		Arm1P	PROD	FEED	FEDAGR	FEDFIS	IMPORTS	EXPORTS
EU	FIML	3133	308	315	178	140	305	297
		13.4%	-8.7%	-18.9%	-22.2%	-13.1%	-18.4%	-7.6%
	FIOL	2484	90	109	91	21	123	85
		10.9%	-7.3%	-19.1%	-18.5%	-10.2%	-16.3%	-5.2%
NONEU_EU	FIML	2907	193	610	104	504	504	87
		15.9%	-26.2%	-14.6%	-15.3%	-14.9%	-11.3%	-24.5%
	FIOL	2079	48	156	38	121	151	41
		12.8%	-14.0%	-14.5%	-20.0%	-10.0%	-13.7%	-11.5%

		Arm1P	PROD	FEED	FEDAGR	FEDFIS	IMPORTS	EXPORTS
AFRICA	FIML	2572	192	124	77	48	97	166
		13.8%	-9.8%	-11.4%	-7.0%	-15.8%	-12.2%	-10.0%
	FIOL	2770	27	10	3	7	13	27
		10.7%	-20.6%	-9.8%	-5.6%	-10.6%	-8.4%	-20.6%
N_AM	FIML	2346	269	302	214	104	100	67
		16.8%	-25.7%	-15.0%	-9.0%	-13.0%	18.2%	-26.6%
	FIOL	2032	106	88	82	9	32	49
		13.7%	-15.9%	-9.5%	-7.1%	-10.2%	-3.9%	-19.7%
MS_AM	FIML	2842	941	181	11	171	83	843
		13.9%	-7.8%	-14.8%	-7.1%	-14.9%	-11.3%	-6.5%
	FIOL	2120	198	64	28	38	37	166
		12.9%	-8.7%	-12.6%	-6.1%	-13.1%	-6.1%	-6.8%
ASIA	FIML	2872	1368	1753	255	1498	697	312
		18.1%	-21.3%	-17.7%	-2.5%	-19.8%	-13.0%	-23.9%
	FIOL	2129	136	128	29	103	90	84
		14.5%	-22.9%	-17.0%	-9.3%	-16.2%	-9.1%	-20.9%
ANZ	FIML	3030	66	51	42	10		24
		12.4%	2.1%	-8.2%	-6.4%	-10.0%		13.7%
	FIOL	2213	5	10	7	4		5
		13.3%	-1.0%	-10.6%	-6.8%	-12.1%		-1.0%
World	FIML	2843	3337	3337	881	2474	1787	1796
		16.4%	-16.5%	-16.5%	-10.8%	-17.8%	-12.1%	-12.2%
	FIOL	2191	609	566	278	302	446	457
		12.7%	-14.2%	-14.9%	-13.1%	-12.7%	-12.2%	-12.2%

Remark: long texts of abbreviations are displayed in Table 8-1 and Table 8-2
Remark: EU: European Union, NONEU: NonEU_EU member countries in Europe, N_AM: North America, MS_AM: Middle and south America, ANZ: Australia and New Zealand
Source: Results of CAPRI fish market version extracted on 18-03-2019

Table 8-32 Revenue analysis of scenario 3-B (% changes compared to baseline)

Continent	Species	NetRev	Producer price	Unit value of feed	Unit value of plant based feed
EU	ACQU	4570	5008	790	1218
		-3.07%	-2.36%	8.06%	0.05%
	MOLS	5065	5065	0	0
		-1.18%	-1.18%	0.00%	0.00%
	FFIS	4322	5081	799	334
		-2.4%	-1.0%	8.3%	0.0%
	DFIS	3755	4674	725	290
		-12.2%	-8.9%	8.1%	0.1%
	PFIS	2026	3692	1383	348
		-43.6%	-28.0%	8.3%	0.0%
	OFIS	2879	4594	1845	245
		-19.6%	-10.4%	11.9%	0.2%
NONEU	ACQU	2351	3527	1304	2502
		-6.1%	-1.6%	8.3%	-0.5%
	MOLS	2978	2978	0	0
		-1.5%	-1.5%	0.0%	0.0%
	FFIS	2362	3598	1355	714

Continent	Species	NetRev	Producer price	Unit value of feed	Unit value of plant based feed
		-5.0%	-0.7%	8.2%	-0.1%
	DFIS	2279	3049	901	511
		-14.4%	-9.9%	6.4%	-0.9%
	PFIS	596	1513	1325	447
		-52.9%	-28.0%	10.6%	-0.4%
	OFIS	2257	3417	926	829
		-6.0%	-3.8%	0.9%	-0.6%
AFRICA	ACQU	2196	2670	485	1659
		-1.2%	-0.7%	2.7%	0.1%
	CRUS	3292	4589	1021	395
		-3.7%	-0.6%	8.5%	0.2%
	MOLS	4454	4454	0	0
		-1.8%	-1.8%	0.0%	0.0%
	FFIS	2196	2645	487	413
		-1.3%	-0.8%	2.5%	0.0%
	DFIS	2008	2567	424	376
		-0.3%	0.1%	1.6%	0.1%
	PFIS	1715	2464	588	476
		-6.4%	-3.8%	2.7%	0.1%
N_AM	ACQU	2095	2578	610	1319
		-3.0%	-1.2%	8.4%	-0.1%
	CRUS	1548	2218	522	183
		-5.3%	-1.0%	10.6%	0.2%
	MOLS	2105	2105	0	0
		-1.5%	-1.5%	0.0%	0.0%
	FFIS	2418	3053	684	348
		-3.0%	-1.2%	7.3%	-0.5%
	DFIS	1474	2508	832	427
		-17.6%	-8.3%	9.3%	0.1%
	PFIS	757	1284	433	361
		-37.2%	-25.3%	2.7%	0.1%
MS_AM	ACQU	2548	3041	627	1762
		-2.4%	-1.2%	5.5%	0.1%
	CRUS	2341	3079	693	330
		-2.1%	-0.2%	7.1%	0.1%
	MOLS	2321	2321	0	0
		-4.6%	-4.6%	0.0%	0.0%
	FFIS	2712	3249	591	407
		-1.9%	-0.9%	4.6%	-0.1%
	DFIS	969	1562	1311	508
		-45.6%	-32.3%	8.5%	0.3%
	PFIS	-590	1080	1355	516
		-713.8%	-25.0%	10.4%	0.1%
ASIA	ACQU	2103	2374	413	1377
		-1.5%	-1.1%	3.3%	0.0%
	CRUS	1978	2528	443	207
		-1.2%	0.3%	8.9%	0.0%
	MOLS	2265	2265	0	0
		-1.1%	-1.1%	0.0%	0.0%
	FFIS	2062	2426	392	355
		-1.2%	-0.9%	1.4%	0.1%
	DFIS	1159	1899	596	288

Continent	Species	NetRev	Producer price	Unit value of feed	Unit value of plant based feed
		-17.6%	-9.3%	7.8%	0.2%
	PFIS	1309	1896	466	259
		-37.3%	-28.1%	7.0%	-0.4%
	OFIS	1594	2430	711	268
		-13.8%	-6.8%	10.5%	0.2%
ANZ	ACQU	6153	6331	688	775
		-1.6%	-1.4%	8.3%	0.2%
	CRUS	5228	6623	983	157
		-3.3%	-0.6%	10.8%	0.2%
	MOLS	6505	6505	0	0
		-1.1%	-1.1%	0.0%	0.0%
	FFIS	5278	5902	635	258
		-2.2%	-1.3%	7.6%	0.1%
	DFIS	6585	5976	0	0
		0.0%	-9.4%	0.0%	0.0%
	PFIS	3174	4053	676	224
		-28.0%	-22.4%	8.6%	0.2%
	OFIS	4435	5029	1674	135
		-7.2%	-5.3%	11.9%	0.3%
World	ACQU	2185	2496	462	1445
		-1.8%	-1.2%	4.3%	0.0%
	CRUS	1999	2570	464	214
		-1.4%	0.2%	8.9%	0.1%
	MOLS	2378	2378	0	0
		-1.2%	-1.2%	0.0%	0.0%
	FFIS	2136	2553	449	369
		-1.5%	-0.9%	2.9%	0.3%
	DFIS	1808	2550	622	324
		-12.7%	-7.8%	6.8%	0.0%
	PFIS	1328	1944	491	263
		-37.2%	-27.7%	6.7%	-0.5%
	OFIS	1629	2481	726	274
		-13.8%	-6.9%	10.2%	0.0%

Remark: EU: European Union, NONEU: NonEU_EU member countries in Europe, N_AM: North America, MS_AM: Middle and south America, ANZ: Australia and New Zealand

Source: Results of CAPRI fish market version extracted on 18-03-2019

Table 8-33 Impacts of Scenario 3-B on land use change in percentage by CAPRI regions (compared to baseline)

CAPRI region	CERE	OILS	OAFC	VGPM	OCRP	MEAS	OANP	OILP
Europe, NonEU_EU	-0.01%	-0.02%	-0.08%	-0.04%	-0.00%	-0.00%	-0.01%	
Switzerland	0.01%	0.00%	-0.00%	-0.01%		0.00%	-0.00%	
Rest of Europe			0.10%	0.10%		-0.01%	-0.02%	
Russia	-0.02%	-0.04%	-0.11%	-0.09%	-0.02%	0.01%	-0.01%	
Ukraine	0.02%	-0.01%	-0.03%	-0.02%	0.01%	-0.00%	-0.00%	
Belarus	-0.00%	0.00%	-0.03%	-0.04%	0.00%	0.00%	0.00%	
Kazachtan	0.00%	-0.01%	-0.05%	-0.05%	-0.01%	-0.01%	-0.00%	

CAPRI region	CERE	OILS	OAFC	VGPM	OCRP	MEAS	OANP	OILP
other Former Soviet Union countries	0.00%	-0.02%	-0.04%	-0.02%	-0.00%	-0.00%	0.00%	
Morocco	-0.00%	-0.01%	-0.05%	-0.13%	0.04%	-0.01%	-0.03%	-0.05%
Mediterranean countries	0.00%	-0.01%	-0.03%	-0.01%	-0.00%	-0.00%	0.00%	-0.03%
Tunesia	0.01%	-0.01%	-0.02%	-0.00%	-0.00%	-0.00%	0.01%	-0.02%
Algeria	-0.00%	-0.01%	-0.04%	-0.01%	-0.03%	-0.00%	0.00%	-0.03%
Egypt	-0.00%	-0.02%	-0.04%	-0.01%	-0.00%	-0.00%	0.00%	
Israel	0.01%	-0.01%	-0.01%	0.00%	0.01%	0.01%	-0.00%	-0.12%
Middle East	0.00%	-0.00%	-0.04%	-0.04%	-0.00%	-0.00%	0.00%	-0.03%
Africa	-0.01%	-0.02%	-0.09%	-0.11%	0.03%	-0.00%	0.00%	-0.09%
Nigeria	-0.04%	0.06%	0.01%	-0.15%	0.05%	0.03%	0.11%	-0.07%
Ethiopia	-0.01%	0.01%	-0.02%	-0.01%	0.00%	-0.00%	0.01%	
South Africa	-0.01%	-0.11%	-0.14%	-0.03%	-0.01%	0.03%	-0.03%	
Africa LDC nes	0.00%		-0.08%	-0.05%	0.02%	0.02%	-0.04%	-0.04%
Africa rest	0.01%	0.04%	-0.20%	-0.43%	0.07%	-0.04%	0.00%	-0.22%
North America	0.01%	0.01%	-0.03%	-0.01%	0.00%	-0.00%	-0.00%	-0.05%
USA	0.01%	0.01%	-0.01%	-0.00%	0.01%	-0.00%	-0.00%	-0.09%
Canada	0.01%	-0.02%	-0.04%	-0.02%	-0.01%	-0.00%	-0.01%	
Mexico	-0.00%	0.01%	-0.04%	-0.03%	0.00%	0.01%	-0.00%	-0.03%
Middle and South America	0.01%	0.02%	-0.03%	-0.02%	0.00%	-0.01%	-0.01%	-0.03%
Middle and South Americs, ACP	0.01%	0.05%	-0.01%	0.00%	0.01%	-0.01%	-0.00%	-0.02%
Mercosur	0.00%	0.02%	-0.05%	-0.02%	-0.00%	-0.01%	-0.01%	-0.05%
Brazil	0.00%	0.03%	-0.04%	-0.02%	-0.00%	-0.01%	-0.01%	-0.05%
Argentina	0.00%	0.02%	-0.05%	-0.02%	-0.01%	-0.01%	-0.01%	-0.06%
Uruguay and Paraguay	-0.00%	0.02%	-0.05%	-0.03%	-0.00%	-0.02%	0.01%	-0.05%
Paraguay	-0.00%	0.02%	-0.05%	-0.03%	-0.00%	-0.02%	0.02%	-0.05%
Uruguay	0.00%	-0.01%	-0.05%	-0.04%	-0.03%	-0.02%	-0.00%	
Mercosur associated	0.02%	0.03%	-0.02%	-0.02%	0.01%	-0.01%	-0.02%	-0.02%
Venezuela	0.01%	0.04%	-0.02%	-0.04%	0.03%	-0.00%	-0.03%	-0.03%
Bolivia	0.00%	0.03%	-0.05%	-0.05%	0.01%	-0.02%	0.01%	
Chile	0.06%	0.03%	-0.01%	0.01%	0.04%	0.02%	-0.05%	0.00%
Rest of Middle and South America	0.00%	0.02%	-0.03%	-0.02%	0.00%	0.00%	-0.00%	-0.02%
Asia	0.03%	-0.00%	-0.02%	-0.03%	0.00%	-0.01%	-0.00%	-0.03%
India	0.01%	-0.00%	-0.01%	-0.01%	0.00%	-0.01%	-0.00%	
Pakistan	0.02%	-0.02%	-0.02%	-0.02%	0.00%	0.00%	0.00%	
Bangladesh	0.01%	-0.01%	-0.01%	-0.02%	0.00%	0.00%	0.01%	
China	0.06%	-0.01%	-0.01%	-0.01%	0.01%	-0.01%	-0.01%	-0.03%
Japan	-0.08%	0.01%	-0.03%	-0.03%	-0.01%	0.03%	0.01%	
Malaysia	0.06%			-0.08%	-0.01%	0.02%	-0.01%	-0.02%
Indonesia	-0.02%	0.01%	-0.07%	-0.18%	-0.02%	0.04%	0.10%	-0.04%
Taiwan	0.04%		0.00%	0.02%	0.01%	-0.03%	0.00%	
South Korea	-0.00%	0.01%	-0.01%	-0.04%	-0.01%	0.01%	0.01%	
Viet nam	0.07%	0.01%	-0.04%	-0.02%	-0.02%	0.01%	-0.01%	

CAPRI region	CERE	OILS	OAFC	VGPM	OCRP	MEAS	OANP	OILP
Thailand	0.08%	0.00%	-0.04%	-0.16%	0.01%	0.01%	0.03%	-0.01%
Australia and New Zealand	0.01%	-0.03%	-0.06%	-0.03%	-0.01%	-0.01%	-0.01%	-0.05%
World	0.01%	0.00%	-0.06%	-0.04%	0.01%	-0.00%	-0.00%	-0.07%

Remark: CERE: Cereals, OILS: oilseeds, OAFC: other arable field crops, VGPM: vegetables and permanent crops, ORCP: all other crops, MEAS: meat; OANP: other animal products, OILP: oils
Source: Results of CAPRI fish market version extracted on 18-03-2019