UNIVERSIDAD DE VALLADOLID

ESCUELA DE INGENIERIAS INDUSTRIALES

Grado en Ingeniería de Organización Industrial

Barriers to the implementation of Circular Economy in fish processing industry

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Valladolid, febrero, 2022.

TFG REALIZADO EN PROGRAMA DE INTERCAMBIO

TÍTULO: Barriers to the implementation of Circular Economy in fish processing industry

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FECHA: 14/02/2022

CENTRO: Faculdade de Ciências e Tecnologia

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RESUMEN

Desde hace varios años las empresas han empezado a dejar atrás un modelo de economía lineal, adoptando el modelo de economía circular que tantos beneficios tanto económicos, sociales y medioambientales genera. Sin embargo, existen diferentes barreras que dificultan su implementación.

El objetivo principal de este estudio es comprender las barreras a las que se enfrentan las empresas de procesado de pescado, un sector que genera muchos residuos y descartes, a la hora de implementar el modelo de economía circular.

De las barreras identificadas por las empresas, pocas son las que coinciden con las que se encuentran en la literatura.

Palabras clave: economía circular, barreras, valorización, pescado, descartes

SUMMARY

For several years now, companies have begun to leave behind a linear economy model, adopting the circular economy model that generates so many economic, social and environmental benefits. However, there are several barriers that hinder its implementation.

The main objective of this study is to understand the barriers faced by fish processing companies, a sector that generates a lot of waste and discards, when implementing the circular economy model.

Of the barriers identified by the companies, few coincide with those found in the literature.

Keywords: circular economy, barriers, valorization, fish, discards

FCTUC FACULDADE DE CIÊNCIAS E TECNOLOGIA
UNIVERSIDADE DE COIMBRA

DEPARTAMENTO DE ENGENHARIA MECÂNICA

Obstáculos à implementação da economia circular na indústria transformadora do pescado

Dissertação apresentada para a obtenção do grau de Mestre em Engenharia e Gestão Industrial

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Coimbra, February, 2022

Acknowledgements

The realization of this thesis would not have been possible without the help of different people who have made it lighter and enriching.

I would like to thank Professor Luis Miguel D. F. Ferreira for his guidance and transmission of knowledge, in addition to always being available to lend a hand even in these difficult times.

I would also like to thank Professor Angel Manuel Gento Municio who has been watching my work from the distance and offering me help when I have needed it.

Thanks to all the employees of the companies interviewed who have sacrificed a few minutes of their work to attend to me and answer my questions.

To my Erasmus friends, my second family. For all the moments spent in our new favorite city, Coimbra. This experience has been unforgettable and I could not have imagined meeting a better group full of incredible people to spend these 6 best months of my life. I know that this friendship is not going to remain in Portugal and then, when this is over, we will continue to strengthen it even if it is from the distance. “Uma vez Coimbra, para sempre saudades”.

Thanks to my family who at any stage of my academic life have offered to help me in any way they could, being a great support for me at all times, and being patience and understanding in the most complicated moments for me, even in Coimbra despite the distance that separates us. I would not be neither the student nor the person I am if it were not for them. Thank you.

Resumo

O modelo "make-take-waste" que tinha sido predominante em todas as empresas, também conhecido como o modelo linear, está a começar a desaparecer das indústrias, especialmente nos países desenvolvidos. É um modelo que cria muitos resíduos, o que o torna nem ambiental nem economicamente insustentável. A economia circular é uma alternativa à economia linear que tem vindo a ganhar ímpeto nos últimos anos. Com base nos seus três princípios, preservar e melhorar o capital natural, optimizar o desempenho dos recursos, e promover a eficácia dos sistemas, a economia circular oferece benefícios claros às empresas que a implementam, não só económicos, mas também ambientais e sociais. Um dos principais objectivos da economia circular é a gestão de resíduos e subprodutos e a procura da sua valorização para garantir que estes descartes tenham valor acrescentado para a empresa. Isto é ainda mais importante na indústria alimentar, pois é um dos sectores que gera mais resíduos.

Este estudo centra-se no sector do peixe, uma vez que normalmente apenas 50% do peixe é colhido para consumo, sendo a outra metade considerada devoluções. O peixe é um dos alimentos mais consumidos no mundo. Com o crescimento da população mundial, tanto a aquacultura como a pesca são forçadas a crescer também. Como a produção está a aumentar, as devoluções na cadeia de produção também estão a aumentar e, portanto, representam um risco para a sustentabilidade do sector.

O principal objectivo deste estudo é compreender as barreiras que as empresas enfrentam quando se trata de implementar um modelo de economia circular. Os principais obstáculos identificados foram o elevado custo da reciclagem, as políticas governamentais e a falta de pleno conhecimento por parte dos trabalhadores do conceito de economia circular. Também é apresentada uma lista das actuais formas mais comuns de valorização das devoluções da produção de peixe, tais como a obtenção de farinha ou óleo de peixe, Quais são as formas mais importantes de valorização, bem como os últimos avanços publicados em estudos, tais como a produção de biocombustíveis ou bioplásticos. A fim de ver os benefícios oferecidos por estas formas de valorização, é apresentada uma tabela comparativa com as formas convencionais de gestão das devoluções.

Poucas barreiras identificadas nas entrevistas coincidem com as extraídas da literatura.

Palavras-chave: Economia Circular, Barreiras, Valorização, Peixes, Descartes, Gestão

Abstract

The "make-take-waste" model that had been predominant in all companies, also known as the linear model, is beginning to disappear from industries, especially in developed countries. Is a model that creates a lot of wastes which makes it both environmentally and economically unsustainable. The circular economy is an alternative to the linear economy which has been gaining momentum in recent years. Based on his three principles, preserving and improving natural capital, optimizing the performance of resources, and promoting the effectiveness of systems, circular economy offers clear benefits to companies which implement it, not only economic, but also environmental and social benefits. One of the main objectives of the circular economy is the management of waste and by-products and the search for their valorization to ensure that these discards have added value for the company. This is even more important in the food industry as is one of the sectors that generates the most waste.

This study focuses on the fish sector, since normally only 50% of the fish is harvested for consumption, the other half being considered discards. Fish is one of the most consumed foods in the world. With the world population growing, both aquaculture and fishing are forced to grow as well. As the production is increasing, the discards in the chain of production are increasing too and therefore poses a risk to the sustainability of the sector.

The primary goal of this study is to understand the barriers that companies faces when it comes to implementing a circular economy model. The main barriers identified were the high cost of recycling, government policies and employees' lack of full awareness of the circular economy concept. Also, a list of the current most common ways to valorize fish production discards, such as the obtention of fishmeal or fish oil, which are the most important ways to valorize them, are presented, as well as the latest advances published in studies, such as the production of biofuels or bioplastics. In order to see the benefits offered by these forms of valorization, a comparison table with conventional forms of discard management is presented.

Few barriers identified in the interviews coincide with those drawn from literature.

Keywords Circular Economy, Barriers, Valorization, Fish, Discards, Management.

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1. INTRODUCTION

In recent years, companies have been paying more attention to valorize wastes and discards from their production process. Nowadays, with new advances in technology and production process, it is possible to get profit of the products that were discarded years ago. This concept belongs what is called Circular Economy.

Circular Economy is an economic model that companies have been using recently which objectives are to use their materials in the more efficient way to minimize wastes, preserving and improving natural capital, and promoting the effectiveness of systems (ITEL, 2019). The benefits that it can be extracted from this model are not only economics, but also environmental and social, as it reduces waste disposal and improve the company appearance.

Specifying a little more on the subject of work, the sector of fish present one of the biggest rates of evolution, talking about production. It has not stopped growing since 2003, and a decline in future years is not expected. In 2019, global production of fish reached the figure of 177.8 in million metric tons, 13 million more than 2014, due to aquaculture increase. From these 177.8 million tons, 156 million were destined to human consumption which is equivalent to an estimated annual supply of 20.5 kg per capita. Aquaculture accounted for 46% of total production and 52% of fish for human consumption (FAO, 2020).

On the other hand, the fish industry generates too much waste and by-products. In some species, only 30% of the raw material is destined to be final product, the rest are considered discards. These by-products are the head, skin, viscera, bones and some muscles which cannot be used to produce the final product.

In the past, these discards were not intended to have a purpose other than to return them to the sea or to serve it as non-optimized animal feed. For a few years now, due to the problem of the management of this waste, since they are increasing each year, and the damage that they cause to the environment, many studies have been devoted to exploiting these materials in order to obtain value-added products. Various ways of valorizing these by-products have been developed, such as obtaining collagen, gelatin, protein hydrolysates, omega-3 fatty acids and hyaluronic acids, but the products derived from these discards that have been on the market longer and are the easiest and cheapest way to valorize fish by-products are fishmeal and fish oil (Ministerio de Agricultura, Pesca y Alimentación, 2012).

The objective of this research is to explore which are the barriers that companies in the fishing processing sector encounter when implementing a circular economy model.

It is also intended to expose the different ways of valorizing the fish by-products, as well as to present the latest advances in new ways of obtaining added value from these discards. A comparison is made in order to see the benefits and disadvantages of different ways of valorization. In addition, a comparison between valorizing the discards and the conventional methods of managing the discards is made to see the benefits of these actions of circular economy.

To begin with, the paper presents a literature review of the circular economy and the barriers that companies face when implementing such a model. Also, within the literature section, the different forms of current valorization of fish discards are presented, as well as new researches that countries deal. The next section will deal with recent fish production data to see the production sizes being carried out. The working methodology is then presented, and the barriers identified by fish production companies when implementing the circular economy model are exposed.

2. LITERATURE REVIEW

2.1. Circular economy

The circular economy model is a concept that was created many years ago, around the 1960s (Badás, 2021). Since its creation, this model has been starting to be used more and more and its definition has been changing with the past of the years. Not so long ago, circular economy was thought as a simpler concept of what it is nowadays. The principles were reducing, reusing and recycling, what is called the 3 Rs, in order to preserve the ecosystem and having an economic development (Yuan et al, 2006).

A more evolved definition of this model could be an economic model aimed at the efficient use of resources through waste minimization, long-term value retention, reduction of primary resources and closed loops of products, by-products and materials within the boundaries of environmental protection and socioeconomic benefits (Murray et al, 2017; Morseletto, 2020).

On the other hand, with a new definition of circular economy, the concept of the 3Rs has been left behind to start talking about the 9Rs (Gutiérrez Villach, 2021):

- Reject what we do not need.
- Reduce our consumption.
- Reuse products in good condition discarded by another consumer.
- Repair to extend the life of a product.
- Refurbish an old product to modernize it.
- Remanufacture or rebuild manually or mechanically what we need.
- Redesign with sustainability and eco-design criteria.
- Recycle raw materials to create new products.
- Recover materials through incineration to generate energy.

To the last decades, almost every industry did not follow this type of work model, in fact they used a linear economic model. The linear economy model is based on two principles: firstly, permanent economic growth, generating industrial growth and the consequent environmental deterioration. Secondly, constant consume, which is made possible thanks to a large number of companies that develop cheap products and accessible to the whole population, so that the development of the economy is boosted and replenished (Morales Tent, 2020). A graphical representation of the linear economy model is shown in Figure 1.

Figure 1. Linear economy (H2AD, 2017).

Nowadays, due to social responsibility and overpopulation, most industries have thrown away the linear economy model in order to reduce economic losses and reduce their environmental impact with their wastes.

The circular economy is based in three principles (ITEL, 2019):

1. **Preserving and improving natural capital.**

Whenever it is necessary to use resources, the circular economy selects them in a clever way using renewable supplies and high-performance resources if it is possible.

2. **Optimizing the performance of resources.**

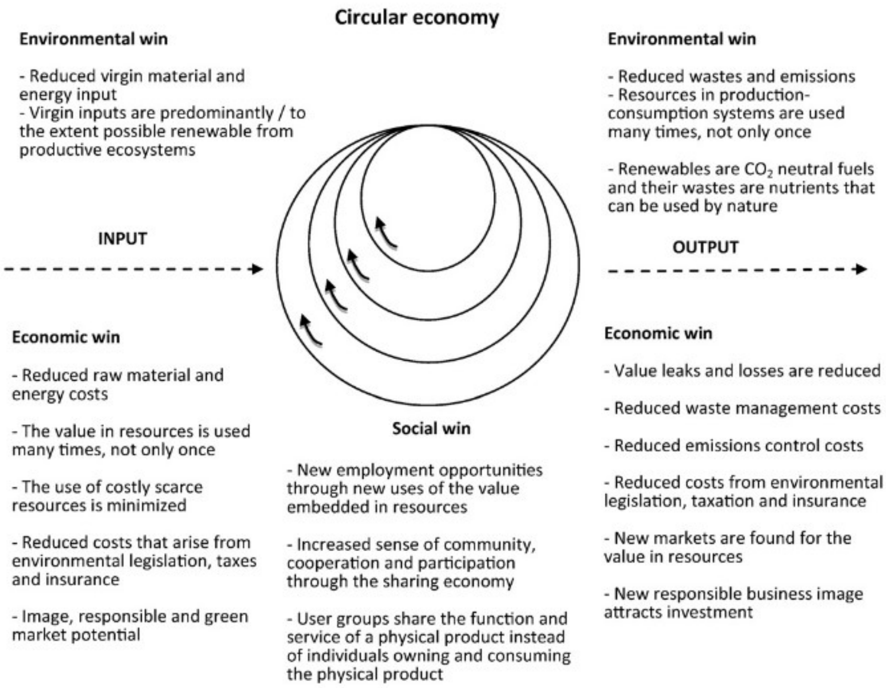
Maximizes utility of all products and components. This involves designing to remanufacture, refurbish and recycle to keep technical components and materials in circulation, thus contributing to optimizing the economy.

By keeping products in use for as long as possible, and by focusing on their performance, we are retaining the maximum economic value.

3. **Promoting the effectiveness of systems**

It detects and removes negatives external factors. This includes controlling in a proper way such issues as land use, air and water pollution, or the discharge of toxic substances.

What can be extracted is that implementing in a proper way this model and following the principles, it is possible to obtain multiples benefits from it, in various aspects, not only in economic or environmental situations but in socials ones too. For example, new employment can be created if circular economy is implemented as new ways of working open up with waste management. Also, climate change is a current topic and reducing wastes and contributing to the environmental problem could attract new clients as the company improve its image (Korhonen et al, 2018). In conclusion, there are a lot of benefits that can be extracted in the implementation of the circular economy. A resume of these benefits can be seen in Scheme 1.



Scheme 1. The win-win-win potential of circular economy (Korhonen et al, 2018).

Over the years, it has been detected a great impact of this model in the European Union thanks to the policy that has been applied. It reduced waste on a per capita basis and landfill and incinerating has been decreasing. In addition, energy recovery and recycling and composting activities have increased. Waste burning in order to produce heat or power is one of the best options to manage the residues and is a matter to be taken into account in the section on renewable energies (Doussoulin, 2020). An evolution of waste management in the European Union is represented in Figure 2.

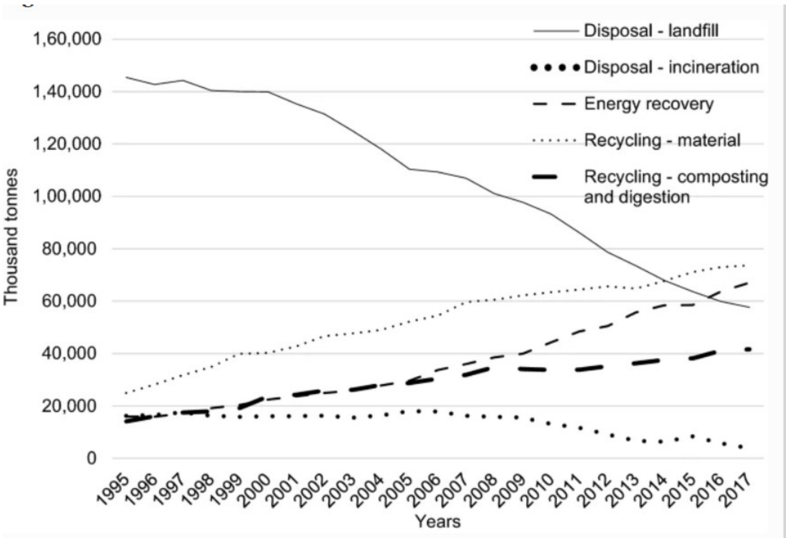


Figure 2. European Union waste management in thousands of tons (Doussoulin, 2020).

So important is the circular economy becoming today that the European Union began developing in 2015 a proposal to lead its countries towards this model. The plan sought to extract maximum value and use from all raw materials, products and waste, promoting energy savings and reducing greenhouse gas emissions. The European Union attaches so much importance to the incorporation of the circular economy model that it the plan had financial backing from the ESI Funds, €650 million from Horizon 2020 and €5.5 billion from the Structural Funds for waste management and circular economy investments at national level (European Comission, 2015).

In March 2020, The European Commission adopted the new circular economy action plan, one of the main building blocks of the European Green Deal, Europe's new agenda for sustainable growth. The EU's transition to a circular economy will reduce pressure on natural resources and will create sustainable growth and jobs. It is also a prerequisite to achieve the EU's 2050 climate neutrality target and to halt biodiversity loss. These are its objectives (European Comission, 2020):

- Make sustainable products the norm in the EU;
- Empower consumers and public buyers;
- Focus on the sectors that use most resources and where the potential for circularity is high such as: electronics and ICT, batteries and vehicles, packaging, plastics, textiles, construction and buildings, food, water and nutrients;
- Ensure less waste;
- Make circularity work for people, regions and cities;
- Lead global efforts on circular economy.

To achieve these objectives, the European Union has established 35 actions divided into 7 groups such as key product value key; less waste, more value; or crosscutting actions (Annex A).

In addition, companies want to represent that they follow a circular economy model, which is why many of them audit to obtain different certificates. ISO certificates are excellent tools that help the circular economy. Some of the ISO standards that are aligned with the circular economy include (Gabarró Sust, 2021):

- ISO 14001 environmental management standard certificate. This is the most common environmental management certification;
- EMAS Verification. It implies excellence in environmental management;
- ISO 50001 energy efficiency certificate, to reduce the carbon footprint in the production process;
- ISO 14006 certificate to implement an eco-design management system;
- ISO 9001 certified. Quality management helps to take on board the strategy linked to the circular economy.

The benefits that countries are experimenting with the circular economy are so favorable that they are starting to create medium-term plans with big objectives. Spain has created "España Circular 2030", a plan with goals such as reducing 15% waste generation comparing with 2010, reducing by 30% the national consumption of materials in relation to GDP, taking 2010 as the reference year, or reducing food waste generation in all food chains: 50% reduction per capita at household and retail consumption level and 20% in production and supply chains from 2020 (Ministerio para la Transición Ecológica y el Reto Demográfico, 2020).

In Spain, some indicators have revealed that changing from a linear model to a circular economy have improved the efficiency of the company through reducing its costs more than 12% and increasing turnover by 20% (Morales Tent, 2020).

It is obvious that the circular economy has a great impact in all kinds of sectors, but it is more important in the food sector. In Spain the food sector is the leading manufacturing branch of the industrial sector. It has 130,795.80 million of Euros of turnover, which represents 23.3% of the industrial sector, 22.1% of people in employment and 19.2% of value added. It also represents 2.5% of Spain's GDP (in GVA) (Ministerio de Agricultura, Pesca y Alimentación, 2020).

One of the principal objectives that this model has is the treatment of the wastes and by-products and the food industry is the one who produce more of these materials. Among the main causes of waste in this sector are the detection of problems that prevent compliance with product quality criteria (23.02%), losses generated during the production process (22.2%) and failures of machinery (18.2%) (Agronegocios, 2020).

The amount of waste resulting from this activity represents millions of tons generated annually, threatening the sustainability of this sector. The objective of this sector is to design a system of solutions to obtain value-added products that can be used or marketed at a later date, through the industry's waste and by-products in order to eliminate waste disposal. (Baniasadi et al, 2016).

In the fish industry is even more significant. Such is the case that not even the 50% of some fishes can be consumed. Taking the tuna example, only the head is about 10% of the whole fish, the skin can be up to 3% and the spines might be between 9 and 15% of the tuna. Viscera of tuna represents almost the 20% of the animal and finally the rest of the muscles which can´t be consumed can go between 15-20% of the fish. That left us that about 40% of the initial product will be good to be consumed. That is why companies must pay attention to by-products, not only for making a profit of these materials but also for reaching an economy circular and being more sustainable (Ministerio de Agricultura, Pesca y Alimentación, 2012).

Most of the by-products generated by this sector are classified as category 3 SANDACH, according to applicable legislation. Category 3 SANDACH[1] is the lowest risk waste, and this group includes bodies or parts of slaughtered animals that are fit for human consumption but are not finally intended for that and do not show signs of communicable disease (Anfaco, 2020).

The objective being set by this sector is to reuse 100% of the by-products through the various forms of recovery that have been investigated so far, trying to ensure that the level of waste generated is zero.

[1] SANDACH is an acronym for composter of aquaculture animal byproducts not intended for human consumption.

2.2. Barriers to circular economy

Although much progress has been made in the fish sector to achieve a circular economy model, there are still drawbacks that prevent it from being achieved in an easier way.

The barriers that can be found are most often connected to each other, and they show the complexity of circular economy and what is required for a transition, both multi-dimensional and multi-domain (Ritzén & Sandström, 2017). Many studies have been made in order to expose the barriers to achieve the circular economy. From an overall point of view, it can be said that exist 2 types of barriers, the external ones (capital support barrier, policy support barrier and information support barrier) and internal ones (tangible resources, intangible resources, capacities) (Galvão et al, 2018).

From all the studies that have been carried out, it can be concluded that the barriers can be organized into 5 categories: financial, technological, market, social and institutional/regulatory. The barriers are interlaced and have inter-dependencies. The fact that the institutional and social barriers might be affected by the financial and technological barriers must be considered when analyzing the obstacles hindering a circular economy to develop (Grafström & Aasma, 2021).

Among all the barriers that can be found in different papers, the most frequently repeated in each category have been collected and exposed in Table 1.

Barrier category	**Challenges**
Financial	• Need for high long-term investments • Costly management and planning processes due to more complex practices • Limited funding for circular economy business models • Low virgin material prices
Technological	• Need for technical and technological know-how and expertise

	• Adoption of specific technologies (e.g., recycling technologies) for the redesign of circular products and production systems maintaining the same quality level • Development of methodologies and procedures for dissemination of innovation without excessive delay between design and diffusion phases • Poor quality of recycled goods • Limited attention to end-of-life design
Market	• Poor institutional cooperation across international supply-chains • Stakeholder relationship: compatibility with partner business models; lack of supply network support; geographical dispersion, poor services and infrastructures, conflict of interest within companies and misaligned profit-share along supply chain • Customer acceptance: specific restrictions, rigidity in customer behaviors and business routines • Lack of market mechanism for recovery
Social	• Lack of consumer enthusiasm and awareness • Limited community and business acceptance for sharing models • Inertia in consumer behavior and business culture • Consumer preference for new products • Low circular economy concept understanding
Institutional/regulatory	• Obstructing laws and innovation • Complex regulations • End to end visibility and forecasting • No sense of urgency for some companies

	• Conservative, uncollaborative and risk-averse industry

Table 1. Barriers that limit the implementation of circular economy (Grafström & Aasma, 2021; Bianchini et al, 2019; Hart et al, 2019).

At the financial level, many studies agree that the high investment costs are the most pressuring one. In addition, another barrier categorized at another level, lack of information, means that when implementing a circular economy model, the objectives are not well defined and the costs are higher than they should be. Also, raw materials are often cheaper than the recycled ones which makes some companies reluctant to invest in them.

For the technological category, the main problem is the need for technical and technological know-how expertise and mechanisms. Monitoring the progress of the circular economy implementation requires greater investment, especially to obtain relevant data both in the production and consumption phases. This is why specialists need technical skills and knowledge and the proper technological mechanisms in order to carry out their work.

At the market level, the main barrier to overcome is the lack of collaboration between supply chains actors. Probably the central reason of this barrier is the competitive instinct that many companies have which makes them not to cooperate between them. Also, collaboration is usually mentioned in terms of vertical collaboration along the supply chain but exists a lack of consideration of horizontal cooperation in the supply chain (Hart et al, 2019).

In the social category, the most evident barrier is the lack of awareness and knowledge from the consumers. They are accustomed to the throwaway model and the misinformation about the use of recycled goods prevent them from changing their mentality. Also, some people who are aware of the concept of circular economy, prefer to pay less for products that come from raw materials than paying more for products which come from recycled materials.

For the last level, the institutional one, the main barriers that are usually mentioned in studies are the obstructing laws and regulations. Countries can find regulations for recycling, waste management and energy recovery, but everything related to eco-design, consumption and reuse has less severe policies. Also, the lack the no sense of urgency of changing from the linear model to circular economy, primarily in developing countries, is one of the most important barriers in this category to overcome.

This is a summary of the barriers that are most frequently repeated in the studies for each category. However, a study carried out by Werning & Spinler (2020) has managed to quantify the barriers by giving them a value of impact within the company, thus being able to observe which barriers have more weight than others and how easy it is to overcome them. The results of the study can be seen in Scheme 2.

#	Barrier	Resistivity	Impact Score
1	Performance based sales	High	45
2	Optimal production setup	High	55
3	Potential cannibalization	High	29
4	Fashion vulnerability	High	64
5	Reverse Logistics Organization	High	
5a	Redesign acquisition process	Low	50
5b	Recovery leakages	High	24
5c	Reverse channel selection	Low	14
5d	Cost of reverse logistics	Low	43
6	End to end visibility and forecastability	High	78
7	Quality uncertainty of returns	High	43
8	Feedstock volatility/Quantity uncertainty	High	43
9	Correct forecast of needed spare parts	High	38
10	Willingness to take on long-term strategy	High	52
11	Recovery Process	Medium	
11a	Redesign recovery process	Medium	36
11b	Design for durability, etc.	Medium	40
11c	Product complexity	Low	19
12	Reduction of volume benefit	Medium	7
13	Willingness to have access over ownership	Low	14
14	Redesign remarketing process	Low	24
15	Control at point of sale	Low	21
16	Integration of IoT for performance-based BM	Low	14
17	Collaboration between departments	Low	66
18	Clean/waste free production	Low	45
19	Awareness of raw material supply	Low	7
20	Reverse Logistics Stability	Low	
20a	Disruption in collection process	Low	36
20b	Fragile return and collection system	Low	36
21	Redesign spare part logistics	Low	5
22	Legislation change	Low	16
23	Raw material availability volatility	Low	22

Scheme 2. Evaluated barriers with organizational resistivity and impact score (Werning & Spinler, 2020).

"End-to-end visibility and forecasting" has the highest score of 78 points and also has a high resistivity to be overcome and the next two, "collaboration between departments" and "fashion vulnerability" have more than 60 points. Using this as a first indication of which barriers have a high impact on the value chain, it can be observed that this often correlates with the resistivity of the barriers. If so, the barrier is important for transitioning yet is difficult to overcome (Werning & Spinler, 2020).

However, this study has been done focusing on a large-scale, international manufacturing firm. Companies from other sectors, sizes or countries may experience different results as other barriers may be encountered or may not have the same importance as those analyzed in this study.

From all the studies that have been published about barriers in the circular economy, it can be said that not all of them have the same weight in different companies; it will depend on many factors.

A factor to be taken into account would be the country where circular economy is being applied. In developing countries, the lack of developed technologies is the main barrier to overcome. In many countries, separation of waste is limited, which causes real or perceived problems with the quality of recycled goods and materials. One issue is how recycled goods can be of lower quality or less flexible than virgin material. Awareness and sense of urgency are probably the following main barriers. Consumers do not have the enough knowledge about sustainability so they do not feel it is important to consume recycled products (Grafström & Aasma, 2021).

In contrast, in the European Union, a region where the countries are more developed, cultural barriers are the most pressing ones, in particular the lack of interest and awareness from the consumer as well as the hesitant company culture. Meanwhile, none of the various technological barriers surveyed are among the most pressing CE barriers. Rather, the technological barrier 'Lacking ability to deliver high quality remanufactured products' even ranks as the least pressing barrier (Kirchherr, et al., 2018).

Another consideration is the sector of the companies. Depending on it, one barrier might be more difficult to overcome than another. For example, in the automobile industry, one extremely relevant barrier to circular economy implementation is the unawareness of the model (Agyemang, et al., 2019).

On the other hand, in the coal sector the main challenge might be the lack of technology. In this sector exists the necessity to refill solid waste as it has an enormous socioeconomic and environmental pressure, but lacks of new technology make it very difficult to surpass these needs (Galvão et al, 2018).

In manufacturing industries, it is difficult to focus only in one main barrier, but it can be concluded that the most repeated category is the technological one as they face barriers as quality issues in recycled materials, design and production of the product and disassembly of products. Other barriers that are very present in the implementation of circular economy in this sector are supply chain complexities, coordination problems between companies and high start-up/investment cost (Jaeger & Ypadhyay, 2020).

Talking about the plastic production sector, where bioplastics have become to gain momentum, among the many barriers they face such as customers' disinterest towards sustainable purchase, absence of constant volume of plastic waste and the more uncompetitive prices of recycles than virgin polymers, the most pressing barrier is the overall lack of information on recycled plastic composition (Paletta et al, 2019).

In the agri-food sector, barriers that have been found follow the line of barriers to a general circular economy model and they can be classified in the same categories. From all the studies that have been made, 10 main barriers to the implementation of the model in this sector have been identified (Liu et al, 2021; Farooque et al, 2019):

1. Weak legal enforcement, especially in developing countries;
2. Inadequate infrastructure for food recovery;
3. Organizational culture and management. In some countries, the habitants don't have the habit of recycling;
4. Lack of expertise, technology and information since circular economy is a relatively new concept;
5. Lack of collaboration from supply chain actors;
6. Lack of financial resources for investments such us advanced technologies;
7. Lack of economies of scale, especially for household food wastes;
8. Lack of environmental education and accountability. The current environmental education system focusses more on professional education and do not pay much attention on non-professional education, day-to-day consumption and business-oriented behavior relating to food wastes;

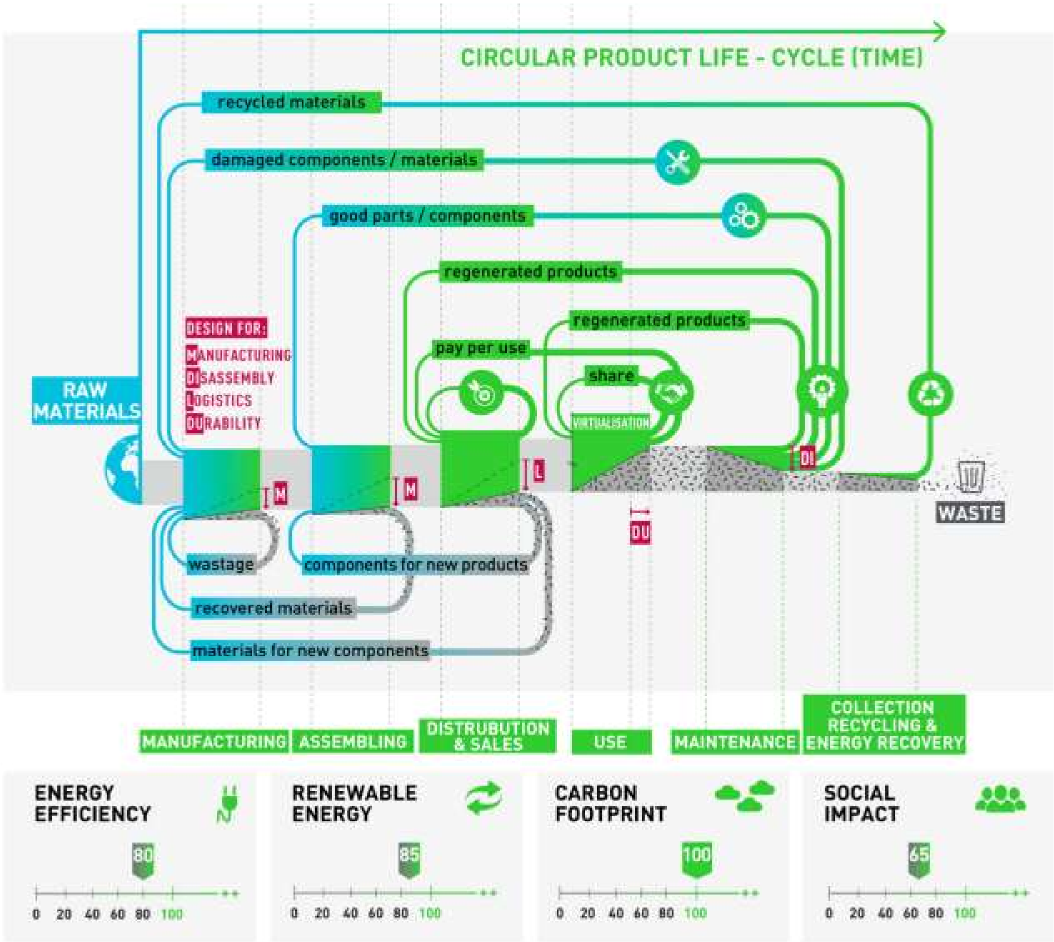
9. Lack of benchmarking and standard. It is not easy to find benchmarking companies or sustainable food and waste management practices in developing countries yet;
10. Cost barrier. The margin in value recovery from food wastes is low and has a high cost in logistics.

In relation with the fish production, it is difficult to find articles related to barriers when implementing the circular economy model. However, (Farnet, 2018) outlines the following 7 challenges as the main ones that fish production companies may face:

- Finding the necessary funding/investment from either the public or private sector in order to investigate new ways to valorize the discards;
- High cost of recycling. It may be expensive and time consuming to collect, sort and process waste;
- Conducting feasibility studies to determine whether a valorization plan can be turned into a viable business;
- Searching for information about different circular economy initiatives, investigating and looking for similar projects to provide a model are all time-consuming factors which can delay profitability;
- Licensing for new innovations can be complicated and legal expertise might be necessary;
- There could be legal constraints to implement certain projects. Different Member States have their own legislation when it comes to fishing waste and marine litter.

The uncertainties and the risks associated with the implementation of a circular business model are related to the CE model framework, which is by nature networked. The idea of closing material loops does not only involve a company and its boundaries, but it is a matter of a system of business models which act together. The complicated interaction between those involved causes unpredictable flows, which have a direct effect in the quality, quantity and price of the products, affecting the value chain of the companies (Bianchini et al, 2019).

Bianchini et al (2019) developed a circular business model visualization tool that includes all the flows of the circular economy and quantifies the results of the levels of waste generated and the benefits obtained if the above-mentioned barriers are overcome and the model is implemented. The visualization tool mentioned can be seen in Scheme 3.



Scheme 3. Visualization tool of a circular business model developed by (Bianchini et al, 2019).

Although many actions have been taken to overcome these barriers, there are some complications. Support from governmental and non-governmental entities is needed, as well as organizations that help, promote, regulate and monitor circular economy implementation. Also, greater societal knowledge about the circular economy would be necessary to put more pressure on companies that do not see the need to switch to a circular economy model (Galvão et al, 2018).

As seen above, there is no consensus on the barriers to implementing the circular economy in a working model. Apart from the fact that the barriers may not be the same depending on different factors, the studies do not agree on which are the most important barriers to overcome. In fact, in the study conducted by Werning & Spinler (2020), they determine that the most important barrier they encounter in the manufacturing sector is the lack of visibility and foresight, but in the article published by Jaeger & Ypadhyay (2020) they do not even mention it.

Much progress has been made in recent years on the road to implementing the circular economy in companies, but until a more detailed analysis and a more precise quantification of the barriers that can be found the way to achieve this model will continue to be complicated.

2.3. Valorization of fish by-products

Every year more fish is being produced and consumed and thus, more by-products are also being generated. Fish processing industries produce large amounts of fish waste every year that represent approximately 25% of the total production. As it was discussed before, between 20 to 70 % of the fish is considered as wastes, depending on the level of processing and type of fish (R. Peñarrubia et al, 2020). These residues should not be seen as waste but as raw materials which will have a value-added.

To begin with, it is necessary to identify what are the fish's by-products. The part of the fish that is consumed are the fillets. In the fish transformation industry, it is necessary to separate the rest of the fish and process only the part that can be consumed. The remaining part of the fish that will not be used in the final product as the head, skin, spines, viscera, like liver and roe, and the muscles of the fish that cannot be consumed, were considered as wastes.

For several years, many studies have focused on the importance of valorize these by-products in order to get profit of them and not considered them as waste. Nowadays, a lot of process are implanted with the aim of obtaining value-added products. Some of them are already very evolved and have been commercialized with for several years, such as fishmeal and fish oil, and there are others that have been obtained by different and innovative processes since a few years, like hyaluronic acid. Some of these value-added products can be extracted only from specific parts of the fish, like collagen or gelatin, and others can be obtained from every part of the fish, like fishmeal. That is why is easier to get this material as it is not necessary to separate the different by-product in order to obtain the final product (Ministerio de Agricultura, Pesca y Alimentación, 2012).

In Table 2 it is exposed the different ways of valorization of fish by-products and from which part of the animal can be extracted.

By-products	Valorization's ways
Head	Fishmeal, fish oil, hyaluronic acid, Omega 3 fatty acids
Skin	Fishmeal, fish oil, collagen, gelatin, hyaluronic acid, Omega 3 fatty acids
Spines	Fishmeal, fish oil, collagen, gelatin, Omega 3 fatty acids
Viscera	Fishmeal, fish oil, protein hydrolysates, Omega 3 fatty acids
Rest of muscles	Fishmeal, fish oil, Omega 3 fatty acids, hyaluronic acid

Table 2. Valorization's ways of fish by-products (Ministerio de Agricultura, Pesca y Alimentación, 2012).

These are the most advanced uses of the by-products generated in fish production, which have some applications that are very useful for other industries.

2.3.1 Collagen

Collagen is a fibrous protein and is used to make connective tissue and it can be found in materials as skin, tendons and bones. It represents between 25-30% of the protein's total content in mammals (Ministerio de Agricultura, Pesca y Alimentación, 2012). 27 types of collagens have been identified and collagen type I is the most frequent one and is known as fibrillar collagen and plays a structural role by contributing to the molecular architecture, shape and mechanical properties of skin tissues (Ben Slimane & Sadok, 2018).

Traditionally, collagen have been obtained from mammalian animals but due to its potential risk for contamination and religious backgrounds, these sources have been avoided (Ideia et al, 2020). Since then, extraction of collagen from fish by-products has been an alternative because of the absence of disease transmission and dietary restriction.

All through fish processing operations, the elimination of collagen-containing materials could account for as much as 30% of the total by-products generated after filleting (Karayannakidis et al, 2014).

So far, collagen extraction has been developed only in fish from marine origin such as cuttlefish, octopus, squid, jellyfish, starfish, sea urchin, sea cucumber and some sponges (Ben Slimane & Sadok, 2018). It would be a good point of interest to develop work in inland fish where the water has warmer temperature and better thermal stability (Rbk, 2019).

Its applications are (Ministerio de Agricultura, Pesca y Alimentación, 2012; Rbk, 2019):

- Cosmetic products for rough skin;
- Scaffolding material and tissue engineering;
- Biomedical applications;
- Agriculture purpose.

2.3.2 Gelatin

Gelatin is a thickening agent made of the protein collagen. It is extracted by boiling the bones, skin and connective tissue of animals with water (Ministerio de Agricultura, Pesca y Alimentación, 2012). Gelatin has been extracted mostly from pig and cattle bones, skins and hides. On these days, getting gelatin from fish discards is growing interest, not only for cultural reasons but also because of better properties (Vázquez et al, 2021).

The great variety of aquatic species results in gelatins with very different characteristics. This has aroused the interest within the scientific community to characterize the gelatins obtained from the different species, both their physic-chemical characteristics and their functional properties, so gelatins extracted from warm water species tend to have better rheological properties and greater thermostability than gelatins obtained from cold water species. However, the quality of the gelatin will also depend on the type of species, the age of the animal, the tissue from which the gelatin is extracted, either skin, spines or scales and mainly the method of extraction (Flores Pino, 2017).

The different uses of gelatin in the food, pharmaceutical or cosmetic industry give it sufficient value to be a strong way of valorization. Apart from the different uses already mentioned, gelatin is being studied for its functional properties including emulsifying, foaming, water and oil holding capacity as well as its mechanical and biological properties (Ideia et al, 2020).

Applications (Ministerio de Agricultura, Pesca y Alimentación, 2012):

- Stabilizer and emulsifier in the food industry.
- Excipient in the pharmacology industry.
- Production of photographic films, graphic films and X-ray films.
- Supporting material with which stem cells are implanted

2.3.3 Protein Hydrolysates

Protein Hydrolysates are a mixture of amino acids prepared by splitting a protein with acid, alkali, or enzyme. Such preparations provide the nutritive equivalent of the original material in the form of its constituent amino acids and are used as nutrient and fluid replenishers in special diets or for patients unable to take ordinary food proteins (Medical Dictionary, 2003).

These products are an excellent nutritional source as they contain all essential and non-essential amino acids. In addition, they have improved functionality with respect to native proteins in various aspects such as better solubility, better water retention capacity and better emulsifying capacity (Villamil et al, 2016).

The degree of hydrolysis is the fundamental property of a hydrolysate and will largely determine the remaining characteristics of it and therefore its possible use. It is defined as the percentage of broken peptide bonds relative to the original protein. The degree of final hydrolysis is determined by the conditions used, these being the substrate concentration, the enzyme/substrate ratio, incubation time and physic-chemical conditions such as pH and temperature (Benítez et al, 2008).

Recently, bacterial fermentation has been proposed in order to obtain fish hydrolysates. The results obtained with these studies promised bioactive properties, both antioxidant and antimicrobial, turning them suitable to be used in food industry. Nowadays, research on fish protein hydrolysates is mainly focused on bioactive peptides due to their reported biological functions with potential applications in the food industry and benefits to human health (Ideia et al, 2020).

The applications that can be given to hydrolyzed proteins are found in the world of food. Depending on their degree of hydrolysis, they can be grouped into three different kinds as shown in Table 3.

Kind of hydrolysis	**Grade of hydrolysis**	**Application**
Low grade	1-10%	Improvement of functional properties
Variable grade		Flavoring
Extended	>10%	Special diets

Table 3. Applications of Protein hydrolysates depending on the kind of hydrolysis (Ministerio de Agricultura, Pesca y Alimentación, 2012).

2.3.4 Omega-3 Fatty Acids

Omega-3 fatty acids are essential fatty acids that are found in high proportion in the tissues of certain fish and in some plant sources. Of these, the most important are eicosapentaenoic acid (EPA) and docosahexaenoic fatty acid (DHA), which are obtained almost exclusively from marine sources. These are some of the fatty acids that contain the best properties for human health (Ministerio de Agricultura, Pesca y Alimentación, 2012).

Omega-3 fatty acids are present in every part of different fishes, so that is why it can be extracted from numerous species. For example, omega-3 can be obtained from the liver and skin of the tuna, different parts of sardines, sea bream and sea bass head, gills, guts and fins. It can also be found in muscles, bones and skins of Atlantic salmon or hake's skin (Ozogul et al, 2021).

Intake of omega-3 fatty acids is important for normal neurobiological functions, for infant brain development during pregnancy and after birth, protection against dementia, Alzheimer's and Parkinson's disease, and maintaining mental health It is also important for reducing the risk of cardiovascular diseases that have arisen in the Western world. Omega-3 fatty acids may reduce this risk by decreasing blood pressure, arrhythmia, heart rate and thrombosis, and increasing vasodilatory response and myocardial efficiency. Furthermore, consumption of omega-3 can reduce lipogenesis and inflammation, and potentially reduce the risk of cancer by inhibiting carcinogenesis (Ozogul et al, 2021). Most recently, Weill et al (2020) hypothesized that omega-3 polyunsaturated fatty acids (PUFA) intake could reduce hospitalization and mortality and accelerate recovery through prevention of the cytokine storm that occurs in around 10% of Coronavirus SARS-Cov-2 patients. In some cases, the correlation between the intake of omega-3 fatty acids and their health benefits lacks the evidence of clinical studies although their role as a functional food component is undisputable.

To obtain these fatty acids, it is necessary to extract the oil from the matrix of the different by-products of the fish. Cooking can be carried out to facilitate the extraction of the oil from the tissues. However, the extraction of these fatty acids has some complications due to the significant taste, odor and stability problems of the oil which is extracted. Furthermore, product quality derived from fish oil is generally dependent on the season and location, and it can be affected by the ocean pollution. The process for purifying these fatty acids from fish oil itself is complicated as well (Ji et al, 2015).

Nevertheless, new sources to obtain this oil have been studied. As Ciriminna et al (2019) comment in their article, obtaining omega-3 fatty acids from fish oil using orange oil-derived d-limonene is advantageous and economically and technically feasible. The capital investment in the low-energy extraction setup, including the bio-based solvent and the solar air dryer, is relatively modest, and the operational costs are mostly due to labor and electricity to separate the oil from the agro solvent.

2.3.5 Hyaluronic Acid

Hyaluronic acid is a substance found in lubricating proteoglycans of synovial fluid, vitreous humor, cartilage, blood vessels, and skin (Medical dictionary, 2003). This material is one of the main components of cartilage and regulates essential processes such as adhesion, mobility, proliferation and cell differentiation. In addition, it participates in structural functions such as a lubricant in joints and providing the cartilage with compressive strength (Valcárcel et al, 2020).

The potential of marine organisms as sources of hyaluronic acid has received increasing attention because of the risks of animal-derived pathogens and inter-species viral contamination of conventional hyaluronic acid sources. These sources are mostly obtained of bacterial origin (grampositive streptococci), isolated from rooster combs or vitreous humor and synovial fluid of cattle joints (Claverie et al, 2020). Nowadays, it is possible to obtain hyaluronic acid from different by-products such as bowels, skin or livers, but the most developed procurement method is obtained from the eyeballs.

Even if it is an important structural element of the aggrecan in cartilaginous fishes, low content renders it economically inaccessible via current industrial extraction practices. For this reason, hyaluronic acid is a high added value product, and can reach sales figures of 50,000 euros per kilogram (Claverie et al, 2020).

New methods have been explored in order to obtain hyaluronic acid from fish eyeballs in an easier and cheaper process. (Murado et al, 2012) succeeded in investigating a method in which the processes for extracting and purifying HA from fisheye vitreous humor were optimized, obtaining a final product of 99% purity. However, this method needs to be further optimized in order to reduce process costs.

Current applications of hyaluronic acid include intra-articular injections for the treatment of osteoarthritis (Maheu et al, 2019), formulation of artificial tears with eye moisturizing function (Beck et al, 2019), as a filler agent in cosmetic surgery and in cosmetic products (Beasly et al, 2009). In tissue engineering it is widely studied as a component of scaffolding and for the controlled release of drugs, sometimes chemically modified (López-Ruiz et al, 2019).

2.3.6 Fish oil

In recent decades, it has been studied that fish oils contain several beneficial properties such us polyunsaturated fatty acids and monounsaturated fatty acids (Mkadem & Kaanane, 2019). Fish oil is commonly extracted from fish species such as tuna, sardine, salmon or mackerel, but it can be obtained from several more (Chas, 2020).

In the past, these fish oils had been used only to produce animal feed and not directly for human consumption. With recent developments, it has been commercialized in capsule form so they can be consumed by humans (Kristbergsson & Arason, 2017).

Many researches have discussed the important role of fish oil in human feed thanks to its essential fatty acids in prevention and therapy for coronary diseases, hypertension, immune and anti-inflammatory reactions, protection of arteries and the heart, brain development and cancer (Mkadem & Kaanane, 2019).

The most common source to obtain fish oil is from fishmeal process. It is the most common and simple procedure to obtain fish oil at the industrial scale and allows the highest extraction yields (Ideia et al, 2020).

The quality of fish oil has been increasing over the years as the way to produce it have been developed. The requirement for higher quality fish meal with better functionality and bioactivity came with the growth of aquaculture, but cultured fish are more sensitive to protein quality than domestic animals (Mkadem & Kaanane, 2019).

Investigations have shown that the result of the fish oil processing will vary depending on various factors such as the fish species that it came from, the geographic location where they were captured and the time of the year they were fished (Byun et al, 2008).

Fish-oil used by aquaculture was 80% in the year 2010, of which an estimated 70% was for salmonids. However, the aquaculture segment for fish oil consumption has been falling since 2007 due to the growth in demand oil for direct human consumption, which accounted for 24% of crude fish oil supply in 2010. Also, there is a trend of substitution of fish oil in aquaculture by vegetable oils. The consumption of fish oil by market segment over the years is reflected in Figure 3.

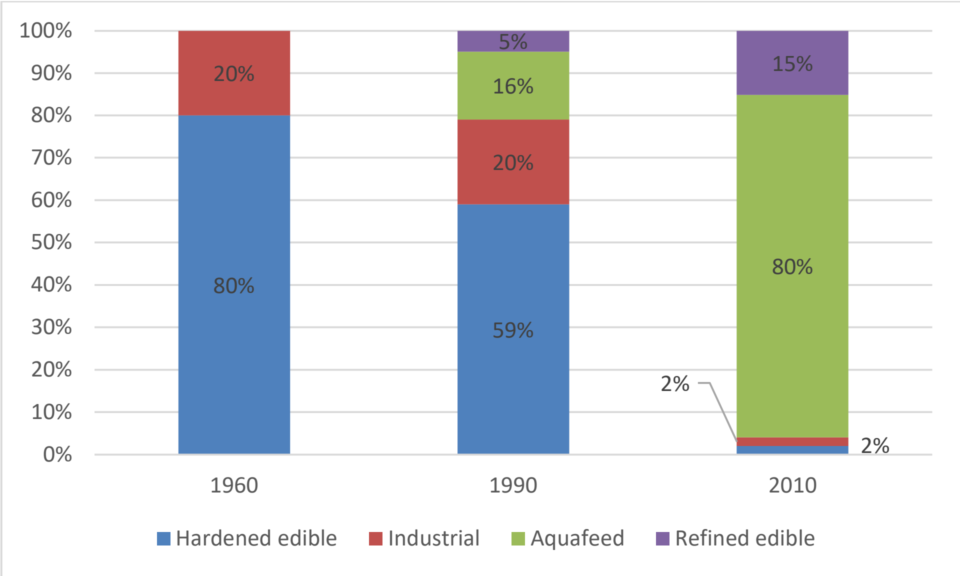


Figure 3. Comparison of world consumption of fish oil by market segment (Sheperd & Jackson, 2013).

2.3.7 Fishmeal

Fishmeal is a product obtained from fish processing, eliminating its water and oil content. It is the most traditional way to valorize the by-products of the fish which its application is animal feeding which has a great demand from food manufacturers. Currently, fishmeal is largely composed of whole fish, with just 25–33% comprised of fishery by-products or unwanted discards, although this fraction is likely to increase in the future (Sheperd & Jackson, 2013). But regional differences exist. For example, by-product use in Europe was estimated at a comparatively high proportion of 54% of total production of fishmeal (FAO,2020).

As fishmeal can be processed from any fish by-product or from whole fish, as in the case of Peru, which is usually produced from anchoveta, almost any species of fish can be used for its production (FAO,2020).

Fishmeal has a protein content of 60-75%, with a high and balanced content of essential amino acids. Fishmeal offers many benefits in animal nutrition as it provides many proteins and nutrients; as an ingredient in food for poultry, laying birds, pigs, ruminants, dairy cows, cattle, sheep, and aquatic animals (shrimp, fish and others), significantly decreasing the industrial production costs of these animals due to their rapid growth, better nutrition, improved fertility and the noticeable decrease in the possibilities of diseases (Mariño et al, 2012).

The consumption of fishmeal has changed over the years. Back in the past, the majority part of the consumption was intended to pig and chicken. Nowadays, 73% of the consumption of fishmeal is meant to aquaculture feed as shown in Figure 4.

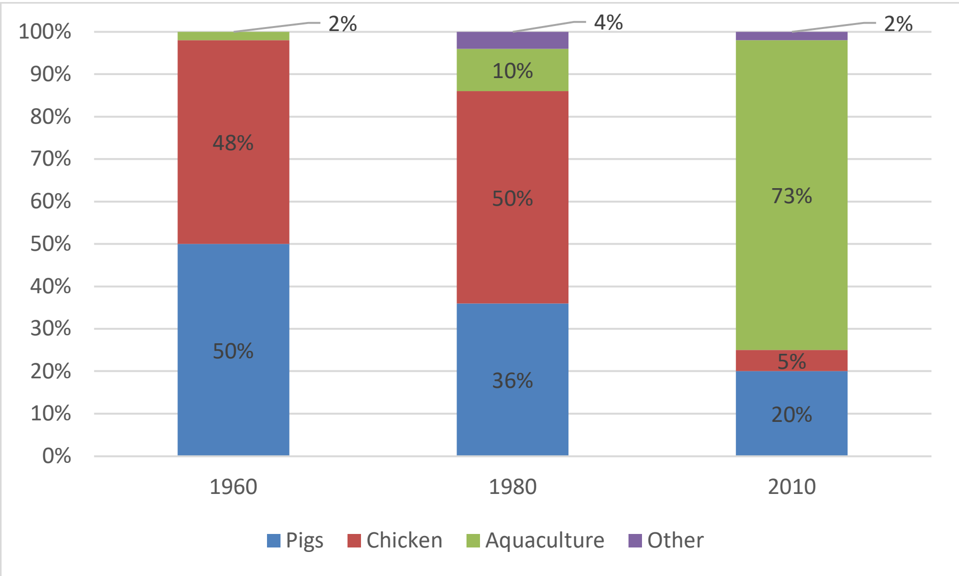


Figure 4. Comparison of world consumption of fishmeal by market segment for 1960,1980 and 2010 (Sheperd & Jackson, 2013).

The quantity used for fishmeal and fish oil production peaked in 1994, with more than 30 million tons, and then declined to less than 14 million tons in 2014.In the 2008-2012 period, it is estimated that approximately 16-20% of global capture fisheries production was reduced to fishmeal either directly through whole fish input or indirectly through fish by-products. In 2018, it was obtained 18 million of tons due to increased catches of Peruvian anchoveta (FAO, 2014; FAO, 2020). However, the production of fishmeal is reducing due to sustainability and biological limits. Global fisheries are not expected to grow, and thus the use of whole fish in fishmeal production is effectively capped. The only potential for raw material growth, although small relative to existing production volume, is to increase the use of fish by-products (Hoddevik & Hogneland, 2018).

Production of fishmeal is mostly happening in the proximity areas in which material is harvested. Top 2 producers of fishmeal are Peru and Chile, with an estimated

18.3 and 8.3% share of global production, respectively. Followed by these two countries, the next top producers are Asian countries as Vietnam, China and Thailand and countries surrounded by the Norwegian Sea (United States Department of Agriculture, 2018). The production and share of global production for fishmeal producing countries is represented in Figure 5.

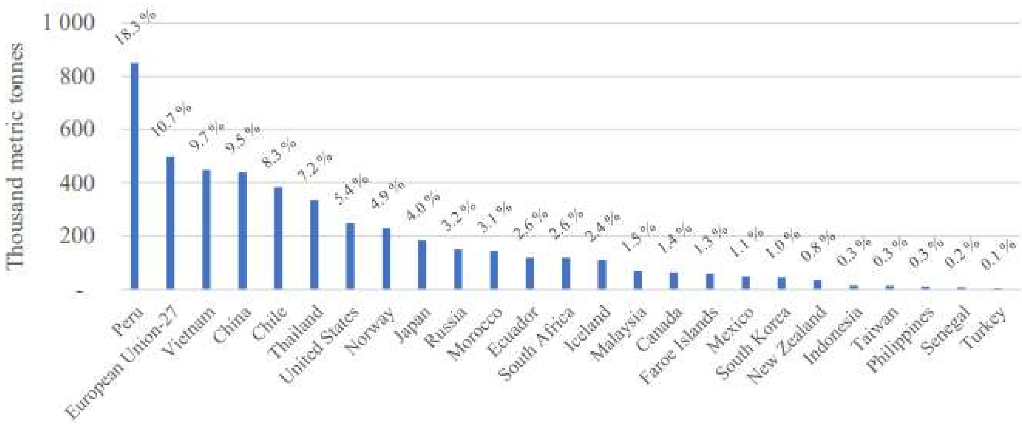


Figure 5. Production and share of global production for fishmeal producing countries (United States Department of Agriculture, 2018)

Talking about consumption, as presented in Figure 6, it can be seen that leading countries in aquaculture are the ones which consume more, such as China, Vietnam or Norway.

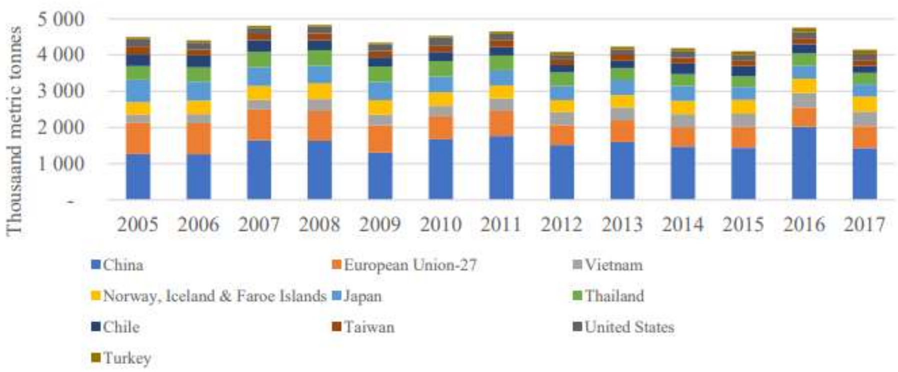


Figure 6. Consumption by top ten domestic consuming countries from 2005 to 2017 (United States Department of Agriculture, 2018).

Notwithstanding Spain uses a lot of fishmeal as it is a country specialized in livestock, it does not produce much fishmeal. In fact, is the seventh European country in fishmeal production, quite far from the top countries as Denmark or Norway as shown in Figure 7.

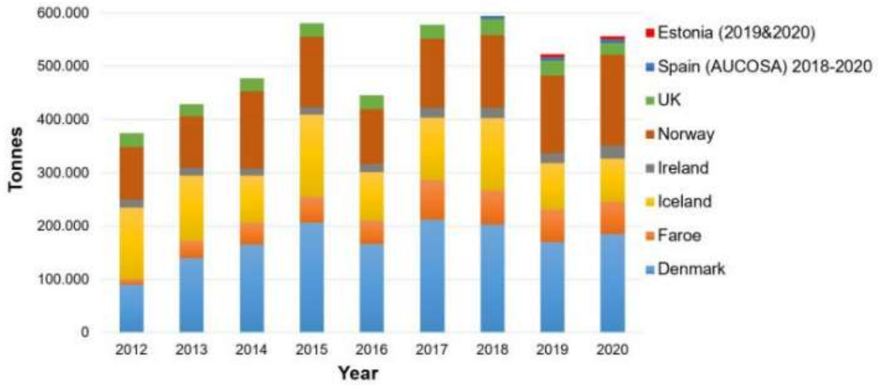


Figure 7. European fishmeal production from 2012 to 2020 (European Fishmeal and Fish Oil Producers, 2021).

2.3.8 Comparison of the different forms of valorization

In order to choose the most profitable way of recovering fish discards, a table has been prepared with the benefits and disadvantages of each of the forms of valorization obtained in the literature. The comparation can be seen in Table 4.

Form of valorization	Benefits	Disadvantages
Collagen and gelatin	• Numerous applications in different sectors. • They are made from fish by-products; it is not necessary to process the entire fish. • They can be obtained from numerous species. • The discards have the potential to be exploited as	• They only have been extracted from marine fish. • They need a complex process to be obtained. • Need a high degree of control of the final properties. • The results vary depending on various factors such as

	an eco-friendly and low-cost collagen and gelatin source.	fish species, age or the method of extraction. • They may need to be chemically treated to bring significant changes in its physical and chemical properties
Protein hydrolysates	• These products are an excellent nutritional source as they contain all essential and non-essential amino acids. • Good properties for human consumption. • Bioactive peptides are originated from fish protein hydrolysates. • Various methods to achieve the hydrolysis.	• Unpleasant flavor which may cause consumers to choose other options. • The level of hydrolysis which quantifies the degree of protein debasement is a limiting factor for the procedure. • Several applications but all of them are in the food sector. • The proteins from fish muscle are more vulnerable to denaturation. This technique and processing situations are serious issues in achieving the desired quality of hydration.
Omega-3 fatty acids	• Eicosapentaenoic acid (EPA) and docosahexaenoic fatty acid (DHA) can be obtained, which are almost exclusive from marine sources. • Since omega-3 fatty acids are obtained from fish oil, they are present in all parts of fish. • Can be obtained from various species. • Several benefits for human health.	• Unpleasant taste and odor. • Stability problem of the oil which is extracted. • Depend on the season and location and can be affected by the ocean pollution. • Complex process. • It is necessary to extract them from fish oil, which makes their production more difficult due to the decrease in their supply.

Hyaluronic acid	• High added value, sell prices up to 50,000 euros per kilogram. • Various applications in human health. • By obtaining it from fish by-products, it reduces the risks of animal-derived pathogens and inter-species viral contamination of conventional hyaluronic acid sources. • As it is obtained from fish eyeballs, almost all species are legged for its processing.	• Very complex and costly procurement method. • It is not possible to obtain it at industrial level. • Need to optimize methods for other by-products so as not to rely solely on fisheyes.
Fish oil	• It is obtained by an easy and inexpensive process. • Applications in both animal feed and human consumption • Can be obtained from the entire fish and from all fish by-products. • Can be obtained from numerous species. • With recent developments, high quality fish oil is being produced lately.	• Result of the fish oil processing will vary depending on various factors such as the fish species that it came from, the geographic location where they were captured and the time of the year they were fished. • The production is reducing due to sustainability and biological limits.
Fishmeal	• Obtained by an easy an inexpensive process. • Can be obtained from the entire fish and from all fish by-products. • As it is the most traditional form of valorization, the process has been optimized several times. • Can be obtained from numerous species.	• Applications only in animal feeding. • Production of fishmeal is reducing due to sustainability and biological limits. • Result of the fishmeal processing will vary depending on various

	• Excellent properties for animal feeding.	factors, but not as much as fish oil.

Table 4. Comparison of fish by-products valorization.

Given the comparison, it can be seen that the fishmeal and fish oil production methods are more advanced than the other ways of valorizing fish by-products. Moreover, they have been marketed for several years. For example, in Peru, a leading country in fishmeal production, fishmeal and fish oil began to be produced on an industrial scale in the 1950s (Universidad Tecnológica de Perú, 2021). Also, of the total production for non-food uses in 2019, fishmeal and fish oil represented the 82% of it (FAO, 2020), so it can be said that this is the preferred alternative for by-product management companies.

2.4. Recent valorization proposals

As in any other field of work, there is a necessity of keep investigating new paths of development in order to obtain better results. Same thing happens in fish industry. As the necessity of still capturing fishes remains due to the market demand, the need of find new ways to valorize fish wastes and by-products remains too.

It will be discussed in the following section the new ways in which fish waste and by-products are being investigating with the aim of obtaining value-added products.

2.4.1 Biodiesel

Today, most of the energy which is being used by humans come from fossil fuels that are non-renewable energy resources. The problem of polluting that comes with these types of fuels have driven the interest in the discovery of alternative renewable fuels.

Due to the environmental problem in which society currently finds itself, biodiesel is acquiring momentum. Biofuels are mainly categorized as three types of the generation depending on the types of feedstocks, first, second and third generation. The first one comprises of edible vegetable oils derived from plant sources such as sunflower, rapeseed, soybean, palm, peanut, etc. for biodiesel and sugarcane, cassava, sweet sorghum, wheat and sugar beet for bioethanol production (Biofuels, 2010a). The second generation includes non-edible oils from sources such as rice bran or coconut and waste cooking oil for biodiesel and lignocelluloses for bioethanol (Biofuels, 2010b). Microalgae form third generation feedstock (Biofuels, 2010c).

In the last years, many investigations have been attempted in order to investigate the production of biodiesel from fish discards. In many investigations it can be found that fish oil derived from fish by-products can be easily converted to biodiesel, with the potential to improve air quality and reduce the dependency of imported fuel. It also could improve fuel flow fluidity at low operating temperatures (S. Karkal & G. Kudre, 2020).

Since the actual ways of producing biodiesel have some disadvantages, these are the benefits of producing biodiesel from fish discards (S. Karkal & G. Kudre, 2020):

- Fish discards comprise lipids, apart from which it can also be the source of biocatalyst and heterogeneous chemical catalyst.
- Utilization of fish discards as biodiesel would not create food shortage problems since it comes from non-edible materials.
- Fish discards could reduce the cost of production since it is a waste and accounts for up to 20-70% of total fish production. In biodiesel production, feedstock itself contributes to around 45-50% of biodiesel production cost.

The main challenges in the biodiesel production are the availability of feedstock during the year, storage stability, varying fatty acid composition and the cost of feedstock. Because of these reasons, fish can be a good alternative as it generates a lot of discards and wastes, which would help in the cost of production and in the availability of feedstock, and it has a good composition of fatty acid. However, the problem of storage stability is not solved.

Anyway, not all of fish discards can be used in the same method in the obtaining of biodiesel. The best technique which can be employed is an ultrasound assisted transesterification reaction, but this way does not use scales and bones. However, these can be utilized to produce chemical catalysts, which can be later employed in the production of biodiesel (S. Karkal & G. Kudre, 2020).

Moreover, it is possible to use the crude fish oil that is produced in the fishmeal processes. It can be good enough for biofuel application, fuel oil for convectional combustors or diesel engines that need low quality fuels such us boilers and furnaces (Adeoti & Hawboldt, 2014).

In conclusion, the investigations of the production of biodiesel from fish discards are obtaining good results as it reduces costs in the process and also avoids the problem of fish wastes management. It offers a sustainable cost-effective strategy for conventional combustors, boiler engines or in-house use. In addition, this may reduce pollution and energy crisis. However, more research is required to improve the storage stability of biodiesel fabricated from fish waste oil.

2.4.2 Bioplastics

During the last years, interest in reducing the negative impact of synthetic polymers on the environment has increased. Therefore, the production of bioplastics has largely grown, since they can be bio-based and biodegradable (Mishra et al, 2020). Nevertheless, they still represent a very small percent of the plastic market as they only correspond to the 1% of the total (Bioplastics Market Development Update, 2020). Nonetheless, the bioplastic market is expanding and differentiating since the market demand is growing with more innovative and advanced products and applications. The global bioplastics production volume is expected to rise from around 2.11 million tons in 2020 to about 2.87 million tons in 2025. Packaging can still be considered the major market segment for bioplastic production with 47 percent (0.99 million tons) of the total bioplastics market in 2020 (Lionetto & Corcione, 2021).

The principal use of bioplastic is food packaging and biopolymers derived from fish discards have the potential to leave behind the conventional way of packaging and lead towards a smart packaging future. Smart packaging comprises both intelligent and active packaging. Intelligent packaging consists in monitoring and reporting product conditions and history, while active packaging interacts with the product in order to extend the shelf life of food maintaining nutritional and sensor quality and microbial safety (Lionetto & Corcione, 2021).

Biopolymers still have a long way to go as is very important to reach top mechanical and technological properties in order to have good results in food packaging. Anyway, numerous researchers are studying the possibility to improve these properties so biopolymers can satisfy the most important requirements for food packaging application, such as optical, barrier and mechanical properties (de la Caba et al, 2019).

Products derived from fish discards, as muscle proteins, gelatin and collagen, are those which are being studied for the production of biopolymers for food packaging. Each one has different applications due to their properties (Lionetto & Corcione, 2021).

1. Biopolymers from Muscle Proteins

Muscle proteins are a good option of conversion into biopolymers as they show a high potential for food packaging as edible film that may be coated, wrapped or spray over foods. They act as a barrier that prevent the transmission of gases and vapor so food can improve both its quality and shelf life. Also, if antioxidants, vitamins and coloring agents are incorporated into these fish protein films, they will improve their functional properties. Many studios have been done, but in general, the results of these biopolymers presented lower strength and flexibility than the commercial PVC films.

Recent investigations have discovered that if these protein films are added with gelatin and plasticizer, it can be achieved the requirements of technical properties to be applied in food packaging.

2. Biopolymers from Marine Collagen

These kinds of biopolymers might be the less advanced in terms of food packaging. Generally, food packaging materials are needed to protect food from the migration of oxygen and moisture. Fish collagen films protect, maintain and extend the shelf life of foods, and have a low-cost production, but cannot avoid the migration of oxygen. The best-known industrial application for this material consists in edible casings for meat processing industries, such as sausages or salami.

These biopolymers have some disadvantages such as low thermal stability and poor mechanical properties. To overcome with the limitations, it is being studied the possibility of blending collagen with other biopolymers and several chemical and enzymatic treatments.

3. Biopolymers from Fish Gelatin

Fish gelatin has been recently recommended in active food packaging thanks to low cost, good film-forming properties, biocompatibility and biodegradability. These films are colorless, water-soluble, tasteless, transparent and present higher flexibility properties than other bio-based films. Even so, they present some drawbacks, such as low oxygen permeability and high hygroscopicity, which is responsible for a drastic reduction in moisture barrier and mechanical strength. To overcome with these problems, there have been studied solutions such as adding chitosan, produce a multi-layer structure and crosslinking.

The main application of these biopolymers are encapsulation and edible film formation. Recent studies have shown the possibility of using them in fish protection as they can delay or even inhibit the growing of microorganisms on fish.

To conclude, biopolymers extracted from fish discards are a good option to valorize wastes and by-products, but the barriers that exist in producing these materials and their weaknesses in some properties need to be addressed in order to be able to offer a product that can compete with traditional plastics.

2.4.3 Fertilizer

Fish have a long tradition as fertilizers as it was used by Egyptians, Incas and Mayans, but it didn't have the same results as the main fertilizers (Ahuja et al, 2020). Composting initiatives using fish discards have been carried out in various parts of the world in search of alternative and viable techniques for transforming fish waste into useful agricultural products (López-Mosquera et al, 2011).

Fish discards can have a proper use for agricultural because of its high content of nutrients, such as nitrogen, phosphorus and calcium. Today, some fertilizers made of fishmeal are being commercialized as they are authorized for use in organic agriculture (Radziemska et al, 2019).

In recent studies, it has been investigated the possibility of producing fertilizer from fishmeal, fish pellets, fish protein hydrolysates and fish bone meal.

Agro fish pellet had a significant impact in the growth parameters of tomato plants by increasing in stem diameter, shoot dry weight, number of flowers and fruits and overall fruit quality. Fishmeal, mixed with a peat-compost, enhanced the weight of greenhouse tomato. Talking about fish bone meal, either alone or in combination with marine sediments or seaweed with fish oil, was applied on a vegetable crop rotation composed of cabbage, carrot and green beans. The results on cabbage and carrots were similar as the results of vegetable mineral fertilizer, whereas the results on green beans were worse. Hydrolyzed fish proteins were studied as fertilizers in calibrachoa and marigold plants. Calibrachoa's results determined that the plant grew healthier but smaller. About the marigold plants, it showed the same high quality as with mineral fertilizer (Ahuja et al, 2020).

Studies show that a number of commercial fish-based fertilizers have increased the growth in several ornamental plants and young trees. In relation with vegetable crops, few studies have been made because it is more difficult and more expensive to apply these fertilizers in arable crops.

On the other hand, there are some studies as (Su García & Arostegui Alfaro, 2020) that have determined that Bocashi, a fertilizer produced from fish discards, have good results as a crop fertilizer for green onion. When this product was applied in the crop, as its components are totally natural, it enriches the product in sugars, vitamins, minerals and proteins increasing its flavor and quality without any chemical additive. In addition, they are able to rebuild degraded soils by the intensive use of chemicals and improve green onion production. In this way it shows that the use of Bocashi fertilizer is healthier, both for water, environment and soil. While the use of chemical fertilizers may improve in the production of the products, but also they can degrade the soil when its use intensifies.

Other use for fish discards when they are fermented is in aquaculture. Once the by-products are processed, they are used for the consumption of the fish, either to improve the quality of sea plants or directly as feed. As fermentation produce more digestible proteins, it improves the nutritional quality of fish product which are later used in human feed (Marti-Quijal et al 2019).

In conclusion, several fish-based products have been studied, where many of them showed positive effects on a variety of crop plants. These products, whether in liquid or solid form, seems that they are applied in order to provide nitrogen, a combination of nitrogen and phosphorus, to enrich a compost, and less often, as a complete fertilizer to cover all the nutritional needs of a crop (Ahuja et al, 2020).

2.5. Comparison of conventional methods with valorization forms

Until companies became concerned about the management of by-products following a circular economy, the discards generated were either returned back to the sea or used in a non-optimized way as feed for farm animals. This missed the opportunity to obtain value-added products and caused problems for the environment.

Although it can be stated that the application of recovery methods in the food sector production is much more beneficial than following a linear model, the conventional methods of fish discards management will be compared with the new forms of fish discards valorization.

One point to take into account when comparing conventional discard management with other forms of valorization of these materials is transportation costs. Due to the large amount of product generated and given that returning them to the sea also requires another means of transport such as ships, it is considered more effective to valorize these materials directly at a dedicated plant.

On the other hand, with direct deposition into the sea and as direct animal feed, infrastructure costs are low, if not zero, compared to those required to valorize these by-products.

The valorization of the sector's discards helps to contribute to the environment. Depositing by-products and waste directly into the sea contributes to a more accelerated pollution of the seas, causing the quality of the fish caught to decrease.

In addition, new research is discovering that fish by-products can be converted in such a way that they can serve as biofuels, which can be used to power production machinery.

The transformation of these large volumes of waste that are generated by the industry into an output with economic value, will enable us to convert the costs of disposal and management into a source of revenue, nutrient recycling, and a way to reduce the pollution generated by the activity in question.

A comparison of conventional methods with current ways of valorization fish by-products are presented in Table 5.

Issues to consider	Deposition in seas and direct feeding	Discards valorization
Transportation costs	High	Moderate
Handling costs	Moderate	Moderate
Infrastructure costs	Low or zero	High
Deposition costs	High	Zero
Environmental impact	High	Low
Animal feeding	Not optimized	Efficient
Water pollution	High	Low or zero
By-product's production	Zero	High
Electric production	Zero	Optimization of this form of valorization will result in significant savings
Social image	Questionable	Considerable

Table 5. Conventional production methods vs. valorization of by-products.

3. FISH DATA

Due to overpopulation, year by year the production of fish is increasing considerably. Next table shows the evolution of the production volume values of the top 20 inland fishery countries. Asia leads the ranking in 2018 with the 66% of the total percentage, especially China and India which have 16 and 14% of the total volume of the world, respectively. Africa represents the 25% of the total volume while America and Europe only represent the 5 and 3%, respectively.

Table 6 shows the evolution of production in millions of tons of top 20 inland fishery countries.

	Production (in millions of tons)			
Country	**2015**	**2016**	**2017**	**2018**
China	1,99	2,00	2,18	1,96
India	1,35	1,46	1,59	1,70
Bangladesh	1,02	1,05	1,16	1,22
Myanmar	0,86	0,89	0,89	0,89
Cambodia	0,49	0,51	0,53	0,54
Indonesia	0,47	0,43	0,43	0,51
Uganda	0,40	0,39	0,39	0,44
Nigeria	0,30	0,38	0,42	0,39
Tanzania	0,31	0,31	0,33	0,31
Russia	0,29	0,29	0,27	0,27
Egypt	0,24	0,23	0,26	0,27
Democratic Republic of Congo	0,23	0,23	0,23	0,23
Brazil	0,23	0,22	0,22	0,22
Mexico	0,15	0,20	0,17	0,22
Malawi	0,14	0,15	0,20	0,22
Thailand	0,18	0,19	0,19	0,20
Philippines	0,20	0,16	0,16	0,16
Vietnam	0,15	0,15	0,16	0,16
Pakistan	0,13	0,14	0,14	0,14
Chad	0,10	0,11	0,11	0,11

Table 6. Evolution of production in millions of tons of inland fishery (Organización de las Naciones Unidas para la Alimentación y la Agricultura, 2020).

As for sea fishery, China is still leading the ranking with a total percentage of 15% with respect to other countries. In the next table more European and American countries show up, like Peru which represent the 8% of the total production of sea fishery. Spain appears in the 20th position, with more than 1% of the total volume.

Table 7 shows the evolution of production in millions of tons of top 20 sea fishery countries. (Organización de las Naciones Unidas para la Alimentación y la Agricultura, 2020).

	Production (in millions of tons)			
Country	**2015**	**2016**	**2017**	**2018**
China	14,39	13,78	13,19	12,68
Perú	4,79	3,77	4,13	7,15
Indonesia	6,22	6,11	6,31	6,71
Russia	4,17	4,47	4,59	4,84
United States of America	5,02	4,88	5,02	4,72
India	3,50	3,71	3,94	3,62
Vietnam	2,71	2,93	3,15	3,19
Japan	3,37	3,17	3,18	3,10
Norway	2,29	2,03	2,38	2,49
Chile	1,79	1,50	1,92	2,12
Philippines	1,95	1,87	1,72	1,89
Thailand	1,32	1,34	1,31	1,51
Mexico	1,32	1,31	1,46	1,47
Malaysia	1,49	1,57	1,47	1,45
Morocco	1,35	1,43	1,36	1,36
South Korea	1,64	1,35	1,35	1,33
Iceland	1,32	1,07	1,18	1,26
Myanmar	1,11	1,16	1,27	1,14
Mauritania	0,36	0,59	0,78	0,95
Spain	0,97	0,91	0,94	0,92

Table 7. Evolution of production in millions of tons of sea fishery (Organización de las Naciones Unidas para la Alimentación y la Agricultura, 2020).

World fish production is estimated to have reached about 178.4 million tons in 2018, with an estimated total first-sale value of 401 billion of dollars, of which 82 million tons, worth 250 billion of dollars, came from aquaculture production. The remaining 96.4 million of tons came from capture fishing, an increase of 5.4% compared to the previous 3 years. The increase in marine catches was mainly due to the increase in anchoveta (Engraulis ringens) catches in Peru and Chile (FAO, 2020).

Of the overall total, 156 million tons were destined for human consumption, equivalent to an estimated annual supply of 20.5 kg per capita. The remaining 22 million tons were destined for non-food uses, and about 82 % of this quantity (18 million of tons) was used to produce fishmeal and fish oil. Live, fresh or refrigerated fish still account for the majority (44%) of fish used for direct human consumption and are often the preferred and highest priced forms of fish. These are followed by frozen (35%), prepared and canned (11%) and cured fish, with 10%. The evolution of utilization of world fisheries and aquaculture production is shown in Figure 8.

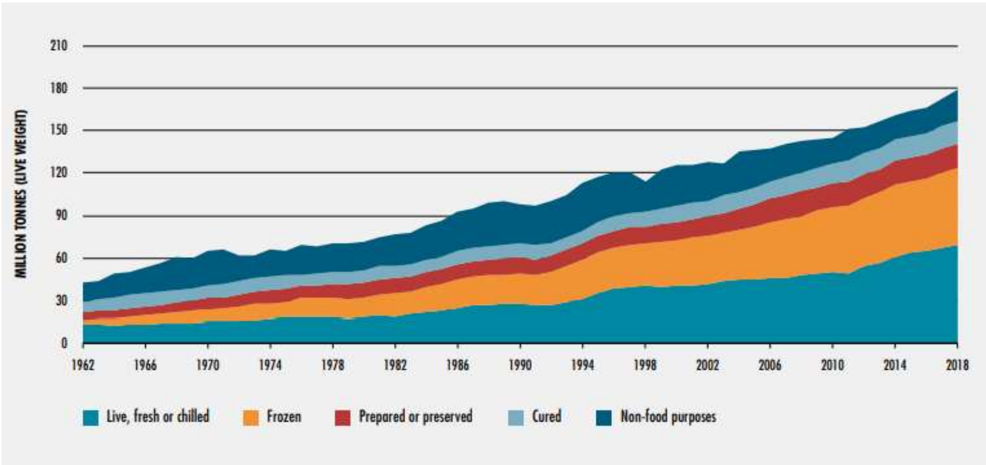


Figure 8. Utilization of world fisheries and aquaculture production, from 1962 to 2018 (FAO, 2020).

In reference to the Spanish fishing sector, Spain generates no less than 20% of the European Union's total production. In 2019, fish catches generated 877,212 tons of fish, with a total value of 1,767,392 thousand euros, aquiculture produced 342,867 tons of fish, with a value equivalent to 501,000 thousand euros, and 825,543 tons was the amount produced by the fish processing industry, equivalent to 4,869,429 thousand euros. It can be seen in Figure 9 and Figure 10 the percentage that represent each sector in terms of volume and value produced, respectively.

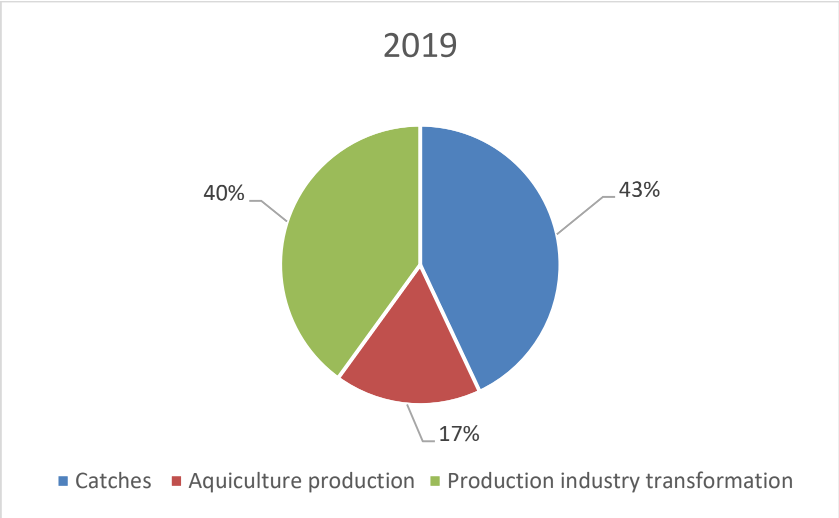


Figure 9. Distribution of fish production in Spain in tons, in 2019 (Anfaco, 2020).

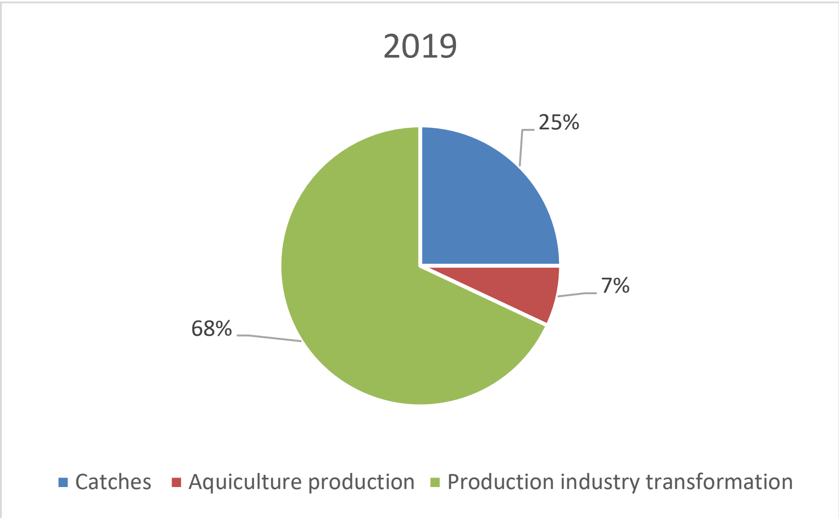


Figure 10. Distribution of fish production in Spain in thousands of euros, in 2019 (Anfaco, 2020).

In terms of distribution within the Spanish production of transformation of fish products, the canned or prepared fish sector is the one that produces the largest number of tons of final product, with a percentage of 63.4% of the total, followed by frozen fish, which accounted for 28.2% of the total. These data can be found in Figure 11 (Anfaco, 2020).

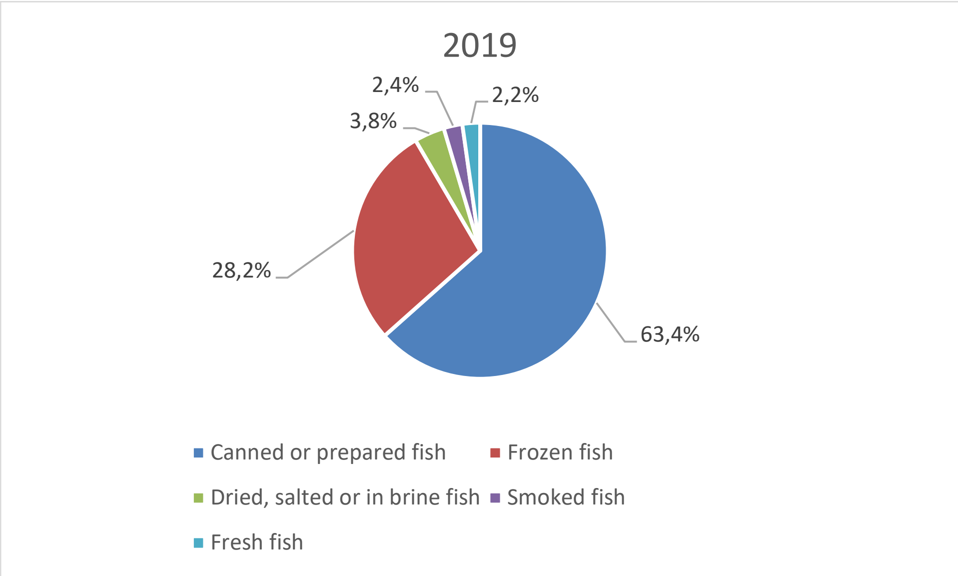


Figure 11. Distribution by presentation of Spain's production of processed fish products in 2019 (Anfaco, 2020).

In 2018, the number of companies involved in the production and preservation of fish in Spain amounted to 648, 41 more than in the previous year. These data have not stopped growing since 2014, when the total number of companies engaged in this sector amounted to 542 (Ministerio de Agricultura, Pesca y Alimentación, 2018).

Respect to canned fish, the production is also ascending. Only in Spain, the total amount of top canned fish, excluding shellfish, produced in 2020 an amounted of 290,910 tons. It can be seen in Table 8 that yellowfin tuna is the most produced product with a huge difference over the second one, which are sardines (Anfaco, 2020).

	2020	
	Volume (tons)	**Value (thousands of euros)**
Sardine	23,784	102,166
Albacore tuna	13,603	133,177
Yellowfin tuna	231,071	884,076
Tuna with vegetables	1,989	11,717
Mackerel	13,428	61,032
Octopus	689	7,836
Squid and cuttlefish	6,346	38,53

Table 8. Production in tons and its value in thousands of euros of top canned fish in Spain in 2020 (Anfaco, 2020).

Speaking of consumption, it is obvious to say after the data seen that canned fish production is widely used in the food of Spanish households. In addition, because of the benefits of fish to human health, the numbers of consumption do not stop growing every year. In 1990, the per capita consumption of canned fish was 2.4 kilos. It raised to 3.1 kilos in 1998 and in 2006 the annual consumption of canned fish per person reached 3.9 kilos. In 2018 the consumption of canned fish increased in Spanish households by 1.6% to 204.66 million kilos, and an increase in value of 4.8%, to 2,048 million euros, which means a consumption of 4.47 kilos per person and an average investment of 44.73 euros per year (Murcia, 2019)

The data consumption submitted by the Ministry of Agriculture, Fisheries and Food (MAP) offer two clear conclusions. On the one hand, consumers are looking for healthy, high-quality food with an emphasis on food safety and, on the other hand, on the Spanish market every time there is a higher demand for time-saving foods because they are comfortable and fast to prepare for (Martín Cerdeño, 2007).

In relation with other countries, for example United States of America, it can be observed that the trend of consumption of canned fish is very similar, being the tuna the most sold. In addition, thanks to Figure 12, it is obvious how the sales of canned fish will raise every year (Grand View Research, 2017).

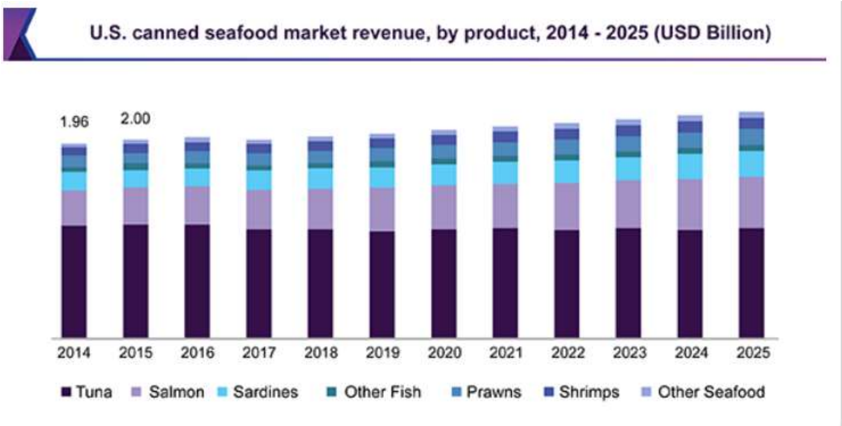


Figure 12. United States canned seafood market revenue in billions of dollars (Grand View Research, 2017).

4. METHODOLOGY

This section presents the research design and sample techniques applied to the study. It also provides the method used to interpret the data that were collected.

This study adopts an explorative approach to understand the barriers in the implementation of circular economy in the fish production sector.

In the case of the food sector, and more specifically of fish production, there are few studies analyzing the barriers and challenges of the sector for the circular economy. For this reason, the study focuses on understanding these barriers that appear in the literature and comparing them with those reported by fish production experts.

Several interviews were conducted, both by telephone and e-mail. The reason some interviews were conducted by e-mail is due to more accurate responses from the companies. Perhaps some questions could not be answered by some workers and therefore were transferred to other colleagues to complete the questionnaire in a more accurate way. If there was a possibility to talk to the company's sustainability manager, it was preferred to conduct the interview via telephone, as more subjective aspects could be collected. The use of the two main sources of data provides the opportunity for triangulation of the data to improve the validity of the findings and enables greater inferences from the results (Agyemang et al, 2019).

All the companies interviewed were Spanish, given that there are enough companies in Spain to be able to carry out a study of this kind and because the author of the thesis is Spanish, so a better understanding of the questions and answers would be carried out.

For the selection of companies to be interviewed, a search of the main fish producing companies was carried out. From there, a process of contacting more than 90 companies was carried out. Of all the companies contacted, a total of 8 agreed to participate in the interviews. The interviews conducted by telephone lasted approximately 20 minutes, while the questionnaires sent by e-mail had between 5 and 6 questions.

For this study, data will be collected from interviews conducted with production, commercial or sustainability managers of different fish production companies, whether frozen, fresh or canned. Interviewing specific companies who work with food processing will give knowledge on the approach towards sustainability and the circular economy concept. The barriers outlined in the paper are an interpretation of both direct and indirect questions asked of the company's employees. This gives an indication of what barriers they face. The companies interviewed are presented in Table 9. The gross margin of every company has been obtained through the website called *Mercado de Facturas*, which provides an economic-financial analysis of the last few years.

Name of the company	Field of work	Gross margin
Orbe S.A.	Canned fish production	8,730,000 €
ANFACO-CECOPESCA	Spanish association of canned fish producers	-
Congalsa S.L.	Fish processing	24,390,000 €
Conservas Cermar S.L.	Canned fish production	3,076,000 €
Congelados Sorymar S.L.	Frozen fish production	2,645,000 €
Conservas Dani, S.A.U.	Canned fish production	23,577,000 €
Angulas Aguinaga SA	Fish processing	60,653,000 €
Elmar Frozen Food	Frozen fish production	11,042,000 €

Table 9. List of companies interviewed.

More interviews to more companies would have been preferred to be conducted but given the difficult times in which we find ourselves due to the COVID-19 and the proximity to the holiday season, many companies did not want to participate in the interviews.

5. RESULTS AND DISCUSSION

In this section, the data that was collected from the interviews and the answers to the questionnaires are discussed and compared with the information that was found in the literature.

To begin with, all the interviewed workers were asked questions about what practices they follow in their companies in order to achieve a circular economy model. The intention of this question, apart from knowing what other ways they have to guarantee this type of sustainable model, was to receive answers about how they valorized their waste and by-products and whether it matched some of the ways mentioned in the literature section. The companies give us several answers to this question, but they all agree on a form of valorization that has already been mentioned in the literature, which is that they deliver all fish discards to companies that are in charge of collecting these materials and transforming them into fishmeal and fish oil. The following response from Congalsa also stands out, *"we use as few resources as possible; we measure all waste to minimize them, we have photovoltaic panels, weather analysis systems to adjust the consumption of our refrigeration equipment, we help the local community, we are committed to work-life balance... many practices aimed at minimizing resources and promoting social economy*".

In addition, Sorymar, which is dedicated to the production of frozen fish, indicated: "*what we have been doing for some time now is that those fish that appear among the fish to be processed from other species are collected and used for other purposes, usually as animal feed*".

There are companies like Elmar Frozen Foods that bet on reducing pollution in their transport. "*We are focusing on reducing emissions from our fleet of vehicles, betting on electric vehicles for commercial equipment and low emission/consumption trucks. We have installed charging points in our delegations to gradually expand the fleet of electric vehicles*".

Finally, there are also companies that decide to donate food that will not be sold before it expires. "*In terms of food, we make sure that no kilo of product that can be* *consumed goes to waste. We donate to the food bank all those products that are not going to be sold but are suitable for consumption"* said Angulas Aguinaga.

Another question that was put to the companies was whether there were any practices that had not yet been implemented but that they wished to do so. Most of them agreed that the lack of local raw materials was a big obstacle because if this could be achieved, it would save a lot of costs, especially transportation costs. Unfortunately, on these days, there are not so many value-for-money alternatives to replace imported ones.

Also, Sorymar exposed that one practice they want to implement is the use of a more renewable energy source for their production plant. The problem they encounter is that their power consumption is very punctual and that at certain times they need a great deal of power to keep all the machinery in action.

5.1. Barriers to the implementation of the circular economy

The companies were asked some questions about the barriers to the circular economy in the fish sector. The most important and most emphasized was to know what are the most important barriers that they encounter in their work.

The following are the barriers that fish production experts encounter when following a circular economy model:

5.1.1. High recycling cost

Some companies emphasize that one of the most important barriers is the high cost of recycling. This is not related to waste management, but rather to the recycling of packaging. They have to invest heavily in order to have packaging that is almost 100% recyclable, and the price does not decrease because consumers are not aware of recycling practices. "*If consumers would always recycle all the products they consume, there would be a much greater supply of recyclable packaging and thus a lower purchase price for companies*" said Cermar. Companies want to take advantage of the momentum of the circular economy and try to work with that model, since they all use recyclable packaging, but the high costs of these materials due to the lack of consumer recycling added to the lack of raw material, which will be discussed in the next point, make it very complicated to continue with that strategy.

There are several reasons for this consumer behavior. One of them, and perhaps the most important, is because salaries in Spain are not very high. "*This added to the way of life of the population, in which a mileurist person wants to have and enjoy the same as those who are not, makes consumers believe that price is the most important thing for them*" said Sorymar. This makes recycling more difficult, since the prices of products with recycled materials are generally higher than those without.

5.1.2. High production costs

One of the barriers mentioned by the companies is that production prices are very high. “*The real problem in Spain is that production costs are higher than in most food producing countries with strong primary sectors, so that we cannot compete with countries where both labor and raw materials are cheaper*” said Sorymar.

A clear example is electricity prices. It is very difficult for companies to use energy sources that are renewable, since it is difficult for the electricity provided to them to be necessary to manage all production and prices are not yet competitive compared to those of non-renewable energies. This can be related to the barrier mentioned by Elmar Frozen Foods, “*Our dependence on fossil energy, that is, we try to our fleet of vehicles but the energy they consume is mostly fossil*”.

In addition, the price of electricity penalizes companies. As Sorymar said in the in the response, “*the price of electricity charged to businesses is higher than the price paid by households*”.

It is understood that as soon as renewable energies can provide enough energy to cover the production of the companies' plants and prices decrease, this barrier will begin to disappear.

5.1.3. Lack of raw materials

Many companies exposed that the lack of raw materials is the main barrier for them. Apart from packaging materials such as aluminum and cardboard, which are increasing in price due to the shortage of these materials, the lack of fish is a major problem. Spanish companies would like to produce fish that can be found on the coasts of the country, thus promoting the country's product. However, the current shortage of fish makes it difficult to follow this strategy. As a solution, many companies have to bring in imported fish from countries such as China as it is cheaper, but this entails several problems. “*We would like to be able to consume more local raw materials but there are not so many value-for-money alternatives that substitute imported ones*” said Congalsa. One of the problems, and maybe the most important, is the environmental footprint of the transportation needed to bring the product from such a distant country. These transports, whether by sea or by air, are a major problem for the environment and therefore a major obstacle to following a circular economy model. The use of raw materials from the Spanish coast would have a much lower impact on the environment and improve the quality of the final product.

Another drawback that companies encounter when importing from distant countries is the long lead times. Minimum delivery times are usually two weeks and can extend up to a month.

5.1.4. Social unawareness

The population has become more environmentally conscious in recent years, but there is still a lot of work to be done, especially in Spain. The social unawareness in relation with recycling is one of the major problems highlighted by the companies. They point out that many consumers do not recycle, not knowing their motives, and this directly harms the companies. As already mentioned in previous points, the lack of recycling by consumers means that there are fewer materials available for companies and their production, thus leading to higher prices.

The solution proposed by some companies is to follow the recycling strategies of countries such as Germany and Sweden. "*In these countries you get benefits for recycling. For example, there are recycling stations where they give you a certain amount of money for recycled material. In addition, if someone is caught without recycling the products they have used, they can be fined financially*" noted Cermar.

These policies make consumers have a much different recycling awareness, and thus make it easier for companies to achieve a circular economy model.

5.1.5. Government policies

Another barrier that is also commented on by fish workers is the lack of support from the government due to its policies. They believe that they do not yet have well-developed policies in the field of circular economy and therefore many opportunities of this model cannot be achieved. "*Associations of fish production companies in Spain have meetings at the European level and we notice that the governments of other countries* *support and give more benefits to their companies that implement the circular economy model*" said Cermar. They say that they do not feel supported by the government at these meetings.

On the other hand, the companies say that if the government does not adopt measures for recycling for consumers, the mentality of not needing to recycle on the part of consumers is not going to change. The companies propose to impose measures such as those taken in Sweden and Germany, not only to give benefits to those who recycle, but also to punish those who do not. This would help people to recycle much more and thus significantly reduce the price of recycled packaging, which makes it possible for companies to be more sustainable

They also ask the government to take measures for fishing off the Spanish coast. They believe that with different fishing policies it can be achieved that in the near future the number of fish of Spanish origin can increase significantly, and this would solve many drawbacks to achieve a circular economy model.

Another issue that involves the government policy barrier is the food safety requirements determined by decrees at both the state and European level. "*Legislation ensuring compliance with food safety requirements for products, prevents certain activities from being carried out within food processing facilities, or from being the beneficiary of such processes*" highlighted Anfaco.

This is common to another area of actions in relation to the circular economy, given that the legislation that guarantees compliance with food safety requirements for products prevents certain actions from being carried out within the processing facilities of products for human consumption, or from being beneficiaries of such processes.

5.1.6. Lack of focus to work in a targeted manner

"*The most important barrier to overcome in his sector is the lack of focus to work in a targeted manner*" noted Congalsa. They believe that if the circular economy model is not monitored at all points of the company's structure, it is very likely that the circular economy model will not be properly implemented, and mistakes may be made.

As it will be explained in the next point, it is very important that all the company's employees are able to understand the circular economy model, not only managers, and that all the measures implemented to achieve it are explained. In this way, all members will be able to put more focus and this model can be achieved in a simpler way.

This does not mean that many measures should be applied to achieve the circular economy model, but the most important thing is that even if there are few objectives to be achieved, they should be set out in a well-defined manner and prioritize the objectives so that when they are set out, the focus can be more on the important ones and a more structured work can be done.

Congalsa concluded "*the most important way to work, not only with a circular economy model, but also in general, is to define well the objectives and to focus well in order to be able to orient the actions*".

5.1.7. Unawareness of the concept of circular economy

This barrier is mentioned because a pair of the interviewees had not fully assimilated the concept of circular economy. It is a barrier not mentioned by them, but it has been concluded after those interviews.

In those interviews, they asked for the exact definition of circular economy to find out if that is what they had in mind about it. They believed that the circular economy is a type of model in which materials are simply recycled to have less impact on the environment, forgetting to mention the other basic principles of this model.

This point has been considered a barrier because without a full understanding of the concept of circular economy by all members of the company, no matter what position you hold, as full internal cooperation is required, it is difficult to implement the model.

5.1.8. Lack of knowledge of forms of valorization

This is a barrier that has been drawn as a conclusion after the responses with the interviewees. When asked how by-products are managed, all of them answered that they are managed through an external company that transforms these discards into fishmeal and fish oil. After this answer, some were asked if they knew of other ways to valorize these by-products obtained from fish production, to which most of the interviewees replied that they did not.

It has already been seen above that the simplest and most economical way to valorize these by-products is their transformation into fish oil and fishmeal. However, a greater knowledge of the possible forms of valorization would be necessary in order to have a better vision of the market and to be able to evaluate other alternatives that could be beneficial for the company.

5.2. Discussion

After the interviews conducted with the companies, different discussions can be held on the results obtained.

Of the barriers mentioned in the literature about the implementation of the circular economy in fish production, we can only find one barrier that matches those that industry experts have exposed in the interviews, the high costs of recycling, which is exposed in Farnet, (2018), Liu et al, (2021) and Farooque et al, (2019).

After what was observed in the literature, it seemed a barrier that was going to be mentioned by more companies as it is mentioned in several articles, however only three of them were the ones that named this barrier in the interviews. All practices to recycle or become more sustainable involve considerable capital investment and considering the ongoing problem of using recycled materials due to the lack of raw materials, it is a barrier that was expected to be mentioned more.

If we go back to the literature, it would be normal for companies to talk to us about the problems they face in finding new projects and how to carry them out, since these are barriers that we find in Liu et al, (2021) and Farooque et al, (2019). However, they only mention the economic difficulty of implementing these projects and not the lack of knowledge as mentioned in the literature.

Another barrier that is often found in the literature is the lack of collaboration between companies in the same sector, but in spite of this, in no interview was this barrier mentioned or implied.

Another barrier mentioned by the companies that can be associated with one that appears in the literature is government policies. In the literature we find this barrier defined as that there could be legal constraints to implement certain projects. "*The implications and scope of development of activities associated to manage the discards are regulated by a European Regulation and it is not the producing companies themselves that are in charge of the transformation process of their by-products*" noted Anfaco.

The rest of the barriers that are mentioned by the companies do not appear in the literature in the part of barriers in the fish sector. However, we can associate the barrier of social unawareness to a barrier that appears in the literature on the food sector side, organizational culture. This barrier is mainly about consumer behavior when it comes to recycling or doing their part of the circular economy model, because they are also involved.

After identifying the barriers that also appear in the literature, the next step would be to discuss why not all of the barriers that fish processing workers tell us about appear in the literature. This is a question that cannot be given an objective resolution since many unknown factors may come into play.

One idea observed is that the barriers that coincide with those mentioned in the literature are barriers that are easily visible from a position far away from the company. That is, the barriers that could be considered external, which do not depend on the firm itself, are those that appear in the literature, such as consumer behavior or recycling prices. That is why barriers such as unawareness of circular economy concept or lack of focus to work in a successful way do not appear in the literature, because they are obstacles that companies encounter while working and are more internal problems.

Another reason why the barriers are not the same could be due to the country where the study was conducted. There are very few articles that can be found in the literature about the barriers of the circular economy in the fish sector, and of those that have been used for the realization of this thesis, none has been made in reference to Spain. From what the companies said in the interviews, barriers such as the high cost of production or government policies vary from country to country and in Spain are a problem for them that might not exist in other countries.

On the other hand, companies do not totally agree on which barrier category is most important to them. This can happen for many reasons such as the productive capacity of the company, how big is the company or the field of work they are involved in, be it processing, canning or freezing fish. These are factors that may alter the responses and make it more difficult for them to overcome some than others.

6. CONCLUSION

The main objective of this research was to explore the barriers that companies in the fish processing sector face when implementing a circular economy model.

Different ways of valorizing the by-products generated in the production of fish are also presented, a way of giving added value to materials that would be considered waste and thus approaching a circular economy model. Although it is clear from the study that fishmeal and fish oil are the simplest and cheapest alternatives, there are several other ways to valorize these discards with potential such as collagen or hyaluronic acid. Furthermore, in comparison with the old ways of managing discards, it can be concluded that valorizing these products is much more beneficial for both the company and the environment.

In the search for barriers in the literature there were difficulties in finding articles, not so much in the food sector but in the fish processing sector. With this it can be concluded that the implementation of the circular economy in this sector has not been investigated in detail.

After the interviews with fish processing companies, several conclusions can be drawn. The first is that few barriers coincide with those found in the literature. This may be because the literature research was not conducted in the same country as this thesis, Spain, or because of the scarcity of previous research on this subject in this sector.

It has also been possible to extract from conversations with several of companies that they are not yet aware about the concept and opportunities of the circular economy model. This is a barrier identified by the author and it is important that it can be overcome. Without full knowledge of all employees of the company of what the circular economy is, it is very easy to fail in some link of the model at the time of its implementation.

On the other hand, from the 5 categories of barriers found in the literature, technological, financial, social, institutional/regulatory or market, the companies were asked which is the most important for them, the one that causes them the most problems. From the answers obtained, it can be said that there is no consensus on this question. There is a lot of variety in the answers, and factors such as the size of the company or its production capacity may come into play.

This work has an important limitation and that is the lack of knowledge of the concept of circular economy, a barrier identified by the interviews. In fact, there were companies that agreed to give me the interview but when I asked the questions, they did not respond due to lack of knowledge. With greater understanding on the part of the companies, more and better conclusions could have been drawn.

Future work should focus on doing a similar study in other geographical areas of Europe. In this way it could be concluded if the problem that the barriers do not coincide with those of the literature is because of the country where the study is carried out, and in this way the barriers found in different countries of the European Union in the same sector could be compared. In addition, new studies should expand the sample size of the research and assessing the interrelations between barrier in order to draw more accurate conclusions.

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ANNEX A

European Comission actions for Circular Economy implementation

Scheme 4 shows the actions established by the european union to achieve the objectives set for a circular economy. They are divided into 7 groups and the scheme also shows the target start of these actions.

Quick Reference on CEAP Implementation

A SUSTAINABLE PRODUCT POLICY FRAMEWORK	
Legislative proposal for **a sustainable product policy initiative**	2021
Legislative proposal **empowering consumers in the green transition**	**2021**
Legislative and non-legislative measures establishing a new **"right to repair"**	2021
Legislative proposal on substantiating **green claims**	**2021**
Mandatory Green Public Procurement criteria and targets in sectoral legislation and phasing-in **mandatory reporting on GPP**	as of 2021
Review of the **Industrial Emissions Directive**, including the integration of circular economy practices in upcoming BREFs	as of 2021
Launch of an **industry-led industrial symbiosis reporting and certification system**	2022

KEY PRODUCT VALUE CHAINS	
Circular Electronics Initiative, **common charger solution**, and **reward systems to return old devices**	**2021/** 2021
Review of the Directive on the **restriction of the use of certain hazardous substances in electrical and electronic equipment** and guidance to clarify its links with REACH and Ecodesign requirements	2021
Proposal for a new regulatory framework for batteries	**2020**
Review of the rules on **end-of-life vehicles**	2021
Review of the rules on proper treatment of **waste oils**	2022
Review to reinforce the **essential requirements for packaging** and **reduce (over)packaging and packaging waste**	2021
Mandatory requirements on **recycled plastic content** and **plastic waste reduction measures** for key products such as packaging, construction materials and vehicles	2021/ 2022
Restriction of **intentionally added microplastics** and measures on **unintentional release of microplastics**	2021
Policy framework for **bio-based plastics and biodegradable or compostable plastics**	2021
EU Strategy for Textiles	2021
Strategy for a Sustainable Built Environment	2021
Initiative to **substitute single-use packaging, tableware and cutlery by reusable products in food services**	2021

LESS WASTE, MORE VALUE	
Waste reduction targets for specific streams and other measures on **waste prevention**	2022
EU-wide **harmonised model for separate collection of waste and labelling** to facilitate separate collection	2022
Methodologies to track and minimise the presence of substances of concern in recycled materials and articles made thereof	2021
Harmonised information systems for the presence of substances of concern	2021
Scoping the development of further **EU-wide end-of-waste and by-product criteria**	2021
Revision of the rules on **waste shipments**	2021

MAKING THE CIRCULAR ECONOMY WORK FOR PEOPLE, REGIONS AND CITIES	
Supporting the circular economy transition through the **Skills Agenda**, the forthcoming **Action Plan for Social Economy**, **the Pact for Skills** and the **European Social Fund Plus.**	as of **2020**
Supporting the circular economy transition through **Cohesion policy funds, the Just Transition Mechanism** and **urban initiatives**	as of **2020**

CROSSCUTTING ACTIONS	
Improving measurement, modelling and policy tools to capture **synergies between the circular economy and climate change mitigation and adaptation** at EU and national level	as of 2020
Regulatory framework for the **certification of carbon removals**	2023
Reflecting circular economy objectives in the revision of the guidelines on **state aid in the field of environment and energy**	2021
Mainstreaming circular economy objectives in the context of the rules on **non-financial reporting**, and initiatives on **sustainable corporate governance** and on **environmental accounting**	**2021/** 2021

LEADING EFFORTS AT GLOBAL LEVEL	
Leading efforts towards reaching a **global agreement on plastics**	as of 2020
Proposing a **Global Circular Economy Alliance,** and initiating discussions on an **international agreement on the management of natural resources**	as of 2021
Mainstreaming circular economy objectives in **free trade agreements**, in **bilateral, regional and multilateral** processes and agreements, and in **EU external policy funding instruments**	as of **2020**

MONITORING THE PROGRESS	
Updating the **Circular Economy Monitoring Framework** to reflect new policy priorities and develop further **indicators on resource use**, including **consumption and material footprints**	2021

Scheme 4. Actions stablished by the European Union on Circular Economy implementation (European Comission, 2020)

ANNEX B

Fishmeal production process

To obtain fishmeal, the raw material, both whole fish and by-products, must undergo a series of processes to achieve the final product. These stages guarantee the healthiness of the fishmeal and its physical characteristics (Cuéllar Sáenz, 2021).

It is a physical transformation process that uses different sub-processes to arrive at the final product. Fish oil can also be obtained through this process.

To begin with, it is necessary to crush the whole fish or the fish by-products in order to obtain a thin material.

Later, this material passes to cooking where it is subjected to a temperature of 100°C for 20 minutes in indirect steam. This process stops microbiological and enzymatic activity in the product and helps to separate the oil.

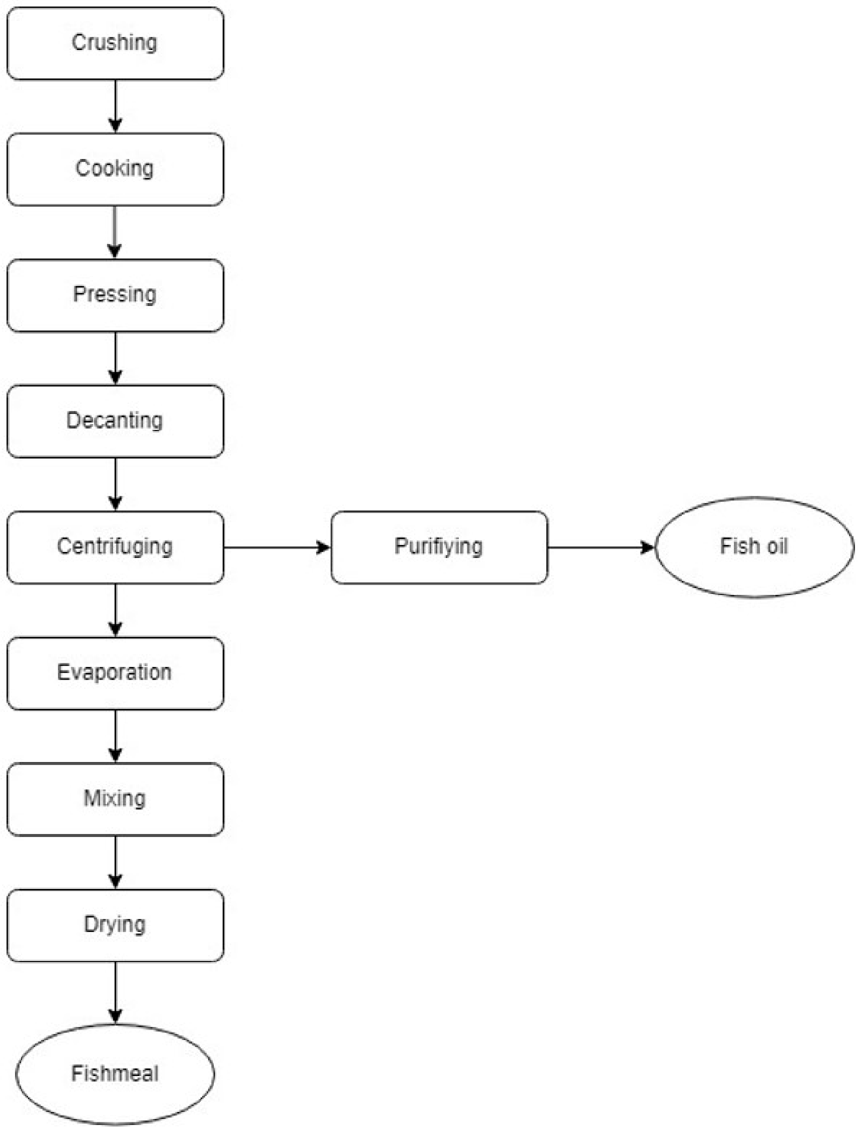
After cooking, the following process is pressing the material. In this process, the material is mechanically pressed to separate it into two types of phases, the liquid phase and the solid phase.

The next processes are decanting and centrifuging. In the first one, the liquid phase is decanted to recover more solid products and add them to the solid phase. Later, the liquid phase is centrifuged. As a result, oil and water will be obtained. The oil obtained can then be purified to obtain the appropriate properties to be marketed.

The water obtained in the centrifugation process is passed through an evaporation process to reduce the volume of the product in order to better concentrate it and obtain solids.

The final subprocesses are mixing and drying. The solids remaining from centrifugation are mixed with the solid material obtained from pressing until a paste is obtained. After this, the product is dried to extract more water from the mixture to a moisture content of 5 to 10%. This prevents bacteria growth and reduces chemical reactions.

All the process is summarized in a process diagram which is shown in Scheme 5



Scheme 5. Process diagram of fishmeal production process (Cuéllar Sáenz, 2021).

ANNEX C

Questionnaire and answer example

In this section, the questionnaire that was sent to the companies is presented.

1. What practices does the company implement to achieve a circular economy model?
2. Are there any practices that have not yet been implemented and that the company would like to start doing so?
3. Do you think that the food sector has more obstacles than other sectors to achieve a circular economy model?
4. What are the main obstacles/barriers that the company encounters when following a circular economy model?
5. Of these 5 categories in which the barriers are qualified, what type of barriers can be more difficult to overcome to achieve a circular economy and why? Social, technological, financial, institutional/regulatory, or market.

An example of an answer that a company gave is shown in Figure 13.

1. ¿Qué prácticas lleva la empresa a cabo para alcanzar un modelo de economía circular? Puedes ver lo que hacemos en [redacted], lo mas relevante es que tenemos una política integral en la que la RSC es eje central. Utilizamos y promovemos materias primas sostenibles, incluso lideramos proyectos de mejora de pesquerias. Usamos los mínimos recursos posibles, medimos todos los desperdicios para minimizarlos, tenemos paneles fotovoltaicos, sistemas de análisis de las condiciones meteorológicas para adecuar el consumo de nuestros equipos de refrigeración, ayudamos a la comunidad local, apostamos por la conciliación...muchas prácticas orientadas a minimizar recursos y a potenciar la economía social

2. ¿Hay alguna práctica que todavía no se haya podido implantar y la empresa quiera empezar a hacerlo? Nos gustaria poder consumir mas materia prima local pero no existen tantas alternativas de relación calidad-precio que sustituyan a otras de importación...

3. ¿Creéis que el sector de la alimentación tiene más obstáculos que otros sectores para alcanzar un modelo de economía circular? No realmente. En cada sector hay retos y oportunidades

4. ¿Cuáles son los principales obstáculos/barreras que se encuentra la empresa a la hora de seguir un modelo de economía circular? Lo mas importante es definir bien los objetivos, enfocarse bien, para poder orientar las acciones. El principal problema suele ser la falta de foco para trabajar de manera orientada

5. De estas 5 categorías, ¿qué tipo de barreras os puede suponer más dificultad de superar para conseguir una economía circular y por qué?
Social, tecnológica, financiera, estructural, o de mercado.
La estructural porque si en tu entorno no existen los medios para poder potenciar la economía circular, es mas difícil conseguirlo

Figure 13. Anonymous reply message of a company.