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Title: Using material flow analysis (MFA) to track the mass of plastics in aquaculture gear in the region of Møre and Romsdal.

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Abstract

This project is part of the blue circular economy (BCE) and is based on previous work done by Deshpande et al. (2020) in using material flow analysis to quantify masses of plastic, focusing in this paper on gear used in fish farming, especially in the region of Møre and Romsdal. The main purpose of this study is to perform a material flow analysis to have clear visibility of the stocks and flows of plastics linked to the aquaculture industry in Norway, especially in the selected area. In this study, the researchers tried to investigate the mass of plastic (MoP) in the aquaculture gear (AGs) used in aquaculture activities. Additionally, this study brings to light the nature of relationships existing among waste management companies, aquaculture companies, and their suppliers and manufacturers of gear. Both qualitative in the form of online semi-structured interviews and quantitative methods in the form of Material Flow Analysis (MFA) have been used to analyze the full scenario. The interviews uncovered the current challenges the region and country are facing with managing plastic waste, specifically generated from the aquaculture industry, plus the different strategies set forth by the different industry players and governments to deal with these challenges. Whereas the results from the MFA show that 52% of the waste gear from fish farming companies is sent to be recycled, 14% is landfilled, and 34% is incinerated in the region. The combination of these results can be useful to help have a better understanding of the contribution of the aquaculture industry in polluting the oceans and therefore inform all the key players who can and should take action to counter this problem primarily through sustainable management of the plastic gear used in the diverse operations.

1 CONTENTS

2 INTRODUCTION:

2.1 BACKGROUND INFORMATION

Is there any place left in this world where we will not find plastic waste? The answer is a plain No. Plastic is everywhere, from the Everest peak (WILKINSON, 2020) to the arctic (Harrabin, 2019). Ocean Cleanup, a non-profit foundation, came up with a statistic revealing that "5 trillion pieces of plastic currently litter the ocean" (The Ocean Cleanup, 2011). Plastic is gradually entering the human body through the food chain and impacting the full ecosystem and economy. A study done by Deloitte for the Ocean Cleanup shows that the estimated economic impact and clean-up cost from Marine Plastic Pollution in land-based water is USD 1.22 per capita in Europe in 2018 (Deloitte, 2020). If no action is taken immediately, the whole world will be a dumping zone and it will cost much more than we have ever imagined.

So, what is the solution? According to Paul Manning Chairman of Ocean resource management, "What the world has missed, is the massive wealth of raw materials floating in the oceans" (TOMRA, 2019, p. 9). If we have the formula to convert plastic waste to assets, we will be able to start a new era and bring a positive economic and environmental shift. Therefore, we all need to be united, open, and eager to positive change and embrace it. For example, The New Plastic Economy, a non-profit organization, builds on a vision called "A circular economy for plastic in which it never becomes waste" bringing all the greatest minds to bring this positive shift (*New Plastics Economy*, 2017). Involving companies with such joint effort might help to find an innovative solution.

At this point, only an average of 5% of plastic material is used for subsequent use (TOMRA, 2019). According to a study conducted by Deloitte mentioned, 95% of plastic packaging material which is valued at USD 80–120 billion is lost to the economy annually after using it once (Deloitte, 2020). To increase the number there is no other way but to improve the infrastructure for waste management locally (TOMRA, 2019) and using high-end technology (Deloitte, 2020), and bringing strict regulations and policies such as the EPR scheme.

The truth is that "there is currently no overview of the actual amount of plastic packaging put on the market in Norway which creates uncertainty over the actual amount is recycled." (Deloitte, 2020, p 2). However, considering the updated policies and initiatives taken by the Norwegian Government it can be said that Norway is putting tons of effort to create policies and develop systems to track plastic waste generated from different systems, and how to create a plastic circular economy. To add more value to the plastic circular economy and blue circular economy, the researchers are going to perform a material flow analysis to have clear visibility of the stocks and flows of plastics linked to the aquaculture industry in Norway, especially Møre Rømsdal region. Researchers will also reflect on the concern, ideas, and future initiatives that are going to be taken by the thought leaders from aquaculture industries.

2.2 Regulations and their impact on the Aquaculture industry

Marine litter, a global issue, threatening to both life along the coast and in the sea, requires a systematic solution (Boucher et al., 2020), and a contribution from the international, national, and local levels is necessary. The UN Sustainability Goal 14.1 states that "all marine pollution, especially from land-based sources, including marine litter and nutrients, must be prevented and significantly reduced by 2025". (United Nations Statistics Division, 2019) According to EU Directive, 2018/852/ of 30 May 2018 amending Directive 94/62/ EC on the packaging and plastic waste, the new target for the recycling of plastic packaging waste is 50% by 31st December 2025 and 55% by 31 December 2030.

Chinese national Sword, bans various plastic including such as PET, PE, PVC and PS, paper and solid waste to import, was a wakeup call for the developed country which came into effect in February 2018. (Tomra Recycling news, 2019) Later, the Basel Convention, a multilateral environmental agreement, introduced a new and stronger, legally binding international control in 2019 on the transboundary movements of certain types of plastic wastes. Based on that, the EU introduced a stricter law where exports of Basel-regulated plastic waste from the EU to non-OECD countries are banned (Ministry of Climate and Environment, 2020), examples of these countries include Argentina, Brazil, India, Malaysia, Singapore, South Africa, and Thailand (OECD, n.d.). The new regulation introduces Prior Informed Consent (PIC) procedure, and exporting country requires prior consent and ensures that it will reach a certain destination in an environmentally friendly way which enters into force as Norwegian law 1.1.2021 (Ministry of Climate and Environment, 2017).

To show solidarity with the global plastic waste movement and be an integral part of it, Norway took the respective initiative to lead and tackle plastic waste (Royal Norwegian Embassy in Washington, 2019). To contribute to the Sustainable Development Goal (SDG) 14.1, in 2018, the Norwegian government launched a new development program with a budget of 1,6 billion NOK which would combat marine litter and microplastics from large sources in developing countries (Ministry of Foreign Affairs, 2020). Under the action plan against marine litter from the Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR), "Norway has endorsed the goal that the supply of waste that has a negative impact in coastal areas, on the sea surface, in the water masses, and on the seabed shall be reduced." (Ministry of Climate and Environment, 2017). To fulfill OSPAR's action plan, Norway has started monitoring and reporting beach litter since 2011 and those reports revealed that fishing lines, nets and pieces of net, rope, and more than 70 % of other objects found are of plastic. Under OSPAR's Marine Litter Regional Action Plan, Norway has adopted the goal of reducing inputs of litter that have negative impacts on coastal waters, the sea surface, the water column, or the seabed. (Ministry of Climate and Environment, 2017) According to the Norwegian Pollution control act (1981), "Industrial waste shall be delivered to a lawful waste treatment and disposal plant unless it can be recovered or used in another way. " Under the Marine Resources Act, "fishermen are required to search for lost fishing gear and report losses to the Norwegian Coast Guard if the gear is not retrieved". Moreover, every year The Directorate of Fisheries organizes a retrieval program for lost fishing gear. (Ministry of Climate and Environment, 2017)

To build a plastic circular economy, there is no other way but EPR (extended producer responsibility) that can play a significant role. However, EPR schemes in Norway which are regulated by the Norwegian Waste Regulations only consider a plastic product which is defined as packaging. That does mean that the following four categories of plastic are not covered by the current legislation.

- "Plastic packaging put on the market by companies that together put on the market less than 1,000 kg.
- Privately imported plastic packaging (internet or cross-border shopping)
- Other plastic products, such as toys, outdoor furniture, and fishing equipment
- Plastic packaging that is not reported by current members of PROs (underreporting)."

(Deloitte, 2020, p. 35)

An example portrayed in the report published by Deloitte mentioned "one fish box in EPS (Expanded polystyrene) weighs 0,6 kg. This means that a producer may put 1667 units of fishing boxes on the market without being obliged" (Deloitte, 2020, p. 35), whereas low-density EPS is one of the main sources of marine littering. The Norwegian Environment Agency is reviewing a proposal for a producer responsibility scheme for the fisheries and aquaculture industry (Ministry of Climate and Environment, 2017).

In a report of Deloitte (2020), they suggested some points to add in the next amendment of the EPR scheme which can help to develop a plastic circular economy some of them are pointed below-

- Putting a tax on virgin material or subsidized recycled plastic because when the virgin material is cheaper than the recycled one, producers will not use the recycled one unless they are legally required to.
- Standardization in product design or digital marking can be a game-changer to sort plastic waste easily. Under the current scheme, producers do not have any operational or financial responsibility for the litter generated by their product. However, by implementing digital marking producers would be liable for every product they use.
- A National Plan to develop infrastructure which would allow the mobilization industry to find which area can use more recycled plastic (Deloitte, 2020).
- Recycled waste shall be measured when it enters the recycling operation (Deloitte, 2020, p. 25), as the loss of plastic waste from the value chain increases the risk of pollution.

2.3 Research problem and objectives

As of today, extensive work has been done to track and monitor plastic waste generating from commercial fishing in Norway, however, very few contributions exist to focus solely on the aquaculture industry and its effect on the ocean's health. This study will target directly this gap, trying to use the same methods of Deshpande's work in material flow analysis (MFA) to track the stocks and flows of plastic waste in the region of Møre and Romsdal. The potential results of this project will be crucial for decision-makers in this area, including government officials and company leaders. For companies, it will reveal the plastic footprint of the aquaculture activities and highlight missed opportunities to adopt more circular business models. As for the government, it can help in introducing new rules and regulations to diminish the effect of plastic waste on the ocean. This project is trying to contribute to innovation in business models and sustainable development, areas that are directly linked to the researchers' fields of study and specializations which are innovation and entrepreneurship.

The main purpose of this study is to focus on the aquaculture companies that have fish farms in the production area "Stadt to Hustadvika" in the region of Møre Og Romsdal in Norway and perform a material flow analysis to first understand the flows of plastic mass linked to the aquaculture activities, and then investigate the waste management strategies and perspectives from specialists in the field. In the end, strategies will be suggested on how to close the loop of materials for the observed companies. This study will be based on the MFA, triple bottom line theory, showing the impact of having a circular business model on people, the planet, and profit.

This study will provide answers to the following research questions:

- What are the stocks and flows of aquaculture plastics in the region of Møre and Romsdal?
- What are the current challenges Norway is facing with managing plastic waste generating from the aquaculture industry?
- What are the strategies set forth by the different industry players to deal with these challenges?

To answer the above questions, researchers used the upstream and downstream approach influenced by 'a network of organizations' theme (Harrison et al., fig 1.3) to identify the parties are involved in dealing with plastic in this particular industry.

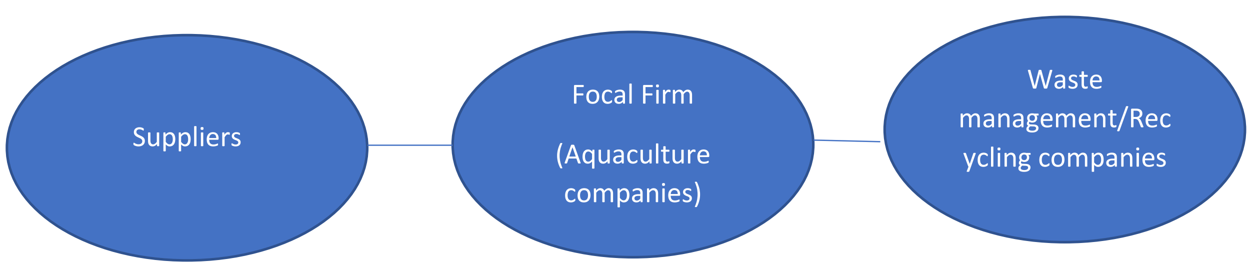

Figure 2-1: Network of the Aquaculture company

Researchers used both quantitative and qualitative methods to collect data. For qualitative research, the researcher conducted the interview and for quantitative research, researchers used survey monkey to collect data. As mentioned above, there is little knowledge about plastic pollution directly linked to the aquaculture industry and there is a lack of quantifiable data about plastics and microplastics that exist in the ocean caused by fish farming activities. This study targets to identify the reason for that gap and creates a bridge. This study explains the current strategies and challenges that Norway is facing to manage plastic waste that is generated from aquaculture companies. Therefore, the following entities would get benefit from this study: aquaculture companies, suppliers of gear, waste management companies, the government and entrepreneurs who would like to work with the plastic recycling business. The different actors involved can use the findings of this project to have a better understanding of the current situation of plastics and how the industry players are handling it.

In the next chapters of this paper, a brief literature review will be presented, followed by the methodology chapter where a detailed explanation of the research process is discussed. The final chapters of this study will be dedicated to describe the results, discussion, contribution, and future research potential.

3 LITERATURE REVIEW

This chapter will focus on reviewing existing literature about diverse topics relevant to this research project, including marine pollution caused by aquaculture activities, current sustainability standards, extended producers' responsibility (EPR), and material flow analysis (MFA).

3.1 MARINE POLLUTION

Grønt Punkt Norge's and Infinitum's analyses revealed that 171,344 tonnes of plastic are put into the market in 2018 and the recycling rate was 44% (Deloitte, 2020). However, this number is only an estimation. According to Deshpande et.al (2020, p.1), "commercial fishing in Norway contributes to around 380 t/yr. mass of plastics from lost fishing gears and parts. Additionally, around 4000 tons of plastic waste is collected in Norway annually from derelict fishing gears out of which 24% is landfilled, and 21% is incinerated for energy recovery." Data from beach clean-up organized in Norway shows that most litter on beaches in the southern part of the country is from land-based sources such as households, industry, construction, and agriculture, while the proportion of litter from the fisheries and other ocean-based sources tends to be higher further north. Additionally, 80 % of plastic waste of all world oceans is assumed to originate from land-based sources and 20% is from sea-based activities in fisheries and shipping (Ministry of Climate and Environment, 2017).

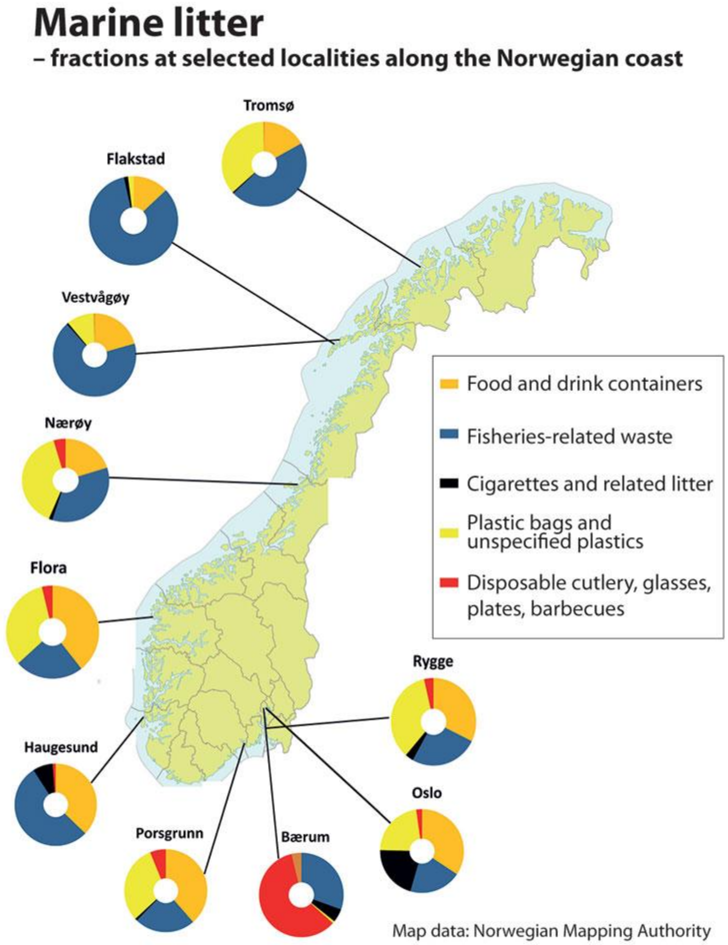

Figure 3-1: Proportions of different fractions of marine litter collected at selected localities in 2011 (Ministry of Climate and Environment, 2017).

3.2 POLLUTION CONTRIBUTION FROM THE AQUACULTURE INDUSTRY

Among the many organizations working towards the goal of having a cleaner and healthier ocean, the Aquaculture Stewardship Council (ASC) appears in most searches especially when it is related to aquaculture. ASC is an international independent not-for-profit organization that specializes in managing the certifications of responsible aquaculture in the globe (ASC, n.d.).

After considering the inclusion of the marine litter problematic in their certification standard, the ASC published a report in 2019 done by Poseidon Aquatic Resources Management Ltd in which the different causes, sources, and consequences of marine litter are tied to the aquaculture industry are discussed (Huntington, 2019). Based on this report, marine health is heavily impacted by plastic pollution, and among the major contributors is ghost fishing and the discarded gear used in fishing and aquaculture activities under the form of abandoned, lost, discarded fishing gear (ALDFG). In the last decade, special attention has been dedicated to the plastic debris related to the aquaculture sector to investigate its potential impact on marine litter (Huntington, 2019). In another article published by the ASC on their official website, the organization posits that there are two main sources directly linked to the aquaculture industry accounting for more than 35 different plastic materials that end up as debris in the environment. The first is the aquaculture gear used including but not limited to nets, pond liners, and buoys, while the second is composed of other plastic tools and materials used for packaging of products (ASC, 2019). These 35 different kinds of plastics can be very hazardous for marine life. Research done by the ASC uncovered that the aquaculture plastic debris is negatively impacting the lives of animals as diverse creatures can be entrapped by this debris, while others face the danger of ingesting it, leading to humans consuming microplastics at the end of the cycle (ASC, 2019).

3.3 Aquaculture Systems and gear

Huntington (2019) in his report for the ASC investigated the different types of plastics used in the diverse aquaculture systems and found out that most of the equipment is composed of high-density polyethylene (HDPE), polystyrene, and polymer. Among the many systems used in the aquaculture industry, the most common ones are open water cages and pens, suspended ropes and longlines, coastal and inland ponds, and finally tanks including recirculated aquaculture systems (RAS) (Huntington, 2019). Having a detailed breakdown of the different types of plastics used in gear manufacturing not only can facilitate assessing which of the equipment is recyclable, but also can uncover what will happen to specific equipment in case it has been lost or discarded. In fact, in the same report, the author showcased the main causes of pollution originating from aquaculture activities and put these causes under three categories: mismanagement, deliberate discharge, and extreme weather (Huntington, 2019).

The table (table 3-1) below was produced by the ASC, and it summarizes the different aquaculture systems, breaking them down to specific equipment, along with what types of plastic are they composed of (Huntington, 2019).

System	Key plastic components	PM MA	EPS	FRP	HD-PE	LLD-PE	LD-PE	Nylon	PE	PET	PP	PVC	UHM w-PE
Open-water cages and pens	Floating collars (inc. handrails)				✓							✓	
	Collar floatation		✓										
	Buoys (in mooring systems)				✓		✓		✓				
	Ropes (in mooring systems)							✓		✓	✓		
	Net enclosures				✓			✓			✓		✓
	Predator and other nets				✓			✓	✓				
	Feeding systems (pipes & hoppers)			✓	✓							✓	
Suspended ropes / longlines	Buoys (in mooring systems)				✓		✓		✓				
	Ropes (in longlines & mooring systems)				✓			✓		✓	✓		
	Raft floatation		✓		✓								
	Stock containment (nets/meshes)				✓			✓			✓		✓
Coastal and inland ponds	Pond liners				✓	✓	✓						
	Sampling / harvest nets				✓			✓			✓		✓
	Plastic green / poly housing						✓						
	Aerators / pumps				✓							✓	
	Feeding systems (pipes, feeders & trays)			✓	✓							✓	
Tanks (inc. recirculated aquacultu-re systems RAS)	Spawning, incubation & stock holding tanks			✓	✓								
	Pipework (inc. connectors, valves)			✓	✓							✓	
	Office / laboratory fixtures & fittings	✓	✓				✓	✓				✓	

Table 3-1:Aquaculture Systems and plastic composition (Huntington, 2019).

3.4 Sustainability, circular economy, and Triple bottom line

When thinking about the end goal of having a closed loop of used materials, the mind goes directly into associating this with sustainability and circular economy. There is an abundance of articles dedicated to defining these two terms, putting them into different contexts and frameworks. Before reviewing the literature, it is salient to define those terms. Geissdoerfer et al. (2017) published an article aiming at establishing the difference between circular economy and sustainability using extensive reviewing of relevant literature. In this work, the authors first dive into the historical origins of both terms, then proceed to extract and compare the different definitions given to each notion.

Putting the spotlight on the importance of defining the terms, Johnson et al. (2007) posit that there are roughly around 300 different definitions to the term 'sustainability'. However, few definitions are strongly agreed upon amongst scholars and researchers. Based on Geissdoerfer et al. (2017), one of the most accepted definitions originated from the 1987 Brundtland report. In this statement of responsibility produced by the World Commission on Environment and Development, Gro Harlem Brundtland (1987) defined sustainability as the development that provides for the needs of the current generations without compromising the ability of future generations to meet their own needs. Other common definitions rotate around the same concepts. For instance, McMichael et al. (2003) defined sustainability as the optimization of human lifestyle and living conditions particularly through maintaining the supply of non-replaceable goods and services, allowing continuous support of health, security, and well-being. Another common definition was given by the International Organization for Standardization (ISO) stating that sustainability is the situation in which all the functions of earth's ecosystems are preserved while human activity is conducted (ISO, 2007). Moreover, according to Geissdoerfer et al. (2017), the concept of sustainability is also associated with the term triple bottom line, a concept first conceived by John Elkington in his book "Cannibals with forks" back in 1997. In his work, Elkington stated that the three pillars of sustainability are people, profit, and the planet, promoting the importance of harmony that should exist among environmental, social, and economic performances. Using all these accumulated definitions, Geissdoerfer et al. (2017) holistically defined sustainability as a "balanced and systemic integration of intra and intergenerational economic, social, and environmental performance" (p.759).

After a good understanding of the notion of sustainability is established, it is crucial to investigate the meaning of circular economy, a term also that has been given a multitude of definitions in the past years. Like the term sustainability, the most commonly accepted definitions of circular economy share the same meaning. Yuan et al. (2006), Geng and Doberstein (2008), Bocken et al. (2016), and Webster et al. (2017) have all used concepts such as restorative economy, regenerative business model, and closing the loop of materials to define the circular economy. Geissdoerfer et al. (2017) used all the above to come up with the following definition: "[the circular economy is] a regenerative system in which resource input and waste, emission, and energy leakage are minimized by slowing, closing, and narrowing material and energy loops. This can be achieved through long-lasting design, maintenance, repair, reuse, remanufacturing, refurbishing, and recycling" (pp.759).

Now that both these notions are defined, it is salient to closely investigate the different contextual frameworks where they are used in literature. Since this project is focusing on the field of aquaculture, this brief review will only tackle some of the articles that use sustainability in the context of fish farming and related activities. Different studies approached the concept of sustainability in aquaculture from different angles. Starting with projects based on Norwegian data, some studies focus on the sustainability standards and the certification requirements (Amundsen et al., 2020), other projects explore how production is affected by the certification schemes (Osmundsen et al., 2020). Larssen (2018) emphasize the development licenses connected to the aquaculture industry in Norway, explaining the different aspects of having such licenses in helping the industry to get into the sustainable path. Moving on to international projects that are very relevant to the topic in hand, Tschirner and klaos from Germany (2017) introduced different suggestions to increase the sustainability of the industry of fish farming. The main suggested strategies include first changing the farmed species from carnivorous to omnivorous fishes, allowing a reduced consumption of limited protein resources. And second, changing the fish diet to insect meals instead of marine aquafeed. Tschirner and klaos from Germany (2017) argue that following these strategies can yield a better future for the aquaculture industry. Ahmed et al. (2020) took another route to assess the current state of sustainability in the aquaculture industry, comparing it with organic agriculture. The authors argue that to promote sustainable practices in fish farming, it is crucial to switch to organic aquaculture (Ahmed et al., 2020). While this project accentuates the importance of organic aquaculture and its many advantages, it also sheds the light on some of its drawbacks, such as the much lower fish production capacity and thus failure to accommodate global fish demand and provide food security (Ahmed et al., 2020). Finally, Lazard et al. (2014) worked on a global scale project to assess and compare aquaculture systems in different countries, closely investigating different sustainability indicators.

3.5 On Material Flow Analysis (MFA)

According to Brunner and Rechberger (2016), MFA is a tool that can be used to systematically assess the state and changes in the stocks and flows of materials within a defined set of space and time boundaries. Using this tool enables connecting all the pathways of a given material from beginning to end. The flows of wastes with their sources become visible and easily identifiable through balancing inputs and outputs of the materials. The overall objective is to recognize whether there is an accumulation or diminution of material stocks so that measures can be taken to restore balance. All these characteristics make MFA an attractive decision-support tool that can be used in waste and environmental management, resource management, and other fields related to policy assessment (Brunner & Rechberger, 2016).

In their technical handbook, Brunner and Rechberger (2016) also explain in detail the process of MFA and the different steps composing it. The first one consists of defining the problem and objectives and selecting materials or substances along with the appropriate boundaries. This step is the essence of system definition and leads to a qualitative model. In the next step, measurements, estimations, or literature data are used to determine mass flows and material concentrations. These stocks and flows should be then balanced using the mass conservation principle, and uncertainties are considered. This second step produces a quantitative model generated usually by an MFA software that facilitates calculations and properly presents results to help in the implementation decisions. It is salient to remember that these procedures and steps should not be strictly followed as described, but they should be optimized and continuously adjusted to adapt to the specific objectives of the project at hand (Brunner & Rechberger, 2016).

Another study by Brunner and Allesch (2015) focuses on showcasing the benefits of utilizing MFA in the fields of waste management. In their project, the researchers try to identify the areas where MFA methods are most successful in being a support tool for the decision-making process in waste management. The use of MFA has become more and more mainstream in other fields as well, such as medicine and urban metabolism. And this growing reliance is attributed to the fact that MFA can serve to accomplish high recycling rates and diminish the loss of potential secondary raw materials (Brunner & Allesch, 2015).

3.5.1 Marine Litter and Material flow analysis

When searching for relevant literature connected to the MFA of plastic ocean waste that is originating from aquaculture activities in Norway, there is a noticeable gap, especially when it comes to specific geographic areas. But before targeting the different takes on the topic and the suggested solutions, it is essential to have a look at the problem itself, which in this case is ocean pollution resulting from aquaculture activities. In a study focusing on the North Atlantic Ocean and its ecosystem services, results extracted from experts' responses reveal that temperature change, pollution, ocean acidification, and fisheries are all threats to deep-sea ecosystem services (Armstrong et al., 2019). Another research project focusing on tuna fishing carried out by Garcia Rellan and other researchers confirms that one of the main sources of marine pollution is nets and litter related to fisheries activities, among other sources such as gaseous emissions and oils dumped in the oceans (García Rellán et al., 2018).

Following the same line, Allesch and Brunner investigated the Western and Central Pacific Ocean by gathering data from fishing vessels operating there. The results of their project revealed that more than 10 000 incidents related to pollution have been reported. Most of these incidents are linked to dumped, lost, or abandoned fishing gear (Allesch & Brunner, 2015). This work relates to the recent contributions of Deshpande who investigated the flows and stocks of plastic waste originating from fishing activities in Norway using material flow analysis. Although Deshpande's work is focusing solely on fisheries and not the aquaculture industry, it is very relevant to the current research project as it provides a framework to follow, one that can be used in the aquaculture context. According to Deshpande et al. (2020), the lack of exact and scientific data estimating the contribution of abandoned, lost, and discarded gear to the plastic pollution in oceans impacts the quality of management of resources worldwide. The same study confirms that the use of MFA shows great potential in being a support tool guiding the introduction of new methods for sustainable management of resources, allowing companies to adopt innovative strategies to help diminish marine pollution of oceans (Deshpande et al., 2020).

3.5.2 Some of the previous studies that used MFA

Many research projects have been using material flow analysis (MFA) as a tool to quantify different materials and substances, resulting in producing numbers that will bring a better understanding of the situation and allow for better mitigation of a multitude of problems. MFA is used in most scientific fields and a combination of contexts. For instance, Duygan and Meylan (2015) from Switzerland combined MFA with structural analysis to assess the material flow originating from laptops and smartphones contributing to the waste electrical electronic equipment (WEEE). The results of this project resulted in suggesting strategies and policies that will help in managing the WEEE. Another research project from South Africa utilized MFA in the field of industrial ecology, where the researchers Hoekman and Blottnitz (2017) investigated Cape Town city's metabolism using an economy-wide MFA assessing several indicators such as direct material input (DMI), domestic material consumption (DMC), and direct material output (DMO). In the same context of industrial ecology, Hodson et al. (2012) attempted to combine MFA with transition analysis (TA) to connect resource flows through cities and urban infrastructures. This work focused on the important role infrastructure design and operation play in shaping the life cycle of city resources. Among other fields where MFA has been used, an interesting study investigated the industry of natural rubber (NR) in Sri Lanka applying MFA jointly with material flow cost accounting (MFCA) and life cycle assessment (LCA). This project aims to study the feasibility of a sustainable manufacturing system of crepe rubber (Dunuwila et al., 2018).

MFA had also been used in the field of aquaculture, tackling different problems. However, most of these studies focus on the wastewater and aquafeed alternatives, while very few -if none- use MFA in the context of plastic pollution from the aquaculture gear. A very recent study applies the concept of MFA to investigate recycling wastewater and sediments from catfish farming ponds and reuse them in agriculture as organic fertilizers for crops (Van Tung et al., 2021). Another study by Philis et al., (2018) compared different protein sources for aquafeed production. The authors used MFA to track transfers of energy and phosphorus of both Brazilian soy protein and Norwegian seaweed protein. In the same direction, Vestrum et al., (2013) tracked the phosphorus flows in the fisheries and aquaculture industries using MFA generated from fish consumption and waste management. Many other relevant projects exist, however, as mentioned before, it is very rare to find literature that used focuses on plastic flows of aquaculture gear using the concepts of MFA.

3.6 EXTENDED PRODUCERS' RESPONSIBILITY (EPR)

Extended producer responsibility (EPR) is a concept that emerged in the early 1990s in Germany and Sweden, intending to internalize the costs of waste management into the product prices, creating incentives to move to more eco-friendly packaging designs (Lifset et al., 2013). This concept of course as any other has been given many definitions. According to Lifset et al. (2013), the most accepted definitions focus on the responsibility shift of products and materials' end of life from the government to the producers. The Organization for Economic Co-operation and Development (OECD 2001) defined this concept as an environmental policy that extends the producer's responsibility for a product to the post-consumer stage. This policy approach has two main features: first, it shifts the responsibility from municipalities directly to producers, and second, it creates incentives for the producers to incorporate eco-friendly designs into their products.

The concept of EPR has been used as the central topic of many interesting research projects, yielding a plethora of relevant literature. Starting with international projects, Lifset et al. (2013) discussed the importance of EPR policy, investigating its practical perspectives in both the national and international contexts. This project also tackled the effects of EPR on the recycling of different types of wastes, including packaging waste, electronic waste, hazardous waste, and household waste. In the United States, Gardner (2013) worked on a research project for the company NESTLE Waters North America, investigating the effect of EPR on the increasing rates of recycling packaging and printed paper (PPP). He also discussed the role of consumers and local governments in the success of implementing the EPR policy. Other studies focus on identifying the concrete benefits of EPR implementation, portraying in detail the financial advantages to be gained. One very important study by Rodrigues et al. (2016) developed an input-output (IO) model with which they captured the opportunity costs of financing an EPR system.

Switching the focus to Norway, several academic and scientific projects have worked on the EPR policy. Røine and Lee (2006) worked on a research project aiming to investigate whether EPR implementation in Norway influenced technological change and innovation (TCI). The authors used a comparative study between the electric and plastic packaging sectors, allowing them to discover that there was indeed a correlation between EPR and TCI, however, the causality was found to be weak (Røine & Lee, 2006). There is the fact an easy to discern the pattern in most studies EPR in Norway, in that the main focus is on the plastic packaging and electric industries.

One of the earliest studies by Røine et al. (1998) investigated the potential economic efficiency and environmental effectiveness in the sector of plastic packaging in Norway resulting from EPR implementation. Another work by Røine collaborating with Chin-Yu Lee aimed at analyzing the empirical data to demonstrate how EPR stimulates innovation change. The paper focused on the electric and electronic industry in Norway, selecting three of the major companies in this sector as a case study (Lee et al., 2004).

4 METHODOLOGY

This chapter will describe in detail the methods used to answer the research questions. This chapter includes research scope and context, methodology, how data was collected and analyzed.

4.1 RESEARCH SCOPE AND CONTEXT

This study is mostly based on the work done by Deshpande et al. (2020). His work guides the material flow analysis (MFA), as he previously provided a holistic approach and targeted all of Norway as his subject. This study aims at conducting the same MFA but with a focus on the region of Møre and Romsdal, especially the production area 'Stadt to Hustadvika'. The choice of this specific region was based on information provided from the website BarentsWatch.no. Based on the official government website Regjeringen.no (2017), Norway has introduced a new traffic light system that splits the country into 13 fishing production areas. This new system was introduced on 15 October 2017, with the purpose to adjust production capacities in salmon and trout farming. The decision to offer an increase or decrease in production capacity for aquaculture facilities is based on their impact on the environment, which is assessed throughout the 13 production areas established along the Norwegian coast. Based on yearly assessments carried out by professionals, the capacity can be adjusted by 6%, increases if green, decreases if red, and remains the same if yellow. Therefore, the colors green, yellow and red are symbols for whether a production area can have an increase in production capacity or not. The figure below portrays a map of the 13 production areas (Figure 4-1).

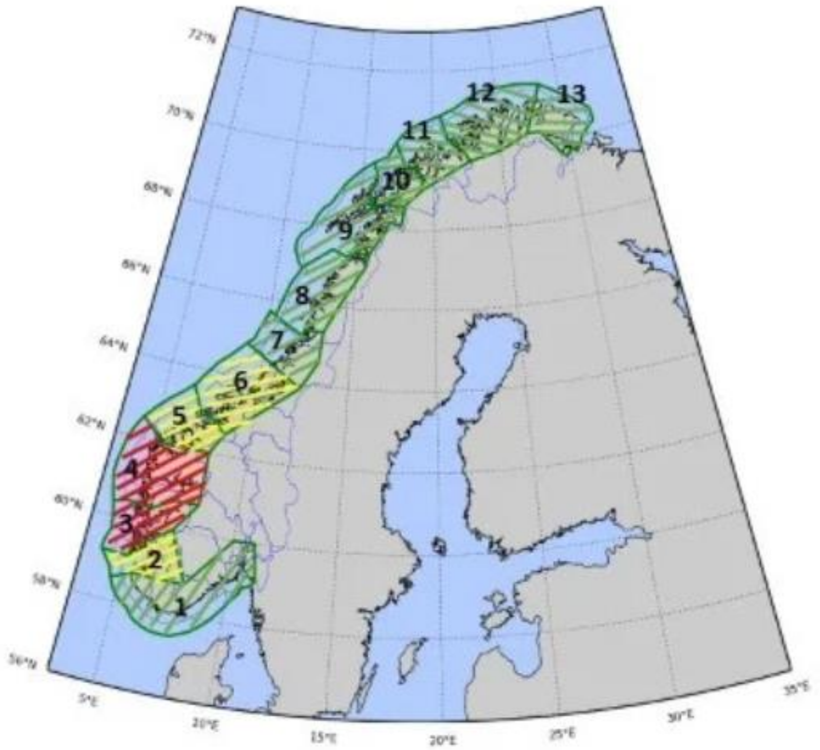

Figure 4-1: The 13 Production Areas along Norway's coast (Regjeringen,2017).

List of production areas:

1. The Swedish border to Jæren
2. Ryfylke
3. Karmøy to Sotra
4. Nordhordland to Stadt
5. Stadt to Hustadvika
6. Nordmøre to Sør-Trøndelag
7. Nord-Trøndelag with Bindal
8. Helgeland to Bodø
9. Vestfjorden and Vesterålen
10. Andøya to Senja
11. Kvaløya to Loppa
12. West Finnmark
13. East Finnmark

As mentioned above, the focus area of this research is Stadt to Hustadvika production area. According to BarentsWatch.no, there are 86 aquaculture sites in the Stadt til Hustadvika production area. However, 60 sites are fallow (inactive), and the rest 26 are operating and get licensed by 13 aquaculture companies. (Data extracted from BarentsWatch.no on week 4, from 25th to 31st January)

The primary motive was to conduct the surveys and interviews with the 13 focal aquaculture companies and their suppliers that supply aquaculture gear, and the waste management partners who play an important role in the transportation and processing of the waste. The input from these parties is considered crucial for this project. However, due to time constraints and the reluctance of companies to co-operate in this project and lack of publicly available transparent data delayed the process, therefore researchers did not get the opportunity to have two-way communication with all 52 companies that were contacted primarily.

4.2 METHODS:

To achieve this project's objectives, a combination of different methods is applied, including reviewing some of the available literature about this topic, analysing current legislations and regulations, and finally conducting semi-structured interviews and online surveys.

To perform Material flow analysis, quantitative methods are used for calculating the plastic stocks and flows. The main source of information is the primary data collected from electronic surveys sent to the sample.

After that, and to obtain a more personalized view from the selected companies and region, qualitative methods under the form of interviews with key stakeholders is conducted, allowing for a deeper understanding of the diverse plastic waste management strategies set by the aquaculture companies and the flow of plastic material supply, as well as revealing any innovative ideas to improve the current situation of ocean health.

4.3 DATA COLLECTION:

Both qualitative and quantitative methods are used to collect data to answer research questions after receiving the NSD (Norsk Senter for forskningsDataapproval). Data collection took place from February to May 2021. Different channels have been used to communicate with companies, the initial contact however was through email and LinkedIn messages. A total of 52 entities have been contacted to contribute to the research project. 33 of these are aquaculture companies with active and fallow sites in the region of Møre and Romsdal, specializing mostly in fish farming, but one company specializes in seaweed aquaculture. The remaining entities are composed of 6 gear suppliers and manufacturers, 11 waste management facilities of which one is a landfilling site, and one a recycling company. One research company was also contacted and interviewed, plus the state manager of municipalities (Statsforvalter). Initially, the focus was only on the 13 companies that have active sea-based farms, however all other companies in the targeted region and production area of focus have been contacted, even if they have fallow sites. This decision was taken to compensate for the small size of the sample. Different persons with different roles and functions in their respective companies have accepted to be interviewed. Positions within the supply chain or logistics departments were targeted to get the knowledge and opinions from specialists. The functions of the persons interviewed ranged from supply chain managers, service managers, procurement and logistics managers, to chief sustainability officers and site managers.

Based on the availability of representatives from companies willing to participate, semi-structured interviews were conducted with the aquaculture companies and other relevant entities for qualitative analysis. All meetings were online due to the current pandemic restrictions, therefore a reliable video telephony platform called Zoom was used for all interviews. This has allowed to save resources, making the process cheaper and more efficient. The researchers conducted a pilot interview with a Ph.D. candidate from NTNU, who has relevant experience in this field, to see the effectiveness of the structure. Eventually, an interview was conducted with a waste management company that provided lots of relevant information which helped to dig deeper and later connected with aquaculture companies that have licenses for fish farming in the area. Furthermore, interviews were conducted with one research firm and with the biggest supplier of aquaculture gear in the region. Other than supplying, this specific company specializes in diverse areas connected to the aquaculture industry, including manufacturing, servicing, repairing, recertifying gear for reuse, and handling waste.

All interviews were conducted through Zoom and were recorded for analysis purposes. Transcription of the interviews was done manually by the investigators, allowing for more detailed extraction of relevant information. During some of the interviews, the interviewees showed some data that was sensitive, therefore a quick summary of what has been shared was noted in separate documents. In other instances, the interviewees shared internal documents that helped retrieve more relevant data. Due to the Corona virus, it was very difficult to arrange site visits.

For quantitative analysis purposes, an online software called SurveyMonkey was used as a primary tool to collect data related to the lifecycle of gear used in the aquaculture industry, the amount of gear lost, and how much plastic is used to produce these tools, fate of the used gear from the focal companies and their suppliers and waste management companies. A combination of primary sources in the surveys and semi-structured interviews, with secondary sources in published literature and government statistics, was used to collect relevant data. Survey questionnaires and interview questions will be available in the appendices.

5 DATA ANALYSIS:

This chapter is dedicated to describing the methods used for this study. Both quantitative and qualitative processes are described below in detail.

5.1 QUANTITATIVE ANALYSIS

After receiving the responses from the sent out electronic surveys, STAN v2.6 was used as a tool for data reconciliation and to create the MFA model (Vienna University of Technology, Vienna, Austria). The results from the surveys along with the interpretation of the final MFA model are presented in chapter 6 (Results).

5.1.1 System description

In this project, aquaculture gear (AGs) are defined as any kind of equipment used in the diverse fish farming activities. Throughout this project, there is an exclusive focus on the plastic components of the gear used, especially on 4 types: polyethylene (PE), polypropylene (PP), High-Density Polyethylene (HDPE), and Nylon. These plastics are the main materials used to build aquaculture gear as portrayed in chapter 3 (table 3-1). The figure below (figure 5-1) shows the lifecycle processes of the AGs used by aquaculture companies in the region of Møre and Romsdal. In this project, we focus on one aquaculture system used for sea-based fish farming, including 5 major pieces of equipment: floating collars/rings, bottom rings, nets, ropes, and buoys.

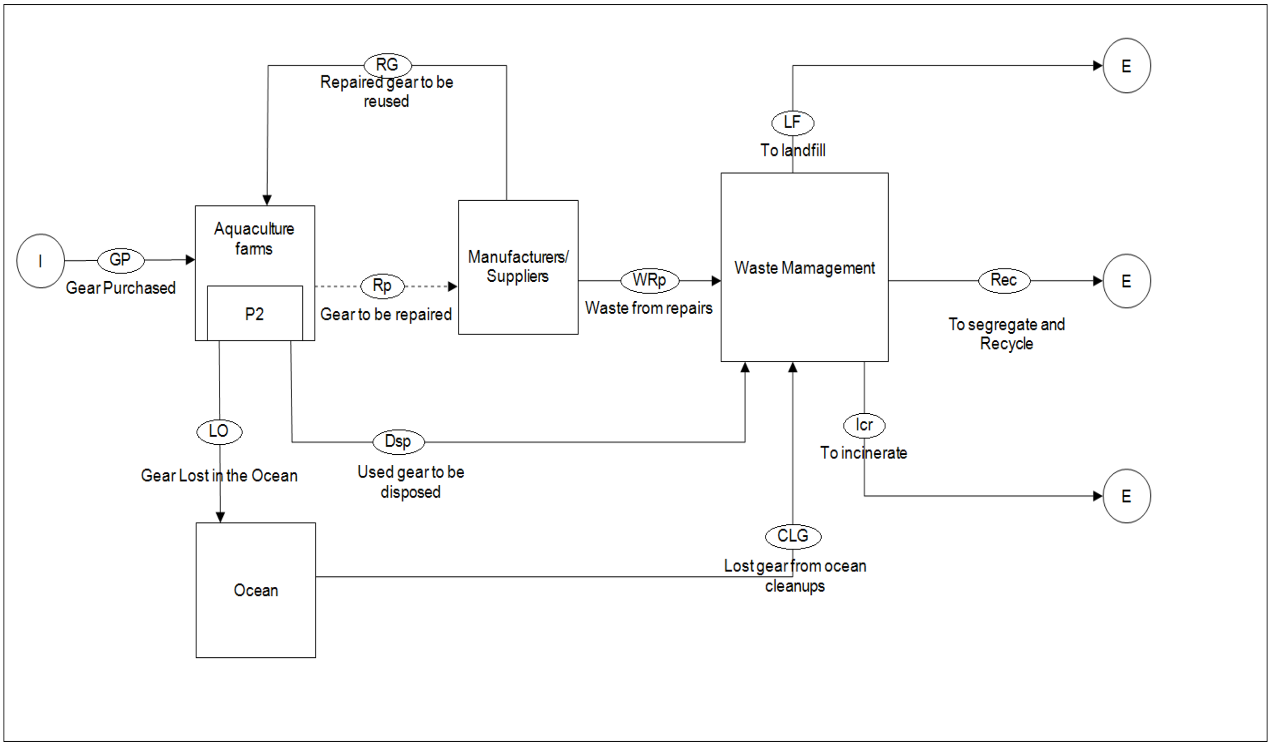

Figure 5-1: Life cycle processes of AGs in fish farming

Based on the interviews and the surveys, losing parts of the gear used in fish farming was reported to never occur, suggesting that very rare incidents related to losing gear happen in this region. This also indicates that the only kind of plastics that end up in the oceans are microplastics as a result of the wear and tear happening to the plastic structures while deployed in the ocean, especially considering the long period of contact of these surfaces with the sea water. Survey responses from the aquaculture companies showed also that the equipment does not get changed that frequently, as most parts are purchased once every 10 years, except for nets that get changed every 4 to 5 year and the feeding systems including pipes every 20 years, suggesting a long lifecycle of the plastics used in this industry. However, some parts of the structures get sent to suppliers and manufacturers to be repaired and serviced, allowing them to be recertified for reuse, extending the overall lifecycle of the used gear. Survey responses show that 5 to 20% of each gear being used gets repaired annually, except for the stock containment nets which are repaired in their entirety after each stocking and when holes are detected.

At the end of their lifecycle. The AGs that cannot be reused get sent to the waste management of choice of the aquaculture company. Waste from the repairs generated from the suppliers and manufacturers also is sent to the waste management facilities they have agreements with. Some of the waste that is lost in the ocean is gathered by associations during ocean clean-ups and eventually ends up with the waste management companies, which have the responsibility to segregate the waste received and send it to 3 main destinations: landfill, recycling, or incineration for energy recovery.

5.1.2 Calculations of plastic masses in aquaculture gear for the MFA model

To be able to use the data received from different sources, some assumptions had to be made. It is assumed that all the equipment below is made purely of plastic (PE, PP, HDPE, Nylon). The information below is cultivated from a combination of sources, including manufacturers' product catalogs, the Norwegian Directorate of Fisheries, one of Sintef's research projects by Hognes and Skaar (2017), plus surveys, interviews, and email communications, and this data is used to form these assumptions. Note that some equipment weights and dimensions could not be identified, those items are therefore not included in the calculations for MFA. It is also assumed that all ropes used for mooring systems are the same. From suppliers of the rope, the most used item in fish farming is a Polyethylene/Polypropylene rope with an average length of 1100 meters, weighing 6.5 kg/220meter (Selstad, 2019). For the buoys, a search has been made to identify the model that is most used in aquaculture in mooring systems, as there are different variants. Dimensions were taken from one of the suppliers' products catalog.

- For floating collars/ rings: Average circumference of the rings 135 m. With a 500 mm pipe, the weight becomes including a walkway of 19 710 kg (Hognes & Skaar, 2017).
- Bottom rings: All rings have a bottom ring of 2856 kg plastic and 4900 kg metal wire (Hognes & Skaar, 2017).
- Nets: All rings have 3 nets, one net weighs 2,156 kg (Hognes & Skaar, 2017).
- Feeding systems: 18 feed-spreaders (usually metal) each weighs 35 kg (Hognes & Skaar, 2017)
- Buoys: 16, the average weight of each is 590 kg (Selstad, 2019).
- Ropes in mooring systems: 120 lines, each line weighs 32.5kg (Selstad, 2019).

Since these numbers were given by the one company that answered the survey, and this company has 4 active sites in the region, we assume that other active sites have the same setup of fish farming gear, amounting to the same numbers of different items. The logic used for this assumption is the fish production capacities in the active sites. The production capacities are compared to assume how much of the same gear is used. This of course is just an effort to compensate for the lack of actual data that could not be retrieved. The table below summarizes the equations used for the calculations.

Flow Symbol	FLOW NAME (tons/year)	DESCRIPTION	DATA SOURCE	EQUATION
P2	AGs owned	Mass of plastics (MoP) in aquaculture gear (AGs) owned by aquaculture sites	Aquaculture surveys and suppliers product catalogues	Σ plastics in owned/currently used AGs (floating collars/rings, bottom rings, nets, ropes, and buoys). *Based on assumptions made around production capacities of the sites*
GP	AGs purchased	MoP in aquaculture gear (AGs) purchased	Aquaculture surveys	Σ plastics in purchased AGs. *Based on buying frequency*
RG	AGs repaired to be resused	MoP in AGs repaired and sent back to be reused	Suppliers surveys	Σ plastics in AGs repaired - Σ plastics in AGs sent to WMC from suppliers
Rp	AGs to be repaired	MoP in AGs repaired by suppliers and manufacturers of gear	Suppliers surveys	Σ plastics in AGs repaired
LO	AGs lost in the ocean	MoP in AGs lost in the ocean	Hold Norge Rent and NIVA	
Dsp	AGs disposed of	MoP in AGs disposed of and sent to waste management companies at end of life phase	Aquaculture surveys	Σ plastics in AGs sent to WMC directly from aquaculture companies
WRp	Waste from repairs	MoP in Waste from repairs of AGs sent from suppliers and manufacturers to waste management companies (WMC)	Suppliers surveys	Σ plastics in AGs sent to WMC from suppliers
CLG	AGs recovered from ocean	MoP in AGs recovered from the ocean by cleanup efforts	Hold Norge Rent	
LF	Waste to Landfill	MoP in collected waste from AGs to be Landfilled	WMC surveys and interviews	Σ plastics in AGs disposed of * %to be landfilled
Rec	Waste to Recycle	MoP in waste collected from AGs to be Recycled	WMC surveys and interviews	Σ plastics in AGs disposed of * %to be recycled
Icr	Waste to Incineration	MoP in waste collected from AGs to be Incinerated	WMC surveys and interviews	Σ plastics in AGs disposed of * %to be incinerated

Table 5-1: Equations used for the MFA model.

5.1.2.1 Gear lost in the ocean

A new study done by the Norwegian Institute for Water Research (NIVA) found that the only data available from close investigation of Norwegian fish farms is on fishing tubes, ranging from 0.1 to 100 tons of discharge per site in the ocean (Lusher & Pettersen, 2021). With 26 active sites being identified in the region of focus, the minimum value is 2.6 tons and a maximal value of 2600 tons. The minimal value is used for MFA calculations. In addition to that, ocean cleanup efforts have been taken into consideration. Data from one facility specializing in this domain was used to estimate the amount of gear lost and collected in the year 2020. Note that the only available data was on ropes, suggesting that the estimation could be larger.

5.1.2.2 Waste gear sent to waste management companies

Data were extracted from 2 different companies handling waste differently. One of them specializes in transporting waste received to be recycled in facilities outside of Norway, while the other recycles the waste inside Norway. A sum of values received from both companies is used to determine waste gear received from aquaculture companies, and amounts of plastics that are recycled, incinerated, or landfilled. Since the numbers received from these two companies are from all of Norway, data from the Directorate of Fisheries has been used to calculate the total number of aquaculture companies in Norway (112), and subsequently the total in the region of Møre and Romsdal (17). Note that the newest data available is from 2019, and it is assumed that all aquaculture companies send equal amounts of gear waste to these two waste management companies.

5.1.2.3 Gear to be repaired/ Gear to be reused after repair

Data was extracted from survey responses and email communications with one of the biggest suppliers of aquaculture gear in the region. The data received however was not restricted to Møre and Romsdal only, so the same method is used in assuming all companies in this area send equal amounts of equipment to be serviced.

5.1.2.4 Gear purchased

The mass of plastic (MoP) from gear purchased is calculated by using the frequency of buying new equipment every year. This information was obtained from survey responses.

5.2 QUALITATIVE ANALYSIS

The researchers have communicated through LinkedIn and email with a total of 52 companies related to the Aquaculture business including fish farming both land-based and sea-based farms, and their suppliers, waste management companies. 9 different companies have accepted to participate, therefore a total of 11 semi-structured interviews were conducted: 9 with the company representatives and 2 with different participants from the department of biology at NTNU. The following table would give an idea of what type of company helped researchers to produce this report.

Type of Company	Number of companies	Position of interviewee
Sea-based fish farming company	2	Middle manager and top management
Land-based fish farming company	1	Middle Manager
Seaweed company	1	Site Manager
Waste management company	2	Top management
Landfilling site	1	Top Management
Recycling company	1	Top management
Supplier	1	Middle Manager

As for the interviews, after the first round is carried out, researchers transcribed the whole conversation into text and deleted the parts that were not necessary then summarized the conversations. From the summary, researchers grouped the information and gave a title for each group, and explained it coherently. As there were not many subjects in the interviews, there was no need to use any software for qualitative data analysis.

6 RESULTS

6.1 MFA RESULTS

Using the survey results and BarentsWatch.no, the company that answered has 3 sites with a production capacity of 2340 tons and one with 3120 tons. We use this as a reference to determine the amount of gear in use for other sites based on their production capacities.

1560 – 3120 – 2340 – 4680 – 3120 – 3120 – 5460 – 5460 – 3120 – 3120 – 3120 – 780 – 4680 – 3900 – 4680 – 1560 – 3900 – 3120 – 5460 – 5460 – 2300 – 3120 – 5460 – 5460 – 2340 – 1560

The numbers above represent the different production capacities of the 26 active sites this study focuses on. Because there is no data about the exact combination of gear used relevant to the production capacity, the following assumptions must be made:

- Sites with 3120 tons of capacity use: 6 floating rings (FR) **[every ring has one bottom ring (BM) and 3 nets (N) each]**, 6 feed-spreaders [metal], 4 buoys (B) and 30 lines of ropes in mooring systems (R):

(6*FR + 6*BM + 6*3*N + 4*B + 30*R) * 8 sites = (118260+17136+38808+2360+975) *8 **= 1420312 KG**

- Sites with 2340 tons of capacity use: 4 floating rings, 4 feed-spreaders (metal), 4 buoys and 30 lines of ropes in mooring systems:

(4*FR + 4*BM + 4*3*N + 4*B + 30*R) * 3 sites = (78840+11424+25872+2360+975) *3 **= 358413 KG**

- Sites with 4680 tons of capacity (33% more than 3120) use: 8 floating rings, 8 feed-spreaders (metal), 6 buoys and 40 lines of ropes in mooring systems:

(8*FR + 8*BM + 8*3*N + 6*B + 40*R) * 3 sites = (157680+17248+51744+3540+1300) *3= **694536 KG**

- Sites with 1560 tons of capacity (50% less than 3120) use: 3 floating rings, 3 feed-spreaders (metal), 2 buoys and 20 lines of ropes in mooring systems:

(3*FR + 3*BM + 3*3*N + 2*B + 20*R) * 3 sites = (59130+8568+19404+1180+650) *3= **266796 KG**

- Sites with 5460 tons of capacity (75% more than 3120) use: 10 floating rings, 10 feed-spreaders (metal), 8 buoys, and 60 lines of ropes in mooring systems:

(10*FR + 10*BM + 10*3*N + 8*B + 60*R) * 6 sites = (197100+28560+64680+4720+1950) *6= **1782060 KG**

- The one site with 780 tons of capacity (75% less than 3120) uses 2 floating rings, 2 feed-spreaders, 2 buoys, and 10 lines of ropes in mooring systems:

(2*FR + 2*BM + 2*3*N + 2*B + 10*R) * 1 site = 39420+5712+12936+1180+325 **= 59573 KG**

- Sites with 3900 tons of capacity (25% more than 3120) use: 8 floating rings, 8 feed-spreaders, 6 buoys, and 40 lines of ropes in mooring systems:

(8*FR + 8*BM + 8*3*N + 6*B + 40*R) * 2 sites = (157680+17248+51744+3540+1300)*2 = **231512 KG**

With these assumptions, we can calculate the mass of plastic (MoP) in gear used/owned in the region of Møre and Romsdal in the selected production area. **TOTAL= 4813202 kg**

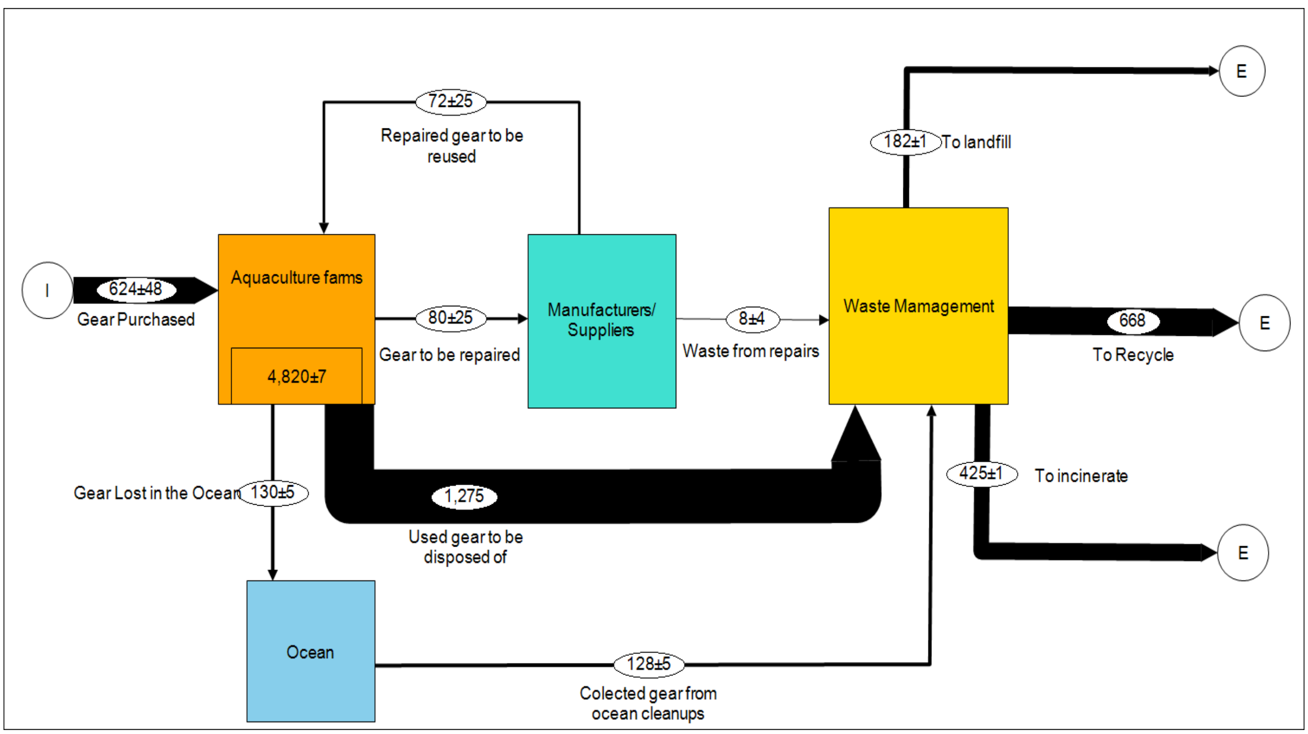

Figure 6-1: MFA model of 5 types of AGs used in the region of Møre and Romsdal.

The figure above (figure 6-1) portrays the final MFA model of plastics in 5 types of AGs used annually in fish farming in the region of Møre and Romsdal. All phases from purchase to the end of life are considered in the calculations of flows and stocks.

6.1.1 *Pre-use phase (Purchase phase)*

From the survey responses, the total MoP owned by aquaculture companies in the region in 2020 is estimated to be 4813 ± 7 tons. After considering different assumptions, an estimation of 624 ± 48 tons MoP in AGs was purchased by fish farmers in 2020.

6.1.2 *Use phase*

6.1.2.1 *Repairing/servicing the gear*

Results from the survey with aquaculture companies revealed repair patterns of the equipment used in sea-based sites. These results indicate that only a small percentage of the gear is repaired, and not all gear types are serviced. Based on survey results, 20% of the floating collars, 10% of the pipes in feeding systems, and 5% of the buoys in mooring systems are the fractions of gear that get repaired every year. The most frequent item to be serviced is the nets, as they get sent to be repaired after each stocking or when holes are detected.

From the survey with suppliers/manufacturers responsible for gear servicing, 90% of the gear received from aquaculture companies to be serviced is resent to be reused, sending the remaining 10% to waste management companies. Note that this data was only about servicing of nets, excluding all other types of gear. In 2020, it is estimated that 80 ± 25 tons of MoP were sent to suppliers/manufacturers for major repairs.

6.1.2.2 *Gear lost in the ocean*

Survey results indicated that incidents of losing AGs in the ocean are very unlikely. The only source of data available on the matter of lost gear from fish farming is brought to light by Lusher and Pettersen in their project with NIVA, where they focus on quantifying the mass of microplastic discharge generated from fish farming activities. Based on this report, the wear and tear of the big plastic structures used in aquaculture is the main contributor to the secondary emission of microplastics in the ocean (Lusher & Pettersen, 2021). The same researchers confirm that there is a noticeable lack of information about the amounts and weights of microplastics released to the ocean generated by the aquaculture industry. The main reason behind this is the variety of plastic polymers used in fish farming across the different facilities. Furthermore, some of these plastic polymers are not exclusively used in aquaculture, but in other industries as well, rendering the task of tracing the origin even more difficult (Lusher & Pettersen, 2021).

Additional information from ocean cleanup operations has been used to include other types of gear other than feeding tubes. Data from operations in the region of Møre and Romsdal revealed the number and weights of ropes collected. Using a combination of these two sources, the MoP in gear lost in the ocean is estimated to be 130 ± 5 tons in 2020, 128 ± 5 tons is retrieved from ocean cleanup operations, leaving approximately 2 tons as microplastics that stay in the ocean indefinitely.

6.1.3 End of life phase (Handling of AGs by waste management companies)

All the gear that cannot be repaired or sent to be recertified for reuse is sent by aquaculture companies to the closest waste management facility or to the one they have an agreement with. AGs are also sent by suppliers/manufacturers after repairs have been made. Data from 3 different waste management companies revealed that 52% of the waste is sent to be recycled, 14% is landfilled, and 34% is incinerated. It is important to note that of the 3 companies that responded, 2 of them specialize in recycling waste from aquaculture companies. However, they each have their unique ways for recycling the plastic; one of them segregates, sorts, then transport it outside of Norway to branches operating mainly in western Europe. The other waste management company is unique in the sense that all its recycling processes are carried out in Norway, producing granulates from the plastic in AGs received.

6.2 INTERVIEWS RESULT

In this sub-chapter the results from the semi-structured interviews are presented. This chapter is divided into 9 sections explaining the types of aquaculture firms that were considered in the study, the regulations impacting the companies, the struggle that companies are facing in handling plastic waste, and the current and future strategies.

6.2.1 Different types of aquaculture farms

The interviewers have communicated with the following 3 types of focal companies- Sea-based fish farming company, Land-based fish farming company, and Seaweed company hence it is important to have a clear definition of what kind of infrastructure a certain company has and the involvement of plastic material.

The basic difference between sea-based and land-based farms is, sea-based sites rely on cages and nets, whereas land-based sites use tanks. Sea sites have a capacity for 200 000 fish, which is way larger than the 2500 that the tanks can take. The main equipment used in land-based are tanks, which are made of glass fiber. Apart from that, there are some other technical types of equipment also used in the land-based farms such as water pumps, oxygen systems, fish sludge treatment, and so on. In land-based, most plastic waste is generated from food bags and pipes for pumping water. However, the pipes are not frequently changed, but cleaned, and frequently reused. On the other hand, in sea-based farms, interviewees believe that most plastic waste is generated from feeding pipes and nets.

When it comes to seaweed farming, the infrastructure/ frame is made from plastic ropes deployed at sea and removed once seaweed grows. The company interviewed being a young venture, is very keen on the cradle-to-cradle principle. The CEO of the company said: “the principle of our seaweed firm is cradle-to-cradle, meaning there is no waste, everything is a resource”. However, there are always challenges in dealing with the different players in the industry.

6.2.2 Lack of publicly available data

There is no exact information of how much plastic waste the aquaculture industry is producing and what is the fate of this waste. To do a Material Flow analysis, the interviewers asked companies to share the Annual waste statement. However, the interviewers got almost the same answer from all companies and that is - “annual waste statement is not publicly available and strictly internal”. Companies received a monthly/yearly waste statement from suppliers and waste management companies which contain detailed information about how much waste a certain company generates and what portion goes to recycling, landfilling and incineration. However, some of them mentioned that “the data is not compiled enough to share with outsiders”. The positive news is that most of the companies have a plan to share their annual waste statement publicly in the upcoming year, the thing that might be helpful for future researchers.

Specialists from waste management sectors mentioned that there are no bindings about registering waste data publicly for private sectors hence companies do not have to register the amounts of waste it generates publicly. This is the reason that there are almost no statistics available publicly on how much waste a company generates and what portion goes to which destination.

The interviewers asked the aquaculture companies whether they are aware of the quantities of gear lost or disappeared in the ocean. The response of the companies’ representatives varied from stating that there was no official documentation for that, to claiming that there were no records of incidents related to losing gear in the ocean.

6.2.3 Collaboration between waste management and aquaculture companies

All the companies interviewed mentioned that they have local/national agreements with waste management companies (WMCs) that are responsible for handling waste. Most aquaculture companies have their waste treatment plants where they clean and sort the waste before it goes to WMCs. Sorting and cleaning are the responsibilities of the aquaculture companies, and they need to pay a certain fee to the WMCs to handle it further. That payment depends on how clean and sorted the wastes are.

When the interviewers asked WMCs to share their experience with equipment that is lost or discarded in the ocean, representatives mentioned that they have some collaborations with entities that collect discarded gear or equipment from the ocean and beach, but the findings from this source claim that most of the waste collected from coasts and beaches are from fishing activities, not aquaculture. The types of waste that come from farming and goes into the ocean are ropes, however, the interviews could not yield any concrete statistics about the quantities. Aquaculture companies mentioned that they continuously make sure when cutting or changing the ropes, they gather and throw them into a container, and then send them to the WMCs. Representatives interviewed from the aquaculture industry also mentioned that they are very aware of both environmental effects and their reputation. They do not want ropes or any other piece of equipment to lay on the beach or anywhere along the coast.

6.2.4 Regulations

6.2.4.1 Impact of Certification

When it comes to changing gear, the Government introduced some standards/rules such as NS9415/NS9416 to keep the ocean and human life safe. Following these rules, the company needs to check the gear after a certain period and make sure that it serves the purpose. For example, if nets are not well conditioned, fish escaping can happen which is not good for ocean health. There are some certification authorities that are operating in this regard and explain the different conditions that the gear should have. Interviews conducted revealed that suppliers of gear are one of the important cogs in the certification process, as they are the ones responsible for servicing and repairing parts of the AGs used, and they are the ones recertifying.

An interview with the service manager at a gear supplier firm helped in understanding the process of certification of AGs. The interviewee explained: “The two main components of the nets are the ropes and the mesh. The nets for example are usually serviced approximately 5 times in their lifetime. All new nets are certified for 24 months, and old nets get a minimum of 5 months to be reused. If the old nets do not get certification for 5 months, then it needs to be thrown away or will go for incineration for energy recovery”. The same interviewee claimed that from his own experience in the field, there are companies that throw some of the nets that can still be recertified. But in other cases the nets cannot be reused because the material (nylon) shrinks down and the nets must have a specific size in order to be cleared for reuse. There is another reason why nets become obsolete, which is different net sizes are used for different sizes of fishes so if the fish size changes then the farm needs to buy/replace a new one**.**

6.2.4.2 The concern of waste Management companies

Some waste management companies have shown concern as previously they were being able to send waste without special permission, but 2020 legislation changed the circumstance hence the challenge is handling to exporting waste properly as fish farming waste is hazardous.

6.2.4.3 Abandoned sites

While doing this research, the interviewers have come across lots of fallow sites in the region, so naturally the following question comes to mind: what happens to the farming structures in this period of inactivity? To answer that question one of the interviewees mentioned that there is a new regulation that dictates those new farms should give a deposit at the start which will be used to remove the infrastructures if the company goes bankrupt. According to the CEO of the seaweed company interviewed: “a couple of decades back, there was a big boom in blue mussel farms and a lot of companies went bankrupt, so they did not have money to remove their farms. So, these blue mussel farms remained in the water and caused a lot of problems”.

6.2.5 Challenges of recycling

6.2.5.1 The recycled product is expensive

“It is expensive to buy recycled products, so it needs to make economical sense”, this is what one of the facility managers said when asked about buying AGs constructed from recycled plastics. When the interviewer asked what is exactly expensive, the facility manager answered: “It is the technology used to recycle”. As a result, equipment produced using recycled plastic are way more expensive than its counterpart originating from virgin material.

6.2.5.2 Doubt about quality

The aquaculture companies interviewed mentioned that gear at this moment coming into the market are sourced from virgin materials and they don't have any clear idea whether it would be viable or safer to get equipment from recycled materials. They think if they cannot maintain quality, it will be even more expensive to use. "It is always a cost question." When the interviewer asked whether they used gear form recycled material yet or not. One of the experts in the industry shared his insights explaining that switching to recycled plastics in the industry will need at least 5 more years. One of the company representatives makes it clear in the conversation that when it comes to recycling it does not mean that product needs to go back to its form rather than waste generating from the fishing industry can go to the textile industry or other industries.

6.2.5.3 Sorting and Segregating

Before recycling it is important to separate the waste properly, for instance, Nylon and Propylene can be recycled however they cannot be sent altogether. It needs to be separated and made homogeneous before sending to the waste treatment facilities. Ropes also can be recycled if they are not costed with copper. Most ropes used in fish farming are copper coated except for the long rope anchoring the platform which is not copper coated and can be recycled. So copper-coated ropes need to go to incineration as the copper coating is considered a hazardous material hence not allowed to be landfilled, not permitted even in Lithuania and some eastern European countries where generally waste management companies transport waste. Apart from ropes, feeding tubes and pipes are hard plastic that can be recycled. For aquaculture, equipment such as floating collars, bottom rings, feed hose are all recyclable if they are not mixed during collection and designed appropriately (Mepex, 2018). But often it consists of different types of plastic melted together. If producers use a different type of plastic continuously, on one hand, it gets hard to recycle as recycling companies need to disseminate and separate it which is costly, and the on the other hand quality decreases drastically.

6.2.5.4 Lack of recycling facilities in Norway

There are not many recycling facilities in Norway. Usually, waste management companies send plastic waste to Germany and Sweden for treatment. In the past, Germany used to send poor-quality plastic to China. However, due to the ban on sending poor quality waste to China, Germany needed to take care of the poor quality of plastics too. Representatives from WMCs also mentioned that they have an agreement with a transportation companies so if they want to transport the plastics, they just give it to them and they transport it as they have collaboration with many companies in Europe where they can send the plastic. The bright side is that some small companies in Norway are trying to initiate some projects to recycle plastic waste. One of the interviewees expresses her relief and happiness that companies like NOPREC are taking initiatives, as earlier the only alternatives are either to send them to a landfill or export outside of the country. The latter is always a challenge because it cannot be properly documented and therefore it would be impossible to know exactly where that portion of waste is going to end up.

6.2.5.5 Lack of market for recycled plastics

One of the companies interviewed specializes in recycling waste from aquaculture gear to produce granulate said: "There is a lack of market for recycled plastic in Norway. So far, the quantity of granules produced exceeds the demand of the market". They also mentioned, trying to compete in the European market is difficult due to pricing. If the market were bigger and the demand were higher, the prices for processing and collecting plastics could be adjusted so that it could be easier and more beneficial for the customers. However, the interviewer got a contradictory message from the suppliers' side mentioning that "Availability is the main challenge for using recycled plastics."

6.2.5.6 A cheaper way of treating and handling waste

Companies look for the cheapest way to get rid of waste. According to the new law, it will push the company to recycle 60% also some downstream solutions. Another big barrier is the existence of the option to landfill, as some local companies can therefore choose to save transportation costs and just send the waste to a landfilling site, which is cheaper. However, lots of businesses are starting to consider waste management as an important part of their sustainable business models, making sure that the waste is handled properly. However, the government and businesses should join forces to stop landfilling practices and encourage better alternatives.

6.2.5.7 Relationship between the price and pattern of waste

Interviewers have interviewed representatives from 4 different waste management companies and got to know that WMCs charge different set of prices based on the level of the waste a given company generates. For example, one of the representatives mentioned that they have a contract with several recycling companies, and they mentioned that they can only recycle that fish farming net if the level of anti-foiling in the fish farming net is below 25%. If it is more than 25% then it must go for incineration and energy recovery. Therefore, they set three types of prices: for 0-5% level of anti-foiling, for 5-25% level of anti-foiling and finally for more than 25% of anti-foil for which they charge the maximum as it needs to go to incineration. The latter option is expensive because the nets should be shredded down to very small pieces so that it can burn, and that process takes more time naturally.

6.2.6 Producer responsibility

6.2.6.1 Producers need to be more aware

To create a bigger positive impact, producers need to be more responsible and aware of the future of plastics. Producers are combining different types of plastics to make a certain product to cut down costs and they are doing it because companies are not willing to pay a high price, so it is a vicious cycle. If the price of the fishing equipment produced by local firms goes up because local suppliers are valuing the environment, then the other suppliers from the different markets where the regulations are not strict can come and get the same products at a cheaper price. Therefore, a sustainable economy and environment-friendly solution are much needed.

6.2.6.2 Sourcing pattern

When the interviewers asked about gear sourcing, most of the companies' representatives claimed that they source locally and try to make sure that it is sourced responsibly. Every company has a supply chain team that cares about and investigates the source of the material. One of the interviewees shared one specific example of a company from Finnmark which has been pressing their suppliers that they will not buy the gear unless the suppliers find a solution for proper waste management and recycling when the AGs reach the end-of-life phase. Within one month, 5 suppliers of one certain product contacted NOPREC for a site visit, showing interest in working with them for potential recycling of waste. This shows that the customers (the aquaculture companies) can have an immense impact on the whole supply chain to bring changes to current practices in waste management.

6.2.6.3 Responsibility

The interviewers also got to know that some major suppliers are taking the responsibility of servicing the AGs including repairs, recoating, and cleaning so that aquaculture companies can keep using the gear for a longer period. One company representative mentioned that suppliers take back the rest of unused gear such as excess rope delivered to the farm infrastructures so that it does not get wasted.

6.2.7 Landfilling

Among the interviews conducted, one was with a representative from a landfilling site in the region of Møre and Romsdal. The interviewee explained that most of the things that cannot be recycled go to their company. In 2020, this site received around 800 tons of waste from fishing industry which was not possible to recycle. Some of the plastic which is in a long time in the sea gets broken like organic waste in the water.

6.2.8 Recycling of aquaculture gear in Norway

Two different interviews were dedicated to conversong with recycling companies that collect, sort, and process several types of industrial waste from aquaculture companies and travel along the coast to collect plastics, especially from the aquaculture industry. One of these two companies goes out to where the aquaculture sites are located, using a shredding machine and a sterile compressor to transport plastic efficiently back to the recycling facility. Materials such as ropes and metal are taken by the recycling company if possible to recycle or else sent directly to the closest waste management facility. The shredding machine shreds most plastic parts of the aquaculture systems, including the floating rings, the walkways, and the feeding tubes. The nets are collected but cannot be shredded and recycled in Norway as they are considered hazardous waste because of the copper coating. These nets usually end up incinerated for energy recovery. These nets often go to a facility that uses high heat to produce bricks. Last year, one of the companies handling waste, found a solution to minimize the percentage of incineration. Firstly, they cut different parts of the nets (top, middle, and bottom) into small pieces and send them to a lab for analyzing the quantity of copper. If the level of copper is higher than the required percentage, it will go to incineration, but the rest will be recycled. This method according to the specialist interviewed is still very expensive and very inefficient as it takes too much time to process just one net.

6.2.9 Microplastics

Microplastics are not getting enough attention and will get into the food chain eventually. Based on the opinion of one of the interviewees, the copper coater is actually “a lesser evil” even though EU regulations highlight it as hazardous. There is the new development of other materials to use for anti-foiling, some of which consider using plastic itself. The problem occurs when the nets start bleeding out of this coating after the reaction with seawater. The service manager from a supplier firm explains: “if the coating is made of plastic, microplastics are generated”. Highpressure washing as well of the nets contributes to losing small particles of the material in the water. Experts believe that, in the future, more recycling opportunities will be possible as more fish farmers move away from using anti-fouling, replacing it with a simple wax.

7 DISCUSSION

7.1 MFA DISCUSSION

The results from the MFA in the region of Møre of Romsdal show the plastic flows during the different processes and use phases alongside the amounts of plastic waste lost in the ocean generated from aquaculture gear used by a selected number of companies in one focus production area. Considering the large scale of the aquaculture industry in Norway, these findings should be a source of motivation for all the relevant stakeholders to take action and find better solutions on how to manage plastics in this industry and therefore contribute to the fight against marine litter.

7.1.1 AGs lost in the ocean

The MFA estimated that 130 tons of AGs were lost in the ocean in 2020 just from one region. Although the study found out that most of this lost gear is recuperated through ocean cleanup operations, it is important to know the different causes for losing gear. Survey and interview results showed that losing AGs in the ocean is a very rare occurrence, and previous research agrees with that in the sense that there is no specific classification by the aquaculture companies showing exactly the quantity of gear lost in the ocean. According to Huntington (2019), different causes are leading to the loss of AGs in the ocean, but there is a noticeable lack of classification from the industry players. Among these causes, Huntington lists mismanagement of gear, deliberate discharge, and extreme weather (2019).

7.1.2 Microplastics from AGs

Since there were no concrete results from the surveys and interviews on the phenomenon of loss of AGs in the ocean and its causes, the real focus should be on microplastics. The MFA estimates an alarming 2 to 3 tons of microplastics from decomposed AGs just from one region. As described in the data analysis chapter, that estimation was drawn from the work of Lusher and Pettersen with Akvaplan NIVA (2021), who used nine different potential sea-based sources connected to maritime activities to update the available data on microplastic discharges. Even though the certainty of the data was classed as medium or low, this report is an important source of information about the current situation of microplastics, especially discharges connected to the aquaculture industry. Very few studies were found that focus on this specific issue.

Schoof and DeNike (2017) worked with shellfish farmers from Washington state to investigate the allegations circulating about the effect of aquaculture gear on microplastics in the ocean. The study concluded that the available published data demonstrated the very limited contribution of the gear used in shellfish farming on the release of microplastics in the ocean. On the other, another study by Chen et al. (2018) confirms that the gear used in aquaculture is a potential source for microplastics in the ocean. Because of the very limited information available on the issue, Chen and colleagues decided to closely investigate a semi-enclosed narrow bay in China that has a long history of mariculture to capture the effects of farming activities in generating microplastics in seawater and sediments. The project results found that indeed there are discharges directly linked to aquaculture gear composed of polyethylene (PE) foam, PE nets, PE film, polypropylene (PP) rope, polystyrene (PS) foam, and rubber (Chen et al., 2018).

After confirming that aquaculture is one of the potential sources of microplastics in the ocean, it is salient to investigate its diverse effects on marine organisms and associated risks from ingestion. Vázquez-Rowe et al. (2021) investigate in a recent study the consequences of microplastics on the health of aquaculture systems and fish species, identifying the links with food safety and sustainability. The results of this study show that among the diverse effects of microplastics, the most alarming is the ingestion risk by marine organisms that can cause neurotoxicity, reduced metabolic rate, increased mortality rates, and many others. The authors suggest that this phenomenon can affect human life through the consumption of marine products, however, more research is needed to determine the exact negative effects of micro and nano plastics on the food chain (Vázquez-Rowe et al., 2021).

7.2 Interview Discussion

The major finding of this paper astonished researchers that there is no national or regional tracking system of how much plastic waste is generated by a fish farming company. There should be a proper policy to track the quantities of plastic waste generated from each industry, especially aquaculture. If the issue is not identified nor quantified enough, bringing a sustainable solution to solve that issue would be nearly impossible.

Norway should focus on building infrastructure to process its waste and make sure that the material loop is closed properly. Furthermore, Norway requires more mobile waste management companies who would move from one place to another and collect the plastic waste and process it. Innovation regarding how to reuse and recycle should be the main focus for both aquaculture and waste management companies.

Producers need to be more responsible and should not mix different types of plastics in AGs just because it makes financial sense or to survive in the competitive market, rather come up with a sustainable plan and let the related authorities know if they need any. On the other hand, the aquaculture companies should not overlook environmental value even though in some scenarios it might not make economic sense in the short run. Apart from that, companies should be more open-minded and proactive when it comes to using a product produced out of recycled plastic. Government should subsidize or relieve tax where required so that using products from recycled materials gets cheaper. And finally, an updated EPR scheme should be there which may make aquaculture companies more accountable and increase transparency in the supply chain, overall make the industry more environmentally conscious (Deloitte, 2020).

8 CONTRIBUTIONS OF THE STUDY

8.1 MANAGERIAL IMPLICATIONS AND RECOMMENDATIONS

Based on the researchers' experience after conducting several interviews with specialists in the relevant fields and performing Material flow analysis, the following recommendations are suggested for all the relevant companies along the supply chain of the aquaculture industry:

1. Proper guidelines about how plastic waste data should be prioritized. When The researchers have asked the interviewees about the plastic waste data then they got to know that there is no prescribed way how to store data. Hence, they do not follow any certain procedure. Most of them contain all data together hence it is hard to distinguish and tell how much plastic waste the company is generating every month/year and among them how much is going to recycle and how much is incineration. Since plastic waste is a very sensitive topic, data should be very transparent and accessible by at least certain authorities. Furthermore, the government should enforce a system of tracking and registering the plastic waste generated by companies.

2. Most of the companies that contributed in the interviews mentioned that using gear that is made of recycled plastic is expensive and this is one of the reasons it cannot be used even if there are options available in the market. If the government introduces a tax exemption policy in this regard such as if a company buys gear that is made of recycled plastic will get a certain tax exemption based on the buying nature, then companies will be motivated.

3. To build a sustainable economy, Norway should be more independent and own treatment plants that specialize in recycling rather than transporting it to other countries. On a large scale, Norway is somehow dependent on other countries when it comes to treating plastic waste. The government and other key players should invest more to build a proper infrastructure in order to close the material loop within the country.

4. The government should invest and influence more young people to build companies or come up with ideas where they can produce products out of recycled plastic and replace

the use of the plastic product. Educational and research institutions should do more research and create agreements with other countries to think out of boundary and implement them in Norway for the betterment of the world.

5. The 5 Rs (Refuse, Reduce, Reuse, Repurpose, Recycle) should be used by all the key players revolving around this industry.

6. The government should move forward to introduce the Extended Producers' Responsibility (EPR) to the aquaculture industry to include plastics in gear and not only plastics used for packaging.

8.2 CONTRIBUTION TO SUSTAINABILITY THEORY

1. This study found out that there is no transparent data in the market in regards to how much plastic waste the Norwegian aquaculture industry is generating. Hence, Governments and related authorities should be more conscious in this regard.
2. This study also found out that there is a huge opportunity for recycling business, where young entrepreneurs should focus on.
3. This study also found the difficulties, opportunities of using and not using plastic waste in a proper manner.

9 LIMITATIONS AND FUTURE RESEARCH:

One of the main limitations of the research project is the lack of publicly available data regarding plastic waste generated by aquaculture companies. Often companies considered this data as strictly private, whereas some companies are not confident enough to share and believe that current data could be misleading. There is no national or public registry from where this data can be found. Due to the lack of publicly available data, the researchers had to rely on a lot of assumptions to complete the necessary calculations of plastic masses for the MFA model. It is crucial to note that this paper is an effort into quantifying the masses of plastics tied to aquaculture gear, the numbers however should not be considered as reliable, since the use of assumptions to compensate for the lack of data helps in creating approximations only.

According to the plan, the researchers communicated with all the aquaculture companies offering licenses to the fish farming site in the production area “Stadt to Hustadvika” in the region of Møre Og Romsdal in Norway alongside their suppliers and the waste management companies they are tied to. However, less than 20% of companies responded after the first round of communications. The researchers were persistent and used several means to contact responsible persons from specific companies, however, it was difficult to get responses from more than 50%. Additionally, not all the targeted companies responded on time, making the number of respondents lower than expected. Most of the companies from where researchers received responses were very open and excited about the project and agreed to speak and share information, and even helped to find further contacts. However, some companies did not want to participate and they either expressed that by stating they do not have enough time or no relevant information.

Another limitation is the limited time on hand. The duration of the thesis project was 6 months, meaning there was not enough time to get more contacts, to conduct more interviews, nor more time to get more survey responses. If previous work of the same nature is to be taken into consideration, Deshpande et al. (2020) for example had 4 years to work on their paper. Having more time would have allowed for more room to deepen the investigation. Furthermore, due to the pandemic situation, the researchers could not schedule any site visits, therefore impossible to supplement the interviews with observations from physical visits to the relevant entities, relying solely on the information that was given by company representatives.

It is also crucial to understand that the sample size was small, and therefore should not be representative of the whole aquaculture industry. It is important to highlight that the project does not cover the whole region of Møre and Romsdal, as explained in the research problem section, the project focuses on one specific production area that covers most of the region. In addition to that, the numbers produced from the MFA model should be regarded as only an approximation of the actual quantities of plastic masses in the region. As Deshpande et. al (2020) explained in his work, the MFA presents only a snapshot of the activities happening during the lifecycle of AGs. Meaning many inconsistencies can be found in the model caused by a variety of reasons, including but not limited to the use of different types of plastics in the gear, sizes of the farms, production capacities and other factors that are difficult to control. In addition to that, this study focuses on only some but not all the AGs used in the industry. The study had to be limited with these constraints because of the very little data available and that could be extracted from the interviews and surveys.

In the future, when the plastic data would be publicly available and transparent enough, and when time is not a constraint then the same research can be conducted in a bigger perspective regarding the aquaculture industry in Norway. This topic has lot of potential to bring together different entities such as private companies, environmental agencies, and governments to come together and work to solve the current pressing problems connected to marine pollution.

10 LESSONS LEARNED

- The researchers spent a good amount of time finding the right contacts and resources. If the school has collaborated with companies who are willing to provide data, then the companies and the country both would benefit from that.
- This is a 6-month project, hence the researchers could not explore nor investigate as deeply as they wanted to. To get the best results, future research should dedicate more time.
- MFA is a good tool to quantify plastic masses, for example, this tool should be more mainstream or should be used more by students. Even though MFA is complex and some people do a Master's on it, the researchers managed to perform it well which proved that learning by doing is a successful strategy to learn new skills.
- The planned schedule is very difficult to keep and follow, however, it is very useful to have one to keep the objectives clear and be on track.
- Communication with the supervisors is very important. It should be frequent and clear from both sides. Both the student and researchers should clear their expectations.
- It is important to be flexible when it comes to choosing a research topic and throughout the research area but not to be distracted. The initial plan was to fully perform the material flow analysis and talk to experts and employees who are involved in the aquaculture industry. However, when the researchers found that there is not much reliable data available, they focused on collecting as much as possible facts from this industry starting from focal aquaculture companies to waste management companies, recycling companies, and their suppliers and partners.

11 CONCLUSION:

Marine litter is one of the biggest concerns for the world and to win against that fight all countries need to work together. Aligning with the UN Development Goals, the EU came up with its approach to tackle this threat, so did countries such as Norway. Now more than ever, investing in research and innovation to diminish marine pollution is a necessity, and businesses should think out of the box about strategies to turn plastic waste into an asset. Before finding what can be done with the plastic waste, it is important to know what types of plastics are contributing to ocean litter and from what industries it is originating. In this study, the researchers performed a material flow analysis (MFA) of plastic waste from the Norwegian aquaculture industry on Stadt to Hustadvika production area in Møre og Romsdal region. Apart from that, the researchers also investigated the current practices and future strategies about how plastic waste is dealt with and how it is registered and the possibilities of recycling. After conducting the interviews and MFA, the researchers understand that there are important possibilities in utilizing plastic waste and make it circular. However, constraints such as costs and quality are important factors when it comes to the use of recycled materials. Government and companies can work together in this regard and be more transparent and come up with the decision and take action in such a way so it makes sense economically and sustainably. Furthermore, companies need to be more transparent about how much plastic is required to continue the operation and be opened and accept the cradle-to-cradle concept to close the loop. Apart from that, Norway should be independent when it comes to recycling its plastic waste rather than depending on other countries. Norway should also introduce waste treatment plants to treat their waste and influence young people to bring more innovative ideas which can truly bring a positive sustainable change.

This paper is an attempt to quantify the stocks and flows of plastic gear used in the aquaculture industry. The focus was on one production area that covers most of the Møre and Romsdal region in Norway. The material flow analysis conducted was about 5 main aquaculture gear used in fish farming in the region of focus, investigating 4 types of plastics (PE, PP, HDPE, and Nylon). The model estimates that in 2020 and only from one production area, a total of 130 tons of AGs get lost in the ocean and up to 2 tons of it is microplastics that stay in the ocean indefinitely. These findings can be useful to encourage more sustainable ways in managing gear in the aquaculture industry, helping ultimately to counter the problem of marine litter.

12 REFERENCES:

Ahmed, Nesar, Thompson, Shirley, & Turchini, Giovanni M. (2020). Organic aquaculture productivity, environmental sustainability, and food security: insights from organic agriculture. *Food Security*, *12*(6), 1253. https://doi.org/10.1007/s12571-020-01090-3

Allesch, A., & Brunner, P. H. (2015). Material Flow Analysis as a Decision Support Tool for Waste Management: A Literature Review. Journal of Industrial Ecology, 19(5), 753-764. doi: https://doi.org/10.1111/jiec.12354

Amundsen, Bailey, Jennifer L:, & Osmundsen, Tonje. (2020). *In the Scheme of Things: Sustainability as Seen Through the Lens of Salmon Aquaculture Sustainability Standards*. NTNU. https://hdl.handle.net/11250/2687498

Armstrong, C. W., Vondolia, G. K., Foley, N. S., Henry, L.-A., Needham, K., & Ressurreição, A. (2019). Expert Assessment of Risks Posed by Climate Change and Anthropogenic Activities to Ecosystem Services in the Deep North Atlantic. Frontiers in Marine Science, 6. https://doi.org/10.3389/fmars.2019.00158

Bocken, N. M., De Pauw, I., Bakker, C., & Van Der Grinten, B. (2016). Product design and business model strategies for a circular economy. Journal of Industrial and Production Engineering, 33(5), 308-320.

Boucher, J., Zgola, M., Liao, X., Kounina, A., Billard, G., Paruta, P., & Bouchet, A. (2020). National guidance for plastic pollution hotspotting and shaping action - Introduction report. United Nations Environment Programme. Nairobi, Kenya.

Brundtland, G. H. (1987). Our common future (pp. XV, 400). Oxford University Press.

Chen, Minglong, Jin, Meng, Tao, Peiran, Wang, Zheng, Xie, Weiping, Yu, Xubiao, & Wang, Kan. (2018). Assessment of microplastics derived from mariculture in Xiangshan Bay, China. *Environmental Pollution (1987)*, *242*(Pt B), 1146–1156. https://doi.org/10.1016/j.envpol.2018.07.133

Deloitte. (2020). Reducing Plastic Pollution and Creating a True Circular Economy for Plastics through Extended Producer Responsibility (pp. 1-56, Rep.). doi:https://www.wwf.no/assets/attachments/Report_Deloitte_AS_WWF.pdf

Deshpande, P. C., Skaar, C., Brattebø, H., & Fet, A. M. (2020). Multi-criteria decision analysis (MCDA) method for assessing the sustainability of end-of-life alternatives for waste plastics: A case study of Norway. Sci Total Environ, 719, 137353-137353. https://doi.org/10.1016/j.scitotenv.2020.137353

Deshpande, P. C., Philis, G., Bratteb, H., & Fet, A. M. (2020). Using Material Flow Analysis (MFA) to generate the evidence on plastic waste management from commercial fishing gears in Norway. Resources, Conservation & Recycling: X, 5, 100024. doi: 10.1016/j.rcrx.2019.100024

Dunuwila, Pasan, Rodrigo, V.H.L, & Goto, Naohiro. (2018). Financial and environmental sustainability in manufacturing of crepe rubber in terms of material flow analysis, material flow cost accounting and life cycle assessment. Journal of Cleaner Production, 182, 587–599. https://doi.org/10.1016/j.jclepro.2018.01.202

Duygan, Mert, & Meylan, Grégoire. (2015). Strategic management of WEEE in Switzerland—combining material flow analysis with structural analysis. *Resources, Conservation and Recycling*, *103*, 98–109. https://doi.org/10.1016/j.resconrec.2015.06.005

Elkington, J. (1997). Cannibals with forks. The triple bottom line of 21st century, 73.

García Rellán, A., Vázquez Brea, C., & Bello Bugallo, P. M. (2018). Towards sustainable mobile systems configurations: Application to a tuna purse seiner. Sci Total Environ, 631-632, 1623-1637. https://doi.org/10.1016/j.scitotenv.2018.03.133

GARDNER, Paul. (2013). Extended Producer Responsibility for Packaging and Printed Paper in the United States: EXTENDED PRODUCER RESPONSIBILITY. *Journal of Industrial Ecology*, *17*(2), 170–174. https://doi.org/10.1111/jiec.12015

Geissdoerfer, M., Savaget, P., Bocken, N. M. P., & Hultink, E. J. (2017). The Circular Economy – A new sustainability paradigm? Journal of cleaner production, 143, 757-768. https://doi.org/10.1016/j.jclepro.2016.12.048

Geng, Y., & Doberstein, B. (2008). Developing the circular economy in China: Challenges and opportunities for achieving'leapfrog development'. The International Journal of Sustainable Development & World Ecology, 15(3), 231-239.

Harrabin, R. (2019, August 14). Plastic particles falling out of sky with snow in Arctic. BBC News. https://www.bbc.com/news/science-environment-49295051

Harrison, A., & Remko Van Hoek. (2011). Logistics management and strategy : competing through the supply chain (3rd ed.). Financial Times Prentice Hall.

Hodson, Mike, Marvin, Simon, Robinson, Blake, & Swilling, Mark. (2012). Reshaping Urban Infrastructure. Journal of Industrial Ecology, 16(6), 789–800. https://doi.org/10.1111/j.1530-9290.2012.00559.x

Hoekman, Paul, & Blottnitz, Harro. (2017). Cape Town's Metabolism: Insights from a Material Flow Analysis. *Journal of Industrial Ecology*, *21*(5), 1237–1249. https://doi.org/10.1111/jiec.12508

Hognes, E. S., & Skaar, C. (2017). Avfallshåndtering fra sjøbasert havbruk.

Huntington, T (2019). Marine Litter and Aquaculture Gear – White Paper. Report produced by Poseidon Aquatic Resources Management Ltd for the Aquaculture Stewardship Council. 20 pp plus appendices.

ISO, E. (2007). 6946. Building components and building elements-Thermal resistance and thermal transmittance-Calculation method.

Johnston, P., Everard, M., Santillo, D., & Robèrt, K. H. (2007). Reclaiming the definition of sustainability [Review]. Environmental Science and Pollution Research, 14(1), 60-66. https://doi.org/10.1065/espr2007.01.375

Larssen. (2018). *Sustainability in Norwegian aquaculture - Path development or sustainable transition? - A case study of the allocation of the development licenses and power, discourse and ideas*. NTNU. http://hdl.handle.net/11250/2507001

Lazard, Jérôme, Rey-Valette, Hélène, Aubin, Joël, Mathé, Syndhia, Chia, Eduardo, Caruso, Domenico, Mikolasek, Olivier, Blancheton, Jean Paul, Legendre, Marc, René, François, Levang, Patrice, Slembrouck, Jacques, Morissens, Pierre, & Clément, Olivier. (2014). Assessing aquaculture sustainability: a comparative methodology. *International Journal of Sustainable Development and World Ecology*, *21*(6), 503–511. https://doi.org/10.1080/13504509.2014.964350

Lee, Røine, & Norges teknisk-naturvitenskapelige universitet, Fakultet for ingeniørvitenskap og teknologi, Program for industriell økologi. (2004). *Extended Producer Responsibility Stimulating Technological Changes and Innovation: Case Study in the Norwegian Electrical and Electronic Industry*. Program for industriell økologi. http://hdl.handle.net/11250/242711

Lifset, Reid, Atasu, Atalay, & Tojo, Naoko. (2013). Extended Producer Responsibility. *Journal of Industrial Ecology*, *17*(2), 162–166. https://doi.org/10.1111/jiec.12022

Lusher, A.L.; Hollman, P.C.H.; Mendoza-Hill, J.J. 2017. Microplastics in fisheries and aquaculture: status of knowledge on their occurrence and implications for aquatic organisms and food safety. FAO Fisheries and Aquaculture Technical Paper. No. 615. Rome, Italy.

Lusher, A., & Pettersen, R. (2021). Sea-based sources of microplastics to the Norwegian marine environment. NIVA-rapport.

McMichael, A. J., Butler, C. D., & Folke, C. (2003). New Visions for Addressing Sustainability [Review]. Science, 302(5652), 1919-1920. https://www.scopus.com/inward/record.uri?eid=2-s2.0-0346874221&partnerID=40&md5=420af445c7900b6969ce0c88f906b12b

MEPEX. (2018). Rapport for Miljødirektoratet Underlag for å utrede produsent- ansvarsordning for fiskeri-og akvakulturnaeringen. MEPEX. https://www.miljodirektoratet.no/globalassets/publikasjoner/m1052/m1052.pdf

Ministry of Climate and Environment (2017). Waste as a resource - waste policy and circular economy. Regjeringen.no. https://www.regjeringen.no/no/dokumenter/meld.-st.-45-20162017/id2558274/?ch=7.

Ministry of Climate and Environment. (2017, April 5). Meld. St. 35 (2016–2017). Government.no. https://www.regjeringen.no/en/dokumenter/meld.-st.-35-20162017/id2547988/?ch=4

Ministry of Climate and Environment. (2020, November 24). Norway implements the 2019. Government.no. https://www.regjeringen.no/en/aktuelt/norway-implements-the-2019-basel-amendments-on-plastic-waste/id2786894/

Ministry of Foreign Affairs. (2020, May 15). The Norwegian Development Program to Combat Marine Litter and Microplastics. Government.no. https://www.regjeringen.no/en/dokumenter/marine_litter/id2642037/

New Plastics Economy. (2017). Ellenmacarthurfoundation.org. https://www.ellenmacarthurfoundation.org/our-work/activities/new-plastics-economy

Non-OECD Member Countries Adhering to the OECD System for Mutual Acceptance of Chemical Safety Data - OECD. (n.d.). Www.oecd.org. Retrieved January 24, 2021, from https://www.oecd.org/env/ehs/non-member-adherens-to-oecd-system-for-mutual-acceptance-of-chemical-safety-data.htm#:~:text=Non%2DOECD%20member%20countries%3A%20Argentina

Norway pushing for stronger global control of plastic waste. (2019). https://www.norway.no/en/usa/norway-usa/news-and-events/norway-pushing-for-stronger-global-control-of-plastic-waste/.

Norwegian Directorate of Fisheries (2019). *Number of companies and licenses with production 1994-2019*. https://www.fiskeridir.no/English/Aquaculture/Statistics/Atlantic-salmon-and-rainbow-trout

Norwegian Fish Health. (n.d.). Retrieved January 22, 2021, from https://www.barentswatch.no/fiskehelse/productionarea/5/2021/2

OECD (Organization for Economic Cooperation and Development). 2001. Extended producer responsibility: *A guidance manual for governments*. Paris, France: OECD.

Osmundsen, Amundsen, Alexander, Asche, Bailey, Finstad, Olsen, Hernandez, & Salgado. (2020). *The operationalisation of sustainability: Sustainable aquaculture production as* *defined by certification schemes*. https://doi.org/https://doi.org/10.1016/j.gloenvcha.2019.102025

Paul H. Brunner, & Helmut Rechberger. (2016). Handbook of Material Flow Analysis. In Handbook of Material Flow Analysis. CRC Press. https://doi.org/10.1201/9781315313450

Philis, Gaspard, Gracey, Erik Olav, Gansel, Lars Christian, Fet, Annik Magerholm, & Rebours, Céline. (2018). Comparing the primary energy and phosphorus consumption of soybean and seaweed-based aquafeed proteins – A material and substance flow analysis. Journal of Cleaner Production, 200, 1142–1153. https://doi.org/10.1016/j.jclepro.2018.07.247

Poseidon Aquatic Resources Management Ltd. (2019). *Marine Litter and Aquaculture Gear* (p. 17). Aquaculture Stewardship Council. https://www.asc-aqua.org/wp-content/uploads/2019/11/ASC_Marine-Litter-and-Aquaculture-Gear-November-2019.pdf

Regjeringen skrur på trafikklyset. (2017, October 30). Retrieved January 22, 2021, from https://www.regjeringen.no/no/aktuelt/regjeringen-skrur-pa-trafikklyset/id2577032/

Rodrigues, João F. D, Lorena, António, Costa, Inês, Ribeiro, Paulo, & Ferrão, Paulo. (2016). An Input-Output Model of Extended Producer Responsibility. *Journal of Industrial Ecology, 20*(6), 1273–1283. https://doi.org/10.1111/jiec.12401

Røine, Asbjørnsen, Brattebø, & Norges teknisk-naturvitenskapelige universitet, Fakultet for ingeniørvitenskap og teknologi, Program for industriell økologi. (1998). *A systems approach to extended producer responsibility: Economic efficiency and environmental effectiveness for packaging in plastic industry in Norway*. http://hdl.handle.net/11250/242685

Røine, Kjetil, & Lee, Chin-Yu. (2006). With a Little Help from EPR: Technological Change and Innovation in the Norwegian Plastic Packaging and Electronics Sectors. *Journal of Industrial Ecology*, *10*(1-2), 217–237. https://doi.org/10.1162/108819806775545448

Schoof, Rosalind A, & DeNike, Jesse. (2017). Microplastics in the context of regulation of commercial shellfish aquaculture operations. *Integrated Environmental Assessment and Management*, *13*(3), 522–527. https://doi.org/10.1002/ieam.1905

Selstad. (2019). PRODUKTKATALOG. Moldøen; Selstad.

The Aquaculture Stewardship Council. (2019, June 6). World Oceans Day: Fighting Ghost Gear and Plastic Waste. https://www.asc-aqua.org/world-oceans-day-fighting-ghost-gear-and-plastic-waste/

The Aquaculture Stewardship Council. (n.d.). About the ASC. https://www.asc-aqua.org/what-we-do/about-us/about-the-asc/

The Ocean Cleanup. (2011). Oceans | The Ocean Cleanup. The Ocean Cleanup. https://theoceancleanup.com/oceans/

Tomra Recycling news. (2019). Could the Chinese National Sword inspire global recycling innovation? Tomra.com. https://recycling.tomra.com/blog/chinese-national-sword-inspire-global-recycling-innovation

TOMRA. (2019). The Plastic Value Chain. Retrieved January 24, 2021, from https://solutions.tomra.com/plastic-value-chain-ebook?utm_medium=ppc&utm_term=recycling%20plastic&utm_campaign=S%5DUS-US-CE+Ebook&utm_source=adwords&hsa_kw=recycling%20plastic&hsa_ad=481610439567&hsa_mt=b&hsa_acc=1739717848&hsa_src=g&hsa_ver=3&hsa_grp=79834083747&hsa_cam=6443723438&hsa_tgt=kwd-16461151&hsa_net=adwords&gclid=Cj0KCQiA0rSABhDlARIsAJtjfCfNITjiKaBfGfef20mceJEAwK4AE769B-R17qPS-RZmKfAkQdc27lcaAt_GEALw_wcB

Tschirner, Martin, & Kloas, Werner. (2017). Increasing the Sustainability of Aquaculture Systems: Insects as Alternative Protein Source for Fish Diets. *Gaia (Heidelberg, Germany)*, *26*(4), 332–340. https://doi.org/10.14512/gaia.26.4.10

United Nations Statistics Division. (2019). — SDG Indicators. Un.org. https://unstats.un.org/sdgs/indicators/database/

Van Tung, Tra, Tran, Quoc Ba, Phuong Thao, Nguyen Thi, Vi, Le Quoc, Hieu, Tran Thi, Le, Son, Tuan, Nguyen Quang, Sonne, Christian, Lam, Su Shiung, Hai, Le Thanh, & Le, Quyet Van. (2021). Recycling of aquaculture wastewater and sediment for sustainable corn and water spinach production. Chemosphere (Oxford), 268, 129329–129329. https://doi.org/10.1016/j.chemosphere.2020.129329

Vázquez-Rowe, Ian, Ita-Nagy, Diana, & Kahhat, Ramzy. (2021). Microplastics in fisheries and aquaculture: implications to food sustainability and safety. *Current Opinion in Green and Sustainable Chemistry*, *29*, 100464. https://doi.org/10.1016/j.cogsc.2021.100464

Vestrum, Müller, Daniel Beat, Steinhoff, Franciska S., & Norges teknisk-naturvitenskapelige universitet, Fakultet for ingeniørvitenskap og teknologi, Institutt for energi- og prosessteknikk. (2013). Feed alternatives and phosphorus efficiency of the Norwegian fisheries and aquaculture system. Institutt for vann- og miljøteknikk. http://hdl.handle.net/11250/235205

Webster, K. (2017). The circular economy: A wealth of flows. Ellen MacArthur Foundation Publishing.

WILKINSON, F. (2020, November 20). Microplastics found near Everest's peak, highest ever detected in the world. Environment. https://www.nationalgeographic.com/environment/2020/11/microplastics-found-near-everests-peak-highest-ever-detected-world/

Yuan, J., Wang, J., Zhang, H., & Yue, D. (2006). Chao Yang.

13 Appendices

13.1 Appendix 1- Interview Questions

Questions for Aquaculture Companies

1. Can you please share the waste management strategy of your company?
2. Can you please share your experience on how the company manages waste aquaculture gear/nets from its operations?
3. Follow-up question: Could you provide more information on how your company processes the gear before it is sent to the waste management companies?
4. Do you need to clean and sort the gear before you send it to waste management companies?
5. How do you deal with the plastic waste generated from gear repairs or replacements?
6. Do you have an obligation to deliver waste to waste management facilities?
7. Do you have your annual waste statement from your waste management company or Annual waste statistics? Can we access this? Is it publicly available?
8. Do you need to pay any kind of tax or penalty for generating any amount of waste?
9. If so, tell us about the laws related to this issue. What are your responsibilities? what is the law about and what are the parties involved?
10. Do you have an obligation to replace parts of your aquaculture platform regularly?
11. Who is obligating you to replace these parts?
12. Are there any other policies that effect how often you replace your aquaculture platform?
13. What does the law say regarding replacement of aquaculture equipment? Be specific regarding the equipment type.
14. Do you enquire your supplier about the origin of the plastic gear material?
15. Do they use any plastic gear that is made from recycled plastics?
16. Who do you buy your aquaculture gear from (different parts)?
17. Could you share some information on how you source your aquaculture gear/equipment?

18. Follow-up question: Are the suppliers local or foreign companies? Are different parts sourced differently from different suppliers locally or abroad? Any challenges on the sourcing process? Any legal requirements?
19. How better waste management systems can add value to your current business models?
20. Could you explain how waste management in your company adds value to your operations?
21. How better plastic waste management systems can add value to your current business models?

Questions for Fallow Sites

1. How much equipment do you have at this moment in Fallow site?
2. Could you please tell us the extent of waste gear/nets/ropes/equipment you have at the fallow site?
3. What is the tonnage? Or could you please mention/specify the quantity of waste gear at the fallow site?
4. How is the company going to deal with those gears?
5. Could you expand on how the company will deal with that level of waste gear/nets/ropes/equipment?
6. DO you have any agreement waste management companies?
7. Could you tell us how you collaborate with the waste management companies in managing the waste?

Waste management agencies

1. Can you describe in detail the process of managing waste in your facility? (Interview)
2. What do you do with waste received from aquaculture companies? Interview
3. Do you send the plastic waste to any other country?
4. What are the challenges you face in terms of processing plastic waste from aquaculture industry?
5. Have you discussed these challenged with aquaculture gear producers?

6. Do you think there are opportunities for getting value from the waste nets/ropes/equipment from the aquaculture firms?
7. Could you explain the value creation activities/potentials from the waste gear?
8. Are you making any progress in addressing these challenges?
9. What are some of your suggestions for better management of waste, especially plastic waste from aquaculture activities?
10. What opportunities are there/ How can we use better the plastic waste generated from aquaculture?
11. Is there any company that collects plastic waste directly from environmental agency for recycling purposes?

<u>Suppliers of the aquaculture gear</u>

1. Do you produce the gear in Norway or abroad?
2. Who is responsible for the design and development of the product? Is it inhouse?
3. What are the challenges do you face producing gears from recyclable plastic materials?
4. Are you developing any new product with recycled plastics or reused plastics? Why/why not?
5. Do you have any agreement with waste management companies to design products for their end-of-life?
6. Do you offer any services to repair gears in your facilities?
7. Do you receive old/used gear from aquaculture companies?
8. If yes: Do you offer any incentives for the aquaculture companies if/when they deliver old and used gear?
9. If no: In your opinion, how circular your business model is? Can you identify any missed opportunities?
10. How feasible it is to recycle the gear you are currently manufacturing? (Interview)
11. What are the different reasons for not using more recycled plastic? Does it cost more? Is it less durable?

12. How plastic waste can add value to your industry/How better waste management systems can add value to your current business models? Interview

13.2 APPENDIX 2: SURVEY QUESTIONS

Short Description: Are you concerned about the ocean's health? If yes, please help us by taking few minutes of your time to answer the following questionnaire. Your answers will help us identify how many aquaculture gears are causing marine plastic pollution, and therefore find solutions to manage this problem.
We are students of NTNU undertaking a study on the management of plastic waste in the aquaculture industry in Møre and Romsdal. It would be highly appreciated if you can respond to the following questions. No personal data will be collected. Data collected will be used for statistical analysis, and no individual respondent/firm would be identified. Data collected will be treated as confidential. Thank you for participating in this survey.

For Aquaculture companies

1. On average, which types of fish species are you farming in your site(s)? Give an average percentage under each of these categories. The sum of the percentages should be equal to 100%

    Atlantic Salmon

    Arctic Trout

    Atlantic Cod

    Atlantic Halibut

    Other fish species

    Blue Mussels

    Other shellfish species

2. On average, what is the number of fish produced per year in your site? Give an average quantity for each category.

    Atlantic Salmon

    Arctic Trout

    Atlantic Cod

    Atlantic Halibut

    Other fish species

    Blue Mussels

    Other shellfish species

3. Which of the following aquaculture systems do you use?

    Open water cages and pens

    Suspended Ropes/Longlines

    Coastal and Inland ponds

    Others (Please specify)

4. On average, how many of the following aquaculture gear do you own at the same time? Example: 2 floating collars, 5 Buoys, 6 pond liners, etc.

    Floating Collars

    Collar Floatation

    Buoys (in mooring systems)

    Ropes (in mooring systems)

    Net enclosures

    Predator or other nets

    Feeding systems (pipes and hoppers)

    Raft Floatation

    Stock containment (nets/meshes)

    Pond liners

    Sampling/Harvest nets

    Plastic green/poly housing

    Aerators/Pumps

    Feeding systems (pipes, feeders, and trays)

    Others (Please specify)

5. On average, how frequently do you buy the following aquaculture gear in a year? Example: 2 floating collars, 5 Buoys, 6 pond liners, etc.

    Floating Collars

    Collar Floatation

    Buoys (in mooring systems)

    Ropes (in mooring systems)

    Net enclosures

    Predator or other nets

    Feeding systems (pipes and hoppers)

Raft Floatation

Stock containment (nets/meshes)

Pond liners

Sampling/Harvest nets

Plastic green/poly housing

Aerators/Pumps

Feeding systems (pipes, feeders, and trays)

Others (Please specify)

6. Can you please upload your annual statement of waste / Annual waste statistics?
7. Which of the following destinations is the waste sent to? Example: 50% landfilled, 10% recycled etc.

Incinerated

Landfilled

Recycled

Reused

8. On average, how much money does your company spend to process plastic gear waste yearly?
9. On average, how many percentages of the following aquaculture gear types you own are being repaired each year? The answer should only include repairs involving the change of gear parts. Write a percentage under the following categories. If you don't use this type of gear, leave the category blank.

Floating Collars

Collar Floatation

Buoys (in mooring systems)

Ropes (in mooring systems)

Net enclosures

Predator or other nets

Feeding systems (pipes and hoppers)

Raft Floatation

Stock containment (nets/meshes)

Pond liners

Sampling/Harvest nets

Plastic green/poly housing

Aerators/Pumps

Feeding systems (pipes, feeders, and trays)

Others (Please specify)

10. On average, how do you spend the budget specified for gear management? Example: new gear = 43% / repair damaged gear = 57%

Percentage used to purchase new gear.

Percentage used to repair damaged gear.

11. On average, what is the lifespan of the following aquaculture gear types?

Floating Collars

Collar Floatation

Buoys (in mooring systems)

Ropes (in mooring systems)

Net enclosures

Predator or other nets

Feeding systems (pipes and hoppers)

Raft Floatation

Stock containment (nets/meshes)

Pond liners

Sampling/Harvest nets

Plastic green/poly housing

Aerators/Pumps

Feeding systems (pipes, feeders, and trays)

Others (Please specify)

12. On average, what is the percentage of the following gear lost during repairs?

Floating Collars

Collar Floatation

Buoys (in mooring systems)

Ropes (in mooring systems)

Net enclosures

Predator or other nets

Feeding systems (pipes and hoppers)

Raft Floatation

Stock containment (nets/meshes)

Pond liners

Sampling/Harvest nets

Plastic green/poly housing

Aerators/Pumps

Feeding systems (pipes, feeders, and trays)

Others (Please specify)

13. How much of your gear needs to be disposed of yearly? Please specify the exact weight in KG or tons.
14. Where do you deliver the gear that you want to dispose of? Write the name of the company/facility/place collecting this waste.
15. On average, how much of the following aquaculture gears do you lose at sea every year? Example: 3 ropes per year.

Floating Collars

Collar Floatation

Buoys (in mooring systems)

Ropes (in mooring systems)

Net enclosures

Predator or other nets

Feeding systems (pipes and hoppers)

Raft Floatation

Stock containment (nets/meshes)

Pond liners

Sampling/Harvest nets

Plastic green/poly housing

Aerators/Pumps

Feeding systems (pipes, feeders, and trays)

Others (Please specify)

For Suppliers/Manufacturers of gear

1. On average, how much of the following aquaculture gear do you produce annually?

    Floating Collars

    Collar Floatation

    Buoys (in mooring systems)

    Ropes (in mooring systems)

    Net enclosures

    Predator or other nets

    Feeding systems (pipes and hoppers)

    Raft Floatation

    Stock containment (nets/meshes)

    Pond liners

    Sampling/Harvest nets

    Plastic green/poly housing

    Aerators/Pumps

    Feeding systems (pipes, feeders, and trays)

    Others (Please specify)

2. Which of the following plastic types are you using to produce aquaculture gear?

    Fiber-reinforced plastic (FRP)

    High-density Polyethylene (HDPE)

    Low-density polyethylene (LDPE)

    Nylon (Polyamide, PA)

    Polyethylene (PE)

    Polyethylene terephthalate (PET) or polyester

    Polypropylene (PP)

    Polyvinyl chloride (PVC)

3. On average, what is the percentage of the following sources of plastic do you use to produce new gear?

    Recycled

    Virgin

    Reused

Others

4. On average, what is the percentage of recycled plastic that you can use for manufacturing new gear?
   (The capacity)

For Waste Management Companies

1. On average, how much waste per year do you receive from aquaculture companies?
   Please provide the average weight

   Plastic waste

   Mixed waste

   Other

2. What is the percentage of plastic waste received from aquaculture companies that gets ...?

   Incinerated

   Landfilled

   Recycled

   Reused