Ragnhild Bjerkvik Alnes

Investigating dynamic quantum of plastics from Fishing Gear in Norway

Master's thesis in Energy and Environmental Engineering
Supervisor: Paritosh Deshpande
Co-supervisor: Cecilia Askham

July 2022

Master's thesis

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Norwegian University of Science and Technology
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Abstract

This thesis is on the mass flows of plastic in fishing equipment in commercial fishing in Norway from 2016 to 2020. The quantities of fishing equipment are calculated by material flow analysis (MFA) and the data are from available literature, sales data on fishing equipment and data from waste companies, statistics collected on fishing equipment from sea and land, and a survey of waste companies.

It is useful to quantify the amount of fishing equipment in the industry, the sea and in use in order to further assess the environmental consequences of fishing, by, for example, life cycle assessment (LCA). The consequences of lost fishing gear are many, including ghost fishing, entanglement, transport of environmental toxins to species via plastic pieces and ingesting plastic pieces, which can lead to; starvation due to blockage or feeling of satiety, damage to organs and in the worst-case death of marine species.

In 2020, 425 tonnes of plastic were lost in the form of fishing equipment in commercial fishing, and 134 tonnes were retrieved from the sea and coastal areas. Pots have the largest loss of plastic per catch, while purse seines have the least loss per catch. The highest loss is from Danish seines, even though they have the second-largest loss of 1.17 kg of plastic per tonne of round weight. Trawls have little loss per catch, but since almost half of the catch is caught with trawls, trawl fishing is the second most lost in total for Norway in 2020.

The thesis' new contribution, equipment-specific plastic loss per catch, can be used together with annual catch data as a dynamic factor to estimate fishing equipment losses from 2000 to 2021 and for the future.

Sammendrag

Denne oppgaven tar for seg massestømmene av plast i fiskeutstyr i det kommersielle fisket i Norge for 2016 til 2020. Mengdene fiskeutstyr er utregnet ved massestrømsanalyse (MFA) og dataen er fra tilgjengelig litteratur, salgsdata over fiskeutstyr og data fra avfallsselskap, statistikk over innsamlet fiskeutstyr fra hav og stand og en spørreundersøkelse av avfallsselskap.

Det er nyttig å tallfeste mengden fiskeutstyr i industrien, havet og i bruk for å videre kunne gjøre en vurdering av de miljømessige konsekvensene til fiskeriet, gjennom for eksempel livssyklusanalyse (LCA). Konsekvensene av tapt fiskeutstyr er mange, deriblant spøkelsesfiske, innvikling, transport av miljøgifter til arter via plastbiter og ved inntak av plastbiter kan det føre til; sult som følge av blokkering eller følelse av metthet, skade på organer og i verste fall død for marine arter.

I 2020 ble det mistet 425 tonn plast i form av fiskeutstyr i det kommersielle fisket, og 134 tonn ble tatt ut av havet og kystnære strøk. Teiner har størst tap av plast per fangst, mens snurpenot har minst tap per fangst. Det er mest totalt tap fra snurrevad, selv om de har det nest største tapet på1.17kg plast per tonn rundvekt. Trål har lite tap per fangst, men siden nær halvparten av fangsten er fanget med trål er trålfisket det som har nest mest plastutslipp i Norge totalt i 2020.

Oppgavens nye bidrag, utstyrsspesifik plasttap per fangst, kan sammen med årlige fangstdata brukes som en dynamisk faktor for å anslå fiskeutstyrstap for 2000 til 2021 og fremover i tid.

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Abbreviations

Abbreviation	*Description*
ALDFG	Abandoned, Lost or otherwise Discarded Fishing Gear
CRI	Centre for Research-based Innovation
DMFA	Dynamic Material Flow Analysis
EF	Effect Factor
EPR	Extended Producer Responsibility
FG	Fishing Gear
FFL	Fishing For Litter
FK	Fishers Knowledge
FU	Functional Unit
HMF	Handelens Miljøfond
HNR	Hold Norge Rent
LCA	Life Cycle Assessment
LCIA	Life Cycle Inventory Analysis
MC	Monte Carlo
MFA	Material Flow Analysis
MoP	Mass of Plastic
SDG	Sustainable Development Goal
SFA	Substance Flow Analysis
SFI	Senter for Forskningsdrevet Innovasjon
TC	Transfer Coefficients
PA	Polyamides
PE	Polyethylene
PP	Polypropylene
WMF	Waste Management Facility

1 Introduction

Combating marine pollution is on the agenda globally and one of the goals of sustainable development, 14.1 (United Nations 2015). It is estimated that 19 to 23 million tonnes of plastics enter the ocean annually, possibly reaching 53 Mt in 2030 (Borrelle et al. 2020). A part of the entering plastics is in the form of mismanaged fishing gear. The amount of fishing gear entering the ocean each year and accumulated is unknown, and there is a misconception that 640,000 tonnes enter annually (Richardson et al. 2021). However, the frequent citing and spread of the number emphasize the importance of having a quantitative number to convey the message of this harmful marine pollution and to promote minimizing efforts.

The quantitative extent of the damage from plastic in the sea is yet to be determined and remains a hot topic of study. Abandoned, lost or otherwise discarded fishing gear (ALDFG) is harmful to marine life in many ways. The effects of marine pollution are ghost-fishing, entanglement, ingestion and mechanical and chemical effects from the plastics. Lost gear can for a period of time continue to catch or trap wildlife such as fish, birds, mammals and crustaceans, this phenomenon is called ghost-fishing (ICES 2022). Creatures can ingest micro- and macro-plastics potentially leading to malnutrition, starvation by obstruction, rupture of intestines, injury or death (Bergmann et al. 2022). Moreover, plastic polymers can function as vectors for environmental toxins transporting the toxic chemicals into wildlife (Bergmann et al. 2022). One study found that out of the 265 bird species globally entangled by marine litter, 83% are entangled by fishing gear, here nets and lines, illustrating the high entanglement potential of this type of marine litter(Ryan 2018). Gilman et al. 2021 relatively ranked the risk from the fishing gear types based on their rate of becoming ALDFG, fishing effort and catch, and impact both socioeconomic and ecological. Among the highest risk ALDFG gillnets score highest, bottom trawling is in the top 5 out of 18 and line equipment such as longlines are at the lowest risk (Gilman et al. 2021).

To assess the damage and find proper mitigation instruments, quantities of derelict fishing gear are vital. Norway is a prominent fishing nation, catching 42% of the total European Union catch in 2015 (Eurostat 2022). One of the main sources of marine litter on beaches in Norway is fisheries and aquaculture with 46% of the weight (Mepex 2020). It is estimated that 380 tonnes of plastic fishing gear were lost by the Norwegian fishing sector in 2016 (Deshpande, Philis et al. 2020). This was calculated with material flow analysis (MFA) and the data comes from surveying 114 fishing companies, sales data from fishing gear suppliers and data on the treatment of worn gear from waste management facilities.

In 2018, Kuczenski et al. 2022 estimated the global plastic gear loss of trawling, seining and longline fishing totaling 60.9% of the total catch to be 53.5 kt. The loss of plastic per tonne catch equals 0.956 kg (Kuczenski et al. 2022). This is in line with the Icelandic research with 1 kg lost plastic gear per tonne as a thumbnail (Personal communication with an expert from Iceland Recycling Fund 2020). The plastic gear loss estimate is among others based on the MFA on Norwegian fisheries by Deshpande, Philis et al. 2020 and fishing effort by vessel telemetry data from GPS and machine learning (Kuczenski et al. 2022) and takes us one step further in understanding and mitigating the consequences of derelict fishing gear.

Substantial changes in plastic policy are arriving. The first international life-cycle plastic agreement was signed in March 2022 by the United Nations Environment Assembly of the United Nations Environment Programme and is expected in 2024 (United Nations Environment Assembly of the United Nations Environment Programme 2022). There will be Extended Producer Responsibility in the EU and Norway for fishing gear from 2025 (European Union 2019b). Moreover, there is an upcoming ISO standard for waste handling on fishing vessels (Standard Norge 2020). The upcoming ship directive will bring changes in the port fee to get rid of questions on whom are to pay to dispose of owner-less waste from the sea (European Union 2019a). This is currently a challenge as fishers get marine litter in their nets or on their hooks. Operators of a longline vessel in the North Sea estimated that their added haul of marine litter cost NOK 40,000 a year to get rid of (Kolseth and Reksnes 2017). The fishers have benefited from Fishing For Litter an initiative ensuring no cost for delivering the caught litter to keep it out of the ocean. Though, with the new ship directive Fishing For Litter might be discontinued.

Following the concern for marine life and policy changes, quantities of fishing gear in use, lost and throughout the system of Norwegian fishery are of interest. Quantities enable measuring of how actions put in place perform towards the target of mitigating marine pollution. Therefore, the objective is to perform a quantifying effort through the method of material flow analysis (MFA) on fishing equipment in Norway. The MFA will look at what the quantities through processes in the life-cycle of fishing equipment. This knowledge on quantities is essential to be able to further calculate and evaluate the environmental burdens, via e.g., Life-Cycle Assessment which is one of the tasks of research group 5 within Dsolve, Centre for Research-based Innovation (CRI)-Biodegradable plastics for marine applications, that this thesis is a part of (Dsolve 2022).

1.1 Problem Description

Examine the status quo of quantities of plastic polymer (s) from fishing gears on a national level and evolve current models with a dynamic material flow analysis approach. The assignment as a part of the research project Dsolve under the area "Circularity of bio-based, biodegradable and non-degradable plastics. This master thesis will aim to quantify mass flows of plastic polymer (s) used in typical fishing gear, including nets and ropes, in the fishing sector of Norway.

The problem description's tasks will be answered by providing a literature review to find historical quantities and research reports, and then performing an MFA with uncertainty analysis and error propagation for 2020. For completing the task information from parts of the sector is required. The data will be gathered from literature, by surveying waste management facilities (WMFs), interviewing fishers, recyclers, researchers, and experts to look at fishing gear patterns, and consulting with researchers to understand the complex fishery industry.

1.2 Scope

The scope is illustrated in Figure 1, it is plastics in fishing gear in the Norwegian commercial fishing sector and focuses on quantum in 2020. Including recreational and foreign fishing would imply an immense task for obtaining data and modelling, and is therefore not prioritized for the thesis. The clean-up operations data will not solely be waste from Norwegian fisheries, as foreign and recreational gear also are lost in the waters. However it is estimated that 77% of the litter found on Norwegian beaches is of Norwegian origin (Mepex 2020). To focus on the Norwegian commercial fishing fleet alone ensures clear results allowing for easier interpretation and guidance for law enforcers.

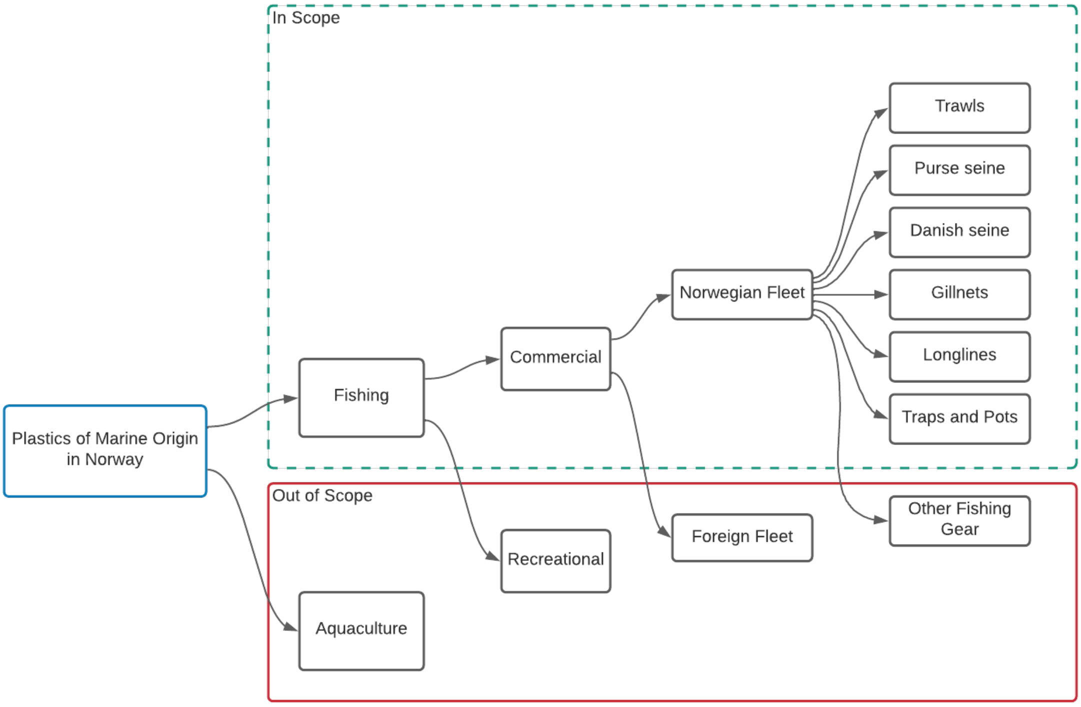

Figure 1: Scope of the Thesis

Fishing gear comes in all shapes and forms, and is often tailored to the needs of the operator. The main fishing gear utilized in Norway can be divided into six categories; trawls, purse seines, danish seines, gillnets, longlines and traps and pots. The fishing gears are illustrated in Figure 2. Gear can both be active and passive meaning that they either are stationary in the ocean and the fish move in the gear, or the gear moves towards the fish. In addition to the fishing gear types ropes are a main gear part. Ropes are used when anchoring the gear, deploying it correctly, for mooring, and are often part of the gear itself i.e, the ropes within gillnets, floating on top and sinking on the bottom with netting in-between, ensuring that the netting is expanded correctly in the water column.

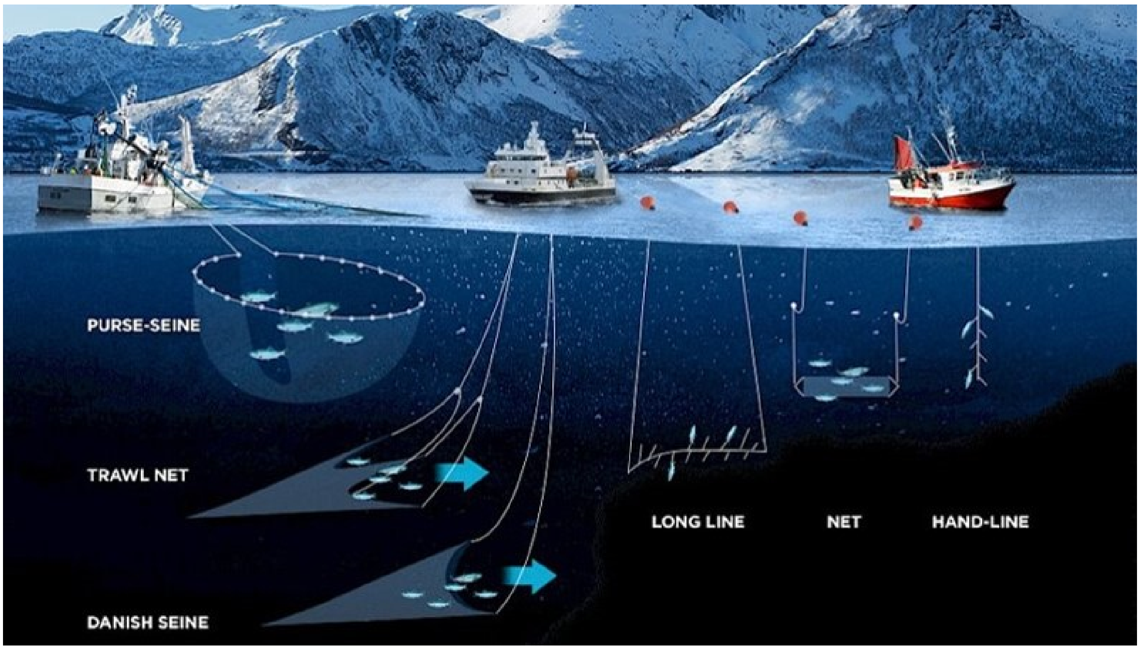

Figure 2: Fishing Gear illustration

Source: Norwegian Seafood Council n.d.

The plastic content in fishing gear mainly PA, PE and PP is the functional unit and is measured in tonnes. The material composition of sold fishing gear is listed in Table 11. 2020 is the main year of evaluation and the years 2016 to 2020 are included to allow for analyzing trends. Moreover, historic quantities in literature are included if present to understand the dynamic aspect of the fishing sector.

2 Background

Regarding the fishing industry and waste management there are numerous policies, definitions and concepts in place. This background will list a few of the policies and their area of application affecting the flow of fishing gear now and in the future. The relevant terms of waste, recycling and waste management are defined in the Waste Framework Directive (European Union 2018). Moreover, two key concepts in waste management and circular economy are explained, namely waste hierarchy and extended producer responsibility (EPR).

2.1 Relevant policies

The **Waste Framework Directive** is the legislative framework within the European Union and defines relevant terms and principles (European Union 2018). It defines terminology used in regards to waste and concepts and principles such as the *extended producer responsibility* (EPR) and *the waste hierarchy*, and the *polluter pays principle*. Preferred waste management for the Union is organized and described in the "waste hierarchy" where the goal is to move away from disposal at landfills and act towards prevention of waste from occurring.

Forskrift om gjennomføring av fiske, fangst og høsting av viltlevende marine ressurser (høstingsforskriften) is the legislative framework for fishery in Norway (Høstingsforskriften [The harvesting regulations] 2022). Regulations in relevance to the field of ALDFG are for instance that traps and pots used for lobsters and common crabs must have an escape opening closed with cotton rope, a biodegradable material, to reduce the risk of ghost-fishing. Fishing gear in the sea must be marked with the vessels registration mark, and equipment with hooks can not be used closer than a 100 meters away from seines (Høstingsforskriften [The harvesting regulations] 2022), which limits the probability of gear conflict, one of the reasons for loss of gear (Macfadyen et al. 2009). Of special importance is paragraph 69, report and removal of lost gear, which states that if the fishing gear is lost or cut it must be sought after. If the gear is not retrieved it shall be reported to the coastal guard promptly with the following details; vessel name and call signal, equipment type, amount of equipment, time of loss and position of loss. If the previously lost gear is found it shall be reported to the coastal guard (Høstingsforskriften [The harvesting regulations] 2022). The Directorate of Fisheries uses these location data of lost gear to retrieve gear at their annual clean-up operation, and states that the efficiency of clean-up is 70-80% of the reported loss (MARFO Senter mot marin forsøpling 2022).

The **Directive on Port Facility for Ships**, EU2019/883, is about waste management at harbors from ships and the cost allocation of found owner-less marine waste, with the goal of reducing marine litter (European Union 2019a). The cost of delivering derelict fishing gear and caught marine waste at the harbors will be covered by an indirect fee, if not other suited schemes are in place (Klima- og miljødepartementet 2022). This Directive is currently in the process of being implemented in Norway. Implementation of EU2019/833 might rule out financial support to Fishing For Litter (E. R. Johannessen and Johnsen 2022).

Following the **Single Use Plastics Directive** fishing gear is set to be in an extended producer responsibility scheme (E. Commission and Environment 2018). In January 2025 extended producer responsibility will be implemented for plastics in fishing gear in Norway. Before enrollment the details of the framework are to be determined by the Environmental Directorate (Klima- og miljødepartementet 2021).

Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR) works vastly within the field of marine plastic pollution. They have guidelines on how to determine and register marine litter found on beaches (O. Commission et al. 2010). Moreover, Fishing For Litter each year reports the quantity of collected waste, participating number of vessels per harbour and waste collected per harbors to OSPAR (Johnsen, Drægni et al. 2019).

The Global Treaty on Plastic Pollution is the first international treaty on plastic pollution. It was signed by Norway's Minister of Climate and Environment Espen Barth Eide in Nairobi. The specifics of the treaty are not determined yet, however the legislation could be of importance in the future for the fishing sector in terms of plastic in fishing gear as the treaty shows will and political means for achieving lower levels of plastic pollution.

2.2 Definitions

"'waste' means any substance or object which the holder discards or intends or is required to discard;" (European Union 2018).

"'waste management' means the collection, transport, recovery (including sorting), and disposal of waste, including the supervision of such operations and the after-care of disposal sites, and including actions taken as a dealer or broker;" (European Union 2018).

"'recycling' means any recovery operation by which waste materials are reprocessed into products, materials or substances whether for the original or other purposes. It includes the reprocessing of organic material but does not include energy recovery and the reprocessing into materials that are to be used as fuels or for backfilling operations;" (European Union 2018).

"In a 'circular economy', the value of products and materials is maintained, waste is avoided, and resources are kept within the economy when a product has reached the end of its life" (Geisendorf and Pietrulla 2018).

'ALDFG' Abandoned, lost or otherwise discarded fishing gear is equipment used for catching fish or other marine animals that are lost to the marine environment. ALDFG is linked to negative impact on the environment, safety and navigation at sea, and is of economic concern (Macfadyen et al. 2009).

"The ability of ALDFG to continue to fish (often referred to as 'ghost fishing') has detrimental impacts on fish stocks and potential impacts on endangered species and benthic environments" (Macfadyen et al. 2009).

2.3 The Waste Hierarchy

Figure 3: Waste Hierarchy

Source: European Union 2022

The level of importance and potential gains in terms of ideal managing of waste is illustrated in the Waste Hierarchy in Figure 3. 'The most preferred and impactful option is to prevent waste from occurring in the first place, this can be exercised by choosing items of higher quality reducing the needed quantity thereby lowering the waste quantum. Preparing the waste for re-use is the second-most preferred action, increasing the re-use potential. Next in line is recycling which can be performed as mechanical recycling or chemical recycling. Incineration to recover the energy contained in the waste is the second to last preferred option. Lastly, disposal, for instance at landfills, is the least preferred option of waste management.

Fishing gear waste is seldom reused after its original use phase; hence the main waste management options are recycling, energy recovery by incineration and disposal at a landfill. Additionally fishing gear is disposed of with or without purpose on land and at sea (Macfadyen et al. 2009).Following the waste hierarchy it is most important to eliminate the waste from being disposed of, and aim at the top of the pyramid.

2.4 Extended Producer Responsibility

Extended producer responsibility is a scheme making the producer or importer arrange for the costs of the product's end-of-life phase (European Union 2018). Extended producer responsibility follows the *polluter pays principle* where the actor responsible for the pollution is the one that pays for the service (OECD 2016). Hence the cost of disposal is to some extent internalized in the purchase price (OECD 2016). The producer or importer forwards the fee for the items to the corresponding Producer Responsibility Organization (PRO) whom distributes the fee to the providers of waste management. In this way at the product's end-of-life it can be delivered for waste management by the customer for free, ensuring a high likelihood of proper disposal and recycling rates. The manufacturers/importers are also responsible for removing environmental toxins from the end-of-life product. Benefits of EPR are projected as lower amounts of harmful components and litter in nature since delivering the waste is not a financial burden, and increased responsibility for the environmental impacts from the design phase to the post-consumer phase (Hilton et al. 2019).

In Norway there are multiple products in the EPR-schemes, for instance cars, windows, electronics, plastic packaging and more (Avfallsforskriften [The Waste Regulations] 2004). Extended producer responsibility for equipment containing plastics in the fishery- and aquaculture industry is projected for January 2025 in Norway (Klima- og miljødepartementet 2021). The Norwegian Environment Agency is responsible for finding the best practice and implementation of the EPR (Klima- og miljødepartementet 2021).

3 Methodology

This chapter presents the research methods used in this thesis and discusses the strengths and weaknesses of the applied methods. The main method for the thesis is an Industrial Ecology based Material Flow Analysis (MFA). As MFA case studies are usually data-intensive, several qualitative and quantitative methods have been applied for gathering the data for the model. Key data sources are obtained through a literature review of quantification efforts throughout the fishery system, both full system MFA and quantities from beach clean-ups and ocean retrieval. Moreover, data and insight from waste management facilities (WMF) are obtained from surveys and interviews. Uncertainty from parameters and constants have been assessed using the tool Simulación in Excel and followed by STAN software for error propagation. Additionally, an expert's opinion is used to verify assumptions and estimations before finalizing the results. The result consists of a mass of plastic (MoP) in tons on six main fishing gear types and ropes throughout the modeled system Norwegian fishing industry of 2020. The data was collected from 17th January to 15th May followed by the expert's opinion to review and refine the MFA findings.

3.1 Material Flow Analysis

Material Flow Analysis (MFA) is a method that accounts for flows and stocks of goods or substances within a set system boundary in time and space (Brunner and Rechberger 2016a). The method have vast applications and is frequently used within environmental engineering for assessing resource efficiency and guiding resource management, waste management and policy-making (Brunner and Rechberger 2016a) (Allesch and Brunner 2015) (Fischer-Kowalski et al. 2011). MFA follows the law of conservation of matter also called the mass balance principle (Brunner and Rechberger 2016a). Hence, the result can be controlled by balancing the inputs, stocks and outputs of each process and the entire system. To calculate the output called system variables, input parameters such as constants and transfer coefficients are utilized in balance and model approach equations(Brunner and Rechberger 2016a). These constants and transfer coefficients are the numbers needed for performing a MFA. Sources for information about the mass flows can be databases, indirect and direct measurements, bureaus of statistics, proceedings, consumer organizations or industrial associations, environmental protection agencies and papers published in scientific journals and more (Brunner and Rechberger 2016a). For this MFA information about the flows is obtained through suppliers sales data, proceedings and statistics from retrieval initiatives, proxy data from waste management facility companies obtained from surveys and questionnaire, along with transfer coefficients found in published literature.

System Description

The aim of this work is to illustrate the quantum of plastics in fishing gear throughout the fishing industry in Norway to point out patterns and potential areas of improvement. Material Flow Analysis (MFA) is a method that follows goods, services, or substances through a modeled version of a system (Brunner and Rechberger 2016b). The model is made up of processes that can contain stocks and the processes are connected by the flows of the selected entity. MFA can be used for understanding a system, visualizing, and structuring data and can be a tool for predictions and forecasting. Thus, MFA is deemed a suited method for the task and selected for assessing the flows of plastics in fishing gear within Norway's fishing industry.

The fishing gear consists of a range of materials; from metal, rubber, natural fibers such as cotton and different plastic composites. Here plastic polymers are chosen as the base of calculation due to their proven threat to marine life in terms of ghost fishing (Macfadyen et al. 2009) and ability to further degrade into microplastics, the material poses more of a threat to marine life in terms of ghost-fishing and build-up of microplastics. Therefore, the functional unit (FU) for the mass flow analysis is one ton of plastic, mainly polyethylene (PE), polypropylene (PP) and polyamide (PA) that are used as major building blocks of any commercial fishing gears (Baeta et al. 2009). Throughout the text, the term "plastics" includes polyethylene (PE), polypropylene (PP) and

Nylon (PA).

Within the selected system boundary of Norway including its waters, fishing gear undergoes several processes; the fishing activity itself, repair and maintenance, and end-of-life management, moreover it can be lost in the ocean, and it can be retrieved from the ocean or beaches. Manufacturing of gear or gear parts is left out of the system as it often occurs outside the Norwegian borders. Repair and maintenance can also take place outside the borders, however, for simplicity, it is modeled within the system. Recycling of worn fishing gear happens both nationally and internationally (Havas et al. 2022). For simplicity, the flow of FG to recycling is chosen to go outside the system boundaries.

For further research, there can be added a sorting and material recycling process within the system boundary and together with a national recycling efficiency parameter, for instance, 60% (Havas et al. 2022), it will give a more descriptive value of the recycling of FG in Norway. One of the disadvantages of using MFA is that a system will never totally reflect the real system, and simplifications and assumptions must be made in order to have solvable equations.

Figure 4 shows the modeled system of plastics in fishing gear in the Norwegian fishing industry. An enlarged version of the system is found in Appendix A.

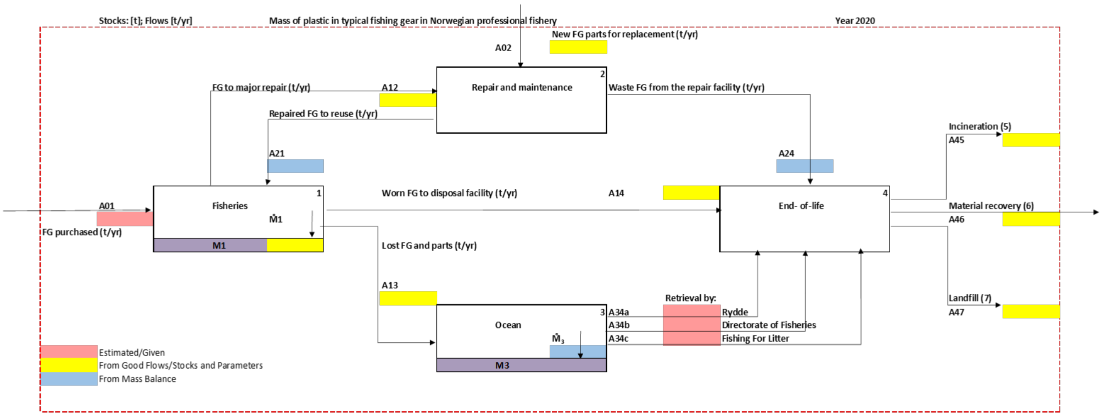

Figure 4

Flows and stocks are calculated by parameters from Deshpande, Philis et al. 2020 and obtained data from suppliers, retrievers, waste management companies and expert opinion. The method of obtaining the data for the MFA is explained in the next paragraphs, and the findings are in the results, chapter 4.

Methods for data collection

As previously mentioned, MFA is data-intensive therefore qualitative and quantitative methods have been applied for data collection. These are namely, literature review, survey and lastly interviews for system understanding, data collection and expert opinion. Table 1 lists the data collection methods to the corresponding flows.

Data for MFA	Relevant System Stakeholders	Methods
Purchase phase	Fishing gear suppliers	1) Questionnaire for suppliers 2) Literature review of previous studies
Use phase	Fishers	1) Literature review of previous studies 2) Interview of fishermen
Collection on land	Hold Norge Rent In The Same Boat Runde Miljøsenter	1) Literature review
Collection from water	Fiskeridirektoratet Fishing For Litter	1) Literature review 2) Expert's opinion
End-of-life phase	Waste Management Facilities (WMF) Recycleres	1) Survey 2) Questionaire for WMFs 3) Interview of WMF operator

Table 1: Methods for data collection

3.2 Literature review

A literature review was performed for quantification efforts of plastics in fishing gear. Both the quantification of full fishery systems and parts were reviewed such as beach clean-ups and ocean retrieval. Scopus and Google Scholar are the databases used with keywords such as plastic*, fishing gear, fish*, Material Flow Analysis OR MFA, quantity, and quantify. In addition, since there are many initiatives and research where the research is not published in journals, sources from key stakeholders are reviewed. The list of key stakeholders to examine is guided by overview from Deshpande, Philis et al. 2020, Sundt et al. 2018 and Table 4.1 in Fiskeridirektoratet 2021.

Initiatives with relevant literature include, Hold Norge Rent, clean-ups by the Directorate of Fisheries, Fishing For Litter, In The Same Boat, and reports for the government, Directorate of Fisheries or Norwegian Environment Agency. Contact persons of different stakeholders were contacted and interviewed with the request of relevant literature. These stakeholders are SALT, Dsolve and Runde Miljøsenter. From them, literature such as yearly reports of the initiatives and project reports were reviewed. Publications by Jannike Falk-Andresson were reviewed as she was mentioned as a person with scientific publications and profound knowledge on the topic. 15 articles from her google scholar profile were examined generating two highly relevant articles on the topic of beach-clean ups.

3.3 Survey

For the waste flow, a survey were performed targeting waste management facilities (WMF) and their practices of handling end-of-life gear. The survey was made with google forms, and it was printed out for being filled out at a waste management conference, Avfallsforum Midt-Norge, on the 17th of February in Trondheim. See Appendix C to find the survey attached.

At the conference, representatives from waste management facility companies, academia, and consultants were present. Thereby, first hand knowledge of people in the industry could be obtained. Additionally, the link to the survey was sent by mail with the conference presentations, allowing for answers by other knowledgeable representatives of the companies.

3.4 Interviews for system understanding, data collection and expert opinions

A good understanding of the system at hand with the different processes, flows and parameters is needed to perform an MFA. Often the MFA contains aspects from different disciplines, therefore it is important to seek advice from relevant experts (Brunner and Rechberger 2016b). Therefore, approaching and interviewing key stakeholders have been an important part of the work. During the work of the thesis, there have been dialogues with researchers, consultants, scientists, suppliers, waste management facility operators, fishers and retrievers. They are listed in Table 2.

Part	**Company**	**Role**	**Date**
Collection from water	The Norwegian Directorate of Fisheries	Clean-up leader	May 5
Collection from land and researcher	Runde Miljøsenter	Project manager	March 24
Collection from water and researcher	SALT, FFL, Dsovle	Project leader	February 7
Waste Management	Masternes Gjenvinning	General manager	February 28

Table 2: List of interviewed stakeholders.

3.5 Uncertainty analysis via Simulación and STAN

For analyzing the uncertainty of MFA calculations the recommended method is Monte Carlo simulation (Wang and Ma 2018). The quantities of plastics in fishing gear is calculated with uncertainty. Uncertainty analysis with error propagation are performed with Monte Carlo simulation in Simulación 5.0 in Excel and followed by MFA mass balance modelling in STAN software.

For running the Monte Carlo (MC) simulation through Simulación the parameters and constants for calculation of the MFA are set as inputs with their mean, uncertainty and distribution. The inputs are further used as building blocks for calculating the MFA equations. After a set high number of iterations simulating the MFA output the result is refined values of the variables with calculated uncertainty.

The uncertainties and parameters are set to the uncertainties and parameters in Supplementary Information to Deshpande, Philis et al. 2020, except for the handling of waste, supplied new fishing gear and retrieved flows where the parameters have values from this work. The normal distribution of the parameters is chosen for the MC simulation. This distribution is chosen since STAN software uses Gaussian error propagation, which is built on the assumption of normal distribution (Van Eygen et al. 2017). Be aware that for a set of parameters from the literature, one standard deviation from the mean are impossible values either exceeding 100% or going below zero. All parameters with their mean and uncertainty are listed in Appendix 6.

After the Monte Carlo simulation with 10,000 iterations, the provided new means and standard deviations are fed to STAN software. For flows determined by mass balance, the mean is set to zero and the uncertainty 1000 times the highest uncertainty, in this way the flows are calculated with mass balance by the software. For instance the stock change of the fishing gear in fishery is calculated directly from mass balance equations in STAN. STAN software calculates the variables and unknowns, and the outcome is visualized through a MFA system illustration. The illustration can be found in Figure15 in the results chapter 4.7.

An MFA is also performed for ropes. The system equations are altered in line with the understanding that ropes are not repaired, and the main difference from the fishing gear system is that the flow of worn equipment to end-of-life management is calculated with the mass balance of the fishery process. The uncertainty is simulated with 10,000 iterations. The resulting MFA on ropes for 2020 is represented with a STAN illustration, Figure 16, in section 4.8.

4 Results and analysis

The results are divided into nine subsections. A summary introduction of the results and how they answer the problem description in 1.1 are presented in the following paragraphs. Since data collection is a large part of MFA, the results include subsections explaining the data and results of the different parts of the MFA system i.e parameters and different flows such as retrieval. The resulting MFA for 2020 for the 6 main gears with uncertainty is in Figure 15 in subsection 4.7. It is produced a separate MFA for ropes, as they are seldom repaired and hence this process is excluded, the MFA of ropes with uncertainty in 2020 is in Figure16 in subsection 4.8. Total gear-specific MFA results for 2016, 2017, 2018, 2019 and 2020 including ropes can be found in Appendix E and the MFA results are summarized in F.

Quantities of the plastic polymers are available in a substance level of the three main types of plastic, PA, PE and PP, by multiplying the obtained material composition of sold gear, in Table 12 with the assumption of equal material composition throughout the system, to the gear specific material flows found in Appendix E.

The problem description includes evolving current models with a dynamic approach. The feasibility of performing a dynamic stock model/dynamic material flow analysis was studied and the available data and resources were deemed insufficient to produce this type of model. The results are five subsequent static MFA and back- and forecasting plastic losses from 2000 to 2021 using the novel measure of gear-specific plastic loss per tonne catch. This measure can be used in the future together with the yearly gear-specific catch data to estimate gear losses to the ocean. In this way, the thesis answers the requested dynamic aspect.

4.1 Literature review

Table 3 lists the most important sources and is the result of the literature review. The relevant literature is cited throughout the text or used for system understanding.

Topic	**Purchase**	**Use**	**End of Life**	**Retrieval**	**Policy and regulation**
Literature	Company reports	Deshpande, Philis et al. 2020	Deshpande, Philis et al. 2020	Deshpande, Philis et al. 2020	European Union 2018
	Sundt et al. 2018	Sundt et al. 2018	Sundt et al. 2018	Havas et al. 2022	European Union 2019b
			Deshpande, Brattebø et al. 2019	Vilma Havas and Johnsen 2017	fiskeridepartementet 2021
				Johnsen, Havas et al. 2018	Klima- og miljødepartementet 2021
				Johnsen, Drægni et al. 2019	O. Commission et al. 2010
				Johnsen, E. R. Johannessen et al. 2020	European Union 2019a
				E. R. Johannessen and Johnsen 2022	Standard Norge 2020
				Fiskeridirektoratet 2022	
				Haarr et al. 2022	
				Falk-Andersson 2021	

Table 3: Summary of sources for literature review.

4.2 Supplied fishing gear

Earlier tools for fishing were created in Norway, now almost all gear is imported. There are many companies that import gear, many are small scale, and some are the main players. Around 7-8 companies are considered to be the main suppliers. The suppliers commonly each specialize in distinct types of gear. Figure 5 shows the process of obtaining the results for supplied fishing gear. The same producers contacted in 2016 by Sundt et al. 2018 along with four industry partners of Dsolve and one producer found online were approached to obtain sales data. In total 11 suppliers of fishing gear to the Norwegian commercial fishing industry were contacted. The suppliers were contacted by mail, then with a proposed digital meeting to discuss and clarify the relevant information, and a telephone number to contact if the suppliers had questions, following with remainder emails.

Data about sales and estimated market share from 3 suppliers were obtained. The received data from suppliers are aggregated and multiplied up with the corresponding estimated market share, as presented in equation 1. The data collected both show similarities and differences from Deshpande, Philis et al. 2020, this is likely due to data from other and fewer suppliers and the estimations of market share. Despite attempts to increase the accuracy of data by reaching out to 11 producers, the level of confidence remains.

Obtaining data with a high level of confidence from several suppliers across the different gear types has been a challenge. Among the reasons are that the requested data might not be available for the suppliers themselves, it takes time and effort to subtract the data from their statistics, they might not have insight over the market and their market share, additionally due to competition there are precautions for sharing sales data.

One instance of data incoherence was that the calculated total market of traps and pots is 10 times lower than the figures in Deshpande, Philis et al. 2020. From consulting with an expert at the Directorate of Fisheries there is no likely reason for a drop in sales and use of traps and pots compared to 2016. Contrarily, the sold volume is likely slightly increased over the years as fishing for crayfish and common crab has increased and it has increased slightly for snow-crab (Personal correspondence with an expert at the Directorate of Fisheries, 2022). Therefore, the amount of traps and pots purchased in 2016 in Deshpande, Philis et al. 2020 is used as a proxy and scaled with the biomass caught by traps and pots in 2016 to the biomass caught in 2020.

That the data obtained from suppliers from the act of reaching out varies from 20 tons to 212 tons illustrates the challenge of obtaining reliable and accurate data. This is the main challenge in the work of MFA and the data bears high uncertainty. It is important to keep in mind the uncertainty when analyzing the results and drawing conclusions and recommendations.

$$A_{01} = \sum \text{Sold fishing gear by major suppliers (kg)/Their estimated market share} \quad (1)$$

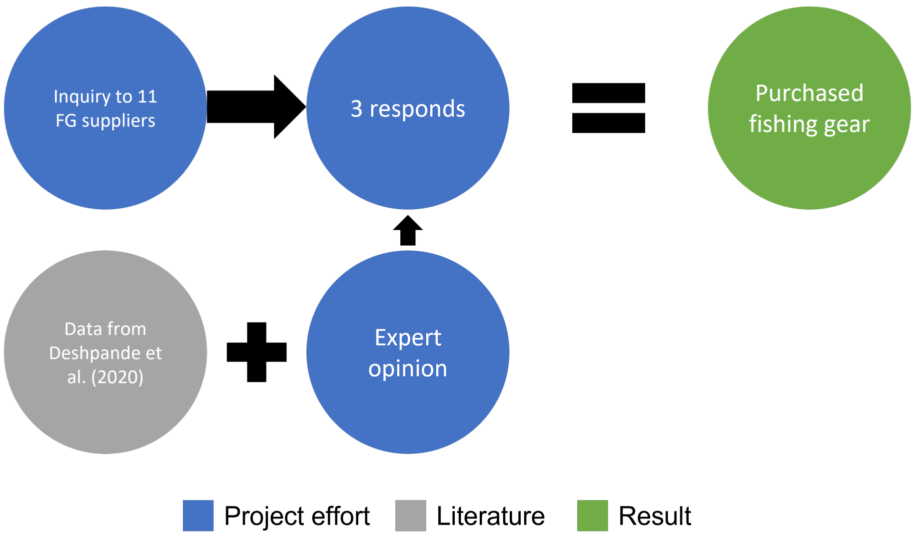

Figure 5: Process for obtaining the purchased gear flow

The amounts of purchased fishing gear in 2020 are shown in Figure 15, and the amounts of ropes are found in Figure 16. More details can be found in Appendix E which includes gear-specific amounts for each flow in the MFA from 2016 to 2020.

4.3 Fishing activity

Fishing companies hold knowledge about patterns of use of gear, repair and maintenance, loss of gear and depositing derelict gear. Patterns regarding fishing activity are found in literature at Deshpande, Philis et al. 2020. The data were found through face-to-face and telephone surveys of 114 fishing companies along the Norwegian coast (Deshpande, Brattebø et al. 2019). Additionally, for this work, the patterns are confirmed by interviewing two fishing companies within the Dsolve network. The process of obtaining the results are in Figure 6.

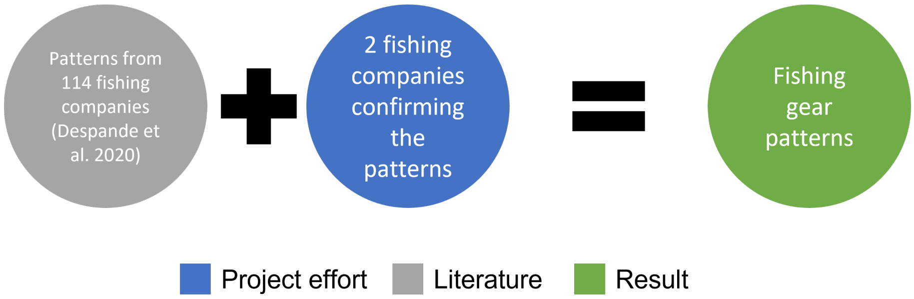

Figure 6: Process for obtaining the fishing gear patterns of fishers

47% of the respondents belong to the coastal fleet and the other 53% belong to the more advanced and high volume fishery of the ocean going fleet (Deshpande, Philis et al. 2020). Table 4 displays the annual patterns of the fishing fleet.

Fishing gear	**Repaired**	**Replaced part**	**Lost**	**Disposed**	**Turnover** (C_{stock})
Trawls	80,7 %	18,9 %	3,1 %	25,1 %	4,43
Purse seine	53,3 %	11,7 %	0,4 %	7,30 %	16,28
Danish seine	29,9 %	14,6 %	1,8 %	11,4 %	9,27
Gillnets	24,0 %	18,7 %	1,0 %	33,1 %	2,74
Longlines	36,8 %	22,4 %	4,4 %	30,8 %	3,12
Traps/pots	24,9 %	13,8 %	4,1 %	16,9 %	5,24
Ropes	0,00 %	0,00 %	2,76 %	18,8 %	7,59

Table 4: Table of transfer coefficients for fishing gear repair, replace, loss, dispose and use patterns

4.4 Retrieved fishing gear

There are numerous efforts of removing derelict fishing gear from both land and ocean. Among the main actors is the Directorate of Fisheries which since the beginning of the 1980s has removed over 1000 tonnes of fishing gear from the ocean(MARFO Senter mot marin forsøpling 2022). Fishing For Litter (FFL) is an initiative by SALT and sponsored by the environmental department and Handelens Miljøfond (HMF). It started up in 2015 and has been collecting litter since 2016. Participating vessels in FFL can deliver the fishing gear they catch from the ocean while fishing for free to participating harbors. Hold Norge Rent is an organization for organizing clean-up operations throughout the country. Ryddenorge.no is an online platform where volunteers can log their findings both in terms of units and total mass, length, and area. This tool is used by many separate groups that clean along the shoreline such as In The Same Boat, Runde Miljøsenter, Lofoten Avfallsselskap, groups organized through Hold Norge Rent or individuals.

For the retrieval flow, the data sources are statistics from ryddenorge.no and the directorate of fisheries, together with extracted numbers from yearly reports by Fishing For Litter. This is added with expert opinion for factors converting unit-based statistics to mass-based. Figure 7 displays the process for finding the retrieved fishing gear flows. The following sub-chapters will explain in-depth how the mass of plastic in collected fishing gear was calculated for each main retriever.

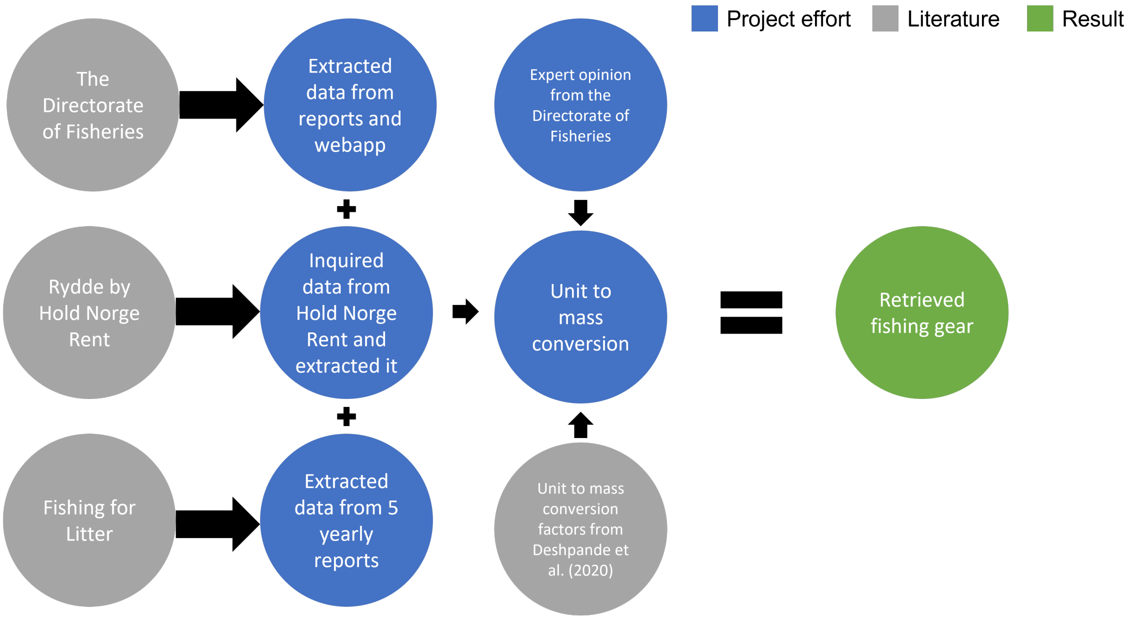

Figure 7: Process for obtaining the retrieval flow

The main takeaway from the retrieval flows of 2020 are summarized in Table 5, where the quantities of plastics are listed in tonnes for each separate retrieval flow and each of the 6 main fishing gear types. In total 133.88 tonnes were retrieved in 2020. The main collected fishing gear are traps with 40% of the mass, next are gillnets with 27% and trawls with 25%. The other types of gear each account for 5% or less of the total collected plastics.

Organization	Location	Trawls	Purse Seine	Danish seine	Gillnets	Longlines	Traps and Pots	Total
Rydde	Land	0,95	0,95	0,95	5,82	0,00	4,42	13,09
FFL	Ocean	32,17	6,03	0,00	21,11	0,00	19,10	78,41
Directorate of Fisheries	Ocean	0,03	0,30	0,00	9,58	3,10	29,37	42,38
Total	Retrieved	33,15	7,28	0,95	36,51	3,10	52,89	133,88

Table 5: Retrieved fishing gear in mass of plastic (tonnes)

4.4.1 Fishing For Litter

This sub-chapter will explain how the amounts of gear collected by Fishing For Litter were assessed. The project leader for the years 2017 to 2021 handed over the initiative's yearly reports containing statistics. In the yearly reports, the fishery-related waste is reported along with material composition and a detailed description of found fishing gear from performing deep dives for evaluating a part of the collected waste. For clean-ups it is important to notice that the quantities found and reported are not solely plastics, they can contain other materials such as metals, rubber, and glass. The total fishery-related waste is multiplied by the calculated plastic share and stated fishing gear shares found by analyses of the waste. The calculation of the flow is shown in equation 2.

$$A_{34c} = \sum \text{FFL fishery rel. waste}\,(kg) \cdot \text{Share of plastics} \cdot \text{Share of resp. FG} \tag{2}$$

Table 6 contains the material composition and plastic content of collected litter. The plastic content is used for calculating the mass of plastic from the total fishery-related waste. Non-fishing gear materials are excluded from the original material compositions found in yearly reports, and the values are normalized. The excluded materials are are non-marine waste, glass/ceramics, textile, expanded polystyrene and others.

Year	Plastic (ropes)	Plastic (soft)	Plastic (hard)	Metal	Rubber	Plastics	Other
2018	60 %	3 %	6 %	9 %	22 %	69 %	31 %
2019	69 %	2 %	8 %	5 %	16 %	78 %	22 %
2020	86 %	0 %	3 %	7 %	3 %	90 %	10 %
2021	68 %	0 %	2 %	21 %	9 %	70 %	30 %

Table 6: Material composition of fishing gear collected by Fishing For Litter

The calculation results in the total mass of caught plastic in fishing gear from the initiative. A total of 87 tonnes worth of plastic in fishing gear were collected by Fishing For Litter in 2020. The resulting mass of plastic from 2018 to 2020 divided into the fishing gear types is shown in Figure 8.

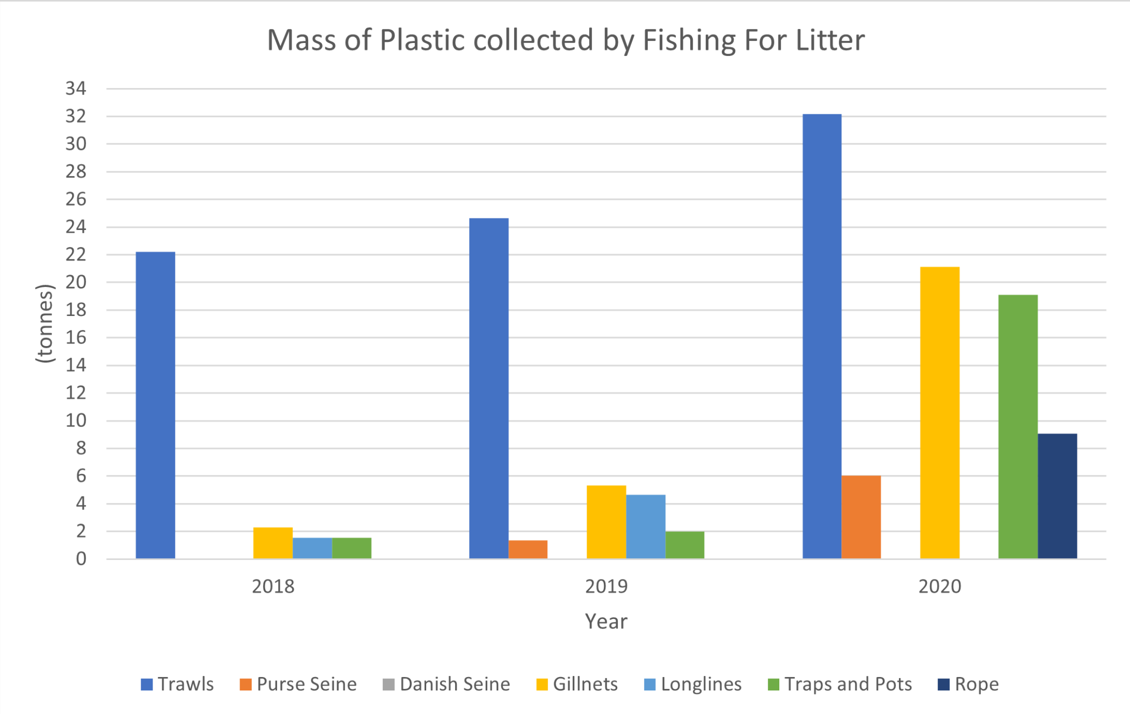

Figure 8: Quantum collected by FFL 2018-2020

Source: Johnsen, Havas et al. 2018, Johnsen, Drægni et al. 2019, Johnsen, E. R. Johannessen et al. 2020

Contrary to the directorate of fisheries clean-up, trawls are a significant part of the total collected mass. Similarly gillnets and traps and pots are on the top of collected plastic mass.

FFL did not report on material composition nor fishing gear shares in the first two years and in 2021. From 2018 material and waste composition are found by analyzing shares of the collected waste, called deep dives. Average plastic share and gear composition from 2018 to 2020 have been applied to total caught fishery-related mass of years 2016, 2017 and 2021, the years without detailed waste composition. The total estimated collected plastic in fishing gear from 2016 to 2021 is presented in Figure 9

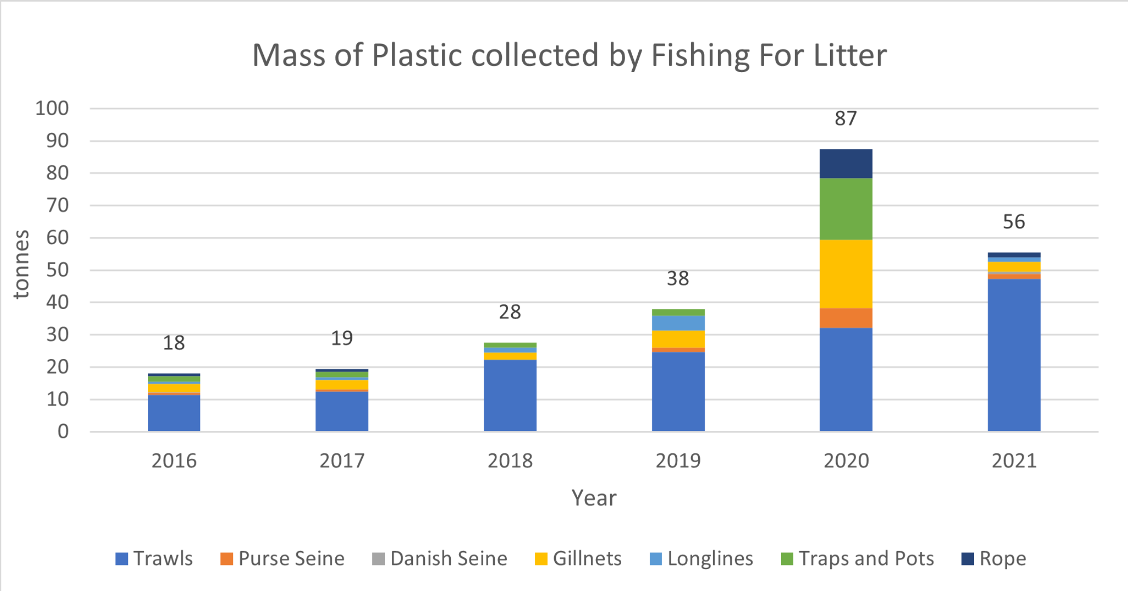

Figure 9: Mass of Plastic in Fishing Gear quantum collected by FFL 2016-2021

Source: Vilma Havas and Johnsen 2017, Johnsen, Havas et al. 2018, Johnsen, Drægni et al. 2019, Johnsen, E. R. Johannessen et al. 2020, E. R. Johannessen and Johnsen 2022

Figure 10 summarizes Fishing For Litter's total quantities of collected litter, divided into fishery-related and other waste. The initiative has proven increased amounts of caught fishery-related and other waste over the years of operation.

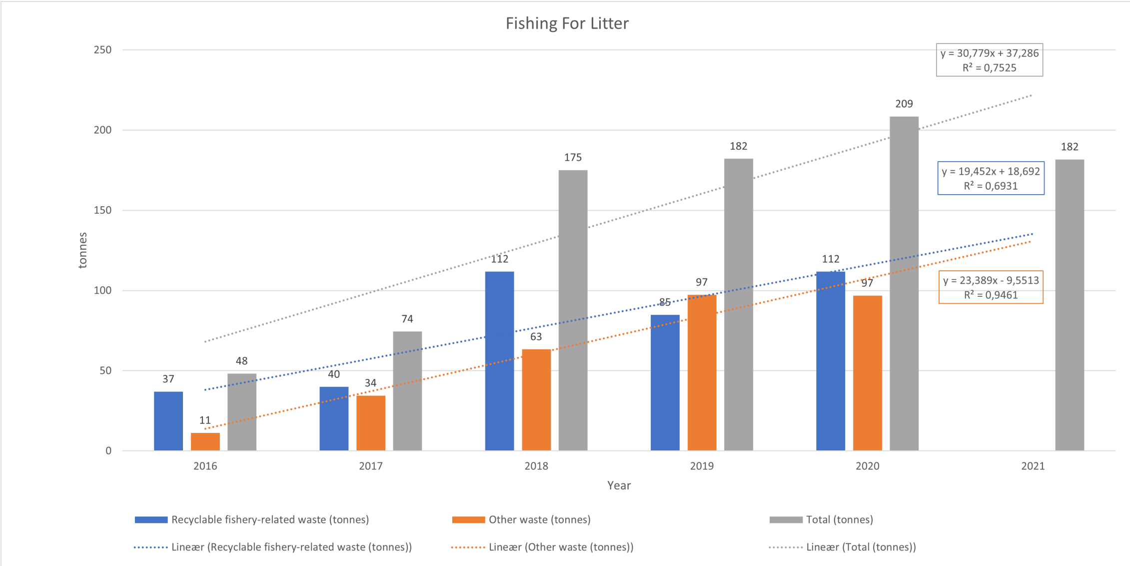

Figure 10: Quantum collected by FFL 2016-2021

Source: Vilma Havas and Johnsen 2017, Johnsen, Havas et al. 2018, Johnsen, Drægni et al. 2019, Johnsen, E. R. Johannessen et al. 2020, E. R. Johannessen and Johnsen 2022

The Figure include linear trendlines with their R^2 value and formula. Regarding the category of other waste, it follows a linear evolution with a R^2 value of 0.9461. On the other hand, the total collected amount for 2021 is not similar to the linear approximation. Recyclable fishery-related waste follows a less steep linear increase trend, than other waste. The overall increase in collected waste does not translate to the fact that there is more waste to be collected from the ocean. During the years of operations for FFL, the number of participating harbors and fishing vessels has increased. Thereby, it is anticipated that the amounts retrieved from the ocean will increase. Over time as the vessels dredge through the ocean floor it is anticipated that yearly collected amounts will drop, as the stock of the ocean is diminished.

4.4.2 The Directorate of Fisheries

Data sources for the flow of retrieved gear by the department of fishery are yearly reports on clean-ups of lost gear found by searching for "opprydning" or "opprenskning" in the department's digital archives and the web tool showing lost and found gear with locations for the years 2017 to 2021 (Fiskeridirektoratets digitalarkiv) (Fiskeridirektoratet 2022). The statistics of retrieved gear are in units of gear or meters, and the statistics are converted to mass-based by multiplying with mass ranges from Table S6 in Supplementary Info to Deshpande, Philis et al. 2020. For mass conversion factors not listed in the literature, expert opinion on conversion factors of 1-5 kg plastic/ 1 m trawl and seine from a representative of the department of fisheries are employed (Personal communication with an expert at the Directorate of Fisheries, 2022). The calculation of the retrieved mass of plastic in fishing gear by the directorate of fisheries follows equation 3.

$$A_{34b} = \sum \text{Collected FG by F.Dir}\,(unit) \cdot \text{MoP in FG from F.Dir}\left(\frac{kg}{unit}\right) \tag{3}$$

Gillnets, traps and pots, and ropes account for the main share of retrieved mass of plastic by the Directorate of Fisheries. A part of the retrieved gear is reunited with its owners to be reused, but as a simplification the flow of retrieved gear is solely directed to the end-of-life process in the model. In 2020 the clean- up activity subtracted 87 tonnes of mass of plastic from the ocean. Figure 11 shows the mass of plastic of fishing gear types collected by the Directorate of Fisheries from 2016 to 2021.

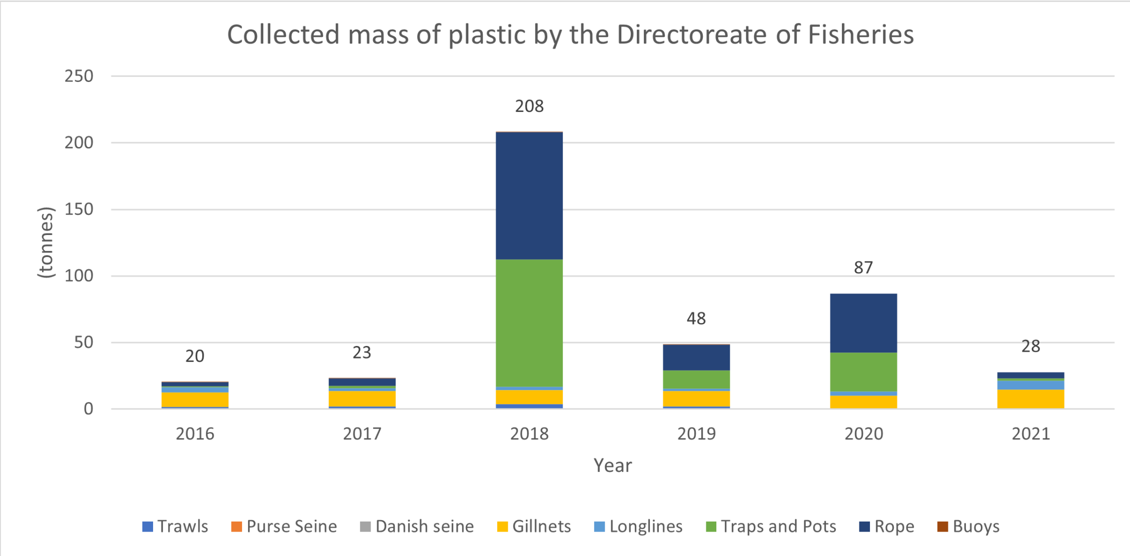

Figure 11: Collected mass of plastic by the Directorate of Fisheries

Source: Data and expert opinion from The Directorate of Fisheries and mass conversion factors from SI to Deshpande, Philis et al. 2020

4.4.3 Ryddenorge.no (from Hold Norge Rent —Keep Norway Beautiful)

Statistics on numerous clean-up operations are received from contacting Hold Norge Rent. They have statistics reported in a tool called Rydde at ryddenorge.no where volunteers can log their collected litter in a set of categories, including total mass and length of cleaned shoreline or area. The Rydde statistics includes operations not only performed via Hold Norge Rent but also other organized collectors such as Runde Miljøsenter, clean-ups by Lofoten Avfallsselskap and In The Same Boat.

$$Rydde = \text{Hold Norge Rent} + \text{Runde Miljøsenter} + \text{Lofoten Avfallsselskap} + \text{Clean-Up Lofoten} \\ + \text{In The Same Boat} + ...$$

The Rydde statistics are inserted by volunteers in the clean-up operations, therefore the data are not uniformly inserted and are in some cases crude estimates. Moreover, not all organizations register their findings specifically item by item. For instance, it is not the main priority for the initiative In The Same Boat. Most importantly for them is to register the location and time of cleaning, then the number of bags and weight, and lastly the different collected items can be specifically registered. According to their manual of clean-up operation number of items shall be left out if there is no total control over the number, as it can result in large discrepancies in the reports derived from the statistics (In The Same Boat 2020b).

Received data are from 2016 to 2021 with the categories; buoys and floaters, fishnet, ropes over 50 cm, ropes under 50 cm and traps. The data on units are summarized in Table 7.

Year	Fishnets	Traps and pots	Ropes over 50 cm	Ropes under 50 cm	Buoys and floaters
2016	10374	100	6367	23044	790
2017	1577	196	18663	147116	4079
2018	3428	1023	29986	1114803	12217
2019	7976	1531	41131	116912	19968
2020	4333	402	10679	44084	17143
2021	6567	1632	11589	35575	5325
Total	**34255**	**4884**	**118415**	**1481534**	**59522**

Table 7: Data from Rydde on collected fishing gear for the years 2016 to 2021

These statistics are unit-based and are transformed to mass quantity by multiplying with mass ranges in Table S5 in Supplementary Info (SI) to Deshpande, Philis et al. 2020).

Fishnet is directly translated from "fiskegarn" and includes multiple distinct types of fishing gear with netting as a component; gillnets, seines and trawls (Rydde 2021). Therefore, the number of collected fishnet is distributed evenly among trawls, purse seines, danish seines and gillnets.

The mass flow of retrieved gear reported in Rydde is calculated with equation 4.

$$A_{34a} = \sum \text{Collected FG at beach}\,(unit) \cdot \text{MoP in FG at beach}\left(\frac{kg}{unit}\right) \tag{4}$$

In total for 2020 36 tonnes of plastic in fishing gear were removed by clean-up operations registered in Rydde. Figure 12 presents the mass of plastic from collected gear from the clean-ups. The data on retrieved buoys are not included in the MFA since they are not easily allocated to the chosen 6 main FG types, but the calculated mass of is presented in Figure 12.

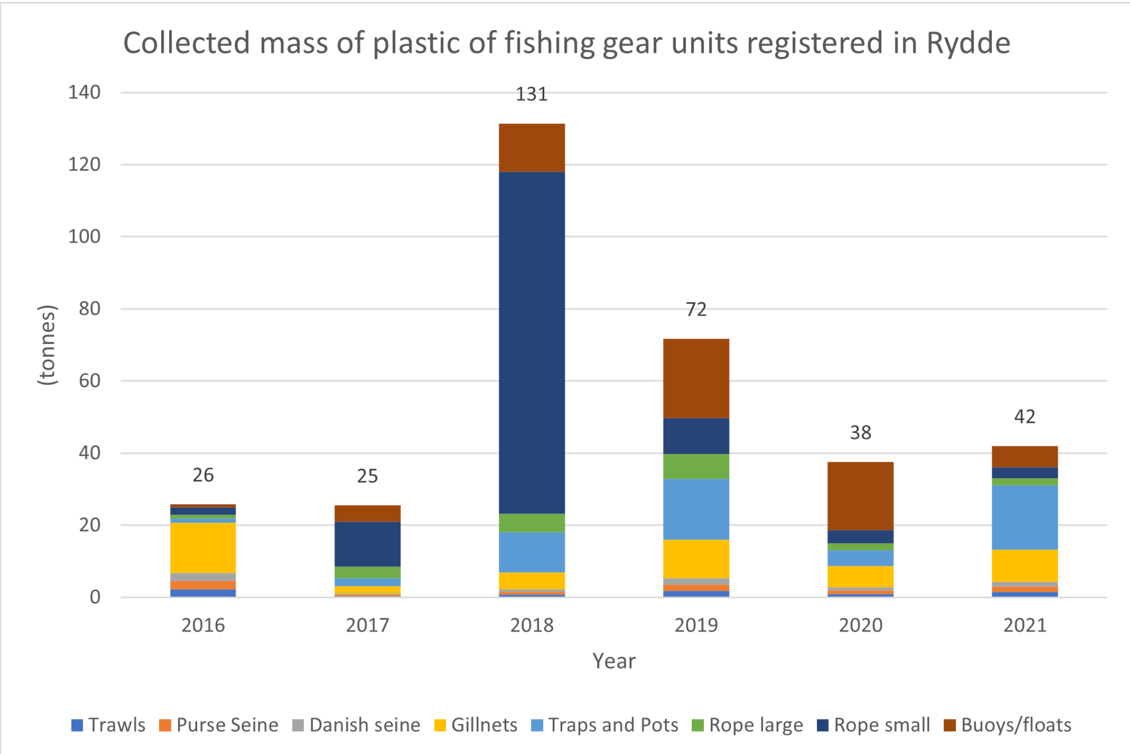

Figure 12: Collected mass of plastic of fishing gear units registered in Rydde

Source: Hold Norge Rent and mass conversion factors from SI to Deshpande, Philis et al. 2020

4.4.4 In The Same Boat

In The Same Boat (ITSB) is a shore clean-up operation initiative started in 2017. Together with Norges Miljøvernforbund they are the project owners of a cooperation called Levende hav. In Levende Hav report of 2019, they state that the whole coastline, consisting of 20,000 hotspots, can be cleaned over a period of 5 years, totaling 6,000-10,000 tons of beach litter, with the estimated cost of 125-150 million NOK (Levende Hav 2019). ITSB operate with sailboat and other boats reaching out to islands and off-site locations. In 8 weeks for a pilot project, they cleaned 50 tons of garbage from Helgeland. According to their calculations, they estimate that there are 100,000 trawl-bags, also called cod-ends along the Norwegian coast (In The Same Boat 2020a). From Rydde statistics, In The Same Boat has reported a total of 177,010 kg in 2020 and 8840 kg in 2021, however, there are no reports of any units of the 5 fishery-related categories. On the other hand, the lack of reporting does not imply that no fishing gear was collected. They report that more than 80% of their findings are from the fishing and aquaculture industry, and an estimated 50% are from Norwegian sources. Furthermore, from 2017 to 2019 they cleaned more than 350 tonnes of litter along the coastline from south to north. Therefore, their contribution is notable, and there is reason to believe that the amount of collected fishing gear is underestimated in the Rydde statistics.

4.5 End-of-life management

In Norway, there are numerous Waste Management Facilities (WMFs). Many of the companies are active in retrieval operations; for a beach clean-up week in 2018 over 300 receptions and 70 waste companies contributed (J. Johannessen 2018). Companies can work as pit-stops, being paid to store and then sell the waste for handling elsewhere, others handle the waste at the site with its recycling facility, incineration plants and landfill area. Other companies operate as a mix, "buying" the waste from the polluter, and both "sell" to recycling or manage waste on-site.

Knowledge from WMFs was collected by performing a survey at a waste conference. The questions asked were the total capacity of the WMF, percentage fishing-related waste of the capacity and its further handling, with three options: recycling, incineration and landfill. Additionally, the survey included questions about related challenges and possibilities to gather first hand knowledge from the people in the industry that easily can be overseen. The survey got 16 replies and of which 5 included data about quantities and percentages of waste handling methods. The link to the survey sent out with the conference presentations resulted in no more replies.

From personal communication with WMFs at Avfallskonferansen in Trondheim, the coastal WMFs report receiving derelict fishing gear, whereas WMFs inland report low to no fishing gear received (personal dialogue with WMF at Waste-conference).

WMF along the coast of fishing heavy areas were contacted by email with a questionnaire. It included specific questions about the quantum of waste from the fishing industry over the last few years and shares going to the three aforementioned handling options. It is added as Appendix C. Out of 16 contacted 4 responded, of which 2 stated specific amounts of fishery-related waste and one gave an interview.

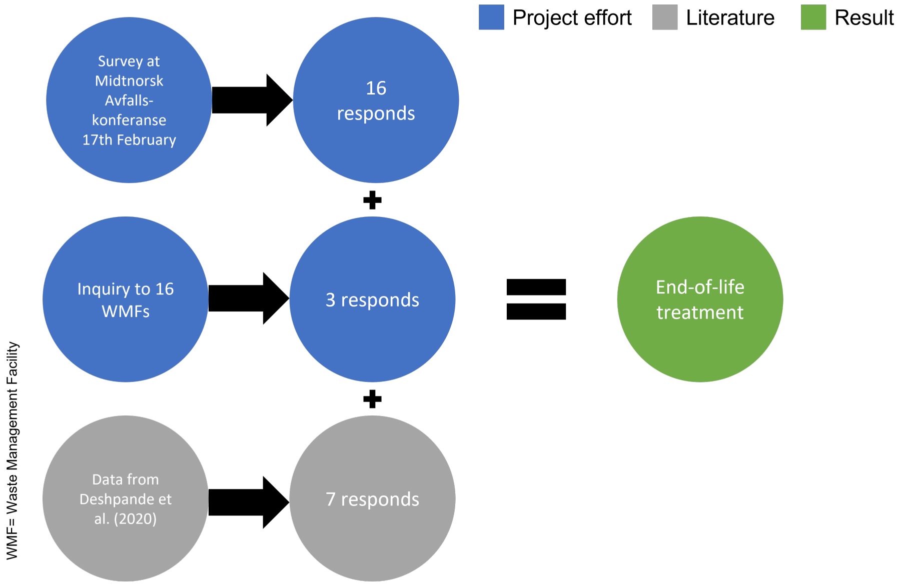

Figure 13: Process for obtaining the patterns of end-of-life management

Figure 13 illustrates the process of acquiring the end-of-life treatment of derelict fishing gear. Responses from the survey and questionnaire were aggregated with literature on the resulting amounts of the different treatments at end-of-life, recycling, incineration and landfill. Figure 14 displays the result for 2020, with 45% of the total fishery-related waste sent for recycling, 48% sent for incineration and 7% deposited at landfills. An earlier study found that in 2016 55% were sent for recycling, 24% were sent to landfills and 24% were incinerated (Deshpande, Philis et al. 2020). For the years between 2016 and 2020, linear interpolation is used for the shares of treatment options. About 4200 tonnes of derelict fishing gear were sent for end-of-life management in 2020.

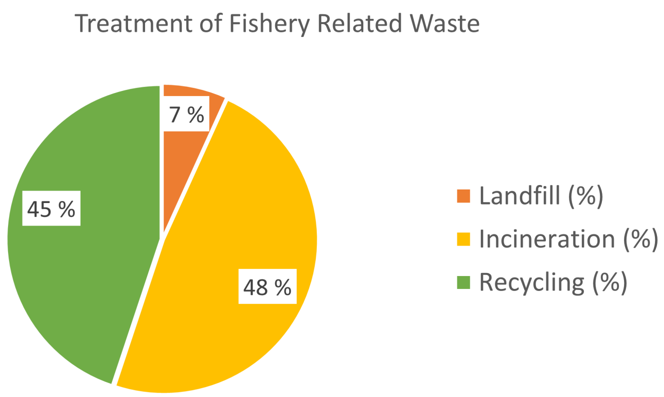

Figure 14: Weighted Average: Treatment of fishery-related waste

Source: Data from survey of WMF

4.6 MFA system

In the MFA system of the Norwegian commercial fishery, there are 7 processes and 16 variables. This is assuming no stock and no stock change in process 2 repair and maintenance, 4 end-of-life. The 16 variables each have 6 sub-variables, one for each main fishing gear type, and they all follow the main variable equations. Excluding the 3 processes of waste management there are 4 remaining main processes for performing mass balance. The equations are listed below, and with a detailed description in Appendix F. The equations include parameters and constants, and they are listed with their value and standard deviation in Appendix 6.

$$A_{01} = \sum \text{plastics in purchased FG} \tag{5}$$

$$A_{12} = \sum C_{repair} \cdot (A_{01} + A_{01} \cdot C_{stock}) \tag{6}$$

$$A_{13} = \sum C_{lost} \cdot (A_{01} + A_{01} \cdot C_{stock}) \tag{7}$$

$$A_{14} = \sum C_{dispose} \cdot (A_{01} + A_{01} \cdot C_{stock}) \tag{8}$$

$$A_{21} = \dot{M}_1 - A_{01} + A_{12} + A_{13} + A_{14} \tag{9}$$

$$A_{02} = \sum C_{repair} \cdot C_{replace} \cdot (A_{01} + A_{01} \cdot C_{stock}) \tag{10}$$

$$A_{24} = A_{02} + A_{12} - A_{21} \tag{11}$$

$$A_{34a} = \sum \text{Collected FG at beach}\,(unit) \cdot \text{MoP in FG at beach}\left(\frac{kg}{unit}\right) \tag{12}$$

$$A_{34b} = \sum \text{Collected FG by F.Dir}\,(unit) \cdot \text{MoP in FG from F.Dir}\left(\frac{kg}{unit}\right) \tag{13}$$

$$A_{34c} = \sum \text{FFL fishery rel. waste}\,(kg) \cdot \text{Share of plastics} \cdot \text{Share of resp. FG} \tag{14}$$

$$A_{45} = \sum C_{incineration} \cdot (A_{24} + A_{14} + A_{34a} + A_{34b} + A_{34c}) \tag{15}$$

$$A_{46} = \sum C_{recycle} \cdot (A_{24} + A_{14} + A_{34a} + A_{34b} + A_{34c}) \tag{16}$$

$$A_{47} = \sum C_{landfill} \cdot (A_{24} + A_{14} + A_{34a} + A_{34b} + A_{34c}) \tag{17}$$

$$M_1 + \dot{M}_1 = C_{stock} \cdot A_{01} \tag{18}$$

$$\dot{M}_3 = A_{13} - A_{34a} - A_{34b} - A_{34c} \tag{19}$$

4.7 MFA results

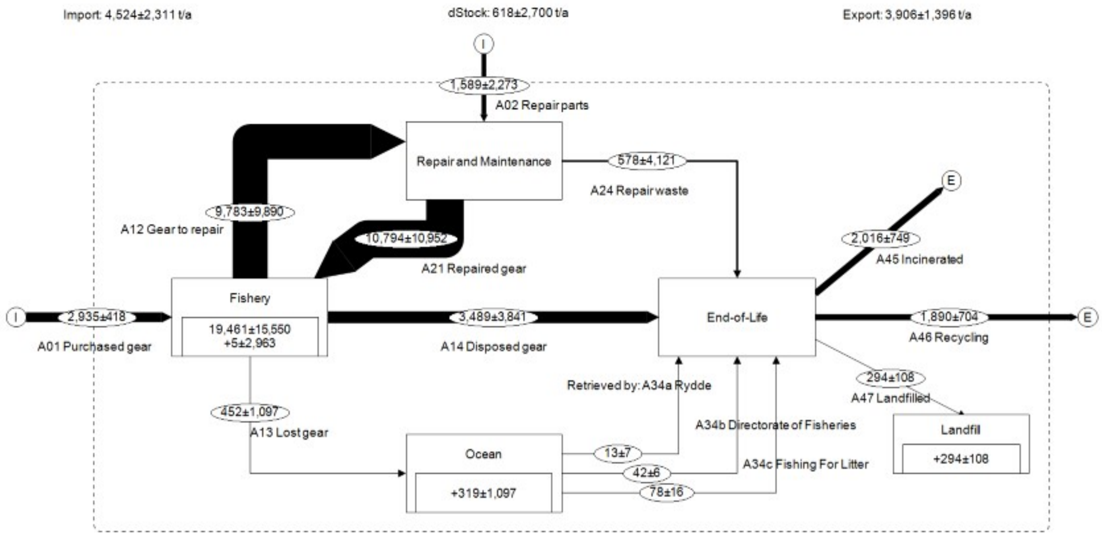

Figure 15: MFA on fishing gear in the Norwegian fishing sector in 2020

The MFA results with uncertainty for the mass of plastic in the form of fishing gear in the commercial fishing industry of Norway are in Figure 15. The numbers in the figure are the mean values of the system variables with calculated uncertainty as ± the standard deviation. In 2020, about 4600 tonnes of fishing gear were purchased in the commercial Norwegian fishing industry. 452 ± 1097 tonnes are expected lost to the marine environment, from which 133 ± 29 tonnes are retrieved (approximately 30%). Worn gear to waste management is around 4200 tonnes worth of plastic, where 2000 tonnes are incinerated, 1900 tonnes are sent for recycling and 300 tonnes are landfilled.

There is high uncertainty in the system, from error propagation of the uncertainty to model parameters and constants. 8 variables have a standard deviation larger than the mean, and negative values for these variables is not reflecting the real system of fishing gear flows. High uncertainty are not surprising as there exists a low quantity of available data with no coherently reporting throughout the fishery system.

4.7.1 Breaking the material flow into substance level of each plastic type

Material flow analysis can also be done on a substance level, for instance each plastic-type. If an MFA's flows are substances, it is commonly called substance flow analysis (SFA). To have the system's flow to be each substance is beneficial as it can be used as inventory for a Life-Cycle Analysis. This requires the material composition of gear throughout the system, yet this data is nonexistent. However, the material composition of purchased gear is requested and received. By assuming that the gear composition stays the same throughout the system a simplified substance layer can be produced. Table 11 in Appendix G lists the material composition of the sold fishing gear in 2020.

Since the project targets the mass of plastics the material composition is normalized to the total plastic quantity of sold gear. This produces the plastic(s) content of the flow and is presented in Table 12 in Appendix G. Out of the total purchased plastic in fishing gear most is PP with 37%, followed up by 29% are PE, 21% PA and 13% other plastics.

The plastic composition of the flow can be used to determine the substance layers of plastic types throughout the MFA system, if the assumption of equal material composition is used throughout the system. This is a simplification, as lost gear will have a different material composition than purchased gear as parts of the gear are more frequently lost than others. PE and PP have floating properties as they have lower density than seawater at approximately 1.027 g per cubic centimeter, while PA has sinking properties (Kershaw and Rochman 2015). Therefore, since different plastic types have different properties, gear retrieved at beaches will likely have a different material composition than gear retrieved from the ocean and the lost gear itself.

With the assumption of equal material composition of owned and lost fishing gear as for the sold, then the lost substances to the ocean will be 75 tonnes of PA, 139 tonnes PP, 173 tonnes PE, and 63 tonnes of other plastics. The beak down of lost plastic types is listed in Table 8.

Lost fishing gear (tonnes)	**Polyamide Nylon (PA)**	**Polypropylene (PP)**	**Polyethylene (PE)**	**Other plastics**	**Total plastics**
Trawls	6	10	97	18	130
Purse Seines	17	0	2	0	19
Danish Seines	9	111	42	0	162
Gillnets	14	1	0	0	15
Lines	5	18	9	45	77
Traps and Pots	24	0	24	0	48
Total	75	139	173	63	451

Table 8: Plastic quantities of the lost gear in 2020.

Subtracting the retrieved mass of plastic results in the plastic specific stock change in the ocean. After clean-ups, it remains 317 tonnes of plastic, of which 6 tonnes are PA, 134 tonnes PP, 120 tonnes PE, and 57 tonnes of other plastics. An interesting discovery is that for gillnets and traps and pots the remaining gear in the ocean is negative. This can mean that the clean-up operations subtract more gillnets and traps and pots than the fishers lose, thereby removing from the stock of ALDFG gillnets and ALDFG traps and pots. On the other hand, estimates on lost gear and conversion factors from retrieved units to mass are uncertain, and retrieved gillnets can originate from recreational and foreign fishers.

4.8 MFA on ropes

Ropes are widely used in marine application.As requested by the problem description ropes in the fishing sector are quantified. Ropes are presented as a separate MFA, as the distinction eases the interpretation of the ghost-fishing potential of fishing gear and micro- and macro-plastic impact from ropes. No MFA on ropes in Norwegian fisheries has been performed earlier, therefore there are no known values and parameters on the fishers patterns in the use of ropes in the literature. For this work supplier data on the sold amounts of ropes are acquired, and retrieved portions are derived from reports and statistics. An average of the parameters for the six main fishing gear types are utilized as a proxy for ropes, as ropes are commonly used together with the fishing gear. Since ropes seldom are repaired the process of repair and maintenance are left out for the MFA on ropes. Therefore, the equations for the MFA are different and A14, the flow of worn ropes for waste management, are changed to be solved by mass balance. Uncertainty is calculated for the MFA on ropes and presented together with the average values in Figure 16.

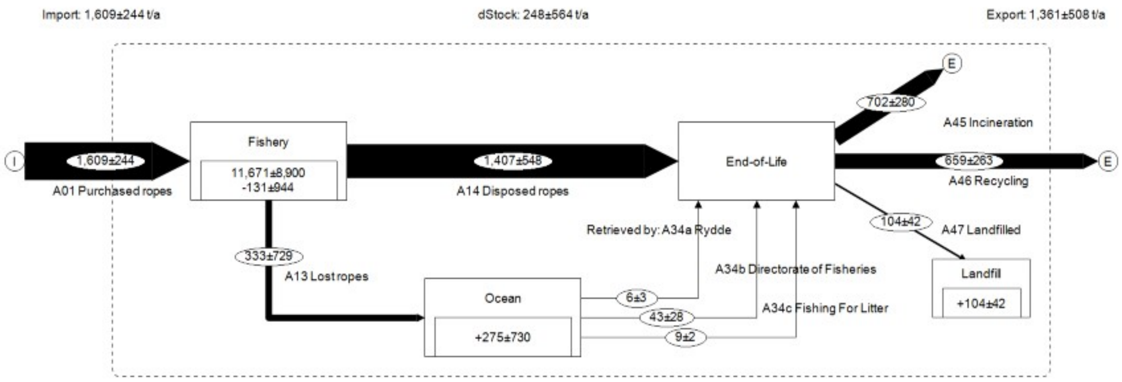

Figure 16: MFA on ropes in the Norwegian fishing sector in 2020

About 1600 tonnes of ropes were purchased in the Norwegian fishing sector in 2020, and 333 tonnes were lost. From retrieval operations, 58 tonnes are retrieved leaving 275 tonnes in the marine environment. For waste management of ropes, the handling is different from other fishing gear, this is learned from interviewing a waste management company and going through their delivery reports on quantities sent and approved for recycling. In general, ropes are one of the equipment most often recycled, therefore the amount going to recycling are likely higher than the 45% for fishing gear in general. Ropes are not commonly incinerated as they can get stuck in the loading for the furnaces and in the incineration plant. Therefore, if not recycled ropes are likely landfilled.

4.9 Dynamic approach finding gear patterns with catch quantum data

Yearly statistics of what kind of gear caught the quantum of fish can be a metric for understanding the dynamism of the mass of plastics in fisheries. The Directorate of Fisheries has statistics on caught fish/marine species in terms of gear used for both Norwegian and Foreign vessels from 2000 to 2021 (The Directorate of Fisheries 2021). The statistics on caught weight by tool use are divided into four main categories, namely trawls ("trål"), seines ("not"), conventional gear ("konvensjonelle") and other ("annet"). Conventional gear includes gear such as gillnets, longlines and traps and pots. Moreover, the statistics are divided into subcategories of fishing gear, for instance, different trawl types.

To compare the caught biomass to the mass of plastics, either used or lost the data are divided into the six main categories; Trawls, Purse Seines, Danish Seine, Gillnets, Longlines and Traps and pots. The subcategories were split into the selected 6 main categories as presented in Table 9. Seaweed-trawls are reassigned to trawls from the "other category", and the rest of the gear from the other category and unspecified seines are not included within the 6 main categories. This division of sub-types into 6 main types is verified by expert opinion from the Directorate of Fisheries. The chosen divisions of subcategories are listed in Table 9.

Trawl	**Purse Seine**	**Danish Seine**	**Gillnets**	**Longlines**	**Traps/Pots**
Bunntrål	Snurpenot/ringnot	Snurrevad	Settegarn	Autoline	Teiner
Bunntrål par	Snurpenot med lys		Drivgarn	Flyteline	Havteiner
Dobbeltrål	Udefinert not		Udefinert garn	Dorg/harp/snik	Ruser
Flytetrål				Juksa/pilk	Udefinert bur og ruser
Flytetrål par				Andre liner	
Krepsetrål				Udefinert krokredskap	
Reketrål					
Taretrål					
Trippeltrål					
Udefinert trål					

Table 9: Division of subcategories into the six main fishing gear types

The result is the gear used by weight of catch split into the 6 main categories shown for Norwegian catch in Figure 17. The share of fishing gear used for total Norwegian catch is further used for scaling the mass flows of plastic in the 6 different gear types to the years 2000 and 2021. Detailed results are in the Appendix H as Table 14 for the catch per gear type and the share of the catch in Table 15.

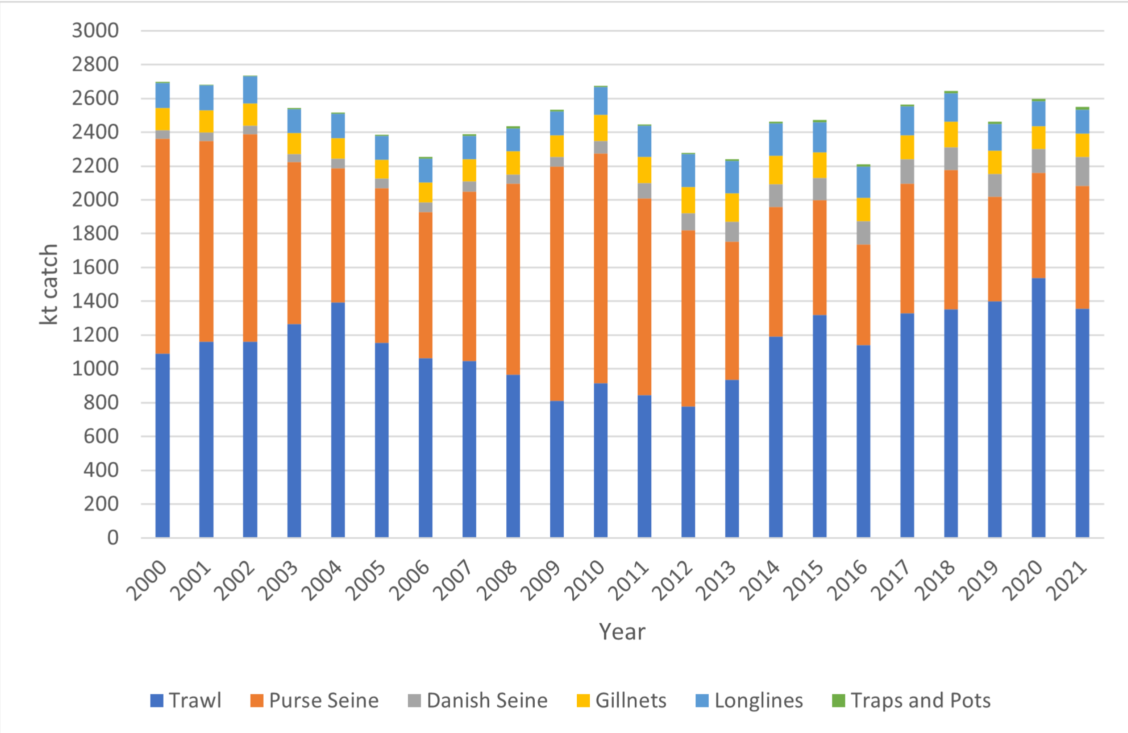

Figure 17: Gear Used for Mass of Fish Collected by Year

Source: Directorate of Fisheries

Gear use and the corresponding catch combined with static MFA values on fishing gear mass of plastic are used to estimate gear losses and gear utilization for the years of data 2000 to 2021. The assumption of correlation between biomass and gear type usage to the mass of plastics of fishing gear has been cross-checked with an expert from the Directorate of Fisheries. Table 10 contains factors of the catch compared to the owned mass of fishing gear. For each owned tonne of fishing gear, the output is 449 tonnes for trawls, hence they are a gear-effective method of fishing. Contrarily, more conventional gear such as gillnets, longlines, traps and pots have less catch per gear use. Traps and pots have the lowest catch per gear used and the highest loss of plastic per catch.

Year 2020 Gear type	**Owned** (tonnes)	**Lost** (tonnes)	**Catch** (tonnes)	**Catch/owned FG** (tonnes/tonnes)	**Lost FG per catch** (kg plastic/ tonne catch)
Trawls	3426	130	1539081	449	0,0846
Purse seine	4477	19,0	620023	138	0,0307
Danish seine	8111	162	142084	17,5	1,14
Gillnets	1096	15,0	134902	123	0,111
Longlines	1326	77,0	147002	111	0,524
Traps/pots	977	47,7	13031	13,3	3,66
In Total	19413	451	2596123	134	0,174

Table 10: Gear-specific metrics in 2020 on catch effectiveness of gear and loss rates per unit of catch.

Total losses are backcasted and forecasted using the loss rates per gear-wise catch of the years 2000 to 2021. For the loss rates, the mean of the losses per catch for the years 2016 to 2020 is used. The mean loss rates are presented in Figure 18.

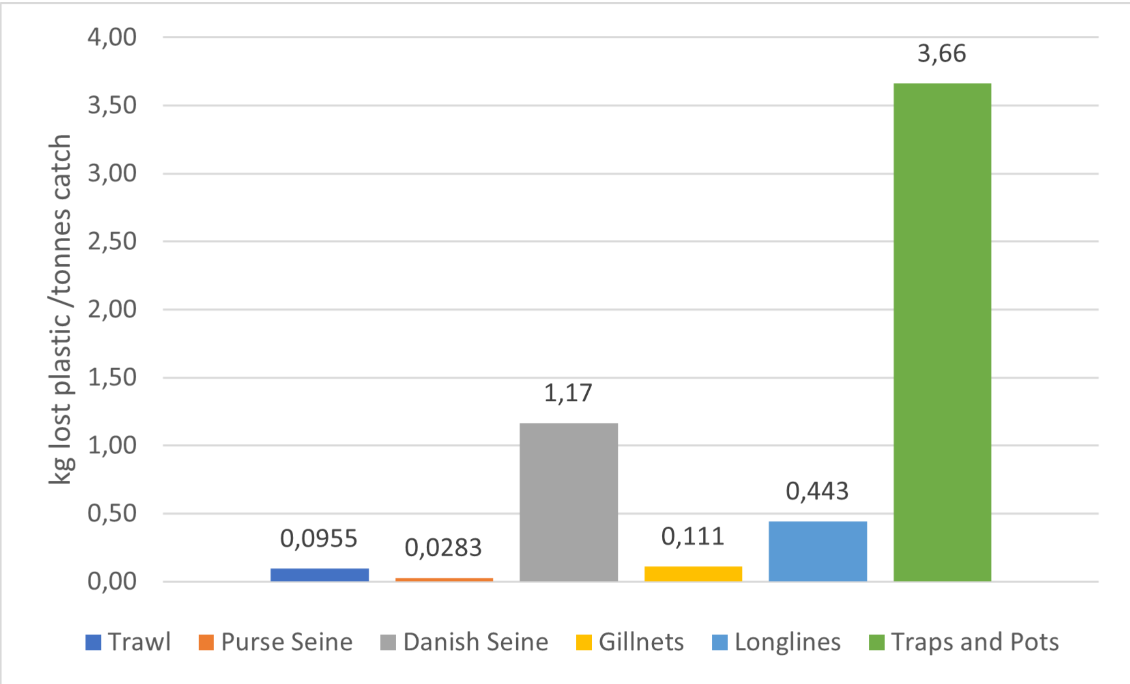

Figure 18: Gear lost per one unit for mass of fish collected

Combining the loss rates and the gear-specific catch data over the years 2000 to 2021 the losses are backcasted for before 2016 and forecasted for 2021. The losses divided into gear types are shown in Figure 19.

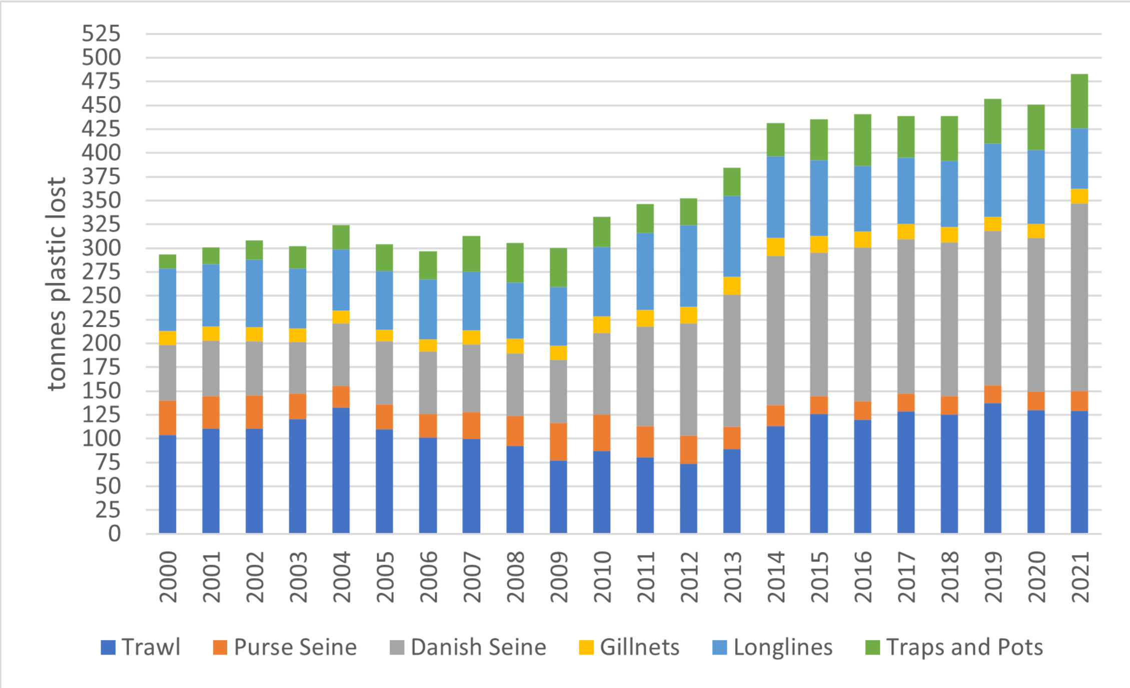

Figure 19: Calculated lost gear by specific biomass and gear type data

From 2000 to 2021 it is estimated that 8000 tonnes of plastic fishing gear have been lost from the commercial fishing sector in Norway. The retrieved amount for the same period is unknown.

5 Discussion

5.1 MFA modeling

It is important to state that the values of this MFA system does not equal the reality, although based on real data. The assumptions and estimations are needed for the modeling and with it comes uncertainty. However, a model can be of value to interpret possible outcomes and variations and can be a guide for policy making (Allesch and Brunner 2015). It is not reality but can aid making real changes. It is not necessarily the values that are of highest importance, but to understand the interactions between different processes and their flows and stocks. As modeling is a way we can calculate and make sense of a system in the real world.

There is high uncertainty in a system with 8 variables having a standard deviation larger than the mean. This is a symptom of the challenge of modeling. An other aspect is that reporting is not done in the same way throughout the system, units being mass, volume and in number of units. This is making it difficult to directly compare data and the way to a common unit gives extra uncertainty. In a MFA model it is common to use mass as the unit, hence the number of units and volume are converted to mass values. At some areas there are no records and assumptions have been made by experts in the field, which included uncertainty. High uncertainty is not surprising as there exists a low quantity of available data with no coherently reporting throughout the fishery industry. However this is the alternative we have at this moment, and can give us an indication and valuable insight in how to improve reporting, and calculations in future research.

The ocean and beach clean-up raw data are registered in units or meter and not mass. Going from units or meters to kg induces increased uncertainty in the data. However, it is needed for the sake of the mass based MFA. The Directorate of Fisheries reported collecting 100 tonnes in 2020 this includes non-plastic components such as metal. Compared to the results in this work with 87 tonnes of plastic including ropes, the mass conversion for the unit based data is rational (MARFO Senter mot marin forsøpling 2022).

Researches suggest that number of meters or number of units more accurately represent the potential danger of ghost fishing (Baeta et al. 2009). The Directorate of Fisheries have intentionally kept the registration units from the 80-ties as number of units and meters since it, in their opinion, reflects more accurately the collected gear and its potential danger. Their ultimate goal is not subtracting the mass of waste or the marine litter itself, but to reduce the potential marine "taxation", in other words reducing the harm to the marine life and ensuring viable stocks.

Since the amount of fishing gear present in the ocean globally is not available, it is challenging to project the total damage caused by derelict fishing gear. Gilman et al. 2021 relatively ranked the risk from the fishing gear types based on their rate of becoming ALDFG, fishing effort and catch, and impact both socioeconomic and ecological. Among the highest risk ALDFG, gillnets score highest, bottom trawling are in the top 5 out of 18 and line equipment such as longline are at lowest risk (Gilman et al. 2021). Gillnets a gear type linked to high levels of entanglement and by-catch of seabirds and marine mammals (ICES 2022). Gillnets are the second-most retrieved gear, with 9 tonnes collected by The Directorate of Fisheries, 21 tonnes from FFL and 6 tonnes from the Rydde register, seen in Table 5. This indicates that the retrieval efforts are reaching the harmful fishing gear. Traps and pots is the gear type that is most retrieved with 53 tonnes in 2020, and also the gear type with highest loss of plastic per tonne catch of 3.66 kg per tonne catch.

Ropes are a large part of the findings at clean-ups, calculated to a total of 58 tonnes in 2020, see Figure 16. At beach clean-ups from 2016 to 2021, 23 to 44 thousands ropes under 50 cm are reported retrieved in Rydde. May of these ropes are presumed cut-offs indicating that the gear are deliberately discarded, lost or a result of improper waste management on board the vessel. During maintenance rope cuttings are left on deck and can thereby easily be lost to the sea (Macfadyen et al. 2009). On the bright side Falk-Andersson 2021 found that attitude among fishers have improved, likely a result of engaging them in clean-up operations and dialogue.

5.2 Waste

There are no national waste statistics on the amount of plastic from fishing activity alone. From agriculture, forestry and fishing the total reported plastic waste in 2020 were 34 000 tonnes (Statistics Norway 2021b). 22 000 tonnes originated from agriculture (Statistics Norway 2021a), resulting in 12 000 tonnes left for forestry and fishery in 2020. It was estimated that there are produced 25 000 tonnes plastic waste from aquaculture in 2016 (Sundt et al. 2018), this is higher than the national statistics with 23 000 tonnes for agriculture, forestry and fishing in total in 2016 (Statistics Norway 2021b). In the MFA 4 200 tonnes of plastic waste originates from fishing, see Figure 15. It was estimated to 2 000 tonnes plastic waste from fishing gear in 2013 by Sundt et al. 2018 and 4 000 tonnes in 2016 by Deshpande, Philis et al. 2020. Hence, the quantity of fishing related waste flows have discrepancies and in the literature and statistics, and 4 200 tonnes stands as the most recent estimate.

In the industry we can see an increased focus on reusing and recycling material. For example buoys are often used on one gear and later used again on another gear. For gillnets the ropes on both sides of the gillnet-netting can be reused many times, if only the netting is replaced when worn, however this is labor intensive. To eliminate the waste from occurring in the first place is a stronger action than recycling it in circular economy terms. To utilize more durable gear that can be used for several years, switch to higher quality ropes and to reuse the buoys are good measures to reduce the amount of waste from fishing gear. This can potentially also cause less loss in the form of torn gear. From a circular economy perspective it is first and foremost important to prevent loss to the ocean, then increase the retrieval and material recycling, closing the loop.

Going from 21% landfilling of fishing gear in 2016 to 7% in 2020 are in accordance with the concept of the waste hierarchy. There are additional types of handling strategies,an undocumented part are burned at the foreshore or thrown in household waste (Håpnes and Busch 2020). Introducing EPR could minimize the use of these improper strategies. At the waste conference a FDV*-documentation as used for buildings, were proposed for fishing gear as it can aid the waste handling to have documentation on how to dismantle the gear and what material it consists of. *FDV is short for Forvaltning Drift og Vedlikehold and are denoted MOM (Management, Operation and Maintenance). This documentation proposal could shift the waste handling of FG towards more recycling and higher up in the waste hierarchy.

Researchers at DTU are testing if discarded fishing gear are suited as a strengthening and filling material in building blocks (Bertelsen et al. 2021), this can in turn lower the need for importing building materials and the use of landfills for fishing gear. So far the addition of fishing gear is promising for building material in Greenland which currently imports all construction material and have a challenge with derelict fishing gear piling up.

One waste management facility was interviewed with focus on the trends and changes in waste management of fishing gear. Recycling has been improved a lot in the recent years, and reports from the recycling facilities on what is accepted and wanted are of great help for segregating for recycling. The prices of plastic delivery has gone down over time, it is the delivery costs that decreases not the cost of transportation. He thinks that this is due to that the material is more demanded lowering the cost of delivery. Furthermore government's demands on recycled content surges the price of the recyclates. According to the WMF it was harder to manage the fishing gear waste before. In 2022 about half of the company's fishing gear waste earlier stored on site are now sent for material recycling as it is now become a feasible option. Yet, there is room for improvement, if the fishing gear sent to the facility is mixed with other waste, it is not recyclable because it takes to much resources and time to separate the gear manually with knives. The WMF detect that a stronger focus on circular economy is prevalent among the customers. Reports on how the waste is handled are also of interest to the customers of WMF. They are not only interested in where the material ends up, but also what it becomes, and wants statistics on waste handling for their sustainability reports.

5.3 Dynamic aspect

Forecasting plastic losses is challenging, since the fishing quotas vary from year to year and are established one year at the time after calculations of available fishing stocks, done by ICES (ICES 2022). In Iceland there is a thumbnail of 1 kg lost plastic fishing gear per 1 tonne of fish (Personal communication with an expert from Iceland Recycling Fund 2020), and this factor makes it easy to convey the message of plastic loss caused by fishing activity. This thesis has taken it one step further with gear-specific plastic losses. This is a figure that can easily be understood and extrapolated. For one tonne of catch caught by gillnets there will be loss of 111 grams of fishing gear plastics. Whereas for longlines there will be a loss 443 grams of fishing gear plastics and 1170 grams for a tonne caught by Danish Seine (Figure 18). The indicator found in this thesis on gear-specific losses is a detailed and clear factor suited for explaining people the important issue of lost gear. This dynamic MFA indicator can be of importance for the EPR, as it can serve as a factor for scenario-developing . In any case this thesis serves as an overview on the dynamic fishing gear quantum and can hence enlighten and guide the stakeholders and policy makers.

5.4 Future work

The indicator over the amount of lost plastic per catch for the gear utilized can be used in the future to easily calculate the loss of fishing gear. However, this assumes that the loss patterns are the same as in (Deshpande, Philis et al. 2020). Going forward, it is desired that the loss rates decreases with increased knowledge about how to avoid gear loss, either trough less gear conflict by reporting location, less loss by weather difficulties, and improved attitudes. Therefore, fishers loss patterns should be updated in the future to evaluate if there has been improvements. Better data sharing and uniform reporting is of essence to limit the challenges in data collection and can enhance the likelihood of making relevant improvements.

This thesis' results will further be used within research group five in Dsolve biodegradable plastics for marine applications. The results will serve as a foundation on mass quantities for evaluating ALDFGs impact on marine life through Life-Cycle Assessment. Moreover, the thesis will be sent out to various stakeholders which have requested the report, which shows excitement over the work. Furthermore an article of the research is planned to be published in a scientific journal. An abstract of this research has been approved by the 7th International Marine Debris Conference (7IMDC) in Seoul in September for an oral presentation. The conference is of high relevance since there will be many of the main publishing authors in the field present.

6 Conclusion

This thesis quantifies the mass flows of plastic polymers used in six typical fishing gear including ropes in the commercial Norwegian fishing industry from 2016 to 2020. About 4 200 tonnes of worn gear is sent for waste management. 452 tonnes of fishing gear plastics are lost in 2020, and 134 tonnes are retrieved from land and ocean. Purse seines is the gear with highest mass lost of 162 tonnes, next is trawls with 130 tonnes, longlines with 77 tonnes, traps and pots with 48 tonnes, purse seines with 19 tonne and lastly gillnets with 15 tonnes (Table 10). Gillnets is considered the most harmful ALDFG and is the second-most retrieved gear from the ocean after traps and pots. Plastic loss per tonne of catch is calculated for the six main fishing gear types and this indicator can be used to determine plastic loss in the future and past. It varies largely for the gear types ranging from 3.66 kg per tonne catch for traps and pots to 0.0283 kg per tonne catch for purse seine (Figure 18). Using gear-specific catch data and the indicator of loss per catch it is estimated that 8000 tonnes of gear was lost from 2000 to 2021. Although these number might seem daunting, there are optimism for cleaner oceans. There are more retrieved gear over time, a range of policy changes are arriving with the EPR, ship directive and ISO standard, and the attitude among fishers have improved.

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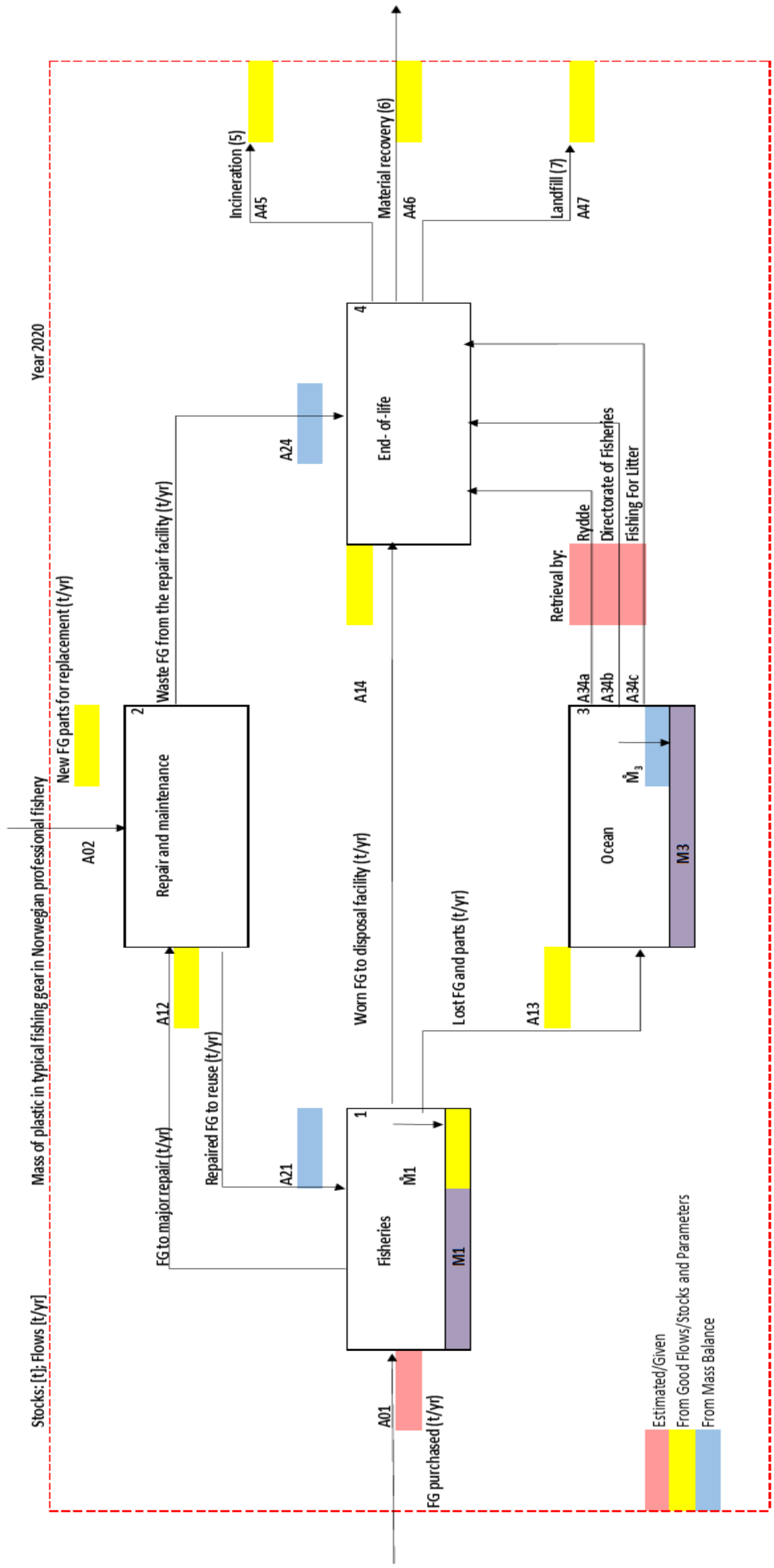
Appendix

A MFA System



Stocks: [t]; Flows [t/yr]
Mass of plastic in typical fishing gear in Norwegian professional fishery
Year 2020
New FG parts for replacement (t/yr)
A02
Repair and maintenance
2
FG to major repair (t/yr)
A12
Repaired FG to reuse (t/yr)
A21
Waste FG from the repair facility (t/yr)
A24
End-of-life
4
Incineration (5)
A45
Material recovery (6)
A46
Landfill (7)
A47
Fisheries
1
M1
FG purchased (t/yr)
A01
Worn FG to disposal facility (t/yr)
A14
Lost FG and parts (t/yr)
A13
Ocean
3
M3
Retrieval by:
Rydde
Directorate of Fisheries
Fishing For Litter
A34a
A34b
A34c
Estimated/Given
From Good Flows/Stocks and Parameters
From Mass Balance

B Parameters for MFA and Sensitivity Analysis

Parameter	Unit	Symbol	Observation	StdDev.	UL	LL	Un- certainty	MCInput	Distribution
Annual turnover of Trawls		CopT	4,43	3,64	8,1	0,8		4,43	Normal
Annual turnover of Purse Seine		CopPS	16,28	7,26	23,5	9,0		16,28	Normal
Annual turnover of Danish Seine		CopDS	9,27	7,86	17,1	1,4		9,27	Normal
Annual turnover of Gillnets		CopG	2,74	2,91	5,7	0,0		2,740	Normal
Annual turnover of Longlines		CopLL	3,12	2,94	6,1	0,2		3,12	Normal
Annual turnover of Traps/Pots		CopP	5,24	5,2	10,4	0,0		5,24	Normal
Annual turnover of Ropes		CopR	7,59	5,37	12,97	2,22		7,592	Normal
Repair % of Trawls	decimal	RT	0,8071	0,2841	1,0	0,523		0,807	Normal
Repair % of Purse Seine	decimal	RPS	0,5326	0,3904	0,923	0,1422		0,533	Normal
Repair% of Danish Seine	decimal	RDS	0,2993	0,1777	0,477	0,1216		0,299	Normal
Repair % of Gillnets	decimal	RG	0,2397	0,2683	0,508	0,000		0,240	Normal
Repair % of Longlines	decimal	RLL	0,368	0,4026	0,7706	0,000		0,368	Normal
Repair % of Pots	decimal	RP	0,2492	0,3232	0,5724	0,000		0,249	Normal
Repair % of Ropes	decimal	RR	0	0	0	0		0	Normal
Replace % of Trawls	decimal	RepT	0,1893	0,125	0,3143	0,0643		0,189	Normal
Replace % of Purse Seine	decimal	RepPS	0,1167	0,0784	0,1951	0,0383		0,117	Normal
Replace% of Danish Seine	decimal	RepDS	0,1464	0,0746	0,221	0,0718		0,146	Normal
Replace% of Gillnets	decimal	RepG	0,1872	0,1877	0,3749	0,000		0,187	Normal
Replace% of Longlines	decimal	RepLL	0,224	0,1826	0,4066	0,0414		0,224	Normal
Replace% of Pots	decimal	RepP	0,1375	0,1384	0,2759	0,000		0,138	Normal
Replace% of Ropes	decimal	RepR	0	0	0	0		0	Normal
% of Total owned Trawls lost in theOcean	decimal	LT	0,031	0,065	0,10	0,000		0,031	Normal
% of Total owned Purse Seine lost inthe Ocean	decimal	LPS	0,004	0,018	0,02	0,000		0,004	Normal
% of Total owned Danish Seine lostin the Ocean	decimal	LDS	0,018	0,032	0,05	0,000		0,018	Normal
% of Total owned Gillnets lost in theOcean	decimal	LG	0,01	0,018	0,03	0,000		0,010	Normal
% of Total owned Longlines lost inthe Ocean	decimal	LLL	0,044	0,051	0,10	0,000		0,044	Normal
% of Total owned Pots lost in theOcean	decimal	LP	0,041	0,055	0,10	0,000		0,041	Normal
% of Total owned Ropes lost in the Ocean	decimal	LR	0,0276	0,0442	0,0718	0,000		0,028	Normal
% of Total owned Trawls Disposedby Fishers	decimal	DT	0,251	0,236	0,49	0,015		0,251	Normal
% of Total owned Purse SeinesDisposed by Fishers	decimal	DPS	0,073	0,093	0,17	0,000		0,073	Normal
% of Total owned Danish SeinesDisposed by Fishers	decimal	DDS	0,114	0,084	0,20	0,030		0,114	Normal
% of Total owned Gillnets Disposedby Fishers	decimal	DG	0,331	0,267	0,60	0,064		0,331	Normal
% of Total owned Longlines Disposedby Fishers	decimal	DLL	0,308	0,265	0,57	0,043		0,308	Normal
% of Total owned Pots Disposed byFishers	decimal	DP	0,169	0,132	0,30	0,037		0,169	Normal
% of Total owned Ropes Disposed by Fishers	decimal	DR	0,1876	0,1624	0,35	0,0252		0,1876	Normal
Total weight of Trawls purchased bycommercial fishing fleet	t/yr	Wt	773,3	146,9333333	920,3	626,4	19 %	773,33	Normal
Total weight of Purse Seinepurchased by commercial fishingfleet	t/yr	Wps	275,0	27,5	302,5	247,5	10 %	275,00	Normal
Total weight of Danish Seinepurchased by commercial fishingfleet	t/yr	Wds	875,0	87,5	962,5	787,5	10 %	875,00	Normal
Total weight of Gillnets purchased bycommercial fishing fleet	t/yr	Wg	400,0	20	420,0	380,0	5 %	400,00	Normal
Total weight of Longlines purchasedby commercial fishing fleet	t/yr	Wll	425,0	63,75	488,8	361,3	15 %	425,00	Normal
Total weight of Traps and Potspurchased by commercial fishingfleet	t/yr	Wp	186,5	74,60140114	261,1	111,9	40 %	186,50	Normal
Total weight of Ropes purchased by commercial fishingfleet	t/yr	Wr	1614	2,71152	1616,71152	1611,28848	17 %	1614	Normal
% of Waste FGs recycled 2016	decimal	ER	0,55	0,083	0,6	0,5	15 %	0,55	Normal
% of Waste FGs incinerated 2016	decimal	EI	0,21	0,031	0,2	0,2	15 %	0,21	Normal
% of waste FGs landfilled 2016	decimal	EL	0,24	0,036	0,3	0,2	15 %	0,24	Normal
% of Waste FGs recycled 2020	decimal	ER	0,45	0,0675	0,5	0,4	15 %	0,45	Normal
% of Waste FGs incinerated 2020	decimal	EI	0,48	0,072	0,6	0,4	15 %	0,48	Normal
% of waste FGs landfilled 2020	decimal	EL	0,07	0,0105	0,1	0,1	15 %	0,07	Normal
ALDFGs collected from beaches (t/yr)									
ALDFG Rydde Trawls	t/yr		0,94784375	0,631895833	1,579739583	0,315947917	67 %	0,94784375	Normal
ALDFG Rydde Purse seine	t/yr		0,94784375	0,631895833	1,579739583	0,315947917	67 %	0,94784375	Normal
ALDFG Rydde Danish seine	t/yr		0,94784375	0,631895833	1,579739583	0,315947917	67 %	0,94784375	Normal
ALDFG Rydde Gillnets	t/yr		5,82246875	5,01003125	10,8325	0,8124375	86 %	5,82246875	Normal
ALDFG Rydde Longlines	t/yr		0	0	0	0	0 %	0	Normal
ALDFG Rydde Traps/pots	t/yr		4,42	0,402	4,824	4,02	9 %	4,422	Normal
ALDFG Rydde Ropes	t/yr		5,56	3,2721	8,83467	2,29047	59 %	5,56257	Normal
ALDFGs retrieved from the FisheryDir (t/yr)									
ALDFG FisheryDir Trawls	t/yr		0,03	0,011538462	0,041538462	0,018461538	38 %	0,03	Normal
ALDFG FisheryDir Purse seine	t/yr		0,3	0,2	0,5	0,1	67 %	0,3	Normal
ALDFG FisheryDir Danish seine	t/yr		0	0	0	0	67 %	0	Normal
ALDFG FisheryDir Gillnets	t/yr		9,576	0,684	10,26	8,892	7 %	9,576	Normal
ALDFG FisheryDir Longlines	t/yr		3,10165	2,00695	5,1086	1,0947	65 %	3,10165	Normal
ALDFG FisheryDir Traps/pots	t/yr		29,37	2,67	32,04	26,7	9 %	29,37	Normal
ALDFG FisheryDir Ropes	t/yr		44,2816	28,416	72,6976	15,8656	64 %	44,2816	Normal
ALDFGs retrieved from the FFL (t/yr)									
ALDFG FFL Trawls	t/yr		32,16872609	6,755432479	38,92415857	25,41329361	21 %	32,16872609	Normal
ALDFG FFL Purse seine	t/yr		6,031636142	1,26664359	7,298279732	4,764992552	21 %	6,031636142	Normal
ALDFG FFL Danish seine	t/yr		0	0	0	0	21 %	0	Normal
ALDFG FFL Gillnets	t/yr		21,1107265	4,433252564	25,54397906	16,67747393	21 %	21,1107265	Normal
ALDFG FFL Longlines	t/yr		0	0	0	0	21 %	0	Normal
ALDFG FFL Traps/pots	t/yr		19,10018112	4,011038035	23,11121915	15,08914308	21 %	19,10018112	Normal
ALDFG FFL Ropes	t/yr		9,047454213	1,899965385	10,9474196	7,147488828	21 %	9,047454213	Normal

C Survey for waste management facilities

Fiskerirelatert avfall

Denne undersøkelsen tar utgangspunkt i fiskeutstyrsavfall fra kommersielt fiske i Norge, akavakultur og fritidsfiske er ikke inkludert. Svarene vil komme til god nytte til en masteroppgave ved NTNU om mengder plast i fiskeutstyr i Norge med dets utfordringer og mulige løsninger. Takk for at du svarer på denne undersøkelsen og bidrar med nyttig førstehåndskunnskap for god materialbruk og rene hav.

1. Bedriftstype

Markér bare én oval.

- ◯ Renovasjon/avfallsselskap/gjenvinning/resirkulerer *Hopp til spørsmål 2*
- ◯ Annet (som f.eks. rådgivende, kommune, transport, akademia) *Hopp til spørsmål 8*

Hopp til spørsmål 2

Spørsmål til avfallsbehandlere om fiskerirelatert avfall

2. Hva er avfalls-anleggets kapasitet? (tonn)

____

3. Hvor stor andel av innsamlet mengde er fiskeri-relatert? (%)

Markér bare én oval per rad

	Ingen	0.1-5	5-10	10-15	15-25
(%)	◯	◯	◯	◯	◯

4. Hva er behandlingen av fiskerirelatert avfall? Andel til deponi (%)

____

5. Hva er behandlingen av fiskerirelatert avfall? Andel til forbrenning/energigjenvinning (%)

____

6. Hva er behandlingen av fiskerirelatert avfall? Andel til resirkulering (%)

7. Hvor sendes det materialet til resirkulering?

Hopp til spørsmål 8

Spørsmål til alle

8. Hvilke utfordringer ser innen avfallsbehandlinga av fiskerirelatert avfall?

9. Hvilke løsninger ser du for å øke materialgjenvinningen av fiskerirelatert avfall?

D Requested information from suppliers of fishing gear

Main Fishing Gear (FG)	Sub categories and parts of Fishing Gear (FG)	Hoved-grupper fiske-utstyr	Underkategorier og deler av fiskeutstyr	Estimert % materialsammensetning av total vekt Estimated % composition of total weight						Tilhørende % tau i fiskeutstyr Associated % Ropes in FG	Estimert markedsandel Estimated market share	Total vekt med tilhørende tau i år: Total Weight (with associated ropes) sold in:				Total vekt med tilhørende tau i år: Total Weight (with associated ropes) sold in:			
												2020	2019	2018	2017	2016	2015	2014	2013
				Polyamide/ Nylon (PA)	% Polypropylene (PP)	% Polyetylene (PE)	% Other plastics	% Metals	% Other material	%	%	(tons)	(tons)	(tons)	(tons)	(tons)	(tons)	(tons)	(tons)
Trawls	Pelagic-/midwater trawl	Trål	Pelagisk/mellomnivå/flyte- trål																
	Bottom/demersal trawl (Cod Fishing)		Bunntrål																
	Semi-demersal trawl (shrimp fishing)		Reketrål																
	Nets, sorting grid, dollies		Nett, sorteringsrist, labbetuss																
	Trawl gear (rock hopper, bobbins, etc.)		Rockhopper gear, gummi fyllstykke, gummibobbins																
	Trawl floats		Trålkuler																
Seines	Purse Seine	Not	Ringnot																
	Danish/Scottish Seine		Snurrevad																
	Floats and Buoys		Flottører og bøyer																
Gillnets	Bottom-set-gillnets	Garn	Garn																
	Gillnet rings		Garnringer																
Lines	Longline and Jigging Lines	Line	Langline og jukse																
Traps and Pots	Crab pots	Teiner	Krabbeteine																
	King-/Snow crab pots		Konge-/snøkrabbeteine																
	Lobster pots		Hummerteine																
	Other Traps		Andre teiner																
	Floats		Bøyer																
Ropes	Mooring Ropes	Tau	Fortøyningstau/ trosse																
	Other Ropes		Andre tau																

Main Fishing Gear (FG)	Hoved-grupper fiske-utstyr	Estimert % materialsammensetning av total vekt Estimated % composition of total weight						Tilhørende % tau i fiskeutstyr Associated % Ropes in FG	Total vekt med tilhørende tau i år: Total Weight with added ropes sold in: 2020 Markeds- andel		Total vekt med tilhørende tau i år: Total Weight with added ropes sold in: 2019 Markeds- andel		Total vekt med tilhørende tau i år: Total Weight with added ropes sold in: 2018 Markeds- andel		Total vekt med tilhørende tau i år: Total Weight with added ropes sold in: 2017 Markeds- andel		Total vekt med tilhørende tau i år: Total Weight with added ropes sold in: 2016 Markeds- andel	
		Polyamide/ Nylon (PA)	% Polypropylene (PP)	% Polyetylene (PE)	% Other plastics	% Metals	% Other material	%	(tons)	%	(tons)	%	(tons)	%	(tons)	%	(tons)	%
Trawls	Trål																	
Danish/ Scottish Seine	Snurrevad																	
Purse Seine	Ringnot																	
Gillnets	Garn (inkl. evt.																	
Lines	Line																	
Traps and Pots	Teiner																	
Ropes	Tau																	

E MFA results for 2016 to 2020 for the six gear types and ropes

M1+M̊1	FG_owned/A01*C_stock (t)	**2016**	**2017**	**2018**	**2019**	**2020**
	Trawls	3167	3389	3304	3610	3426
	Purse seine	4477	4477	4477	4477	4477
	Danish seine	8111	8111	8111	8111	8111
	Gillnets	1187	1187	1187	1096	1096
	Longlines	1193	1193	1193	1326	1326
	Traps/pots	1111	898	955	960	977
	Ropes	6074	6597	8442	11517	12253
A01	FG purchased (t/yr)					
	Trawls	715	765	746	815	773
	Purse seine	275	275	275	275	275
	Danish seine	875	875	875	875	875
	Gillnets	433	433	433	400	400
	Longlines	383	383	383	425	425
	Traps/pots	212	171	182	183	187
	Ropes	800	869	1112	1517	1614
A12	FG to major repair (t/yr)					
	Trawls	3134	3353	3269	3572	3389
	Purse seine	2531	2531	2531	2531	2531
	Danish seine	2690	2690	2690	2690	2690
	Gillnets	388	388	388	359	359
	Longlines	580	580	580	644	644
	Traps/pots	330	267	283	285	290
	Ropes	0	0	0	0	0
A13	Lost FG and parts (t/yr)					
	Trawls	120	129	126	137	130
	Purse seine	19	19	19	19	19
	Danish seine	162	162	162	162	162
	Gillnets	16	16	16	15	15
	Longlines	69	69	69	77	77
	Traps/pots	54	44	47	47	48
	Ropes	190	206	264	360	383
A14	Worn FG to disposal facility (t/yr)					
	Trawls	974	1043	1017	1111	1054
	Purse seine	347	347	347	347	347
	Danish seine	1024	1024	1024	1024	1024
	Gillnets	536	536	536	495	495
	Longlines	485	485	485	539	539
	Traps/pots	224	181	192	193	197
	Ropes	610	663	848	1157	1231
A21	Repaired FG to reuse (t/yr)					
	Trawls	3513	3759	3665	4005	3800
	Purse seine	2622	2622	2622	2622	2622
	Danish seine	3001	3001	3001	3001	3001
	Gillnets	508	508	508	469	469
	Longlines	752	752	752	836	836
	Traps/pots	395	320	340	342	348
	Ropes	0	0	0	0	0
A02	New FG parts for replacement (t/yr)					
	Trawls	593	635	619	676	642
	Purse seine	295	295	295	295	295
	Danish seine	394	394	394	394	394
	Gillnets	73	73	73	67	67

	Longlines	130	130	130	144	144
	Traps/pots	45	37	39	39	40
	Ropes	0	0	0	0	0
A24	Waste FG from the repair facility (t/yr)					
	Trawls	213	228	223	243	231
	Purse seine	204	204	204	204	204
	Danish seine	83	83	83	83	83
	Gillnets	-47	-47	-47	-43	-43
	Longlines	-42	-42	-42	-47	-47
	Traps/pots	-20	-17	-18	-18	-18
	Ropes	0	0	0	0	0
A34a	ALDFGs collected from beaches (t/yr)					
	Trawls	2	0	1	2	1
	Purse seine	2	0	1	2	1
	Danish seine	2	0	1	2	1
	Gillnets	14	2	5	11	6
	Longlines					
	Traps/pots	1	2	11	17	4
	Ropes	3	16	100	6	5
A34b	ALDFGs retrieved from the FisheryDir (t/yr)					
	Trawls	2	2	4	2	0
	Purse seine	0	0	0	0	0
	Danish seine	0	0	0	0	0
	Gillnets	11	11	11	11	10
	Longlines	4	2	3	2	3
	Traps/pots	1	2	96	14	29
	Ropes	3	6	96	19	44
A34c	ALDFGs retrieved from the FFL (t/yr)					
	Trawls	11	12	22	25	32
	Purse seine	1	1	0	1	6
	Danish seine	0	0	0	0	0
	Gillnets	3	3	2	5	21
	Longlines	1	1	2	5	0
	Traps/pots	2	2	2	2	19
	Ropes	1	1	0	0	9
A45	Waste FGs to incineration (t/yr)					
	Trawls	253	357	437	570	633
	Purse seine	116	153	190	229	268
	Danish seine	233	307	382	457	532
	Gillnets	109	140	175	198	235
	Longlines	94	124	154	206	238
	Traps/pots	43	47	98	86	111
	Ropes	130	190	360	488	619
A46	Segregation and processing of recycling (t/yr)					
	Trawls	662	675	633	657	593
	Purse seine	305	290	276	263	251
	Danish seine	610	581	554	527	499
	Gillnets	284	266	254	228	220
	Longlines	246	234	224	237	223
	Traps/pots	114	89	141	99	104
	Ropes	339	360	522	561	580
A47	Waste FG to landfill(t/yr)					
	Trawls	289	254	196	156	92

	Purse seine	133	109	86	62	39
	Danish seine	266	219	172	125	78
	Gillnets	124	100	79	54	34
	Longlines	107	88	69	56	35
	Traps/pots	50	34	44	23	16
	Ropes	148	135	162	133	90
$\mathring{M}3$	Stock change of ALDFG in the ocean (t)					
	Trawls	105	114	99	109	97
	Purse seine	16	18	18	16	12
	Danish seine	159	161	161	160	161
	Gillnets	-11	0	-1	-13	-22
	Longlines	65	66	65	70	74
	Traps/pots	51	38	-62	14	-5
	Ropes	183	184	68	335	324

F Summary of MFA results for 2016 to 2020 with description

Variable	Variable name	Decription	Data source	Equation	Without ropes (MoP in tonnes) 2016	2017	2018	2019	2020	Only ropes (Mop in tonnes) 2016	2017	2018	2019	2020
A01	Fishing gear (FG) purchased (t/yr)	Mass of Plastics (MoP) in purchased commercial FGs	Fishing gear suppliers	A01 = ∑ plastics in purchased FG	2893	2902	2894	2973	2935	800	869	1112	1517	1614
A12	FG to major repair (t/yr)	MoP in FGs sent for major repairs including replacement of parts	Deshpande et al. 2020 &FG suppliers	A12 = ∑ Crepair · (A01 + A01 · Cstock)	9652	9808	9741	10080	9903	0	0	0	0	0
A13	Lost FG and parts (t/yr)	MoP in FGs entering in the ocean from lost FGs or parts upon deployment.	Deshpande et al. 2020 &FG suppliers	A13 = ∑ Clost · (A01 + A01 · Cstock)	441	439	438	457	451	190	206	264	360	383
A14	Worn FG to disposal facility (t/yr)	MoP in end-of-life FGs disposed of by fishers at the WMFs or ports.	Deshpande et al. 2020 &FG suppliers	A14 = ∑ Cdispose · (A01 + A01 · Cstock)	3591	3617	3602	3710	3656	610	663	848	1157	1231
A21	Repaired FG to reuse (t/yr)	MoP in repaired FGs being reuse.	Mass balance	A21 =Ṁ1− A01 + A12 + A13 + A14	10791	10961	10887	11274	11075	0	0	0	0	0
A02	New FG parts for replacement (t/yr)	MoP in replacement parts used by repair facilities	Deshpande et al. 2020 &FG suppliers	A02 = ∑ Crepair · Creplace · (A01 + A01 · Cstock)	1530	1563	1549	1616	1582	0	0	0	0	0
A24	Waste FG from the repair facility (t/yr)	MoP in the waste from FG generated during repair	Mass balance	A24 = A02 + A12 − A21	391	410	403	422	410	0	0	0	0	0
A34a	ALDFGs collected from beaches (t/yr)	MoP in the collected ALDFG from the beach cleanups	Rydde/HNR	A34a = ∑ Collected FG at beach (unit) · MoP in FG at beach(kg/unit)	22	5	18	33	13	3	16	100	6	5
A34b	ALDFGs retrieved from the ocean (t/yr)	MoP in the collected ALDFG from the ocean cleanups	The Directorate of Fisheries	A34b = ∑ Collected FG by F.Dir (unit) · MoP in FG from F.Dir	17	17	112	29	42	3	6	96	19	44
A34c	ALDFGs retrieved from the FFL (t/yr)	MoP in the collected ALDFG from the FFL ocean cleanups	Fishing For Litter	A34c = ∑ FFL fishery rel. waste (kg) · Share of plastics · Share of resp. FG	17	19	28	38	78	1	1	0	0	9
A45	Waste FGs to incineration (t/yr)	MoP in collected waste FGs incinerated at the Waste Management Facilities (WMFs)	WMFs survey	A45 = ∑ Cincineration · (A24 + A14 + A34a + A34b + A34c)	848	1129	1436	1746	2016	130	190	360	488	619
A46	Segregation and processing of recycling (t/yr)	MoP in collected waste FGs sent for recycling abroad	WMFs survey	A46 = ∑ Crecycle · (A24 + A14 + A34a + A34b + A34c)	2221	2135	2081	2010	1890	339	360	522	561	580
A47	Waste FG to landfill(t/yr)	MoP in collected waste FGs landfilled at the WMFs.	WMFs survey	A47 = ∑ Clandf ill · (A24 + A14 + A34a + A34b + A34c)	969	803	645	476	294	148	135	162	133	90
M1+Ṁ1	Stock and stock change of total FG owned by commercial fishers (t)	MoP in the stocks of FGs owned by the Norwegian fishing fleet.	Deshpande et al. 2020 &FG suppliers	M1+Ṁ1 = Cstock · A01	19247	19256	19228	19581	19413	6074	6597	8442	11517	12253
Ṁ3	Stock change of ALDFG in the ocean (t)	MoP accumulating annually in the ocean as ALDFG.	Mass balance	Ṁ3 = A13 − A34a − A34b − A34c	385	398	280	357	317	183	184	68	335	324

G Material composition

Fishing gear	Polyamide/ Nylon (PA)	Polypropylene (PP)	Polyetylene (PE)	Other plastics	Metals	Other material
Trawls	3 %	5 %	46 %	9 %	37 %	0 %
Purse Seines	73 %	0 %	2 %	0 %	20 %	5 %
Danish Seines	5 %	59 %	21 %	0 %	15 %	0 %
Gillnets	95 %	5 %	0 %	0 %	0 %	0 %
Lines	5 %	20 %	10 %	50 %	15 %	0 %
Traps and Pots	10 %	0 %	10 %	0 %	80 %	0 %
Ropes	5 %	60 %	20 %	15 %	0 %	0 %

Table 11: Material composition of sold fishing gear in 2020

	Polyamide Nylon (PA)	Polypropylene (PP)	Polyetylene (PE)	Other plastics	Total
Trawls	5 %	7 %	74 %	14 %	100 %
Purse Seines	91 %	0 %	9 %	0 %	100 %
Danish Seines	6 %	69 %	26 %	0 %	100 %
Gillnets	95 %	5 %	0 %	0 %	100 %
Lines	6 %	24 %	12 %	59 %	100 %
Traps and Pots	50 %	0 %	50 %	0 %	100 %
Ropes	5 %	60 %	20 %	15 %	100 %
Total	21 %	37 %	29 %	13 %	100 %

Table 12: Material composition of plastics in sold fishing gear in 2020

Lost fishing gear (tonnes)	Polyamide Nylon (PA)	Polypropylene (PP)	Polyethylene (PE)	Other plastics	Total plastics
Trawls	6	10	97	18	130
Purse Seines	17	0	2	0	19
Danish Seines	9	111	42	0	162
Gillnets	14	1	0	0	15
Lines	5	18	9	45	77
Traps and Pots	24	0	24	0	48
Total	75	139	173	63	451

Table 13: Plastic quantities of the lost gear in 2020.

H Results on catch quantities by gear utilized

Year	Trawl	Purse Seine	Danish Seine	Gillnets	Longlines	Traps and Pots	Totalsum
2000	1091317	1271529	50101	130500	149004	3860	2696311
2001	1162666	1186622	50520	129668	148565	4633	2682673
2002	1162644	1227234	48543	131415	160069	5491	2735395
2003	1264270	959338	46288	124128	143003	6404	2543430
2004	1391878	796232	56335	121493	144841	7046	2517826
2005	1155199	915348	56660	109994	139772	7578	2384552
2006	1064741	862435	56128	119936	141155	8004	2252399
2007	1048100	1001515	60877	130675	138358	10363	2389887
2008	966880	1127348	55998	138973	134050	11247	2434496
2009	810086	1385946	57221	130003	138426	11283	2532964
2010	914104	1360666	73343	153080	165212	8596	2675002
2011	844529	1164008	89419	157066	183190	8116	2446328
2012	776407	1043243	101055	155865	192529	7676	2276775
2013	935985	816643	119009	168031	192268	8062	2239999
2014	1189955	767712	134400	168329	193163	9577	2463137
2015	1318100	680796	129323	151788	180498	11602	2472106
2016	1142031	593346	139164	138252	183189	14813	2210795
2017	1330041	766031	143391	143934	169221	11976	2564593
2018	1353395	822463	134441	153356	166296	12733	2642683
2019	1398826	619805	135384	137032	157919	12807	2461772
2020	1539081	620023	142084	134902	147002	13031	2596123
2021	1357195	726510	169202	138221	142256	15591	2548975

Table 14: Catch per utilized gear type by year in tonnes.

Year	Trawl	Purse Seine	Danish Seine	Gillnets	Longlines	Traps and Pots
2000	40,5 %	47,2 %	1,86 %	4,84 %	5,53 %	0,14 %
2001	43,3 %	44,2 %	1,88 %	4,83 %	5,54 %	0,17 %
2002	42,5 %	44,9 %	1,77 %	4,80 %	5,85 %	0,20 %
2003	49,7 %	37,7 %	1,82 %	4,88 %	5,62 %	0,25 %
2004	55,3 %	31,6 %	2,24 %	4,83 %	5,75 %	0,28 %
2005	48,4 %	38,4 %	2,38 %	4,61 %	5,86 %	0,32 %
2006	47,3 %	38,3 %	2,49 %	5,32 %	6,27 %	0,36 %
2007	43,9 %	41,9 %	2,55 %	5,47 %	5,79 %	0,43 %
2008	39,7 %	46,3 %	2,30 %	5,71 %	5,51 %	0,46 %
2009	32,0 %	54,7 %	2,26 %	5,13 %	5,46 %	0,45 %
2010	34,2 %	50,9 %	2,74 %	5,72 %	6,18 %	0,32 %
2011	34,5 %	47,6 %	3,66 %	6,42 %	7,49 %	0,33 %
2012	34,1 %	45,8 %	4,44 %	6,85 %	8,46 %	0,34 %
2013	41,8 %	36,5 %	5,31 %	7,50 %	8,58 %	0,36 %
2014	48,3 %	31,2 %	5,46 %	6,83 %	7,84 %	0,39 %
2015	53,3 %	27,5 %	5,23 %	6,14 %	7,30 %	0,47 %
2016	51,7 %	26,8 %	6,29 %	6,25 %	8,29 %	0,67 %
2017	51,9 %	29,9 %	5,59 %	5,61 %	6,60 %	0,47 %
2018	51,2 %	31,1 %	5,09 %	5,80 %	6,29 %	0,48 %
2019	56,8 %	25,2 %	5,50 %	5,57 %	6,41 %	0,52 %
2020	59,3 %	23,9 %	5,47 %	5,20 %	5,66 %	0,50 %
2021	53,2 %	28,5 %	6,64 %	5,42 %	5,58 %	0,61 %

Table 15: Percentage of the total catch caught by the main fishing gear.

NTNU

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