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A material flow analysis of recycling of gillnets from Norwegian fisheries

Case study of the Northern periphery and Arctic region

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Problem description

The thesis aims to develop a quantified system model of plastic recycling from fisheries (and potentially aquaculture) equipment to identify and assess pertinent flows and processes. The following tasks are considered relevant in this regard:

- Literature review/state of the art assessment of the topic, covering earlier research in the area, current state of countries in the NPA-region and relevant initiatives targeting the problem with lost fishing equipment
- Develop a system model of plastic recycling from fishing equipment covering the most important flows and processes.
- Select one or several sub-regions within the NPA-region and develop scenarios to analyze the current state and potential for improvement of the system. Scenarios could cover potential changes in industrial practices, political decision-making, market development (fisheries and aquaculture) and relate to one or more countries in the NPA-region.
- Analyze, assess and discuss the selected system, model and improvement potential.

Preface

This report is my master thesis at MSc. Industrial Ecology at NTNU and acts as my concluding work at the university. The thesis deals with the problem of derelict fishnets, more specific gillnets, in Norway and the focus of the study is set to attempt estimating the mass of fishnets in-use, lost during fishing and recycled. The project was carried out as an initiative from NTNU in connection to the EU-project Circular Oceans.

This project has been a pleasure to undertake, and has given me a profound insight into the Norwegian fisheries. The study would not have been possible without the exceptional help from Dina Margrethe Aspen. She has provided me with industrial contacts and gathered information that has been relevant throughout the project. I would also like to thank John Eilif Hermansen for helping me structure the report and supervise the progress of the project. I am sincerely thankful for all help and support I have gotten throughout during my work with the thesis. Last, but not least, I would like to mention the Executive Manager of Nofir AS, Øistein Alexandersen, for providing data on recycling of gillnets.

Abstract

This study attempts to quantify the flows of gillnets in Norway by using Material Flow Analysis. The research consist of mapping the extent of lost fishing gear in European and Norwegian fisheries and using the gathered data to design a MFA-model.

We humans have learned to harvest these marine resources and we have become more efficient in doing so trough technological development within the marine sector (Fiskeridirektoratet, 2014). Scientist have reason to believe that within a few years there will be more plastic waste in the ocean than fish and that the ever increasing global population will become far more dependent on marine nutrients in order to sustain the population growth. This implies an increased exploitation of marine resources resulting in intensified fishing.

The issue of derelict fishing gear has in the recent years received increased focus and has been found to have a profound negative impact on marine organisms and ecosystems. The causes for loss of equipment are well known bot little effort has been done to find the extent that gear loss occurs.

The finding in this study suggest that the loss of fishing equipment is low compared to the amount of gillnets that are in use. The study is concluded by the development and simulation of scenarios for recycling. These scenarios are based on a industrial example from a Norwegian recycler. The display the potential for improvement within recycling of gillnets.

List of abbreviations and definitions

ACFM:	Advisory Committee of Fishery Management
ALDFG:	Abandoned, lost and discarded fishing gear
EEZ:	Exclusive Economic Zone
FANTARED:	Study of the issue of Ghost fishing in Europe
FAO:	The Food and Agriculture Organization of the United Nations
Fishnet:	Includes gillnets as well as trawls and nets for pots
Gillnet:	Fishnet that operates by the principle of entanglement
ICES:	International Council for the Exploration of the Seas
IUU:	Illegal, unreported and unregulated
MFA:	Material Flow Analysis
NAFO:	Northwest Atlantic Fisheries Organization
NAFTA:	North-American Free Trade Agreement
NPA:	North European and Arctic region. The region includes Greenland, Svalbard, Norway, Sweden, Finland, Northern Ireland, Republic of Ireland, Scotland, Faroe Islands and Iceland.
NTNU:	Norwegian University of Science and Technology
RFMO:	Regional Fisheries Management Organization
SPC:	Secretariat of the Pacific Community
TAC:	Total Allowed Catch

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1 INTRODUCTION

This thesis aims to quantify the mass and flows of gillnets in Norway by the use of the methodology of Material Flow Analysis. The focus on lost and abandonment fishing gear has received increased attention and a quantification of the magnitude of the issue is required. The study is a part of the EU-project Circular Oceans and was initiated by NTNU. The Norwegian government has just recently published a statement proposing actions to reduce the amounts of marine litter in Norwegian waters making this study highly relevant. The following chapter will highlight the background for the study as well as the relevancy, the objective of the report and is concluded by providing a overview of the report’s structure of content.

1.1 BACKGROUND

In the recent year’s there has been an increased focus on the causes and impacts of abandoned, lost and discarded fishing gear (ALDFG). ALDFG is proven to have a profound negative effect on the marine ecosystems and due to the increasing efforts within fishing it has become a growing worldwide concern. The world’s oceans are connected with each other allowing waste to flow between regions making the issue global. It is estimated that around 10 % of all marine debris can be allocated ALDFG (Gilman, 2015; Macfayden, Huntington, & Cappel, 2009), stemming from the large amounts of fishing vessels operating in our seas. ALDFG has been defined to include all fishing gear used for both commercial and recreational fishing creating the need for awareness among the general public. Ghost fishing is stated to be one of the main problems in connection lost fishing gear, and the phenomena occurs when lost gear continues to catch after the nets have been lost (Gilman, 2015; Kaiser et al., 1996; Macfayden et al., 2009). The ghost nets not only continue to catch targeted commercial species, but also affect non-targeted, and this involves endangering endangered species creating an ecological hazard for the marine ecosystems. ALDFG can be connected to several environmental impacts including entanglement with often lethal effect, indigestion, and the release of toxins into the marine environment. Reducing the amounts of toxins is often hard, for not to say impossible, since they are transferred through generations.

The Norwegian Ministry for climate and Environment did in June 2016 propose seven actions to reduce and combat marine littering of Norwegian coastal waters. These include making the producers and importers of equipment used within fisheries responsible for the product through its whole life-cycle, making it free of charge for fishermen to depose of equipment as well as increasing the research and control of the extent and impacts of marine litter (Miljødirektoratet, 2016). The establishment of governmental initiatives understates the importance of the issue and makes it a highly relevant area of research.

1.2 OBJECTIVE AND RESEARCH QUESTION

This study aims to develop a quantified system model of plastic recycling from fisheries equipment to identify and assess pertinent flows and processes. The following tasks are included:

- Literature review/state of the art assessment of the topic, covering earlier research in the area, current state of countries in the NPA-region and relevant initiatives targeting the problem with lost fishing equipment
- Develop/select a methodology and methods to analyze selected environmental concerns relating to plastic recycling from fishing equipment
- Develop a system model of plastic recycling from fishing equipment covering the most important flows and processes.
- Select one or several subregions within the NPA-region and develop scenarios to analyze the current state and potential for improvement of the system. Scenarios could cover potential changes in industrial practices, political decision-making, market development (fisheries and aquaculture) and relate to one or more countries in the NPA-region.
- Analyze, assess and discuss the selected system, model and improvement potential.

The main focus of study is the quantification of the flow of gillnets within Norway through the value chain from vendor to recycled fishnets. The goal is to quantify all the major flows and stocks within Norway.

Delimitations of the study

The demarcation of the project is limited to the **flow of gillnets within Norway**. The MFA-model is built on the foundation of catch done by Norwegian fishermen. I not taken into account the catch done by foreign fishermen done within Norway.

The calculations in the MFA-model is based on selected data from the study and all information on recycling is based on information provided by the Norwegian recycler Nofir AS.

1.3 RELEVANCE AND CONTRIBUTION

The Norwegian government has in the recent years highlighted the importance of tackling discarded fishing gear in Norwegian waters, but there has been done little effort to quantify the amount of gear that is lost by the Norwegian fishing fleet. Studies have been done finding the ratio of which gear is lost for specific types of fisheries, but these studies have not quantified the mass of fishnets that are lost. This report includes an estimation of the mass of fishnets in Norway to date, including an attempt on estimating the share mass of lost fishnets lost by Norwegian fishermen. The findings can be used to examine the potential for establishing a recycling practice based on fishnets, as well as it contributes to highlight the extent of lost fishnets in a quantitative way. The study is unique and is the first to quantify the mass of fishnets in Norway.

1.4 STRUCTURE OF STUDY

This section provides information about the outline of the study and information and provides information on the structure of the report.

1.4.1 Outline of the study

The study is opened by examining the distribution and impacts of abandoned, lost and discarded fishing gear in different regions. This is followed by a study of the Norwegian fishing industry including the development of fish quotas and a study of the vessels used. Since the focus of the study lays on gillnets it is only natural to take a look at the design and use of such equipment. Here I also examine the phenomena of ghost fishing and introduce two European initiatives aimed to reduce the amounts of fishing gear lost and discarded into the ocean. The study is concluded by MFA-analysis quantifying the flows of fishnets within Norway.

1.4.2 Structure of the report

Chapter 2 Methodology and theoretical framework provides a review of the methodology and theoretical framework applied in the study. Chapter 3 Abandoned, lost or otherwise discarded fishing gear (ALDFG) examines the causes of the phenomena and gives an overview of the extent of the issue. Chapter 4 Global fishing industry and 5 Norwegian fishing industry has the intention to give the reader insight to the Norwegian fisheries concerning fishing gear, regulations and fishing vessels. Chapter 6 focus on the use and regulation of gillnets in Norway and includes a collection of data found from previous research on the loss rate of gillnets in different regions around the world. The chapter is concluded by an attempt on estimating the average weight of a gillnet. Chapter 8 Recycling of fishnets is a case study of the Norwegian recycler Nofir AS showing how recycling is practiced in an industrial scale. Chapter 9 Material Flow Analysis (MFA) presents results from the simulation of scenarios for recycling of gillnets. Chapter 10 is a synthesis on reflections on the findings presenting the a discussion of results of the study. Chapter 11 presents the conclusion for the study and presents suggestions for further work on the on the issue. Chapter 12 presents a list of the literature used in the report.

2 METHODOLOGY AND THEORETICAL FRAMEWORK

The methods used in this project consist of both qualitative and quantitative. The main task of the project has been data collection so it has been natural to apply a quantitative approach from the very start. In order to ensure the quality, of the MFA-model and its input data, I have found it suitable to apply some qualitative research e.g. interview and physical weight measurement of gillnets. This chapter gives an overview of the scientific research methods used in the project as well as information about the different theoretical perspectives and approaches in use.

2.1 DATA COLLECTION

Material flow analysis forms the basis for this thesis. In order to develop a realistic model with regard of both physical model design and data input solid data and information is needed. The data has been extracted from public statistics from governmental agencies, commercial companies that handle and use fishnets within Norway, and also scientific papers. Key sources of information has been:

- **NOFIR AS** - Collection and recycling of fishnets
- **General Manager of Nofir Øistein Alexandersen** – Collection and recycling of fishnets
- **Fiskeridirektoratet** - Fisheries statistics
- **Kystverket** - Statistics on collection of derelict gillnets in Norway
- **FAO** – Data on the extent of ALDFG
- **UNEP Regional Seas Report -** Information about environmental impacts and causes of ALDFG, and reducing measures

The data that deal with recycling of fishnets are all collected from NOFIR and is based on their EUfir recycling system. The data regarding recycling rates and information about the processes involved in recycling of fishnets has been from NOFIR's website and trough mail correspondence with the company.

2.2 SEARCH PROCEDURE

A search procedure has been developed in order to find quality information about the subject at hand. The website Oria has been the main source for searching for publications and other literature. The website is a Norwegian joint portal containing written material from Norwegian research institutions Oria gives the user the opportunity to limit the search through the use of binary operators e.g. AND, OR and NOT.

It has been most useful to utilize key words in order to filter out the less relevant publications and articles. Common key words used for finding relevant literature throughout the study have been:

- Ghost fishing
- ALDFG
- Lost fishing equipment
- Lost fishing gear
- Environmental impacts of ALDFG
- Lost gillnets

To further limit the search the use of binary operators has been useful. The search that resulted in providing the most relevant articles was proven to be the combination of "ALDFG" AND "gillnets".

2.3 INTERVIEW

Since there are such uncertainties surrounding the data and estimation of the simulation values there has been some need for quality insurance. During the project I have used NOFIR's expertise to evaluate the MFA-model in regard of the system architecture and the values of the models flows and stocks.

Recycling of fish nets is a specialized task with little information available in scientific papers and publications. NOFIRS is Norway's leading recycler of fish nets and holds valuable information about the subject. NOFIR has been a valuable source of information and the company has been a key factor in the work of data quality assurance and evaluation of the MFA-models system architecture. NOFIR is located in Bodø and because of the geographical distance the interview was conducted over Skype.

2.4 INDUSTRIAL ECOLOGY

Industrial ecology focuses on having a symbiotic perspective on industrial processes (Smith et al., 2015). The main goal of applying such an approach to an environmental and industrial project is to minimize the waste generated and the negative impacts on the external environment. Such a theoretical approach liberates one to find solutions for reuse of e.g. surplus energy and, in this case, material. Industrial ecology invites the user to think holistically on the subject of matter in order to place the investigated subject into a bigger picture, by being aware that the industry and industrial processes are a part of and affect the environment around.

This approach fits neatly into this project since the focus lies on creating a proposed model for estimating the flows of gillnets within Norway and evaluating their potential for recycling. Gillnets that are not recycled tend to either end up on land fillings or, more often, drifting in the oceans. By mapping the different flows and stocks of gillnets one can easier propose strategic ways to recycle and handle derelict gillnets.

By having a holistic perspective approaching on such a task one can combine an industrial way of thinking with an environmental perspective. These two perspectives together puts profits up against the environmental benefits, thus arranging for a solution where one can advocate that gillnets are to be collected and recycled creating both economic and environmental value.

2.5 SYSTEMS THINKING

Systems engineering is a method for development of complex multidisciplinary projects and systems. Systems engineering defines a system as "… integrated composite of people, products and processes that provide a capability to satisfy a stated need or objective"(National Defence, 2001). The approach is commonly used to be able to see the entirety of comprehensive and complex systems and gives the user the opportunity to gain insight into the different parts of the system. Systems thinking however focus on understanding how the different parts of a system influence each other. Systems engineering and systems thinking both involve decomposing systems into smaller parts in order to see how the different parts are interconnected.

The method is naturally used in this project as it provides a systematic way to proceed in order to familiarize with the subject, which is quite comprehensive. A MFA-model is composed of several flows and processes and can become large and complex. A systems engineering approach allows us to see the entirety of the system in light of the sub processes and their respective flows.

2.6 MATERIAL FLOW ANALYSIS

Material flow analysis, more commonly referred to as MFA, is a methodology developed to assess the flows and stocks of goods and materials within a set time and space (Rechberger, 2005). The method was developed to describe the metabolic processes of large and complex systems like cities, religions, nations and industrial companies. By breaking the system into its most basic components and map the interconnections between these one can gain a transparent overview of how the different components are interrelated, and more importantly, it enables the possibility to simulate different scenarios where we tweak the input parameters. MFA is based on connecting processes trough their respective inputs and outputs. The calculation of the system is done by conducting a material balance built on the condition that the all the processes and the system as a whole is at a mass equilibrium (see Chapter 9 Material Flow Analysis (MFA)) (Rechberger, 2005).

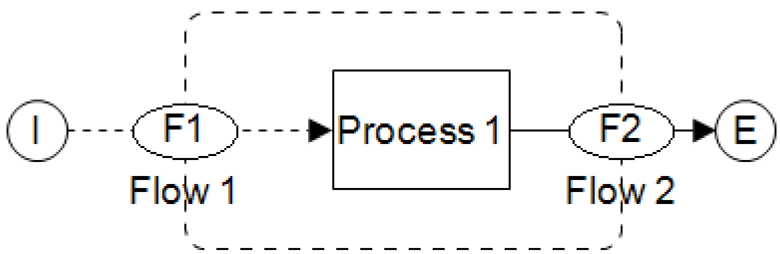

Figure 1: A simple MFA-model with one input flow, one process and an output flow. The stippled line defines the system boundary.

MFA is a tool that is highly suitable in regard of providing a transparent overview of complex systems, such as the mapping of discarded and lost gillnets within Norway. The main advantage of applying MFA on such a project is the systematic approach in setting up the model, the so-called system architecture. The method gives us the opportunity to

- Evaluate the systems sensitivity to changes in flows
- Reduce the complexity of the system
- Evaluate the potential of changes in industrial practices
- Create loop-closing practices

3 ABANDONED, LOST OR OTHERWISE DISCARDED FISHING GEAR (ALDFG)

FAO (UNEP) has defined abandoned, lost and discarded fishing gear (ALDFG) as intentional or unintentional loss of fishing gear and occurs when gear is either abandoned, lost or discarded during fishing. ALDFG has become an increasing problem, and has in the recent years gained international recognition both form the media and governmental agencies due to its diverse ecological and socioeconomic effects. The extent of the issue has become larger in the last 50 years as a result of the increase of fishing on a global extent (Macfayden et al., 2009). Since the world oceans are interconnected the problem is viewed as international calling for international cooperation. This chapter will highlight the distribution and causes of ALDFG as well as provide a brief introduction the environmental impacts associated.

3.1 DISTRIBUTION OF ALDFG ACROSS REGIONS

The ever increasing use of plastics in relationship with both industrial and municipal context generates large amounts of plastic waste which need to be handled to avoid landfill congestion and environmental pollution. Polymers are made to be durable and withstand wear and tear and this constitutes a major hazard to marine life and ecosystems due to their long decomposition time. In 2014 and estimated 4.76 megatons, corresponding to 1.7 % of the annual produced plastics, entered the marine environment (Kellen, 2014), and 10 % of all plastic debris end up in the world's oceans (Bergmann, Gutow, & Klages, 2015). In 2003 an estimated 1.2 billion people lived within 100 km distance to the marine coastline, with an expected increase in migration to coastal areas in the coming years (Bergmann et al., 2015). Estimates of the volume of marine plastic waste are largely made on the basis of what is found on the surface and along coastlines, since this is readily available and easy to collect. But research has found that the majority of the waste is concentrated at the seabed where an estimated 70 % of marine plastic debris sink to the bottom. (Bergmann et al., 2015).

UNEP did in 2009 estimate that 6.4 million tons litter ended up in the oceans, and that fish nets accounted for 10 % (Northern Periphery and Arctic Programme, 2014). In 2014 a marine water sample contained more than six times more plastic material compared to plankton (European Comission, 2015). Research suggests that marine litter reduce around 1 % of the total revenues of the European fishing fleet (European Comission, 2015). Other research suggest this number to be between 2 % and 0.03 % (UNEP, 2014).

The main sources of marine litter are listed as the following (European Comission, 2015):

Land-based activities:

- *Landfills*
- *Rivers and floodwaters*
- *Industrial outfalls*
- *Discharge from storm water drains*
- *Untreated municipal sewage*
- *Littering of beaches and coastal areas*

Marine based activities:

- *Fishing industry*
- *Shipping*
- *Offshore mining and extraction*
- *Illegal dumping at sea*
- *Discarded fishing gear*

Studies has found it difficult, not to say, impossible, to estimate the amount of ALDFG in the oceans stating that there is no exact number on the volume of ALDFG (Macfayden et al., 2009). But a rough estimation done by UNEP states that around 8 million items find it way into the oceans every day (UNEP, 2009). Of these an estimated 5 million can be traced to the shipping and fishing industry (Macfayden et al., 2009).

Some of the reasons why it is difficult to estimate the amount of ALDFG are (Macfayden et al., 2009):

- Deliberate dispose and abandonment of fishing equipment
- Gear loss during illegal, unreported and unregulated fishing (IUU)
- Lack of reporting
- Insufficient management and monitoring
- Lack of standard for recording gear loss
- Poor experimental design on research
- Lack of data regarding absolute/total levels of gear loss

Some research has been done on the matter indicating that about 10 % of all marine litter can be allocated to ALDFG, but very few studies have focused on the causes and rates of gear loss (Macfayden et al., 2009). There are however a few studies that has estimated the magnitude of ALDFG in different regions. In remote areas the fishing and shipping industry can be found accountable for between 50 % and 90 % of the marine debris. The distribution of ADLFG among marine debris across different regions differ and are summarized in table 1.

Table 1: Loss rates of fishnets and fishing gear for selected regions (Macfayden et al., 2009)

Country/Region	Ratio of fish nets	Ratio of fishing gear
Remote areas	n/a	50 % to 90 %
Japan	1 %	11 %
Mediterranean	0 %	0 %
United States of America	n/a	6,10 %
United States of America	n/a	12,70 %
United Kingdom	n/a	11,20 %

Table 1 shows that the loss rates vary between regions peaking in remote areas. Fishing in remote areas leaves the equipment exposed to the environment and often involve fishing in deep waters. The table illustrates a substantial lack of data regarding the ratio of fishnets compared to the more general category of fishing gear.

There has been undertaken studies to assess the volume and magnitude of ALDFG in specific regions including the following (Macfayden et al., 2009):

- **FANTARED 1:** Studying the loss rate of gillnets in United Kingdom, Spain and Portugal
- **FANTARED 2:** Studying the loss rate of gillnets in Norway, Sweden, United Kingdom, Spain and traps in Portugal.
- **DeepNet project:** Deepwater net fisheries in Great Britain, Ireland, Rockall and Hatton Bank.
- **SPC Fisheries Observer Program in South Pacific:** Study with focus on longline Fisheries.
- **International Pacific Halibut Commission Logbooks: Study with the focus on** longline gear.

Some of the findings from these studies are presented in the following chapter 3.1.1.

3.1.1 ALDFG from gillnet fisheries by region

This sub-chapter includes data on the extent of ALDFG from fisheries in Europe, Baltic, Northeast Atlantic, Mediterranean, United Kingdom, France, Spain, Southeast Asia and Pacific.

Europe

A study done by Brown et al, (2005) found the amount of lost fishing nets within European fisheries to be low compared to the amount of nets deployed during fishing, with an estimated loss below 1 % (Macfayden et al., 2009).

Baltic

One has found that gear loss only occurs with the use of bottom-sea gillnets set at open sea. The FANTARED 2 expedition estimated a yearly loss of 1500 nets with the total length of 155-165 km, equal to 3.6-3.8 nets per vessel. The recovery rate was reported to be 10 %. Main reasons for gear loss were conflicts (Macfayden et al., 2009).

Northeast Atlantic from deep-water fisheries

The DeepNet project (Hareide et al., 2005) state that vessels involved with deep-water fisheries often don’t have the capacity to bring their nets back to shore after fishing due to storing of catch. Their research found that shark vessels deliberately discarded around 30 km of fishing nets, on a 45 day tip, due to damage on the equipment. The study estimates a total length of 1 254 km of nets are lost or discarded by shark vessels. From the fishing for Greenland halibut and estimated 750 meters of net was lost per day by the fleet (Macfayden et al., 2009). Table 2 show estimated loss rates formulated by FANTARED 2 from the Norteast Atlantic fisheries.

Table 2: Estimates of loss rates of gillnets in Northeast Atlantic fisheries (Macfayden et al., 2009)

Estimates of gillnet loss in selected Northeast Atlantic fisheries

Region Northeast Atlantic	Fishery	No. of vessels in fishery	Km of net lost (boat / yr)	% loss (nets/boat/yr)	No. of nets lost (per year)
Continental shelf fisheries					
Baltic (Sweden)	Mixed (mainly cod)	...	156	0.10	1 448
North Sea & NE Atlantic (Norway)	Spawning saithe	...	...	0.09	431
	Cod	...	...	0.02	187
	Monkfish	...	...	-	-
	Greenland halibut	...	...	0.04	5
	Blue ling and ling	...	...	0.04	62
UK (all coastal fisheries)	Tangle	18	24	...	263
	Hake	12	12	...	62
	Wreck	26	n.a.	...	...
English Channel and North Sea (France)	Flatfishes & monkfish	...	1.5	0.42	...
	Cod	...	1.2	0.24	...
	Wreck	...	0.4	0.33	...
	Seabass	...	0.8	2.11	...
	Sole & plaice	...	2.8	0.20	...
	Plaice	...	1.1	0.37	...
	Cuttlefish	...	n/a	n.a	...
Brittany (France)	Flatfishes & monkfish	...	5.0	0.50	...
	Spider crab	...	0.3	0.04	...
	Wreck	...	0.2	2.81	...
Cantabria (North Spain)	Red mullet (bottom gillnet)	413	...	...	661
	Hake (bottom gillnet)	309	...	...	556
	Sole (trammel)	217	...	...	195
	Several species (trammel)	215	...	...	774
	Shellfish (trammel)	158	...	...	521
	Scorpion fish (trammel)	111	...	...	100
	Red mullet (bottom gillnet)	79	...	...	600
	Monkfish (bottom gillnet)	74	...	...	2 065
	Hake (gillnet)	59	...	...	159
	Monkfish (trammel)	53	...	...	101
	Inshore species (bottom gillnet)	34	...	...	228
	Shellfish (bottom gillnet)	22	...	...	332
Algarve (Portugal)	Inshore species (gill/trammel)	439	...	...	3
	Coastal (gill/trammel)	64	...	...	6
	Hake (gill/trammel)	22	...	...	7
Mediterranean (France)	Crawfish	...	1.2	1.60	...
	Hake	...	1.2	0.20	...
	Sea bream	...	1.2	3.20	...
	Scorpion fish	...	1.1	1.00	...
	Red mullet	...	0.7	0.50	...
	Sole	...	0.9	0.25	...
	Hake (inshore)	32	...	0.15	13
	Hake (offshore)	65	...	0.20	55
Deepwater fisheries	**N & NW of UK & Ireland**		**1 254**		**25 080**

Mediterranean

A study of the French hake fisheries found that their offshore fleet, consisting of 65 vessels, has been estimated to lose 0.2 % of its nets per year, in numbers between 36 and 73 nets. The costal fleet, consisting of 32 vessels, has the same loss rate, with between 9 to 17 nets per year. Study of other French gillnet fisheries found a loss rate ranging from 0.2 % or 0.7 km of net per boat for mullet, 3.2 % or 1.2 km of net for hake and 1.6 % corresponding to 1.2 km of net per boat for crawfish (Macfayden et al., 2009).

The total quantity of fishing gear lost in the Mediterranean has been estimated to be between 2 637 and 3 342 tonnes per year (Macfayden et al., 2009).

United Kingdom

A study looking at the loss rate of hake, gillnets and wreck nets found the respective loss rate of gillnets to be 5 nets per vessel with a recovery rate of 50 %. Wreck gillnetting had the largest proportional loss rate of 3 % and by lost net length the fishing for flatfish and monkfish with around 5 km of net per vessel per year (Macfayden et al., 2009).

France

A study of French coastal fishing vessels found that less than 0.5 % loss of fish nets and this number also reflects the general loss rates in the region (Macfayden et al., 2009).

Spain

The FANTARED 2 expedition studied the loss rate of 645 vessels and found an average loss of 13.3 nets per vessel. The largest loss rates occurred during deep-water fishing. The findings suggest that large vessels have a greater loss rate than those under 10 meters of length. The main reason for the loss was found to be interaction of trawling gear.

Southeast Asia and western central pacific

There has been little effort to quantify the volume and loss rates of fishing gear in this region whereas the majority of studies only have focused on examining the ratio of fishing gear found in the coastal areas. A study done on the Queensland coastline, under name Carpentaria Ghost Net Programme, found that around 250 kg of fishing net per km coastline (Kiessling, 2003). During their 29 months of collection they collected 73 444 meters of fishing net. The origin of these nets was found to be Taiwanese (17 %), Indonesian (6 %), Korean (6 %), Australian (5 %) whereas 41 % of unknown origin {Kiessling, 2003 and Macfayden, 2009). Each year around 1 000 tonnes of ALDFG are fished up from the ocean in Japan {Inoue, 2002}. In American waters an estimated 0.6 % of all driftnets are lost during use (Macfayden et al., 2009).

Pacific

The Republic of Korea estimated 18.9 kg/ha (kg/10 000 m^2), consisting of 83 % fishing nets and other fishing equipment {Chang-Gu, 2003).

Table 3 contains further values for gear loss from around the world.

Table 3: Overview of loss rates of ALDFG from around the World (Macfayden et al., 2009)

Region	Fishery/gear type	Indicator of gear loss (data source)
North Sea & NE Atlantic	Bottom-set gillnets	0.02–0.09% nets lost per boat per year (EC contract FAIR-PL98-4338 (2003))
English Channel & North Sea (France)	Gillnets	0.2% (sole & plaice) to 2.11% (sea bass) nets lost per boat per year (EC contract FAIR-PL98-4338 (2003))
Mediterranean	Gillnets	0.05% (inshore hake) to 3.2% (sea bream) nets lost per boat per year (EC contract FAIR-PL98-4338 (2003)
Gulf of Aden	Traps	c. 20% lost per boat per year (Al-Masroori, 2002)
ROPME Sea Area (UAE)	Traps	260 000 lost per year in 2002 (Gary Morgan, personal communication, 2007)
Indian Ocean	Maldives tuna longline	3% loss of hooks/set (Anderson & Waheed, 1998)
Australia (Queensland)	Blue swimmer crab trap fishery	35 traps lost per boat per year (McKauge, undated)
NE Pacific	Bristol Bay king crab trap fishery	7 000 to 31 000 traps lost in the fishery per year (Stevens, 1996; Paul *et al.*; 1994; Kruse and Kimker, 1993)
NW Atlantic	Newfoundland cod gillnet fishery	5 000 nets per year (Breen, 1990)
	Canadian Atlantic gillnet fisheries	2% nets lost per boat per year (Chopin *et al.*, 1995)
	Gulf of St Lawrence snow crab	792 traps per year
	New England lobster fishery	20–30% traps lost per boat per year (Smolowitz, 1978)
	Chesapeake Bay	Up to 30% traps lost per boat per year (NOAA Chesapeake Bay Office, 2007)
Caribbean	Guadeloupe trap fishery	20 000 traps lost per year, mainly in the hurricane season (Burke and Maidens, 2004)

3.1.2 ALDFG from gillnets in Norway

A study done in 2004 found that there was a clear connection between the loss rates of gillnets and working water depth. During the fishery for Greenland halibut they estimate a net loss rate of between 0.14 and 0.17 %, summing up to 15 nets per day (Hareide et al., 2005)Figure 5 displays the loss rates of gillnets used for catching, saith, cod, monkfish, Greenland halibut and ling/blue ling by water depth. The graph is prepared with data from Norwegian fisheries.

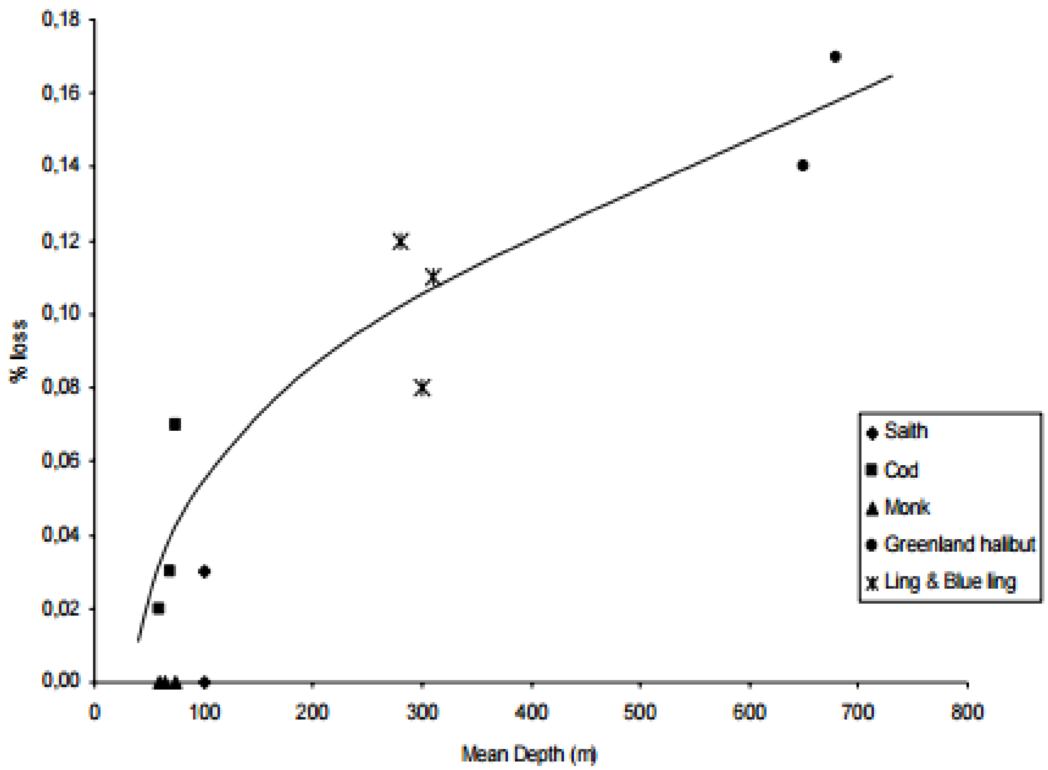

Figure 2: Loss rate of gillnets by depth found in Norwegian fisheries between 1998 – 2000 (MacMullen, 2004)

Figure 2 supports the of higher loss rates at deeper waters peaking at 0.18 % for fisheries for Greenland halibut. The graph shows a steep incline in loss rate from the depths between 40 and 200 meters, moving into a more linear increase in loss rate for water depths under 250 meters.

A general study of the loss rate of fishnets from Norwegian fisheries found that most of the gear loss occurs during offshore fishing, represented by a 0.1 % loss rate The recovery rate was found to be between 80 % and 100 % (Macfayden et al., 2009).

The average % nets lost per boat in the Norwegian region can be calculated by using numbers provided in table 4. The average of loss rates in the North Sea and NA Atlantic is calculated to be 0.059 %. The sum of nets lost per year in the region is calculated to be 680 nets. From these numbers an estimation of the amount of fishnets in use can be derived:

$$\frac{680}{0.000059} \approx 1\ 152\ 5424 \text{ number of gillnets in use by Norwegian fishermen}$$

Table 4: Estimated loss rates of gillnets in Norway in 2005 (Macfayden et al., 2009)

Fish species	% loss [nets/boat/yr]	No. of nets lost per year
Spawning Saithe	0,09	431
Cod	0,02	187
Monkfish	n/a	n/a
Greenland Halibut	0,04	5
Blue Ling and Ling	0,04	62

An extraction form table 4 show that the loss rates are low within Norwegian fisheries. Fishing for spawing saithe tops the list with a loss rate of 0.09 % per year representing 431 nets. All loss rates are found to be below 0.1 %.

3.2 IMPACTS OF ALDFG

ALDFG is associated with a wide range of environmental impacts, affecting both marine wildlife and marine users (Macfayden et al., 2009). One of the main concerns is the influence this has on marine wildlife and the ecosystems in general. The environmental impacts can be summarized to the following (Macfayden et al., 2009):

- Catch of target and non-target species
- Catch or harm to threatened and endangered species
- Introducing toxins to the marine food web
- Physical impact to the benthic fauna

The environmental influences of ALDFG are to a large extent the same posed by the fishing industry in general, and this is only natural since the fishing industry is the primary cause of ALDFG. But at the same time it is only natural to assess the influence the phenomena constitute to the fishing industry itself as well as the problems it poses to the marine users in general. The impacts of ALDFG upon marine users is comprised of damage to vessels, reduced economic income as well as environmental and visual pollution of beaches and sea surface. This can be summarized into three main types (Macfayden et al., 2009):

- Navigational hazards
- Economic casts from reduced catch and entanglement of gear upon vessels
- Pollution of the coastlines

3.3 CAUSES OF ALDFG

Identifying why fishing gear is lost is important in regard of developing mitigating strategies and reduction strategies. The causes for ALDFG are diverse and the causes differ whether they were abandoned, lost or discarded. Studies have shown that the main reasons for the loss, in general, can be summarized to (Macfayden et al, 2009):

- Conflict
- Working in deep water
- Working grounds
- Weather conditions
- Poor quality on gear
- Working with long chains of gillnets
- Working more gear than can be hauled regularly

Reasons for gear to be derelict or abandoned are cause by different external pressures. The most common causes for ADLFG are summarized in table 5.

Table 5: Causes for ALDFG in the cases of whether it is abandoned, discarded or lost (Macfayden et al., 2009)

	Reported reason for gear loss
Abandoned	• IUU fishing • Illegal gear • Too much gear for time
Discarded	• Too much gear for space • Chosen over onshore disposal • Damaged gear
Lost	• Gear conflict • Misplaced gear • Poor ground • Extreme weather

3.4 MEASURES FOR REDUCING ALDFG

Each year large amounts of litter find its way into our oceans through several complex pathways, causing problems to both humans and wildlife. This has in turn made our oceans to the world's largest landfill (UNEP, 2009). The problem is acknowledged global and affects populations all around the world. The international community has recognized the problem and developed a list of activities with the goal of reducing the extent and environmental impacts of ALDFG. These measuers can be devided between measures that prevent, mitigate and cure. The following chapter will highlight the scources and composition of marine litter as well as cover initiatives for reducing stram of litter entering the marine environment.

3.4.1 Preventive measures

Preventive measures aim to reduce the occurrence of ALDFG and are namely composed of gear marking, technology improvements and fish stock and fishing gear management. UNEP (Macfayden et al., 2009) states that there exist national standard for marking fishing gear, but that the majority of these are classified as guidelines. Many countries follow the FAO Code of Conduct for Responsible Fisheries which states that *fishing gear should be marked in accordance with national legislation in order that the owner of the gear can be identified. Gear marking requirements should take into account uniform and internationally recognizable gear marking systems (FAO, 1995).*

The development and use of GPS has enabled the options to digitally trace in which areas fishing vessels operate and this technology is widely used by fishermen to mark the locations of where they deploy their nets. Modern GPS systems have high accuracy often within a few meters. This reduces the risk of collisions between vessels and fishing equipment and loss of gear. When fishers are able to accurately report where the loss occurred it rises the probability of the equipment being found and retrieved (Macfayden et al., 2009). GPS is less often used by vessels operating in coastal areas since these navigate by the help of landmarks.

Onshore collection facilities have been developed to make it easier for fishermen to dispose damaged equipment. This reduces the risk of gear dumping at sea and makes it possible to establish recycling initiatives for fishnets and other fishing equipment. The economic cost of onshore disposal is often low giving fishermen less of a reason to discard their nets into the oceans.

Another way of reducing ALDFG is to reduce the fishing effort in catch intensive areas. By reducing quotas and limiting the amount of gear in use one lowers the likelihood of loss and disposal of gear at sea. UNEP (Macfayden et al., 2009) states that the likelihood of gear loss increases with soak time and that reducing the allowed soak time for static gear, such as fishnets, pots and longlines, can reduce the amount of ALDFG. Another measure mentioned is reducing the allowed water depth fishermen are allowed to set their nets. As shown in figure 2 the loss rate increases with the water depth the nets are set.

3.4.2 Mitigating measures

Mitigating measures have the intention of reducing the chance of gear loss and decrease the impacts lost gear have on the environment. Some research has been done on the use of biodegradable fishnets and anchoring lines. The nets are produced with specialized plastics developed to have a short decomposing time, often down to only a few months. This technology is little used today, and has to be viewed as an opportunity for the future and research is still being done on the subject (Macfayden et al. 2009).

An approach to reduce the incidental catch of non-targeted species such as seabirds, cetaceans and turtles, is focused on the design of the fishing net. The nets are equipped with acoustic beacons, often referred to as “pingers”, and light reflectors. These devices sends out small signals of sound and light enabling the animals to avoid the nets. The effectiveness of these devices rely on a steady supply of electric power (Macfayden et al.).

3.4.3 Curative measures

Curative measures refer to efforts of recovery and disposal of fishing gear in a legal way by enhancing the awareness of the fishermen of the possibilities that exist within gear retrieval and land disposal. The aim of utilizing a curative approach in order to reduce the amounts of ALDFG is to implement initiatives that make it easier to discard out-of-date and damaged equipment in a environmental and socially acceptable way. Due to the high count of purchasing new equipment fishermen are often highly motivated to recover lost gear, but in many cases such recovery is not possible due to strong ocean currents and poor marking. There has been developed standardized reporting systems through collaboration between the fishing industry and authorities, which allows for better mapping of the extent of gear loss (Macfayden et al., 2009). This allows for the implementation of gear retrieval programs. An example of such project is Fishing for Litter which is covered in chapter 6.4.2 Norwegian Incentive. Gear retrieval are governmental funded and can been seen as a direct measure towards reducing the amounts of drifting fishing gear.

Disposal and recycling is one of the more recent initiatives implemented. Technological development within recycling has made it economically sustainable to recycle fishnets and an example of such practice is studied in more detail in chapter 8 Recycling of fishnets. Recycling of fishnets is characterized by private-public collaboration with the compilation of new standards and regulations (Macfayden et al., 2009). By offering deposit boxes in harbors and making disposal free of charge one seeks to lower the threshold for disposing equipment on land rather than illegally at sea (Macfayden et al., 2009). Deposit boxes are now being offered in some harbors in Norway and a presentation of the solution is provided in chapter 9 Recycling of fishnets.

4 GLOBAL FISHING INDUSTRY

The fishing industry is said to be a key factor in reducing world hunger and poverty due to the economic and nutritious value of fish (FAO, 2014). The global fish production has in the recent years had a faster growth than the global population increase and this is expected to continue in the coming years (FAO, 2014).The Food and Agriculture Organization of the United Nations (FAO) proposed an estimated global reported production of 93.8 million tons in 1996 and 93.7 million tons in 2011 showing a stagnation in the global production from fisheries and aquaculture (FAO, 2014). Marine fisheries employ a large multitude of people worldwide and has had a rapid growth in the recent years. FAO found that an estimated 58.3 million people where engaged in the industry in 2012, of these about 18.9 million worked within aquaculture (FAO, 2014).

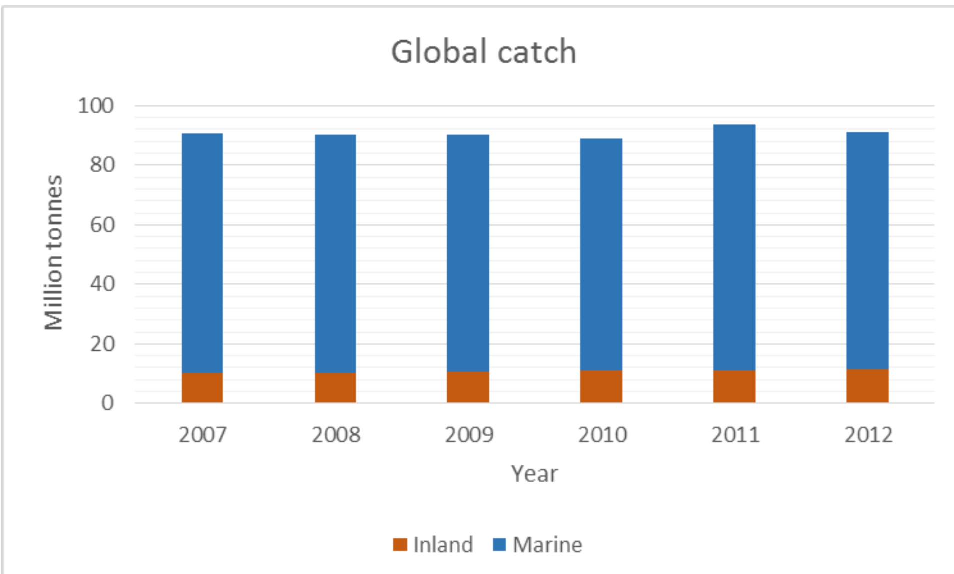

Figure 3: An overview of the global catch from both inland and marine fisheries (FAO, 2014).

In 2011 the global marine fish production reached 82.6 million tonnes whereas 18 countries stood for over 76 % of the catch. The total catch in the European region was in 2016 7 919 000 tonnes {eurostat, 2016). One has is the recent years sees a decline in the fish stocks all over the planet due to overfishing, and this is reflected in the decline of catch in the Northern Atlantic and Black Sea (FAO, 2014).

4.1 ENVIRONMENTAL IMPACTS

The environmental impacts of fishing are many and complex and can be traced in both a molecular level as well as affecting whole ecosystems in more visual ways trough entanglement and indigestion. The activity of fishing has been found to be followed by altering marine habitats trough gear entanglement with organisms and bedrock damaging the sea-bed and well as disturbing the dynamic of the ecosystems trough noise pollution posing stress and change in the behavior of the marine wildlife. In turn there has been observed an absent return of spawning species in heavily exploited regions (FAO, 2014).

Modern commercial fishing is characterized by large vessels and equipment designed to catch substantial amounts of fish. Equipment and fishing methods have been developed through hundreds of years and have become so effective that we now catch more fish than the planet is able to produce. The industry has had a profound negative effect on the global fish stocks and overfishing has resulted in a decline in the marine biomass (FAO, 2014). An example worth mentioning is the collapse in stock of Norwegian herring at the end of 1980s. The biomass of caught herring plummeted from around 9 000 to 3 000 hectoliters in the years between 1973 and 1987. The stock has in the recent years increased shown in the catch in 2012 of 9 400 hectoliters (Flåten & Skonhoft, 2014).

One of the more direct and evident consequences posed by the industry is the catch of non-targeted species. The incidental catch of endangered species is said to be one of the main reasons contributing to the extinction of i.a. dolphins and turtles (Garcia, Zerbi, Aliaume, Do Chi, & Lasserre, 2003). It is often difficult for the fishermen to avoid catching non-targeted species due to the use of large-scale equipment like purse seins, gillnets and trawls. This equipment is designed to cover large areas of water and does not distinguish between commercially targeted species from non-targeted species. The catch of non-targeted species is often followed by illegal dumping at sea where the fishermen discard the catch in order to avoid fines and penalties set by the regulatory authorities (Garcia et al., 2003).

5 NORWEGIAN FISHING INDUSTRY

The Norwegian fishing industry have long traditions in Norway and has trough time sustained families economically and provided a stable source for food. One can trough time observe a high amount of innovation in both equipment and vessel-design. We can today observe the results of these innovations as automated fishing machines and net haulers, GPS-navigation and mapping, and echo sounding. The fishing industry is still, to this date, of high value for the Norwegian economy and employs considerable number of people including the ripple effect surrounding the industry. The following chapter will give an historical overview of the development of the industry and also provide insight on how the fishing is conducted.

5.1 CATCH AND QUOTAS

A quota is defined as the upper number of fish you are allowed to catch within one season of fishing. Quotas are assigned once a year and are based on the size of the specific fish stock. The quotas are worked out in collaboration between marine research, interest groups and national and international agencies. Figure 4 provides and overview of how the Norwegian fish quotas are assessed and further defined.

Figure 4: Compilation of show how fishing quotas are decided (Fiskeridirektoratet, 2012)

The basis for establishing sustainable quotas is created through marine research where monitoring and estimating future spawns constitutes the information input regulating agencies and governments utilize for defining quotas. The International Council for the Exploration of the Seas (ICES) and Advisory Committee of Fishery Management (ACFM) act as global councils producing advisory global quotas for the global fishing industry. These quotas are defined for each respective nation through negotiations, and represent the total allowed catch (Sørensen et al.) for the nation. The national quota for Norway is prepared in collaboration with neighboring countries to the

Norwegian EEZ. Between 80 and 90 % of the Norwegian fish stocks are shared with other countries (Fiskeridepartementet, 2002). The quotas are distributed between fishing methods and commercial and recreational fishing, where commercial fishing represent the majority.

Over 29 species of fish and mollusk are fish after under governmental regulation (Fiskeridirektoratet, 2015a). In 2012 the total catch done by Norwegian fishermen was 2 136 769 tons and has increased with around 200 000 tons from 2012 to 2015 with an annual catch of 2 334 394 tons (Fiskeridirektoratet, 2015a). Statistics from 2015 place the catch of pelagic species on top with a total caught biomass of 1 330 884 tons led by blue whiting with a catch of 489 439 tons. Pelagic species includes the species of mackerel, herring, brisling, capelin, Norway Pout and blue whiting. An reported 710 920 tons of cod fish was reported landed where 422 267 tons where allocated to cod. The defined national quota for cod was 414 920 tons in 2015 (Fiskeridirektoratet, 2015b). The harvest of seaweed and kelp has laid steady at around 150 000 tons in the years between 2012 and 2015 (Fiskeridirektoratet, 2015b).

5.2 COMMERCIAL FISHING GEAR

The fishing methods used by the Norwegian fishing fleet is as diverse as the number of species they harvest. The Norwegian vessel fleet is made up of a number of different types vessel types with regard of length and type of fishing equipment they have onboard. The different fishing methods used to catch the most common species of fish are summarized in table 6 and 7. Table 6 shows the most commonly used fishing methods used for catching pelagic species and table 7 undertakes to display the methods preferred to catch bottom fish species.

Table 6: Fishing methods divided by their usage on catching pelagic fish species (Aasjord, 2010). Gillnets are marked in the color red.

	Fishing methods							
Fish species	**Fishing rod**	**Drifting longline**	**Drifting nets**	**Bottom nets**	**Trolling lines**	**Danish seine**	**Purse seine**	**Pelagic trawl**
Atlantic salmon	x	x	x	x		x		
Trout	x	x	x	x		x		
Tuba	x	x					x	
Mackerel			x		x		x	x
Herring			x	x		x	x	x
Capelin							x	x
Sprat							x	x

Table 6 shows that several fishing methods are used to catch each specific species. Capelin and Sprat display a narrow use of equipment with the use of only purse seine and trawl. The species targeted by the use of gillnets are Salmon, Trout, Mackerel and herring where the use of drifting nets seem to be the most preferred method.

Table 7: Fishing methods divided by their usage on catching bottom fish species (Aasjord, 2010). Gillnets are marked in the color red.

	Fishing methods								
Fish species	**Fish pots**	**Hand lines**	**Longlines**	**Drifting nets**	**Bottom nets**	**Trolling lines**	**Danish seine**	**Purse seine**	**Bottom trawl**
Atlantic halibut			x		x		x		
Greenland halibut			x		x				x
Turbot					x		x		x
Plaice					x		x		x
Wolffish			x						x
Redfish					x		x		x
Anglerfish			x		x				x
Cod	x	x	x		x		x	x	x
Saithe		x	x	x	x	x	x	x	x
Haddock			x		x		x		x
Pollack					x	x			x
Ling					x				x
Tusk	x		x						

Bottom nets top the list over the most used type of gillnet used for targeting bottom species. Bottom nets are represented in all species except wolfish and Tusk. Drift nets are only evidently used in the catch for Saithe and Coalfish. These two species can be found in all layers of the ocean and are fished after using every represented method except fish pots.

Both table 6 and 7 shows an extensive use of trawl and seine. These fishing methods can be characterized as active methods providing a haul at site and are often preferred when targeting shoals of fish.

5.3 A HISTORICAL FLASHBACK OF THE NORWEGIAN FISHERIES

"The fish in the ocean, that is our bread"

– Petter Dass-

The first Norwegian settlers found the Norwegian coastline to be rich on fish and other wildlife. They learned to utilize the natural resources, and fishing quickly became the main way for harvesting. The first known export of dried cod, often referred to as the famous clipfish, and herring found place around year 1100, whit the basis of winter cod from northern Norway. By the 1300s the German Hanseatics gained control over the export of Norwegian clipfish which at that time got exported to central and southern Europe (Hallenstvedt, 2014).

The 1800s is characterized by prosperity. The export price of Norwegian fish tripled within the years 1840 – 1880, which in turn enhanced the industries recruitment. Due to an over-population of fishermen the industry experienced an economic downturn which set the ground for technological innovation within the fields of vessel design and fishing equipment. In the beginning of the 1900s there were no motorized fishing vessels in use, but in 1914 we find 2500 registered motorized vessels used during the fishing for winter cod outside Lofoten (Hallenstvedt, 2014).

5.4 Regulatory Agency - The Norwegian Directorate of Fisheries

The Norwegian Directorate of Fisheries, hereby known as Fiskeridirektoratet, was established in the year 1946 as the first of its kind (Hallenstvedt, 2014). Before this the agency had acted as the industries occupational agency. Today one of their main tasks are to ensure the external conditions for profitable and sustainable fisheries in Norway, together with being responsible for manage the registration of Norwegian fishing vessels (Fiskeridirektoratet, 2014). The Norwegian fishing vessels in occupational use have to register in “merkeregisteret” with both the name of the owner and technical data. Merkeregisteret also include information concerning. In order to use the vessel for commercial fishing the owner must have a permit from the fishery authorities (Fiskeridirektoratet, 2014).

Over 90 % of the Norwegian fish stock is regulated trough international co-operation (Fiskeridirektoratet, 2015a). Fiskeridirektoratet calls attention to the fact that Norwegian fishermen catch in both Norwegian and international waters which in order calls for co-operational fish stock management adjoining nations (Fiskeridirektoratet, 2015a). This is also reflected in tradable quotas between nations.

Fiskerdirektoratet participate in several organizations including:

- **North East Atlantic Fisheries Commission (NEAFC):** *Acts as the Regional Fisheries Management Organization (RFMO) for the North East Atlantic (NEAFC, 2011).*

- **Northwest Atlantic Fisheries Organization (NAFO):** … *Intergovernmental fisheries science and management organization that ensures a long-term conservation sustainable use of the fishery resources in the Northwest Atlantic (NAFO, 2016)*
- **Commission for the Conservation of Antartic Living Recources (CCAMLR):** The organizations main task is to conserve Antarctic marine life. The Commission has 25 members which in agrees on how the marine resources are to be used and conserved (CCAMLR, 2015).
- **International Whaling Commission (IWC):** The organization works towards conserving the international whale stocks trough catch limits, whale sanctuaries, protection of calves and females and restrictions in hunting methods (IWC, 2016).

5.5 NORWAY'S EXCLUSIVE ECONOMIC ZONE (EEZ)

Norway's EEZ is defined within 200 nautical miles from the Norwegian shoreline. Within this area the costal state has an exclusive legal right to exploit, manage and preserve the natural resources, this includes those found on the seabed, subsurface as well as in the water (Helgesen, 2009). Figure 5 shows the geographical borders of the Norwegian EEZ.

Figure 5: Overview of the Norwegian Exclusive Economic Zone (Sojtaric, 2008)

The fishery zone around Jan Mayen and protection zone around Svalbard constitute for around six times the area of continental Norway (Fiskeridepartementet, 2002). The zone represent the geographical investigated with the regard of estimating the mass of gillnets in use by the Norwegian fishing fleet.

5.6 THE NORWEGIAN VESSEL FLEET

The Norwegian vessel fleet has undergone a substantial transition in vessels both regarding size and onboard technology. According to a report prepared by Sintef back in 2010 the fishing fleet has moved towards fewer and larger and more effective vessels (Aasjord, 2010). This statement is supported by the statistics that show a decline in the number of vessels between 2010 and 2015 from 5443 to 5097 (Fiskeridirektoratet, 2016b).

The Norwegian fishing vessels are divided into two groups, namely inshore and offshore vessels. Inshore vessels are often smaller vessel with lengths up to 28 meters. These vessels have received larger holds with increased capacity and the older vessels have been replaced with larger more modern ones. Offshore vessels are large ships over 28 meters long made to withstand rough weather out in the open seas. The number of such vessels has declined with the decline of operating revenues (Aasjord, 2010). Table 8 shows the number of registered fishing vessels distributed for each length class.

Table 8: The number of active Norwegian fishing vessels divided into length class (Fiskeridirektoratet, 2016a)

Vessel length [meters]	Number of vessels
< 10	2530
10 -	1432
11 -	646
15 -	139
21 -	114
28 -	236
Sum total	**5743**

The majority of fishing vessels are located in the northern parts of Norway in the counties Troms (677 vessels), Finnmark (832 vessels) and Nordland (1 370 vessels). The counties of Buskerud, Oppland and Hedmark have no registered active vessels on record. This can be explained by their geographical location in inland Norway with no connection to the marine coastline. Of the total number registered vessels 5097 had a recorded economic income. Numbers from the Norwegian cod fisheries tells that the average catch per vessel using gillnets where around 22.3 tons in year 2008 (Aasjord, 2010).

In 2009 there was completed an profitability analysis of a sample of 1 776 Norwegian fishing vessels. Of these and estimated 1 317 vessels, or 74 %, fished using conventional equipment as longline and gillnets mainly targeting bottom fish. All the vessels were under 28 meters of length. (Aasjord, 2010).

From this we can derive a estimation for the number of vessels using gillnets as their main fishing method in 2016 by multiplying the sum of number of vessels under 28 meters, found in table 8, with 74 %. This gives an estimated 3 598 vessels.

6 GILLNETS

Fishnets are the general notion including gill nets, fish farm nets, trawls, fish pots and fish traps. The idea behind these contraptions are to either to entangle the fish or keep them confined inside the pots. The following chapter will focus on gillnets, mainly types and regulations regarding use of gillnets. The chapter is concluded by highlighting the subject of ghost fishing and the efforts taken to reduce this phenomena.

6.1 TYPES OF GILLNETS

Gillnets work by the simple, yet effective, principle of entangling fish in a net made of thin plastic wire. The wire is often almost invisible when submerged in water making it hard for the fish to detect. There are different types of gillnets designed to catch specific types of fish. Gill nets are designed to both catch the fish and select which type of fish to catch. The selection of fish type is determined by mesh size and net-design – larger mesh size for catching larger fish. The different net-types are distinguished trough length, height and mesh size. Mesh size is measured form knot to knot (Norges Fiskeforbund, 2016).

Gill nets can be divided into several groups including, bottom and floating nets, gill net with and without knots and twisted gill nets. The two last categories are usually only used by the producers of the nets, so we will focus on the two main groups used by the fishers, namely bottom nets and floating nets.

Table 9 displays the most common gillnets used in Norway and their characteristics regarding mesh size and the type of plastic in which they are made. Plastics are examined in more detail in chapter 7.

Table 9: Tabell including the most common gillnets used in Norway (Hareide et al., 2005)

Type of gillnet	Characteristics
Trollgarn	• Large-meshed bottom net • Most commonly made of nylon
Gillnet for cod	• Large-meshed bottom net • Most commonly made of nylon
Gillnet for Pollack	• Large-meshed bottom net • Most commonly made of nylon
Fjordgarn	• Middle size meshed bottom net • Not in use for commercial fishing
Gillnet for herring	• Small-meshed floating/bottom net
Gillnet for mackerel	• Small-meshed drift net
Gillnet for flatfish	• Large-meshed bottom net Commonly 1 meter of height
Crab net	• Large-meshed bottom net
Gillnet for anglerfish	• Large meshed bottom net • Commonly 4 meters of height

Of the above mentioned net types only gillnets designed for use on coalfish and Pollack, herring and mackrell can be classified as floating nets since they are designed to target fish that thrive in the upper layers of the ocean. The fishing industry is interested in maximizing the tonnage catch and target larger fish types. This is also reflected in the table 9 since the majority of the gillnets large-meshed.

The physical design of a gillnet is quite simple. At the top of the net one can find the so-called floating line. The rope is equipped with floatation rings with the main task of keeping the net vertical in the water. The bottom of the net is made up of so-called sink rope, or regular plastic wire with metal weights holding the net stationary. Mooring lines are on each side attached to a piece of anchoring stretching maintaining he horizontal profile of the net. At the surface buoys are used to mark the beginning and the end of the installation. In the use of very long nets several buoys can be used. A visual illustration of a common setup for gillnet is shown in figure 7.

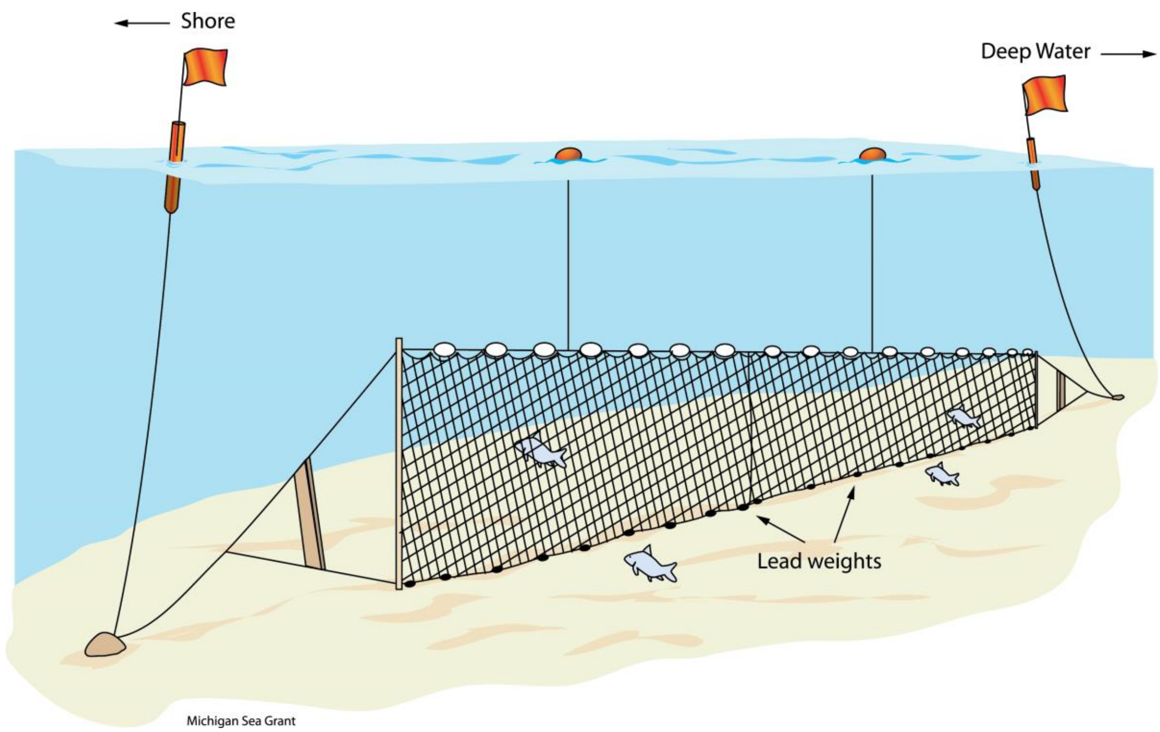

Figure 6: A figure showing the practical placement of a gillnet (Grant, 2012)

Gillnets are often used in longer chains of nets in order to cover larger areas (Hareide et al., 2005). The length of these installations can stretch several km in length making them exposed for strong currents. This will in turn increase the chance of damage on the gear.

6.2 REGULATIONS FOR USE OF GILLNETS IN NORWAY

Regulations for the use of gill nets is stated in two categories, namely private and commercial use. In order to protect the most heavily targeted fishing ground the Norwegian regulations are quite strict with regard of when and where the nets can be set. Regulations for **private use** include (Norges Fiskeforbund, 2016):

- In the period between 1. Mars including 30. September all gillnets with mesh size larger than 32 mm shall be set minimum 3 meters under the surface (Does not apply for commercial use).
- Maximum length of gillnet allowed is 210 meters
- All stationary fishing gear has to have an ownership mark including owners name and address.
- Preservation zones are to be respected

Regulations for commercial use (Norges Fiskeforbund, 2016):

- All stationary fishing gear has to have an ownership mark showing the vessels registration number.
- Preservation zones are to be respected
- Requirements for tendering of gill nets:
  - Gillnets used for cod above 62ºN has to be mended daily
  - Gill nets used for anglerfish and halibut shall be mended minimum every third day
  - Gill nets used for Norwegian halibut, blue ling, white ling and Norway haddock above 62ºN shall be mended minimum every second day.

The geographical border of 62ºN can be seen in figure 8.

Figure 7: Map showing the mark of 62ºN

- Vessels using stationary equipment and fishing for Norwegian halibut above 62ºN, as well as vessels using gill nets for anglerfish is obliged to report to The Norwegian Coast Guard about:
  - Placement of gill net
  - Pull of equipment after fishing

Table 10 shown the number of reported lost fishnets by Norwegian fishermen between 2004 and 2015.

Table 10: Number of gillnets reported lost by Norwegian fishermen from 2004 to 2015 (Kystvaktsentralen, 2015)

Year	Reported lost fishnets
2004 - 2005	8
2006 - 2007	12
2009 - 2010	15
2010 - 2011	26
2011 - 2012	156
2012 - 2013	312
2014 - 2015	279

There are also special ownership mark regulations on fishing more than 4 nautical miles from the Norwegian coastline and inside the Norwegian Exclusive Economic Zone. This fishery is labelled as offshore fisheries and embrace a stricter and more comprehensive body of rules and guidelines. For this kind of fishing the fishing gear must be equipped with a radar reflector, reflection tags and lighting. The legal framework indicate that the distance between the ownership marks shall not exceed 1 nautical mile for stationary equipment, and 2 nautical miles for drift nets. Drift nets with a length over 1 nautical mile must have buoys with light reflecting color between the ownership buoys (N.-o. fiskeridirektoratet, 2005).

If one lose equipment during fishing one is obliged to search and attempt a recovery of the missing fishing gear. When equipment is impossible to recover one has to report the matter to Kystvaktsentralen. The reporting shall include information about (N.-o. fiskeridirektoratet, 2005):

- The fishing vessels name and call signal
- Type of equipment lost
- Amount/quantity of equipment lost
- Time and date that the loss occurred
- Position/coordinates for where the loss occurred

When equipment in entangled one is obliged to reduce the damage as much as possible, and involved parties are to be contacted immediately after the incident. All equipment that is broken and hauled is to be brought to land and disposed responsibly (N.-o. fiskeridirektoratet, 2005).

6.3 GHOST FISHING

Ghost fishing occurs when abandoned, lost or discarded fishing equipment continues to catch marine organisms after they were initially lost. The issue caught attention in 1985 under the 16th Session of the FAO Committee on Fisheries and has in the recent years received increased focus. The phenomena is of a worldwide concern and occurs in all areas where fishing happens.

6.3.1 Catch rates of ALD gillnets/ghost nets

One of the main concerns regarding ALDFG is the continued catch of marine organisms after the initial loss. This can occur over longer periods of time where ALD gillnets continue to catch marine organisms, often over several years. The effectiveness of the catch for gillnets after their initial loss is determined by:

- The location/Sea bottom type
- Weather in set location
- Net design
- Changes in the transparency of the net
- The accumulation of catch in the gillnet

Catch by gillnets set at sea bottom and open ground

Due to heavy anchoring and entanglement around rocks nets set on deep waters have been found to maintain their vertical profile in the water over of time. When the anchoring line is thorn off the nets tend to drift into rocky formations which in turn act as a natural mooring point. The nets set in these areas to degrade after a rather short time due to wear and tear from the elements. Research has found the catch rates to decline to almost zero after 6 to 12 months.

Nets set on open ground has been found to have a fast decrease in catch due to reduced net height and degradation (Macfayden et al., 2009). The nets are often set in the in the upper layers of the water and this calls for the use of long mooring lines connecting the net to the anchoring. Longer lines involves a natural higher risk of tear due to tension put on the line from ocean currents and waves. When the anchoring lines break it frees the net to get entangled in itself reducing the potential for catch.

Catch rates by different types of ALD gillnets

The continued catch of ALD gillnets vary between type of net, location and species targeted. Research has concluded that ALD gillnets on deep waters (below 500 meters) have a higher catch rate over a longer time period compared to nets found in the upper layer of water. The continued catch rate of ghost nets is also dependent on which species of fish they are designed to catch as well as the concentration of fish in the area (Macfayden et al., 2009). Table 11 shows the catch efficiency, compared to a net in commercial use, over a given time period for various types of gillnets. It acts as a summary of the findings stated by Macfayden et al. (Macfayden et al.). The catch efficiency of ALD gillnets compared to initial catch is found to decline over time often stabilizing at between 0 and 5 % from respectively driftnets and bottom-set gillnets.

Table 11: Synthesis of catch efficiencies and stabilizing time for gillnets stated by Macfayden (Macfayden et al.). The catch efficiency and stabilizing catch rate is measured relative to the expected catch of a similar in-use net that is supervised.

Net type	Location/area	Time period of study	Catch efficiency	Stabilizing time	Stabilized catch rate
Gillnet	Open seas	4 weeks	90 %	n/a	n/a
Gillnet	Open seas	4 weeks	50 %	n/a	n/a
Cod gillnet	Baltic sea	3 months	20 %	27 months	5 -6 %
Bottom-set gillnet	n/a	n/a	n/a	142 days	5 %
Gillnet	Near shore	n/a	15 %	n/a	n/a
Gillnet	Shallow water	15 - 20 weeks	n/a	8 - 11 months	0 %
Trammel net	Shallow water	4 months	20 %	n/a	n/a
Trammel net	Celtiberian region	135 days	90 - 100 %	224 days	0 %
Deep-water gillnet	Norwgian coast	45 days	20 - 30 %	Several years	n/a
Pelagic drift net	n/a	4 months	Close to 0 %	A few days	Close to 0 %
Gillnet for Greenland halibut	Norway	n/a	n/a	3 - 3 years	n/a

6.4 REDUCING THE LOSS AND RECOVERY OF FISHING EQUIPMENT

This sub-chapter will describe the international initiative Fishing-for-litter and is concluded by presenting the Norwegian governmental project of collection of fishing gear.

6.4.1 Fishing-for-litter

Fishing-for-litter is an initiative initiated by the Local Authorities International Environmental Organization, known as KIMO, in August 1990. The organization is composed of local costal authorities from United Kingdom, Sweden, Denmark, The Netherlands, Belgium, Lithuania, Estonia, Germany, Faroe Islands and the Isle of Man. The project seeks to remove the litter from the seas as well as communicating the importance of waste management to the local fishing fleets in the North Sea. The organization provides the fishermen with bags so that the worn out fishnets, and other litter that is caught during fishing, can be discarded in an environmentally friendly way (KIMO International, 2013)

6.4.2 Norwegian initiative

The Norwegian Directorate of Fisheries have since the early 1980s carried out yearly missions collecting ALD gillnets from Norwegian coastal waters. In 2015 the haul was conducted in the area between Runde (Møre- og Romsdal) and Vardø (Finnmark) and collected over 800 fishnets of different types, in addition to 4 000 meters rope, 20 000 meters longline and 3 000 meters of steel wire (Fiskeridirektoratet, 2015b). The amount of fish found in the nets varied, dominated by Greenland halibut. Research show that gillnets have a substantial effect on the Norwegian fish stocks from latent harvesting. All lost fishing equipment constitute an increased risk of vessel entanglement and further loss of fishing equipment.

The project has collected over 18 000 gillnets in the period between 1983 and 2014, together with a diversity of other fishing equipment. The search operation and collection has been coordinated through reporting from fishermen and dialog with central and governmental administration agencies. The administrative regulations for commercial fishing states a demand for reporting of lost fishing equipment to the Norwegian Coast Guard if the respective fishing vessel is unable to haul or find the lost gear. The amount of fishing gear hauled during the 2015 mission is displayed in table 12. The average yearly haul for the years 1990 to 2015 has been calculated to be 656 nets. The haul of gear between the years 1990 and 2015 can be found in Appendix 1.

Table 12: Amount of hauled fishing gear in Norway in 2015 (Fiskeridirektoratet, 2015b)

Item	Amount
Gillnet	815 nets
Rope	4000 m
Fishing line	20 000 m

The vessel used in project is a combined purse sein/trawl vessel. The vessel is equipped with specialized grapnel designed for the purpose of snagging fishnets. A picture of the equipment is shown in figure 9. The vessel is equipped with 3 grapnels connected to a steel wire with length of 1.3 to 2 times the water depth trawled. In areas where the seafloor is composed of a lot of rocks only one grapnel is used. The wire is then coupled with a chain between the grapnel and wire to reduce the risk of tear.

Figure 8: Grapnel used during trawling for lost fishnets in Norway {Fiskeridirektoratet, 2015)

6.5 THE WEIGHT OF A GILLNET

Little of no data had been found displaying the mass of gillnets. The reason is that there is no interest in the matter from fishermen or the industry in general since the loading capacity of the fishing vessels given in volume and space rather than mass.

The weight of a gillnet varies with the size of the net (length x height), mesh size and the type of thread the nets is produced the length and high of the net can vary even within the same net type du to different design and producers. It is therefore difficult to both find numbers and estimate the general weight of a gillnet only using data provided by the producers. There was there for carried out a practical experiment of weighing gillnets found in the storage area of a local shallow water fisher located in the village of Aure on the western coast of Norway. 8 different nets were weighed using an analog bathroom scale. The different nets were found to weigh between 2 kg and 22 kg.

The average weight of the nets was found to be 10.6 kg. The results from the experiment can be seen in appendix 2.

The weight found in this experiment is probably too low to be representable for the gillnets used by larger fishing vessels operating offshore. And the result should be seen as a lower estimate the mass of a gillnet.

7 PLASTICS

Polymers are the scientific conception for the most widely used material today, namely plastics. This material is easily formable to desired shapes, cheap to produce and durable, and is without doubt the most versatile material we know of to date. Plastics inhabit a wide range of application both for industrial and domestic purposes. The material can be found in almost any product from milk cartons, shoes, cars, computers, fishnets etc. These are only a few examples of the many uses of this versatile material. Since 1995 the plastic production has doubled to a global production volume of 311 Mt in 2014 (Statista, 2016). This chapter highlights the usage and production of plastics and is concluded by a scientific approach looking at the material properties.

Plastics production has increased substantially from 1.7 million tons in 1950 to 311 million tons (Statista, 2015), with a yearly increase of about 8.7 % (UNEP, 2014). Europe accounted for 20 % in 2013 and 19 % in 2014.

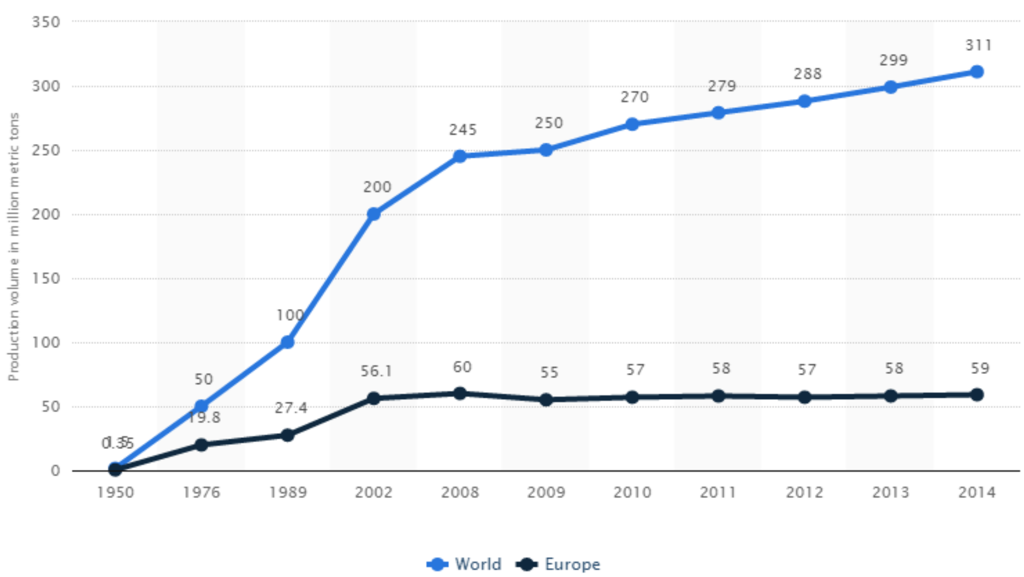

Figure 9: Plastics production worldwide and Europe from 1950 to 2014 (Statista, 2016)

As shown in figure 3 China was, in 2013, the main producer (24.8 %) followed by Europe (20 %) and North-America (NAFTA) (19.4 %).

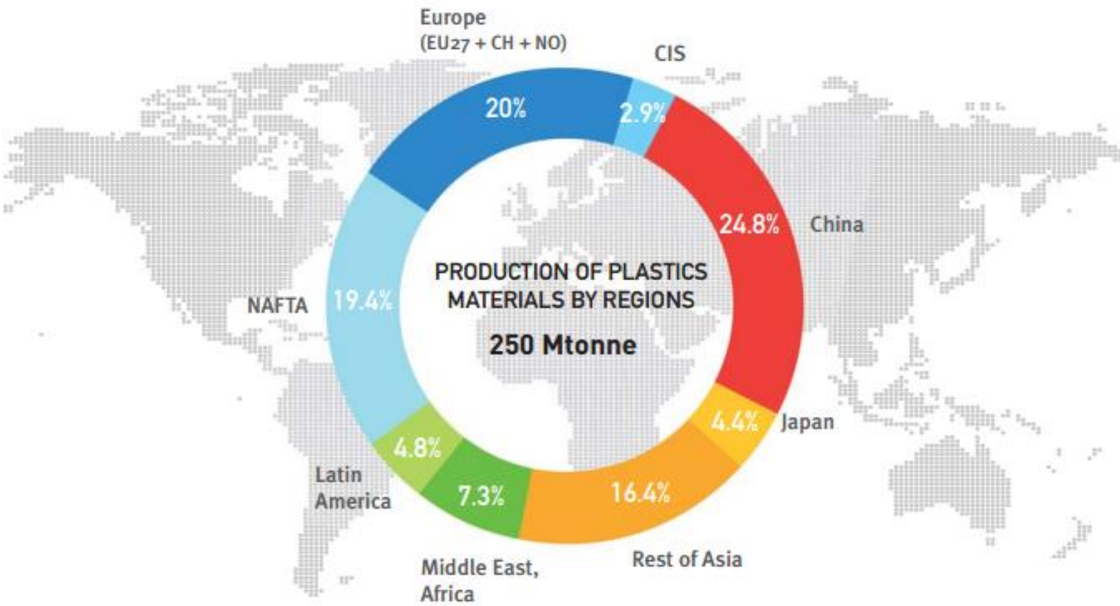

Figure 10: Global plastics production by region (thermoplastics and polyurethanes) in 2013 (Europe, 2015)

7.1 PRODUCTION PROCESS OF PLASTICS

Today we can find a multitude of different plastics produced for assorted products. The production process of plastics starts with the distillation of crude oil. The oil is broken down to lighter fractions known as hydrocarbon chains. The oil is distilled into hydrocarbon chains which get cracked into monomers. Cracking refers to the process of breaking up large hydrocarbons into smaller parts (Clark, 2003). Monomer inhabit the property of bonding with other monomers creating long chains of polymers, thus funding the base for the production of polymer materials, referred to as plastics (Christensen, 2011).

Polymers are long-chained molecules that can be entangled, in solution or in solid state, into structures and fibers (Mark, Allcock, & West, 2005). This enables the production of strong and elastic materials which are durable and hard to break down naturally.

There are two main processes used to produce plastics, namely polymerization and polycondencation (PlasticsEurope, 2016). Polymerization refers to the process of combining monomers chemically into long chained polymers. There are two types of polymerization in use today (Mark et al., 2005):

Condensation polymerization: The process is based on separation producing a by-product e.g. water. Polycondensation refers to the process of *a gas or vapor to liquid or solid form (Ecyclopedic Dictionary of Polymers, 2007).* The expression polycondensation is used when the process is used to create a polymer.

- Addition polymerization: Utilizes a catalysts which enables control of the chemical properties.

The fundamental chemical compounds in plastics production are ethylene and polypropylene. By the use of a catalyst these hydrocarbons react and create polymer chains (PlasticsEurope, 2016).

Plastics are divided into two main groups based on their behavior to thermal exposure, namely thermoplastics (Linear polymers) and thermoset plastics (Cross-linked polymers). Characteristic material properties for each of the plastics groups are listed as the following (Christensen, 2011):

Thermoplastics

- Dissolve in specific liquids
- Can be re-melted when exposed to the right pressure and temperature
- Are chemically stable (Does not melt or evaporate) over a large temperature range
- Known for their flexibility. This is due to their chemical structure of long chains of polymers

Thermoset plastics

- Resistant to heat and chemicals
- Robust when exposed to mechanical force
- Known to be hard to recycle due to the materials low temperature range
- The material is hard and durable. The material gets is stiffness from the having a grid structure. Not as flexible as thermoplastics.

Both thermoplastics and thermoset plastics consist of a number of specific types of with unique structural abilities. Table 13 gives an overview of the different types of plastics associated with the two main groups of thermoplastics and thermoset plastics.

Table 13: Plastic types divided by thermoplastics and thermoset plastics (PlasticsEurope, 2016)

Thermoplastics	Thermoset plastics
Acrylonitrile butadiene styrene (ABS)	Polytetrafluoroethylene
Polycarbonate (PC)	Phenol-formaldehyde
Polyethylene (PE)	Epoxide
Polyethylene terephthalate	
Polyvinyl chloride	
Polyomethacrylate	
Polypropylene	
Polystyrene	
Nylon	

7.2 PLASTIC USAGE

Plastics have a dominant role in our society and the material can be found in almost every household. The use of plastics have shad a substantial growth the recent years and this phenomena is predicted to persist in the coming years. Its applications range from building materials, packaging, consumer products, furniture, electronic components, medical products, oil spill recovery and others (Mark et al., 2005). The primary end-use markets are packaging (30 %) and building and construction (28 %). Followed by consumer goods and electrical applications (Mark et al., 2005).

The demand for plastics are mostly due to their low production cost the fact that they are easy to mold into desired products (Aguado & Serrano, 1999). The material enables production of lightweight products that with *...high corrosion resistance and long degradation rates* (Aguado & Serrano, 1999). The material properties of the material can be altered to meet the desired requirements of the manufacturer. This enables unlimited possibilities for use.

Several different types of plastic material are produced which are used for different products and can be summarized as the following (Aguado & Serrano, 1999):

Thermoplastics

- **Polyethylene (PE):** Used in films, food containers, toys gas tanks, pipes, plastic bags, bottles and cable insulation etc.
- **Polypropylene (PP):** Used in pipes, carpet textiles, bottles, toys and as coating material etc.

- **Polystyrene (PS):** Used in toys, electronic components, packaging, building insulation, food containers etc.
- **Polyvinyl Chloride (PVC):** Used in pipes, floor coverings, toys, films and tubing, raincoats etc.
- **Polyethylene Terephthalate (P, M, & C):** Used in the manufacturing of fibers, film bottles etc.

Thermoset plastics

- **Unsaturated polyester (Smith et al., 2015):** Used in fiberglass and pipes.
- **Epoxide (EP):** Used for surface coating and as an adhesive in laminates and composites.
- **Polyurethane (Andres, Georg, & Philip, 2015):** Used in foam-products and for thermal insulation.
- **Phenol-formaldehyde 0(Pfrang-Stotz, Reichelt, & Roos, 2000):** Used in the production of Bakelite. Bakelite is used in billiard balls, countertops etc.

8 RECYCLING OF FISHNETS

Nofir AS, also known as Norsk Fiskeriretur AS, is the leading recycler of fishing and aquaculture equipment in Norway. The company was established in 2008 as a response to the lack of environmentally friendly recycling and disposal of plastic equipment from the marine industries (Nofir, 2016). Today Nofir has divisions in Lithuania and Canada. The following chapter highlights the recycling practices of fishnets in Norway using the EUfir model developed by Nofir. The chapter is concluded by a introduction to some of the recycling methods used to recycle fishnets.

8.1 INDUSTRIAL EXAMPLE - NOFIR AS

Nofir AS, hereby referred to as Nofir, is a Norwegian based recycler that specializes on recycling discarded equipment from fisheries and aquaculture (Nofir, 2016). The company collects fish nets and fish farm nets which are transported to subsidiary companies for processing, and collection is free of charge. Fish nets collected in Norway and Canada are transported to Lithuania while nets collected in Marocco are sent to Turkey for further processing (Nofir, 2016). In 2015 the company collected and recycled 5699 tonnes of material and reduced CO2-emissions by 20 516 tonnes CO”-equivalents compared to the production of virgin material (Nofir, 2016). The company is the main recycler of fish nets in Norway and has the leading competence on the subject.

Nofir AS has been the main information source used to extract knowledge on how fish nets can be recycled in an industrial scale. The information has been gained through telephone interviews with the companys general manager, Øistein Aleksandersen. This information forms the basis for the preparation and design of the flow diagram shown in figure 10.

Nofir has been the main source of information on how fish nets can be recycled in an industrial scale. The information has been collected through telephone interview with their general manager, Øistein Aleksandersen and from their web site. The information forms the basis for the preparation and design for the recycling in the MFA-model.

8.2 RECYCLING OF GILLNETS USING THE EUFIR-SYSTEM

Nofir has published a Life Cycle Assessment (LCA) of the EUfir-system. The EUfir-system was developed as a result of the EU funded project by the name *A European system for collecting and recycling discarded equipment from the fishing and fish farming industry* with the goal of developing a sustainable system for recycling and collection of fishing equipment in the European region (Nofir, 2014). According to a LCA done for Nofir an estimated 114 000 tons fishing gear is legally discarded each year in Europe and an average 640 000 tons are lost at sea world wide (Nofir, 2014).

Nofir recycles ropes, fish farming nets and nets, trawl, purse seins and gillnets. In 2015 the company recycled around 200 tons fishnets in total, this including all of the companies operational regions. Of the total input 76 % is recycled, 2 % reused and 22 % end up as waste. It is unclear what happens to the waste, but some of it is sent to incineration while a portion is stored at the plant. The output from the process are 70 % PA6 (Nylon), 20 % PP and PE, 5 % lead and 5 % steel. Around 10 % of the fishnets are found to be not recyclable together with around 10 % the belonging flotation rope accounting for around 40 tons yearly (Aleksandersen, 2016). Fish farming nets contain copper impregnation that to date cannot be recycled (Nofir, 2014). The company have no exact number on the amount of waste sent to landfill, but estimates this number to be low.

Fish nets are collected directly on piers or at specific collection points, so called reception cites. Current reception cites and collectors are located in northern Norway (Aleksandersen, 2009):

- Iris Produsksjon
- Lofoten Avfallsselskap IKS
- Conteinerservice Ottersøy
- Ascas Miljø AS
- Nordmiljø AS
- Senja Avfall

A few ports and marinas have established collection containers that fishermen can use to get rid of their unwanted fishing nets, and Nofir are often in direct dialog with local fishermen whom wish to dispose their equipment. Before the fish nets can be collected they have to be cleaned, fractioned and packed in accordance with Nofir standards. In order to transport collected fishnets from Norway to the recycling plants in central Europe with profit, the company always seek to maximize the trailers cargo. This also reduce the environmental impacts per kg recycled material.

The nets have to manually sorted to ensure that the sorted material is free of visual contaminants like kelp and clusters of algae. According to Aleksandersen (Aleksandersen), the fishnets collected in Norway gets sorted and washed when they arrive at the sorting plant in Lithuania.

The collected fish nets contain residue of mooring lines and other rope when they are collected. The rope and fish nets are made of different types of plastic and have to be recycled separately in order to ensure a homogeneous end product. The rope is in most cases made from polypropylene while the nets are made from nylon. These to types of plastic require the use of different recycling methods. The ropes are sent to be recycled mechanically ending up as granules, or pellets. These are further sold to manufacturers. The nylon nets are preferably recycled chemically, where they are broken down to the most basic building block for nylon, namely caprolactam. The caprolactam is used for producing nylon 6, and is sold to producers of raw nylon (Aleksandersen, 2015). Desired recycling methods for the types of plastic handled by Nofir is summarized in table 14.

Table 14: Gill net material composition, recycling process and end-product (Aleksandersen, 2009)

Input product	Plastic	Recycling method	End-product
Gillnet	Nylon (PA6)	Chemical	Caprolactam
Rope	Polypropylene	Mechanical	Polypropylene granules or pellets
Fishnet and rope	Nylon and polypropylene	Incineration	Heat and electricity

Both chemical and mechanical recycling requires a homogeneous input composed of only one type of polymer. Sorting is therefore viewed as a highly important part of the overall process (Aleksandersen, 2015). Some parts of the nets can be found unsuitable for recycling and sent for energy recovery (Aleksandersen, 2015).

Ropes and cordage are sorted manually where contaminants and un-recyclable sections are taken out. Exposure to UV-light and salt water breaks down the polymer on a molecular level making it less appropriate to recycle (Aleksandersen, 2015). Including wearied out material to the recycling process will affect the end-product negatively and lower the quality. The wearied sections are sent to energy recovery. According to Aleksandersen (Aleksandersen), around 2 % of the collected ropes are reused. Due to strict requirements demanding certification of ropes for industrial use, the majority of the reused ropes are used for private purposes (Aleksandersen, 2015). The ropes are made of polypropylene and are naturally sent to mechanical processing and end up as granules or pellets which are re-sold (Aleksandersen, 2015).

Figure 10 is a flow diagram made to show the main routes for fishnets and rope used by Nofir. The flowdiagram is designed from information gathered trough Nofir and includes the most common processes used for recycling.

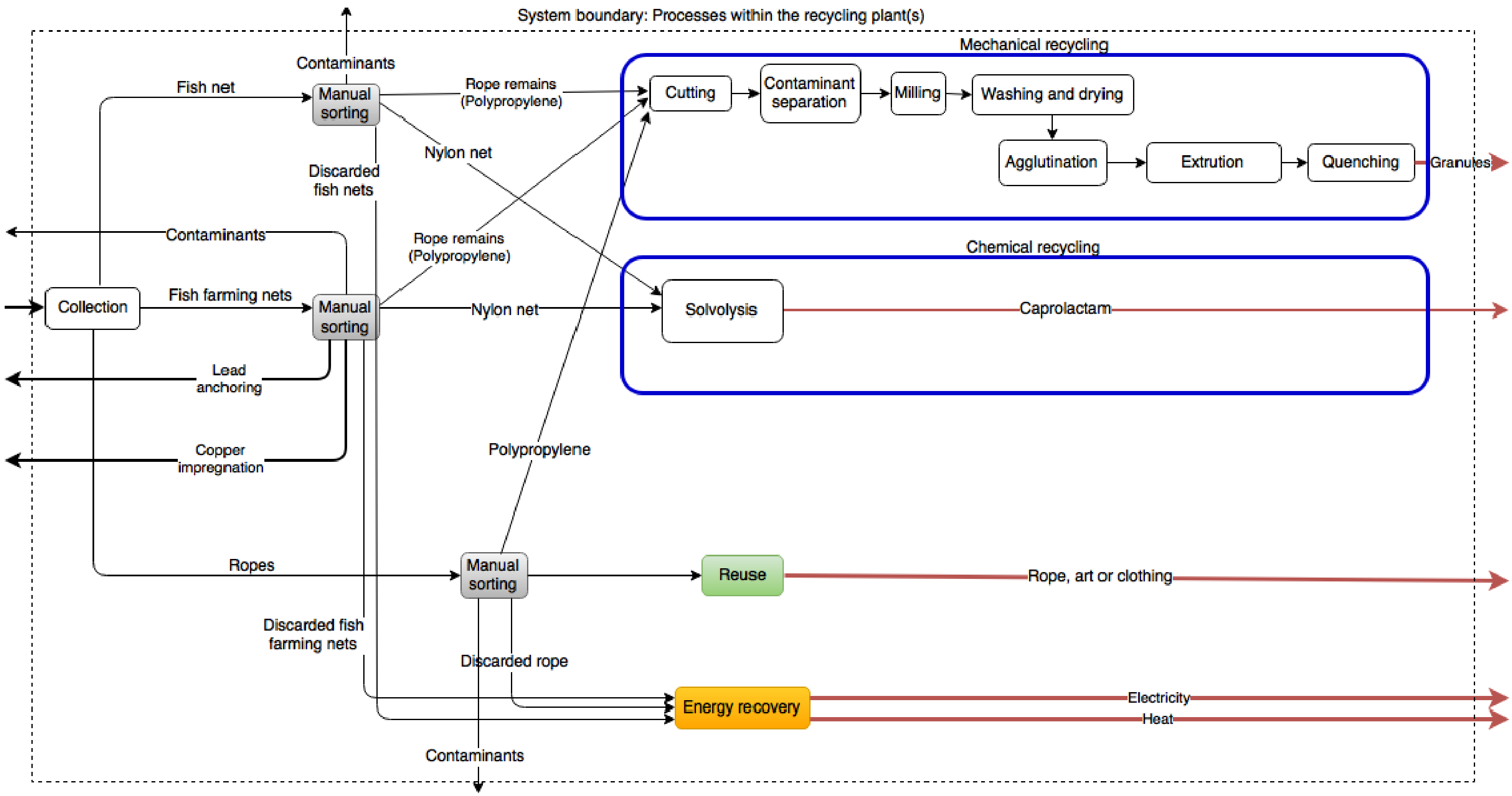

Figure 11: Flow diagram showing the flows of materials and recycling processes in the EUfir system

As displayed in figure 11 the nylon nets can be recycled trough two main routes, that being mechanically or chemically. The chemical route does not include the different sub processes, as displayed in mechanical recycling, since the process of solvolysis varies with temperature and pressure.

The process of material sorting is, in the model, shown as three separate processes. In reality all sorting is done as one process at a designated sorting facility. By dividing sorting into minor sub processes one gets a more transparent view of the different inputs and outputs making it easier to understand the connections between the separate material inputs.

Energy recovery is seen as a more direct way of utilizing the waste converting it into heat or electricity. The method is preferred in preference to incineration which only generates the output of ash.

9 MATERIAL FLOW ANALYSIS (MFA)

The Material Flow Analysis is composed of the aspects of material-flow accounting, data estimation and quantification of flows and stock. The following chapter focuses on the development of the MFA-model and the results from the scenario modelling.

9.1 DEVELOPMENT OF THE MFA MODEL

The main tasks of building a MFA-model involve data gathering and model design/layout. The model has been designed to be to visualize and calculate all mass flows from acquired gillnets to recycled material. In order to be able to evaluate the potential of the current recycling system there has been developed scenarios that are compared to a reference scenario.

The reference scenario is designed to reflect the current state of the system and assumes that the gillnets are recycled in accordance with the EUfir-system. The calculations for the reference scenario are shown in chapter 9.3 Quantification of flows and Stocks. The model displays a best-case-scenario, showing the potential for recycling of gillnets utilizing the EUfir-system that is described in chapter 8.2 Recycling of fishnets using the EUfir-system. The model assumes that all material input is gillnets, and disregards rope, fish farming nets and trawl.

9.2 SCENARIO MODELLING AND RESULTS

In order to compare the potential upside by optimizing the base model it is appropriate to include scenarios. Scenario modelling gives the opportunity to explore the limits of the system at study and, more specific, find opportunities to maximize the recycling rate. Beside the reference scenario, the study examines two scenarios:

- **Reference scenario:** This scenario reflects the estimated current mass of gillnets in Norway and assumes that all collected gillnets are recycled using the EUfir-system. The flow diagram for the scenario is shown in figure 13.
- **Scenario 1:** No fishnets are discarded to ocean. This implies setting flow F2 Fishnets discarded to ocean to 0.
- **Scenario 2:** No fishnets discarded to ocean, setting flow F2 Fishnets discarded to ocean equal 0, and reducing the flow of material to incineration to a minimum setting flow F9 Sorting to incineration equal 0.

Both scenarios include a constant uptake of discarded gillnets from the ocean, as collection of lost gillnets is evaluated to be necessary in order to reduce the existing stock of ghost nets. Scenario 1 and 2 represent the extremities within the system by reducing gear loss into the ocean to a minimum as well as reducing the waste generation form recycling to zero.

Scenario 1 is developed under the assumption that new policies and incentives are implemented into the fishing and recycling industry, making it easier and less costly to discard fishnets on land. The scenario also includes the assumption of technological development regarding marking of gear and increased robustness of gillnets making them less vulnerable for tear under use.

Scenario 2 include the same assumptions as scenario 1, as well as including an expectation of process optimization for the recycling process that reduces the waste generated to a minimum. Some of the gillnets that are collected today are found to be unrecyclable due to structural damage of the material. The scenario displays the potential of developing new and improved recycling technology making even the most damaged material recyclable.

Table 15 shows the results of the simulations including the above mentioned scenarios compared to the base scenario based on the existing EUfir system. Deviations from the reference scenario are marked in the color red.

Table 15: Results from scenario simulation.

Flow		Reference scenario	Scenario 1	Scenario 2
Symbol	**Name**			
F1	New fishnets	2920	2797	2797
F2	Fishnets discarded to ocean	123	0	0
F3	Fishnets storage	2797	2797	2797
F4	Fishnets collected from ocean	6.95	6.95	6.95
F5	Fishnets collected for recycling	2803.95	2803.95	2803.95
F6	Fishnets sent to sorting	2803.95	2804	2804
F7	Sorting to reuse	56.08	56.08	56.08
F8	Sorting to incineration	616.87	616.87	0
F9	Sorting to landfill	0	0	0
F10	Sorting to recycling	2131	2131	2747
F11	Recycling to incineration	0	0	0
F12	Recycling to landfill	0	0	0
F13	Recycled fishnets	2131	2131	2747
F14	Land to incineration	0	0	0
F15	Land to landfill	0	0	0

Figure 13 shows the MFA-model that is used to simulate the flows of gillnets within Norway, and displays the calculated values for the reference scenario.

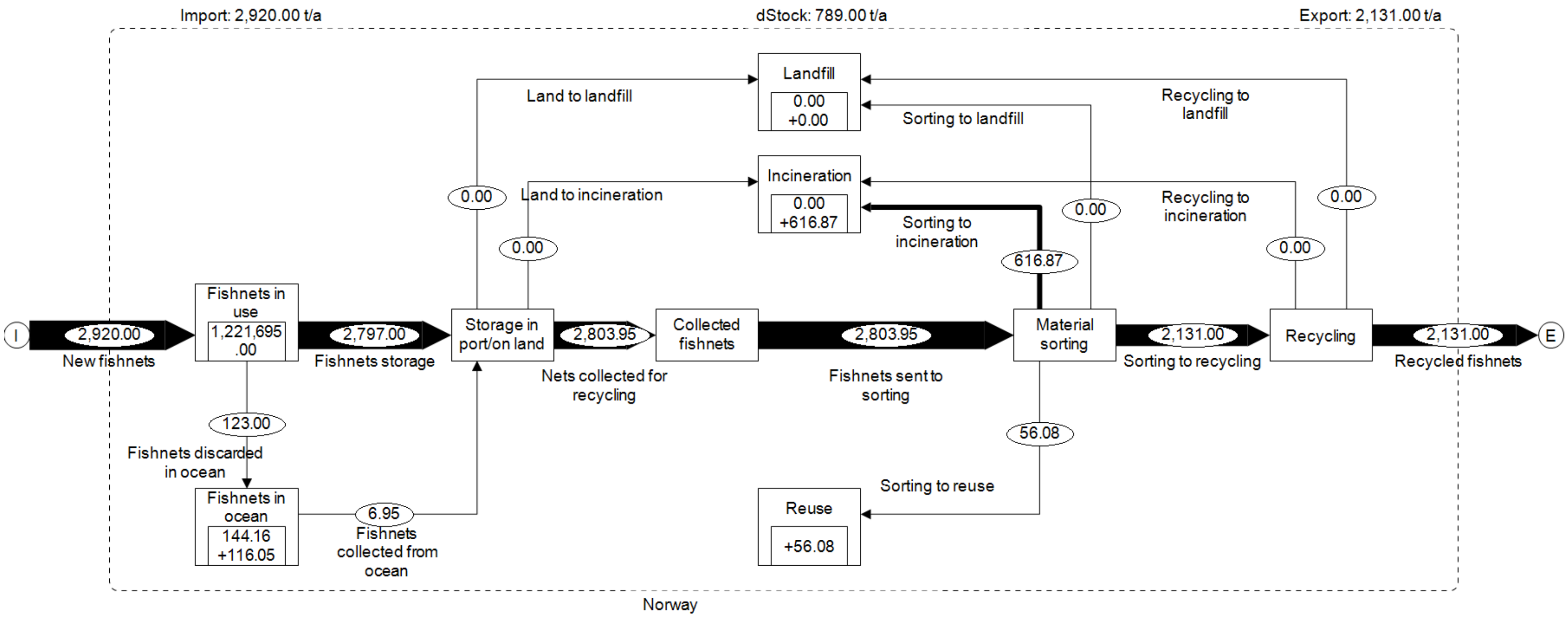

Figure 12: MFA-model of the reference scenario with calculated value

9.3 QUANTIFICATION OF FLOWS AND STOCKS

The model displayed in this subchapter contains the calculated values for the base scenario. All flows and stocks are given in the unit tons. The quantifications are based on estimates gathered by previous studies and the calculations include a mix of these. All numbers used are found in this report.

Table 16 contain all parameters used to calculate flows and stocks and table 17 shows the equations used for calculating the flows. Table 18 include the calculations for the stocks Following table 16 a description is added explaining the reasoning for the choice of parameters used in the calculations for the base model including flows and stocks.

.For transparency only single letter symbols are used for the parameters.

Table 16: Parameters used in the MFA-model

Symbol	Parameter discription	Value
a	% gillnets lost/boat	0.059
b	Number of fishingvessels in 2015	5097
c	Tones catch by Norwegian fishermen	2 136 769
d	Tones catch	7 919 000
e	Tons legally discarded fishing gear	114 000
f	Tons lost fishing gear worldwide per year	640 000
g	Weight of a gillnet in tons	0.0106
h	Pcs of gillnet gathered from ocean/yr	656
i	% collected gillnets reused	2
j	% collected gillnets recycled	76
k	% of collected gillnets waste	22
l	% of collected from sorting to landfill	0
m	% of collected from recycling to landfill	0
n	% of collected gillnets from recycling to incineration	0
o	Fishnets in use by Norwegian fishermen	11 525 424
p	% gillnets sent to landfill from storage	0
q	% gillnets sent to incineration from storage	0
r	No. nets lost per year in North sea and NE Atantic	680
s	Estimated weight of a gillnet	0.0106

F1 New fishnets

For the input flow of new fishnets we assume that all nets lost or discarded have to be replaced by the fishing fleet in order to maintain the productivity capacity of the Norwegian fishing industry.

F2 Fishnets discarded to ocean

The flow is calculated with the assumption that the total number of fishnets lost by the Norwegian fishing fleet is 680 net per year, with a loss rate of 0.056 %.

F3 Fishnets to storage

The calculation is based on numbers from Nofirs LCA stating a total of 114 000 tons fishing gear is legally discarded each year in Europe. This not only include gillnets, but also other fishing gear which makes the estimated amount higher than it should be.

F4 Fishnets collected from ocean

The calculation is wholly based on the average uptake of fishnets done by Fiskeridirektoratet between 1990 and 2015, assuming the numbers provided are accurate.

F5 Fishnets collected for recycling

The flow is the sum of fishnets collected from ocean and fishnets found in storage. We assume that all collected and stored fishnets are sent to recycling.

F6 Fishnets sent to sorting

This flow is equal to F5. It acts as a output for the process by the name *Collected fishnet.* The process is included to highlight that the fishnets have to be collected from the storage on land to be sent to sorting.

F7 Sorting to reuse

The calculation is based on the stated reuse rate of 2 % found in Nofirs LCA.

F8 Sorting to incineration

The calculation is based on the stated rate of waste of 22 % found in Nofirs LCA. Here we assume that all waste from the sorting process is sent to incineration/energy recovery. Nofir has stated that 10 % of the gillnets are found to be unrecyclable, but in order to have coherent numbers the LCA from Nofir is used as a reference throughout the simulation.

It is important to point out that the company does not do any sorting within Norway, but in order to present a transparent model of the recycling system it is natural to display and add the flow in the simulation.

F9 Sorting to landfill

As we don't have any detailed information about what happens to the waste, we assume that all waste is sent to incineration. This process is viewed as more environmentally friendly compared to landfilling and it is reasonable to assume this is the preferred end process for the waste.

F10 Sorting to recycling

This is a plain mass-balance of the inputs and outputs in to the process of Material sorting.

F11 Recycling to incineration

The calculation is based on the assumption that all waste material is taken out in the process of Material sorting. There has not been found any data on the amounts of waste material generated in the process of Recycling and we therefor assume a 100 % recycling rate after the material is sorted.

F12 Recycling to landfill

Same reasoning as for flow F11 Recycling to incineration. Assuming a 100 % recycling rate after the material is sorted.

F13 Recycled fishnets

The calculation is a plain mass-balance of the process Recycling.

F14 Land to incineration

Nofir has stated that there are no numbers on the amounts of gillnets sent directly from land storage to incineration, and they assume that the number is low. The leakage from storage to incineration is therefor set to be 0 %.

F15 Land to landfill

Same argument as stated for flow F14 Land to incineration. The leakage from storage to landfill is set to be 0 %.

Table 17: Equations for flows with calculated values

Symbol	Flow name	Equation	Calculated value [tons]
F1	New fishnets	F2+F3	2920
F2	Fishnets discarded to ocean	(s/a)*o	123
F3	Fishnets storage	(e*(c/d))	2797
F4	Fishnets collected from ocean	i*g	6.95
F5	Fishnets collected for recycling	F4+F3	2803.95
F6	Fishnets sent to sorting	F5	2803.95
F7	Sorting to reuse	F6*j	56.08
F8	Sorting to incineration	F6*l	616.87
F9	Sorting to landfill	F6*m	0
F10	Sorting to recycling	F6-(F7+F8+F9)	2131
F11	Recycling to incineration	F10*o	0
F12	Recycling to landfill	F10*n	0
F13	Recycled fishnets	F10-(F11+F12)	2131
F14	Land to incineration	F3*r	0
F15	Land to landfill	F3*q	0

P1 Fishnets in use

From earlier we have calculated an estimated number for fishnets in use by Norwegian fishermen. P1 is found by multiplying number of fishnets in use with the average weight of a fishnet.

P2 Fishnets in ocean

The calculation of the stock is calculated for 20 years back in time.

The calculations for stock P2 and P3 are shown in table 18.

Table 18: Equations and values for premade stocks

Stock symbol	Name	Equation	Value [tons]
P1	Fishnets in use	p*t	122169.5
P2	Fishnets in ocean	s*t*20	144.16

10 RESULTS AND DISCUSSION

In this chapter includes a discussion of the results on the extent and reasons for ALDFG, recycling practice of gillnets and the results for MFA-modelling. The chapter is concluded by presenting limitations and validity of the study as well as presenting a proposal for further work on the research area.

10.1 EXTENT OF ALDFG

With regard of the focus ALDFG and ghost fishing has received from the international and national Norwegian authorities little data support reasoning for large amounts of gear loss. If we compare the recovery rates in different regions we find a high variation in values. With estimated loss rates under 1 % and high recovery rates, European fisheries can be found to be quite good at reducing the probability of the occurrence of gear loss and hold high standards in fishing responsibly. Nevertheless, the findings from the study show fluctuating values regarding gear loss. In a world wide perspective the European and Norwegian fisheries, in particular, have very low loss rates followed by incomparable recovery rates nearing 100 %. This may be the result of strict regulations from the European authorities regarding marking of gear and quota regulations, thus reducing the pressure on pressured fishing grounds and therefor limiting the amount of gear in use.

When we evaluate the Norwegian fisheries one find strict regulations regarding use of gillnets in Norwegian coastal regions. The regulations are tightened in the most pressured areas in the northern part of Norway with regulations stating that, among others, gillnets used for cod have to be mended and supervised on a daily basis. Since cod is one of the most fished after specie within coastal Norway, it is reasonable to assume that the loss rates for cod-fisheries are low compared to offshore deep-water fishing. The loss rate of fishing equipment, is in figure 2, shown to increase with the operational water depths, peaking at a loss rate of 0.18 % for fisheries for Greenland Halibut. The loss rates for Cod is stated to be between 0.02 and 0.07 %. The assumption that cod represents a lower loss rate is through these numbers strengthened.

The study has reviled that the amount of gear loss is found to increase with vessel size. The reasons for this connection has not been stated, but some reasoning can be made through deduction. Larger vessels are designed to operate in rough marine environments at open sea and makes them exposed to bad weather. Fishing in remote areas also involve deploying the gillnets at large water depths.

The combination of weather conditions and deep waters may be the reason for the connection between vessel size and equipment loss.

Table 1 reveals a lack of data on the ratio of fish nets among the amounts of fishing gear that is lost. Although implying that the amount of fish nets among ALDFG may be quite low with ratios between 0 and 1 %. The only study proposing an estimate for the mass of fishnets from marine litter was done on the Pacific region. The study found 15.7kg/10 000km^2 of fish nets in the coastal waters, corresponding to 83 % of the ALDFG in the area. No such estimates has been found for Europe or Norway. The low loss rates and the high recovery rates within European fisheries may be the main cause for the lack of research on the subject as the issue may be perceived as irrelevant or non-existing.

Several measures to reduce the amount of gear loss have been mentioned, but the potential environmental gain of these actions have to be discussed more in detail. Since the recovery rate within European and Norwegian fisheries lay between 80 and 100 % it implies that the fishermen are able to locate the gear and recover it. This means there will be little to gain in improving the marking of the fishing gear. It is therefore more appropriate to focus on the end-of-life disposal of the gillnet, namely onshore disposal and recycling. This is further discussed in chapter 10.2 Recycling of gillnets.

10.2 RECYCLING OF GILLNETS

Nofir has established collaborations with several harbors in northern Norway offering a environmentally friendly way of discarding old gillnets. One of the main issues of the existing system is the high cost of gear disposal. By offering the fishermen the opportunity to deliver their damaged and worn out gear at harbor one can lower the motivation for dumping the gear at sea. This can in turn ensure a steady and predictable flow of gillnets which in turn can provide the necessary motivation for establishing a national recycling industry based in gillnets. Gillnets are often made from the same material, namely nylon, requiring little preparation trough material sorting. The main objective of sorting is to separate the nets from the cordage and the process is perceived to be costly. The necessity for material sorting could be reduced by instructing the disposer to separate rope from the nets before they are delivered for disposal. This could in order lower the overall cost of recycling making the industry more profitable.

Creating a recycling system for gillnets has to include the 4 processes storage, collection, sorting and recycling. In order to be able to collect discarded nets one need to establish collection sites near the harbors where the vessels are located. By reducing the effort a fisher has to expend in order to dispose discarded equipment one lowers the threshold for utilizing land-based collection sites. The process of collection includes transport to the designated sorting facility, and is key factor on making the stored nets available for the recycler. Waste material is normally generated during sorting or recycling, and I consider the potential for process improvement to be found in these two processes. Developing new technology that can recycle material we today view as waste can improve the recycling rates drastically as Nofir stated that 22 % of the input material end up as waste and is sent to incineration and energy recovery. The waste consists of contaminated lead, copper and unrecyclable fish nets and roping. As chemical recycling is the preferred method for recycling it is reasonable to propose that the solution may be found trough chemical research.

10.3MFA AND SCENARIO MODELLING

The MFA-model suggests an annual gear loss, caused by Norwegian fishermen, of 123 tons accompanied with an estimated annual gear recovery 6.95 tons. This shows that the amounts of gear lost or illegally discarded is much higher than the amounts that are hauled resulting in a accumulating stock of drifting gillnets in the ocean. The model propose a total mass of gillnets in use of 122 169.5 tons. The accumulated stock of ghost nets is estimated to be 144 tons. The stock ghost nets in the ocean is only slightly larger than the yearly inflow of lost gear. One would expect the accumulated stock to be a lot larger than the yearly inflow. This inconsistency is most probably caused by the use of incoherent data.

The MFA-model shows that the, reference scenario, representing the EUfir-system, gives a recycling rate of 76.4 % corresponding to 2131 tons recycled material. The input material to recycling is composed of a combination of disposed nets and collected ghost nets from the ocean summed up to be 2790 tons. The model suggests that the fishing fleet acquires approximately 2920 tons of new gillnets each year, and of this around 2803 tons are sent to material sorting. From material sorting an estimated 56.08 tons are reused and 616.9 tons end up as waste. The waste represents 22 % of the collected gillnets and consists of steel anchoring, steel wire and floatation line. These by-products all consist of recyclable materials providing the existing system a huge potential of improvement. In scenario 2 we examined the potential of recycling these waste products.

All material from storage is sent to material sorting, and as the figure 12 shows, there is only one flow with numerical value flowing in to incineration. This implies that the only process that generates waste is the process of *Material sorting.*

Scenario 1 displays what happens if there does not occur any loss of equipment, setting flow F2 Discarded fishnets to ocean, equal 0. This corresponds to a 100 % recovery rate of lost gear. The stock of ghost nets in the ocean will decrease and descend towards zero thus eliminating the problem of ghost fishing. With a constant annual haul of 6.95 tons of gillnets from the ocean, it will take about 21 years to get rid of the ghost net-stock. This presuppose that Fiskeridirektoratet and Fishing-For-Litter is able to find all the ghost nets that exist in Norwegian waters which can be advocated to somehow unrealistic and a unattainable goal.

Scenario 2 is designed to show what would happen if there does not occur any loss of equipment during fishing and we reduce the waste from recycling to zero. The flow F9 Sorting to incineration has been added to the flow of material sent to recycling, increasing the amount of recycled material from 2131 tons to 2747 tons, raising the recycled mass with 13.6 %. The total recycling rate increases to a staggering 98 %. The remaining 2 % are sent to re-use. Re-use can be viewed as a more direct way of recycling a product and does not requiring any processing. Processing utilizes energy in the form of electricity and heat, and this generates emissions that are harmful for the environment. By reducing the need for processing one in turn lower the emissions. This is advantageous in an environmental perspective.

Both scenarios display possible solutions to lower the need for buying new gillnets. The need for new gillnets is lowered by reducing the loss of equipment during fishing. This assumes that all lost gillnets are replaced with new ones.

10.4 LIMITATION OF DATA

The data has in general been found to be insufficient, covered by only a few studies. This has made it hard to estimate the mass and flows of fishnets in Norway with a high certainty.

The lack of consistency in the data have made it difficult to compare values between fisheries and regions. The gathered data inhabits large differences in values and are often only applicable for specific species of fish. The fact that the extent of ALDFG differs by fish species makes it difficult to estimate a general value for the overall mass of ALDFG.

Throughout the study I have come across a lack of data regarding:

- The mass and extent of abandoned, lost or discarded gillnets
- The volume and mass of gillnets in use
- The weight of gillnets

10.5 VALIDITY OF THE STUDY

In order to utilize the numbers in the MFA-model I have found it necessary to apply rough estimates based on the numbers gathered trough the literature review. It is therefore suitable to emphasize that the calculations used in the scenario-modelling are rough estimates.

The MFA-model is designed from the assumption that all of the quantified fishnets are collected for recycling. But the fact that only a fraction of gillnets are recycled in Norway today and it is therefore reasonable to suggest that the model does not show the current state within Norway. It should be viewed as a “Best-case-scenario” displaying the potential for recycling.

It is also worth mentioning that gillnets not only consist of netting, but also rope, floating line, sinking line and anchoring line. The MFA-model does not distinguish between these parts, and include the mass of rope and line in the calculated values of the MFA. This makes the estimated mass of gillnets too high.

10.6FURTHER WORK

Research has to be done on the matter of ALDFG in order to be able to enable a more accurate model of quantifying the extent of the issue as there today are large gaps and defects in the collected data. Since all previous research present the extent of ALDFG and loss ratios, it would be advantageous to conduct a survey on the weight of different gillnets in order to map the mass of ALDFG. Such a study would enable a wider range if use of the current data.

Future studies should aim to:

- Identify the mass of ALDFG for specific fisheries
- Develop a standardized practice for data collection in order to make the data comparable for different regions and fisheries

11 CONCLUSION

The issue of ALDFG has in the recent years received increased focus from governmental and environmental authorities and the phenomena is assumed to affect marine organisms and ecosystems. The focus of this study has been Norway and Norwegian fisheries and the findings suggest that the loss rates of gillnets are low. Under 1 % of deployed nets are lost and the recovery rate of lost equipment is found to be close to 100 %.

The loss of gillnets are found to be connected to:

- Operating water depths
- Targeted fish species
- Vessel size
- Operating grounds

The findings show a clear connection between water depth and loss of equipment, revealing an increased loss rate in relation to increasing water depths. The study did also find higher loss rates for larger fishing vessels as these tend to operate in open waters characterized by rough water conditions and large water depths.

The Norwegian Directorate of Fisheries does each year organize a raid where they collect discarded gillnets and other fishing equipment from Norwegian coastal waters. The project has in total hauled over 18 000 gillnets between the years of 1983 and 2015, and did in 2015 collect 815 gillnets. The project is expected to continue in the coming years removing lost and discarded fishing gear from the marine environment.

The essence of this study was estimating the mass and flows of gillnets in Norway using Material Flow Analysis. The data has been collected through review of previous research on the issue and this enabled the quantification of the MFA-model. The study estimates that 123 tons of gillnets are lost or discarded by Norwegian fishermen each year, corresponding to a loss rate of 0.059 %. An annual 6.95 tons gillnets are recovered. By the implementation of the EUfir-recycling system a potential 2803.95 tons gillnets can be recycled on a national basis, corresponding to 2131 tons recycled material and a recycling rate of 76.4 %. Scenario modeling of MFA-model reveals that the recycling rate can be raised to 98 % by eliminating the waste generated from the recycling process. The stock of ghost nets in Norwegian wasters has been calculated to be 144.16 tons.

The study has revealed that ALDFG is characterized by lack of data and has uncovered an urgent need for more detailed research on the issue. The data from previous research has been found to be incoherent making it difficult to compare different regions and fisheries. There has not been found any data covering the mass of ALDFG in Europe or Norway and all previous research state the extent of ALDFG as ratio of equipment loss given in %. I therefor suggest that future research should focus on mapping the mass of lost fishing gear. A goal for the future should be to implement and organize a standardized research template in order to a database of coherent and comparable data.

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Appendix 1

Table 19: ALD gillnets collected by the Norwegian Coast Guard from year 1990 to 2015 (Fiskeridirektoratet 2015)

Year	Total
1990	273
1991	317
1992	1180
1993	633
1994	659
1995	701
1996	543
1997	672
1998	598
1999	401
2000	383
2001	197
2002	731
2003	630
2004	589
2005	536
2006	542
2007	577
2008	751
2009	466
2010	1000
2011	1127
2012	906
2013	898
2014	935
2015	815
Total	**17060**
Average per year	**656**

Appendix 2

Results from experiment of weighing 8 random gillnets:

Table 20: Weight of gillnets from experimental weighing

Sample no.	**Weight [kg]**
1	17.5
2	17.5
3	2.5
4	5.5
5	8.0
6	7.0
7	22.0
8	5.0
Average weight	**10.6**